Internet of Things
Technology, Communications and Computing

Mohamed Lahby
Virginia Pilloni
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Advanced AI and Internet of Health Things for Combating Pandemics

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Internet of Things

Technology, Communications and Computing

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Advanced AI and Internet of Health Things for Combating Pandemics

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Preface

Immediately after the identification of the novel coronavirus disease (COVID-19) in early 2020, it was declared a global pandemic due to its aggressive spread which impacted nearly 99.5% of the countries and territories around the globe. Since 2020, the COVID-19 virus created havoc globally with over 630 million confirmed cases worldwide and over 6.5 million deaths. With the rapid spread of the virus over different continents, the exponential growth of the number of infected people and the appearance of new variants such as delta and omicron, the attitudes and behaviours of people towards the usage of technologies have shifted during their life under quarantine.

The Healthcare 5.0 paradigm has allowed us to move towards a human-centred healthcare ecosystem by integrating the latest advancements in Information and Communication Technologies (ICT) and Artificial Intelligence (AI). Indeed, with the emergence of the Internet of Medical Things (IoMT) paradigm and the development of intelligent systems based on Artificial Intelligence, smart devices can be used for delivering healthcare services on the body, at home, in the clinic or hospital settings, and associated real-time location, telehealth and other services.

The authors present key applications of ICT and AI that have witnessed significant successes in tackling the COVID-19 pandemic. Focussing on these success examples, the current edited volume collates 19 chapters that cover a plethora of technological fields supporting the fight against COVID-19. Organised in the five subareas, these chapters prove credence to the versatility and effectiveness of ICT and AI advances in diagnosing and managing people who contracted the COVID-19 virus. The technological examples presented in this book illustrate how ICT and AI have been successfully implemented to allow for a better appreciation of the advancement of these technologies. Of the included 19 chapters, this volume starts with reviews that highlight the roles of the knowledge graph, effective practices, machine learning and deep learning in tackling the pandemic. Other contributions cover ICT and AI in key emergent areas including the Internet of Healthcare Things, Blockchain, Frameworks and Case Studies.

The book will be ideal for individuals new to the notion and application of ICT and AI in combatting COVID-19 and for early career scholars as well as advanced undergraduate and graduate-level students who wish to learn and further extend their knowledge of data-driven informatics in COVID-19 diagnosis and management.

This book contains a total of 18 chapters classified into 5 main parts. The first part presents a state-of-the-art related to Artificial Intelligence (AI) and Internet of Medical Things (IoMT) and their applications for combating COVID-19 pandemic. The second part focuses on some machine learning techniques that can be used for tackling the COVID-19 crisis. The third part explores the exploitation of deep learning approaches to combat COVID-19 pandemic. The fourth part provides some chapters related to Internet of Health Things and Blockchain technologies and their applications to fight the COVID-19 pandemic. Finally, the last part presents some frameworks and valuable case studies that can be beneficial for promoting health during COVID-19 pandemic.

We want to take this opportunity to express our sincere thanks to the contributors to this volume and the reviewers for their outstanding efforts in reviewing and providing interesting feedback to the authors of the chapters. The editors would like to thank Prof. Giancarlo Fortino (Series Editor-in-Chief), Ms. Mary James (Executive Editor) and Mr. Thiyagarajan. A (Springer Project Coordinator) for the editorial assistance and support to produce this important scientific work. Without this collective effort, this book would not have been possible to be completed.

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Contents

Part I State-of-the-Art

Part II Machine Learning and COVID-19 Pandemic

Part III Deep Learning and COVID-19 Pandemic

Part IV Internet of Health Things, Blockchain and COVID-19 Pandemic

Part V Case Studies and Frameworks

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Part I
State-of-the-Art

Knowledge Graphs for COVID-19: A Survey

Madhupa Minoli and Thanuja D. Ambegoda

1 Introduction

COVID-19 is a disease that was first identified towards the end of 2019 that resulted in a global pandemic. While COVID-19 has been continuing to spread all over the world, thousands of researchers in several research organizations have been seeking and sharing information on the coronavirus and COVID-19. In an effort to organize this rapidly expanding stream of information and to come up with efficient methods to organize and analyze this information, over 1,000,000 scholarly articles on COVID-19, SARS-CoV-2, and the coronavirus group has been collected into a publicly available dataset called the COVID-19 Open Research Dataset (CORD-19) [1]. With the increase in research activities and scientific publications, this dataset also rapidly increases and becomes challenging to analyze entirely and efficiently. To represent this complex knowledge related to COVID-19, a graph-based model gives significant advantages more than normal relational models or non-relational alternatives.

To organize and represent semantic information of related entities, a *knowledge graph* is constructed which represents a set of interlinked entities, events, or concepts [2]. Representing data in a graph-based structure provides users to gain lots of benefits. One such benefit is that the dataset can be enhanced with the knowledge that was previously not available by connecting concepts to external resources. When new knowledge items extracted from unknown external sources can be inserted into the knowledge graph easily and existing items in the graph can be modified, updated, or removed simultaneously. Another benefit results from

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the fact that edges represent an interconnection between two entities, which can be considered in the analysis phase of the dataset.

When it comes to the medical domain, improving discoverability, monitoring the newest trends and developments, managing appropriate information, and maintaining referential knowledge of pre-identified medical facts are some of the benefits of a constructed knowledge graph. Valuable insights and hidden correlational data of COVID-19 clinical research can be gained by mining relevant data across knowledge graphs quickly. Since it aggregates large volumes of information, information can be easily managed across different medical repositories. Data quality also can be optimized and can identify medical data discrepancies reliably. Therefore productivity will increase and researchers and scientists can quickly mine precise information from documents and apply the results in their context. Since knowledge graphs act as a central intelligence system connecting data related to the medical domain from various sources like PubMed [3], and CORD-19 [1], they can be used to analyze, classify and find new potential drug targets reliably to combat pandemics. In addition to that safety information throughout the entire drug development life cycle can be managed in a single intelligent system. It will speed up bench-to-clinical trial time by identifying suitable research candidates to repurpose drugs for COVID-19.

During the COVID-19 pandemic situation, when increasing the number of patients, knowledge graphs are ideal to transform the raw patient data into structured knowledge which leads to increased coding workflow productivity [4]. It will save time looking for particular patient details and tacking down patient data while eliminating ambiguity. In the process, patient data can be converted into structured knowledge on par with standardized medical terminologies. This may enhance data interoperability and can integrate internal data with widely available public open data economically.

Since knowledge graphs describe data itself in a uniform machine-processable schema-less form, users can easily understand the content and can ask ad-hoc questions. This shrinks the gap between users and technology as well as the time from idea to answer (decision cycle). Figures 1 and 2 depicts how time from question to answer shrinks between the default decision cycle and the knowledge graph decision cycle. This advantage is provided by the semantic layer of the knowledge graph which consists of meaningful data that draws from various sources to allow users to access the data immediately. This is advantageous to analyze ideas within a short time for health and biomedical domains under a pandemic situation.

Considering the numerous advantages of knowledge graphs, most researchers tend to construct knowledge graphs using different COVID-19-related datasets and various methodologies. Nowadays there are few publicly available knowledge graphs related to COVID-19 [5–8]. A schematic representation of the data of one of the commercially available knowledge graphs called **“KG-COVID-19”** is shown in Fig. 3. Here polygons represent different data sources connected to the knowledge graph, and the tiny colored circles represent the data types connected from corresponding source [8].

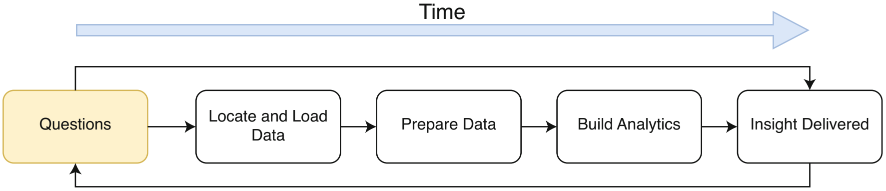

Fig. 1 Default decision cycle

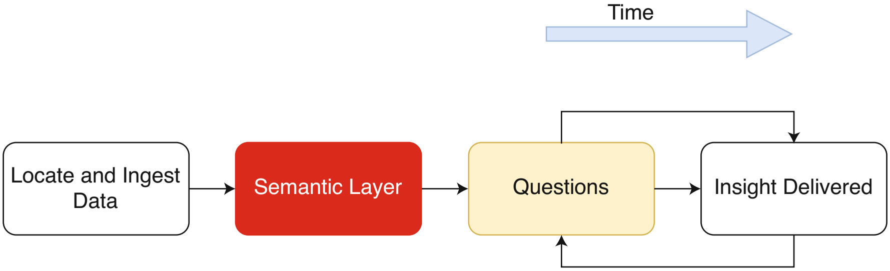

Fig. 2 Decision cycle using knowledge graph

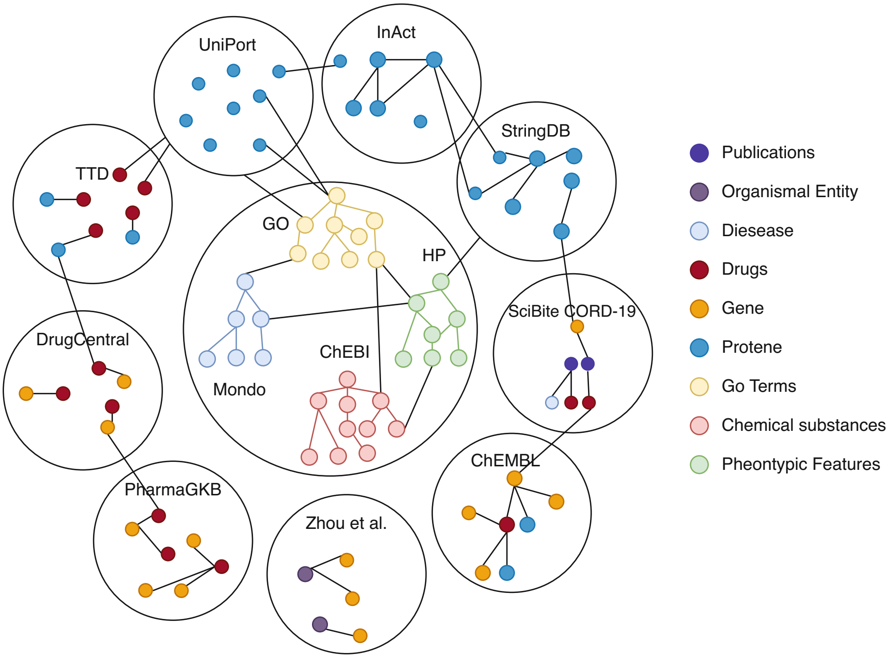

Fig. 3 Schematic representation of the data currently connected into the COVID-19 knowledge graph [8]

In this chapter, we survey to analyze previous studies concerning the utilization of machine learning and deep learning approaches to construct knowledge graphs from textual data and its application in the medical domain especially related to COVID-19. This chapter is structured as below. We present the background of the knowledge graph and one of the popular deep learning models—Transformer Language Model which is used to construct knowledge graphs in Sect. 2. In Sect. 3, we describe how to construct such a valuable graph representation and what machine learning and deep learning techniques are used in each construction phase. Identified applications in the medical domain and applications related to COVID-19 are listed in Sect. 4. Two main challenges in knowledge graph construction are presented in Sect. 5. From the final section, we conclude our work briefly.

2 Background

2.1 Knowledge Graph

A knowledge graph represents knowledge in the form of interconnections between nodes and edges in the graph. It provides a structured representation of information extracted from the context which has relationships between entities. Here entities can be real-world objects, events, or concepts. Relationships are the arrows connecting specific two entities. Each edge is represented as a triple which is also called a *fact* [9]. This triple consists of the following three elements, respectively.

1. Head entity
2. Relation
3. Tail entity

Consider the following sample text:

Text 01 *Albert Einstein was a German-born theoretical physicist who developed the theory of relativity.*

A mini knowledge graph can be constructed by extracting the entities and relationships of *Text 01*. The constructed mini-knowledge graph can be visualized as in Fig. 4.

Here, the head entity is colored yellow and the tail entities are colored red. It has three facts; (Albert Einstein, born in, Germany), (Albert Einstein, occupation of, Theoretical physicist),(Albert Einstein, developed, Theory of relativity).

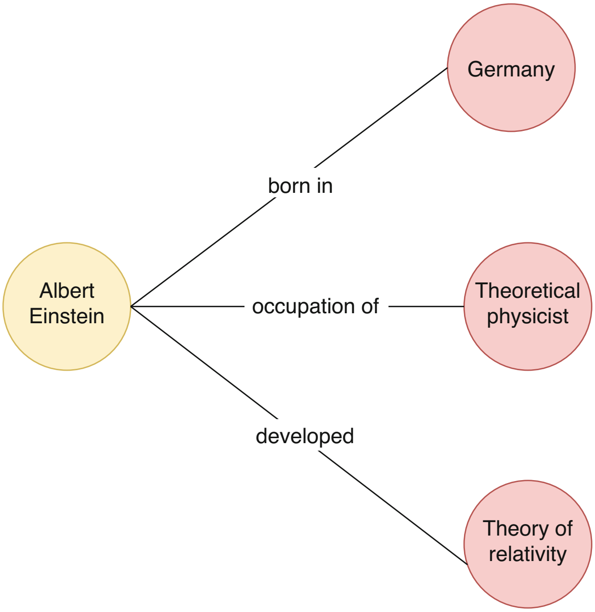

Fig. 4 Knowledge graph created using *Text 01*

2.2 Transformer

Capturing the relationship of sequences of words in a sentence is vital to understand a natural language for a machine. This is where the transformer concept plays a major role. Nowadays, Transformer [10] based deep neural network is in demand in computer vision [11] and Natural Language Processing (NLP) [12] due to its high performance. The transformer adopts a self-attention mechanism and accomplishes considerable performance without using any Recurrent Neural Network (RNN) or Long Short Term Memory (LSTM) cells. The basic architecture of a transformer has a set of encoders interconnected to another set of decoders [13]. Every encoder layer contains multi-head attention with padding mask and point-wise feed-forward networks. Every decoder layer contains masked multi-head attention, multi-head attention, and feed-forward networks [14]. Figure 5 shows the model architecture of a transformer with its basic components.

2.2.1 Bidirectional Encoder Representations from Transformers (BERT)

BERT was proposed back in 2018 by researchers at Google Artificial Intelligence (AI) Language and it was influenced by different deep learning models like semi-supervised sequence learning, Embeddings from Language Model(ELMo), and the

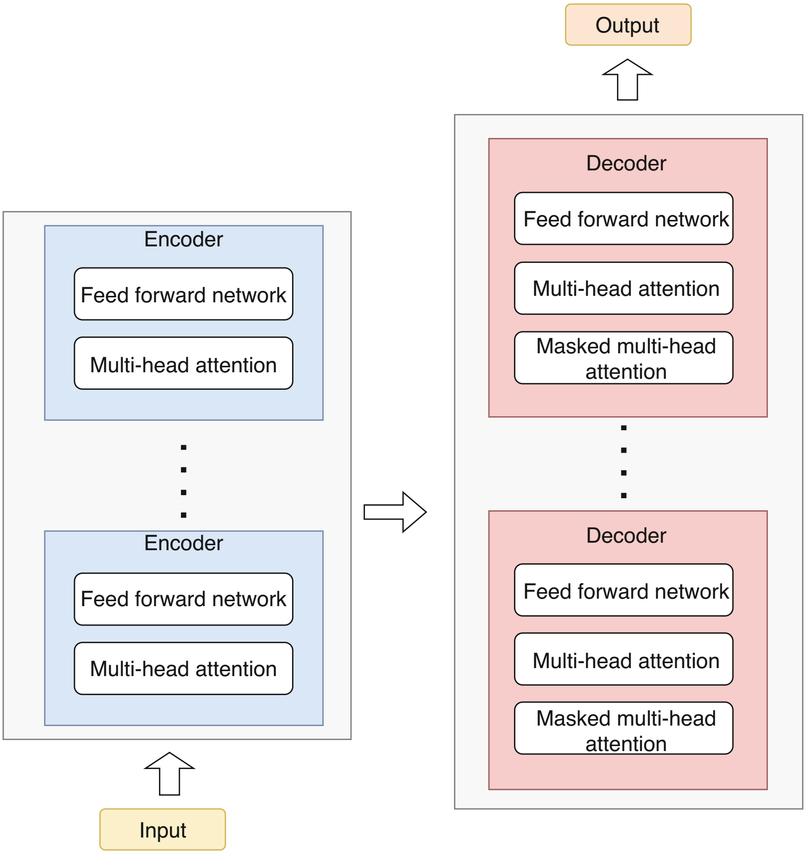

Fig. 5 Architecture of a transformer [10]

transformer architecture. BERT [15] pre-trained model has shown to be easily fine-tuned to achieve state-of-the-art performance for a broad span of NLP tasks.

BERT uses the transformer-based architecture, an attention mechanism to learn contextual relationships between words in a sentence. Encoders in the BERT reads the text input and decoders output the prediction.

Following are the main steps in using the BERT framework [16].

1. Pre-training—It trains massive unlabeled data by two training strategies.
   (a) Masked language modeling (MLM)—predict the original input from the masked token
   (b) Next sentence prediction (NSP)—predict the next sentence by checking the following sentence
2. Fine-tuning—hyperparameters are tuned using labeled data

Fine-tuning BERT is widely used for different types of language tasks by combining another layer to the vanilla model. Following are some widely used language tasks.

1. Classification tasks—combining a classification layer on top of the transformer output
2. Question answering tasks—learning two additional vectors which spot the start and the end of the answer
3. Named entity recognition (NER) tasks—marking different types of entities in the text. It predicts the correct entity category label by using BERT

BERT has two models in the English language. They are,

1. $\text{BERT}_{\text{BASE}}$—12 encoder layers with 12 attention heads and 110 million parameters
2. $\text{BERT}_{\text{LARGE}}$—24 encoder layers with 16 attention heads and 340 million parameters

BERT-base and BERT-large have hundreds of different parameters, which makes handling difficult. With the help of the distillation technique, another BERT variant was introduced named DistilBERT [17] which can be used to minimize the size of these two models.

There are several major BERT variants in the biomedical domain. Such as,

- SciBERT [18]—a pre-trained BERT-based domain-specific language model for performing scientific tasks in NLP
- BioBERT [19]—a pre-trained BERT-based domain-specific language representation model based on biomedical corpus
- ClinicalBERT [20]—a pre-trained BERT-based domain-specific model on patient clinical notes/Electronic Health Records (EHR) and used for downstream predictive tasks
- MedBERT—a pre-trained BERT-based domain-specific language model on a structured EHR dataset of patients

Since BERT outperforms Convolutional Neural Network (CNN) and RNN models in the process of constructing knowledge graphs, more researchers start to fine-tune BERT models for specific tasks.

3 Knowledge Graph Construction

Mainly research work has been carried out in different construction techniques of knowledge graphs. Among them, some analyzed the development procedures of knowledge graphs and their related technologies. According to paper [21], Top-down Approach and Bottom-up Approach are the two types of approaches in the development of knowledge graphs. The top-down Approach focuses on knowledge schema such as domain ontologies, and Bottom-up Approach focuses on knowledge instances such as Linked Open Data datasets and other knowledge resources. In the general procedure of developing knowledge graphs, entity extraction, relation extraction, knowledge fusion, knowledge storage, knowledge query, and visual display are the main aspects that need to be taken into consideration.

Many performance metrics can be used to check how well machine learning and deep learning model has performed in each construction phase. The quality of knowledge graph completion approaches is usually measured in the recall, precision, and F-measure. In this section, different construction phases are described and compared prominent studies under performance metrics. In addition to that briefly discuss knowledge graph storage and visualization approaches.

3.1 Entity Extraction

The primary sources of knowledge include heterogeneous data such as structured data, semi-structured data, and unstructured data. Due to this diversity of knowledge sources, a lot of studies have been carried out for knowledge acquisition techniques and possible solutions to information fusion to deal with these heterogeneous data sources [22, 23]. One type of knowledge extraction is NER which discovers entities from various knowledge resources. Afterward, it classifies discovered entities into pre-defined three classes [13]. Those classes are,

- Entity class—people's name, places, organizations
- Time class—time expressions
- Number class—percentage, currency

Table 1 illustrates extracted named entities and their categories from sample Text 01. Here "Albert Einstein", "German" and "Physicist" name entities can be categorized into PERSON, LOCATION, and PERSON TYPE respectively.

Early manually annotated corpus was presented for knowledge extraction using rule-based and dictionary-based methods. With the advancement of technology, NLP, text mining, and machine learning (ML) techniques are often used to extract knowledge. However, supervised learning algorithms in ML need a manually annotated training dataset. Usually, a large number of domain experts and a considerable amount of time are needed to generate a manually annotated corpus. At present, some semi-supervised and unsupervised algorithms in ML such as Hidden Markov Models, k-Nearest-Neighbors, Conditional Random Fields (CRF),

Table 1 Named entity extraction for Text 01

Name entity	Entity category
Albert Einstein	PERSON
German	LOCATION/GPE (geopolitical entity)
Physicist	PERSON TYPE

Maximum Entropy Models, and Support Vector Machines (SVM) can be applied to avoid part of the annotation effort.

The joint neural model is one of the popular neural models in text mining and NLP that is used for entity recognition and relation classification. This model is used to extract harmful incidents between the drug and disease entities and the relationship between the bacteria and location entities in biomedical text and evaluate them [24].

Further studies were carried out to identify different language entities in the medical domain. One [25] is using a combination of the BERT model, BiLSTM network, and CRF model to identify entities in Chinese medical records. This combined model provides the following advantages.

– BERT model—enhance the semantic representation of sentences
– Bidirectional LSTM network—tackle the problems aroused in past methods
– CRF—aware of context annotation information

The advantages of the BERT + BiLSTM + CRF model were taken into account and extracted entities from scientific documents in the CORD-19 dataset to build another knowledge graph called "CORD-19 Argumentative Knowledge Graph (CORD19-AKG)". In the process of name entity extraction, the hyperparameters in the BERT model are initialized using one of the BERT variants—the SciBERT model and fine-tuned using the dataset annotated with argumentative components which results in f1-score of 0.90 [26].

Apart from the BERT + BiLSTM + CRF model, other different combined neural models such as bi-directional LSTM + CRF, RNN + CNN + CRF, and SVM + CRF were created for different types of datasets. Table 2 shows the above-discussed NER models and their performance for different datasets.

Table 2 Summary of biomedical NER models

Method	Dataset	Performance
Dictionary lookup	Mayo clinic EMR	F1: exact matches—0.715 overlapping matches 0.824
CRF and Rule-based	Stockholm EPR Corpus	P—0.88 and R- 0.82 for body structure, P—0.80 and R—0.82 for disorders, P—0.72 and R—0.65 for findings, and P—0.95 and R—0.83 for drugs
Rule-based	n2c2-1 challenge	F1-score of 0.90
Bi-directional LSTM and CRF	Clinical notes—cancer	F1—0.81
RNN,CNN and CRF	2010 i2b2	RNN outperformed CNN with F1—0.8594
SVM and CRF	2010 i2b2	CRF outperformed SVM F1—0.84 (concept extraction) and F1—0.93 (assertion classification)
BERT	Spanish Clinical Text	F1—0.73

Table 3 Relationship extraction for Text 01

Head Entity	Relationship	Tail entity
Albert Einstein	**Born in**	Germany
Albert Einstein	**Work as**	Physicist
Albert Einstein	**Developed**	Theory of relativity

3.2 Relation Extraction

Relation extraction is the task of detecting relationships and attributes in a given sentence. Detected relationships are commonly presented between two or a few other entities. They are classified into several semantic categories such as born in, employed by, developed by, etc. Relation extraction is the core concept in building a knowledge graph and it has a crucial significance to NLP applications.

Table 3 shows extracted relationship between the head entity and the tail entity from sample Text 01.

Most of the relation classification techniques are based on CNN or RNN. A CNN architecture [27] was introduced to extract semantic relationships, which depend upon two degrees of attention that lead to distinguish patterns in a given heterogeneous text. It can learn task-specific labeled data easily without the use of any external knowledge.

A hierarchical RNN [28] was proposed for relationship-extracting tasks and classification that has prominent features as follows.

- A sentence is split into three contextual sub-sequences corresponding to two annotated nominals
- Two hierarchical RNNs
    1. Learn the contextual representations of these three sub-sequences
    2. Determine the semantic composition of these three sub-sequences and classify the relationship among annotated two nominals
- Attention mechanism

Nowadays, the pre-trained BERT model achieves success over RNN and CNN in the results of many NLP classification and sequence labeling tasks. One model [29] has been developed for relation classification by enriching the pre-trained BERT model with entity information. Here, located target entities were transferred through the pre-trained architecture and incorporated the corresponding encoding of both entities. Different experiments based on the SemEval-2010 benchmark dataset showed that the model remarkably outperformed the state-of-the-art methods.

One of the BERT variants called the SciBERT can be used to generate the numerical representation of the textual data by adding a linear layer for relationship classification related to COVID-19. This model has been fine-tuned using an argumentative relations dataset in the medical domain achieving F1—0.68 [26].

Table 2 shows the above-discussed RE models and a few more models and their performance for different datasets (Table 4).

Table 4 Summary of clinical RE models

Model	Dataset	Performance
CNN on multiple features	2010 i2b2	F1—0.7116
CNN and BiLSTM	2010 i2b2	BiLSTM outperformed with a 9-class F1—0.8808 and a 6-class F1—0.8894
BERT, BioBERT, ClinicalBERT, and Random Forest	Biomedical and clinical texts	BERT models performed on the MADE corpus
BERT, BioBERT, and ClinicalBERT along with other methods	2018 n2c2	BERT models performed with a micro-averaged F1—0.94 and a macro-averaged F1—0.93

3.3 Knowledge Fusion/Coreference Resolution

Knowledge fusion is an iterative process, which needs to constantly build an ontology and keep its quality by realizing entity alignment. The iterative process of ontology construction will end once the results of quality evaluation meet requirements. Entity alignment is an important phase in knowledge fusion, which can use not only NLP methods but also knowledge inference methods. It groups expressions that refer to the same entity to minimize ambiguity in a given text [13]. Most of the approaches to entity alignment need large expert participation for designing model features or handling external source contributions. Recently, embedding-based methods [14] have been proposed to address this issue.

The LSTM-based encoder was completely replaced by BERT transformers for knowledge fusion, gaining performance improvement on the OntoNotes and GAP benchmarks [30]. They have compared their model predictions quantitatively with ELMo and BERT-base but still some improvements are needed.

SpanBERT [31] is one of the BERT variants designed for a better representation and prediction of text spans. This BERT variant avoids random tokenization and masks contiguous random extents. In addition, SpanBERT predicts the entire content of the masked extent by training extent boundary representations. Therefore SpanBERT outperforms the BERT in tasks related to span selection like QA and coreference resolution.

3.4 Knowledge Graph Storage

The primary requirements of the large-scale knowledge graphs storage can be listed below. Because there is no proper storage scheme proposed for knowledge graphs.

- Storage should be scalable and highly available
- Data segmentation should be done
- Caching and indexing

- Large volume of knowledge graph should be handled

By considering the above facts, knowledge graphs are usually stored in NoSQL databases. Two main storage types can be found such as,

1. Resource Description Framework (RDF) based store
2. Graph database store

The RDF graph model represents a knowledge graph using triples. Therefore, this data model is usually called a triple store which includes subject, predicate, and object [32]. Both native and none native storage systems can be used as RDF storage. SPARQL is widely used as the standard native storage query language of knowledge graphs. Nowadays combined NoSQL databases with RDF storage systems can be found. The advantage of these types of storage is, that they can handle a massive volume of knowledge easily.

- Jena + HBase
- Hive + HBase
- Cassandra + Sesame

Graph databases store nodes, edges, and properties of graphs. In addition, they provide query languages and support different mining algorithms to retrieve data from the graph.

3.5 Knowledge Graph Visualization

When querying knowledge graph storage, sometimes output formats are not human-readable. The visualization of the knowledge graph allows the overall picture to discover the related knowledge. Therefore most researchers pay attention to the visualization of knowledge making this a hot research topic. Visualization using a browser is the most widely used approach.

4 Application of Knowledge Graphs in Covid-19

The applications of knowledge graphs are seen in question-answering systems, recommender systems, and information retrieval systems in general. In the medical domain at present, knowledge graphs are mainly used in clinical decision support systems, medical intelligent semantic search engines, medical question-answering systems, chronic disease management systems, drug repurposing, and patient tracking systems.

PubMed contains more than 34 million citations of biomedical articles from journals and books. Using this dataset the PubMed knowledge graph [33] was constructed to extract useful concepts and address ambiguous issues parsing abstracts from 1781 to 2019. A NER model based on the BioBERT is used to recognize the bio-entities from PubMed abstracts. This model achieved F1—0.51 for recognizing different entities like Genes/Proteins, Diseases, and Drugs/Chemicals. For the author name disambiguation in abstracts, this model gained F1—0.9809 on average. García-Crespo et al. [34] proposed an ontology-driven clinical decision support system for infectious disease diagnosis and antibiotic prescription. The system includes a medical ontology knowledge base, which integrates multiple medical ontology resources like infectious diseases, syndromes, bacteria, drugs, etc. Cheng [35] builds a Traditional Chinese Medicine (TCM) knowledge graph including a disease database, a symptom database, and a Chinese herbal medicine database. It realizes the intelligent application of TCM knowledge graph, including template-based TCM knowledge question answering (QA) system and knowledge graph reasoning-based auxiliary medication. This has been able to help clinical decision support systems used by medical professionals.

With the inspiration of general medical knowledge graphs, dedicated knowledge graphs were built for COVID-19. A COVID-19 knowledge graph [5] was built based on 145 articles and a visual representation for the built graph was given using a web application. This graph consists of nearly 4000 entity nodes (10 entity categories) and nearly 10,000 relationships.

In another approach [35], a supervised entity relation extraction network [36] was applied to build a cause-effect knowledge graph by identifying drugs related to COVID-19 literature papers. In its current state, it has 4016 nodes, covering 10 entity types and 10,232 relationships. These two mentioned efforts still absent the large knowledge graph construction techniques which are necessary to determine insights on possible diseases and treatments.

In addition to that, a self-supervised context-aware [37] COVID-19 document exploration was built using a BERT [38] to extract COVID-19 radiological findings by referring to COVID-19 articles in the CORD-19 dataset.

Another COVID-19 Knowledge graph [7] was constructed by fine-tuning the BioBERT model and vanilla BERT model. It achieved a METEOR score of 0.95 for fine-tuned vanilla BERT and a METEOR score of 0.93 for fine-tuned bioBERT model. The following are the key points in entity extraction and relation extraction.

- Entity extraction—candidate entity items were extracted from Wikipedia articles and several filter rules were applied to extract the COVID-19-related entities
- Relation extraction—unsupervised learning-based Open Information Extraction system was used to identify a relation between COVID-19-related entities using BERT (general documents such as news articles)

“Covid-on-the-web” knowledge graph was constructed by fine-tuning the SciBERT model for the CORD-19 dataset. It achieved an F1 score of 0.90 for entity extraction and an F1 score of 0.68 for relation extraction. To visualize and explore data, an RDF dataset and a software application were produced [26].

Following are some key points in entity extraction and relation extraction.

- Entity extraction—sequence tagging task combined the BERT, LSTM, and CRF to classify token inputs
- Relation extraction—generate the numerical representation of the textual data by combining a linear layer

Question Answering is a prominent NLP task applied in chatbots and information retrieval systems. Answering questions using knowledge graphs is a completely new approach because of knowledge graph advantages.

Alzubi et al. [39] proposed a retriever-reader dual algorithmic system (COBERT) that provides answers to compound queries by crawling research documents in the CORD-19 dataset by fine-tuning the BERT and DistilBERT in the Reader phase by achieving F1—0.883 and 0.873 respectively. Ding et al. [40] established a QA system creating a framework based on knowledge bases for COVID-19. They designed the schema of the COVID-19 knowledge graph and extracted knowledge from textual data by a rule-based classifier to seek answers to a given input question. This system achieved 81.6% accuracy out of 86 questions.

5 Challenges in Knowledge Graph Construction

Creating a massive knowledge base is quite a challenge in part due to the difficulties of language and the continuously evolving facts and knowledge. Recent developments in deep learning still lag in understanding ambiguous phrases of text. When it comes to visualizing knowledge, is also a tricky part. This section briefly covered a few challenges when creating a knowledge graph for pandemic situations like COVID-19.

5.1 Quality of Knowledge Graph Construction

Research papers about COVID-19 released from various research laboratories and different sources may include redundant, complementary, or conflicting data. Sometimes publications and social media platforms promote false information intendedly. As a result of that, some knowledge graphs were constructed based on misleading or erroneous facts. If the quality of a COVID-19 knowledge graph is not sufficient enough, scientists and researchers cannot use them and it may cause wasting resources by relying on untrustworthy data, especially in the medical field.

Recently, explainable AI has been used in the medical domain to facilitate transparency and trust [41]. AI researchers have discovered an ensemble of algorithms to boost the quality and calibrate the algorithm's parameters to provide better uncertainty estimates [6].

5.2 Visualizing a Knowledge Graph

Organizations rely on knowledge graphs to make the most of their growing volumes of data. Though, the large knowledge graphs have brought challenges in usability. Here are a few visualization tools published to enhance the usability of a knowledge graph.

"KGViz" is a knowledge graph visualization framework that has an inbuilt user interface with better performance and easy access. It promotes community contributions to extend the knowledge graph for better visualization [42].

Another tool called "SAVIZ" was published and demonstrated to enable users to visualize the classification output of knowledge graph [6].

6 Conclusion

Knowledge graphs can provide semantically structured information that can be applied to any domain. This chapter reviews different applications, different construction techniques of knowledge graphs, and how transformer-based language models are used to construct knowledge graphs. The creation of knowledge graphs from the vast amount of research information on COVID-19 offers numerous benefits such as improving discoverability, monitoring the newest trends and developments, and providing means of efficiently managing appropriate information. When constructing knowledge graphs, deep learning-based algorithms are widely used, particularly in understanding information that is represented in natural language. Transformer-based language models such as BERT and its variants can outperform CNN and RNN models in entity extraction, relation extraction, and knowledge fusion stages of the life cycle of building a knowledge graph. Examples of such variants of BERT are MedBERT, ClinicalBERT, and BioBERT which are particularly fine-tuned for the various biomedical domain tasks, especially for the creation and completion of COVID-19 knowledge graphs. When building knowledge graphs, recent developments in deep learning still seem to have trouble understanding ambiguous phrases in a text. Such issues typically affect the quality of the knowledge graphs constructed. In addition to that, it is crucial to have a user-friendly visualization technique to observe extracted knowledge. Although there are many challenges to be tackled when dealing with massive knowledge, researchers have gained success in experimenting with newer paths to resolve the challenging issues associated with the leveraging of combating pandemics with computational intelligence techniques in just under a decade.

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Mapping Effective Practices and Frameworks During the AEC Industry's Combat with COVID-19: Scientometric Analysis

Khalil Idrissi Gartoumi, Mohamed Aboussaleh, and Smail Zaki

1 Introduction

No one can deny that the health crisis caused by COVID-19 has disrupted every industry. This virus has been considered a huge global disruption with immense economic, social, health, and environmental repercussions worldwide. Even human behaviours and principles have been changed. Worldwide, hospital infra-structure has suffered from the phenomenal growth of cases affected by this virus. As an indication, the World Health Organization (WHO) counted 15,785,641 cases of infection and 640,016 deaths worldwide on July 26, 2020, [1], 4 months after the official declaration of a global health emergency [2]. These numbers have increased since then, which has forced governments to adopt a policy of strengthening hospital infrastructure. The only solution was to build and install new hospitals to accommodate the different cases attacked by COVID-19. In this emergency context, construction is confronted with the hyper constraint of rapid delivery. Before delivery, a construction cycle goes through three phases: Architecture, Engineering and Construction (AEC). The AEC industry, as a pillar of national economies should absorb health measures and restrictions as well as deploy the techniques and means necessary to deliver hospitals in record time. Taking the example of Leishenshan Hospital in Wuhan, under nor-mal conditions, such a hospital can be built after 3–5 years [3]. In contrast, this hospital began operation in 12 days [4]. Each country, depending on its AEC industry's capacity, resilience, and innovation, has tried to consolidate its ability to accommodate patients with symptoms. This struggle with hospital infrastructure has resulted in amazing achievements. In China, emergency hospitals were built in a record 2 weeks [5]. In the United States, the Division of Military Engineers made seventeen case management sites [6]. The UK government

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established eight new hospitals [7]. Indeed, the AEC industry's experience with COVID-19 is fruitful, with many lessons learned that merit capitalising on all the approaches, frameworks, and technologies deployed to address this virus and its impact.

1.1 Research Gap and Objective

Most of the literature studies before COVID-19 (2010–2020), which synthesize the global scientific trend, have revealed that the AEC is a sector reluctant to adopt recent technologies and managerial approaches [8]. At the same time, this literature demonstrates the existence of several studies that have succeeded in bringing out new methods to put the AEC industry on track for performance improvement. COVID-19 has emerged at a time when the AEC industry is in full exploration and investigation to align with the performance requirements [9], sustainable development [10] and join the transformation 4.0 of industrial sectors [11]. To this end, this sector has experienced significant changes through the adoption of several technologies namely Building Information Modelling (BIM) [12], virtual reality [13], mixed reality [14], 5G [15], Machine learning [16], and managerial approaches such as Lean Construction (LC) [17], Lean6sigma [18], Green [19], Sustainability certification systems [20]. In many countries, the AEC industry has taken advantage of the experience with these tools to address the many constraints encountered in strengthening hospital infrastructure and ensuring continuity of productivity. Since the appearance of COVID-19, scientific production about AEC has continued to increase and has taken a derivative path, characterised by studies around this virus from 2020 onwards. As shown in Fig. 1, out of 535 publications published between 2020 and July 2022, 249 were dedicated to the AEC industry versus COVID-19.

This number of publications is essential on two levels. Firstly, it confirms the prominent place of the AEC industry. Secondly, it shows this period's importance in the transformation, especially the digital and technological transformation that this

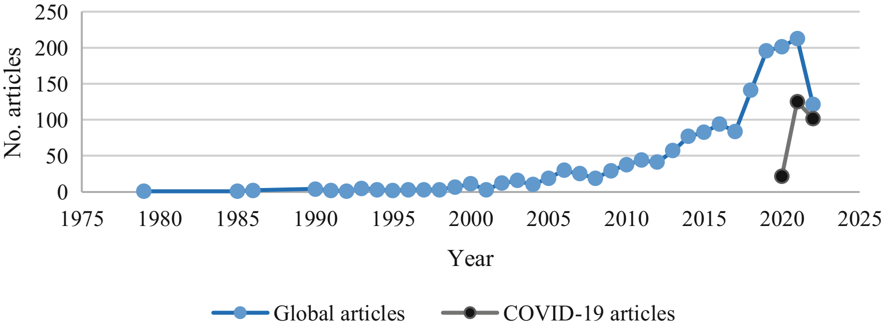


Fig. 1 Evolution of documents during the COVID-19 period

Fig. 2 The overall review workflow

sector is undergoing. Despite this relevant number of publications, no study maps the practices and frameworks deployed in the AEC industry to confront COVID-19. As shown in Fig. 2, there are nineteen apparent literature reviews (LRs) in the renowned databases Web of Science and Scopus. By eliminating the common LRs between the two databases, the number is reduced to 14 LRs. By carefully reading the abstracts, we identified relevant articles in 7 LRs. These are micro literature, and none of them focused on this topic. For example, Alfadil et al. developed an integrative review to limit the environmental risks of pandemic on construction projects [21]. Pamidimukkala et al., through an extensive literature search, identified health and safety problems faced by workers on construction sites and proposed recommendations to combat these risks [22]. In the same perspective, Li et al. systematically reviews the influence of COVID-19 on the distinct phases of the life cycle of a construction and opportunities and challenge faced by project management [23]. Burton et al. conducted a scientometric analysis to elucidate the integration of innovative digital technologies in the telework of AEC professionals [24]. Zakaria et al. summarised the effect and changes produced due to COVID-19 [25]. In the case of Malaysia, the policy of accelerating the installation of medical shelters to cope with the spread of the virus was summarised by Hanapi et al. [26].

However, these previous works of literature have focused on topics restricted to one aspect of the AEC experience of the virus. They take a form of manual review that is neither comprehensive nor in-depth. Moreover, none of this literature has examined the framework deployed to combat this pandemic. As a result, these studies are flawed in three ways. First, most of them analyse publications published between 2020 and 2021 while the fight against COVID-19 continues. Second, studies on the AEC at the time of COVID-19 have focused on one specific topic, such as challenges, changes, or a particular country's experience. However, there is a need to analyse and synthesise the tools globally, means and frameworks studied by academics and deployed by professionals. A more comprehensive study is required.

Thirdly, the research methods deployed might miss links between keywords, topics, and relevant documents. As a result, research gaps appear. A broad micro-level review of all technological and managerial assets, tools and means put in place by the AEC facing pandemic is vital to highlight good practices to capitalise on for the upcoming, especially since this future requires a post-COVID-19 revival [27], and conservation of the renovation and digitalisation path [28].

Therefore, in this study, authors attempt to answer the following questions:

1. What is the status of all the tools, technologies, approaches, and frameworks contributing to strengthening the hospital infrastructure in the face of COVID-19?
2. What are the current aspects of the AEC response to COVID-19?
3. What lessons and recommendations for the future of the AEC?

This chapter aims to present a comprehensive and inclusive scientometric analyse of obtainable research on the entirety of all ACE's efforts during COVID-19 to reveal good practices and frameworks. This study examined articles of diverse types, the most important institutions and countries, the most used keywords, the most famous and cited paper journals. This study contributes significantly by providing a comprehensive and an inclusive mapping of approaches and frameworks to combat the COVID-19 pandemic. The results of this study could provide a valuable platform for AEC researchers and practitioners to be more resilient in the post-COVID-19 and other health and other crises. After the introduction and background and introduction of topic, the "Research Methods" section defines the research tools and outlines process, including exploration of scientometric and thematic analysis. Results section then presents the links, information, and results. These have been equated with the literature to generate a fruitful discussion. Finally, the last section summarises the findings and presents the conclusions drawn.

2 Research Method

To achieve the objectives of this study, we adopt a bibliometric analysis and scientometric analysis. First, the bibliometric analysis is conducted to identify and evaluate relevant publications [29]. After this first phase the scientometric analysis, which is the primary method of this study, is conducted. This method belongs to the category of scientific mapping [30]. This method provides a clear, inclusive, and thorough picture of the available aspects and areas of research [31]. The adoption of this method is known in several fields, including the field of AEC. Much literature has been conducted based on scientometric analysis [32]. As this study is concerned with the experience of COVID-19, the search terms focus on studies published from the time of COVID-19's appearance in Wuhan on 16 November 2019 [33], addressing any case studies, tools or approaches conducted during this struggle. The works are collected from the well-known databases Scopus, Web of Science (WoS) and Springer. The flow of the study is illustrated in Fig. 1. The projected methodology contains: the stage of data collection (step 01), sorting and application of exclusion criteria (step 02), thematic and scientometric analysis of the data (step 03) and examination of the identified results (step 04).

2.1 Phase One: Searching Publications

To conduct a systematic review of the literature, three types of inclusion criteria need to be met: the databases to be included, the keywords to be chosen, and the nature of the publications to be included [34]. In the first instance, the Scopus, Wos, and Springer databases were the data sources and corresponding articles collection. These databases cover most scientific productions, known by the quality of the content, which undergoes a careful evaluation by peers. Thus, it is a data source accepted by most academics and scholars.

The second determinant is the keywords. Three sets of words were used to capture the search set:

(i) "Architecture, Engineering, Construction industry" AND COVID-19 OR "Post-COVID-19".
(ii) AEC AND "COVID-19".
(iii) "Construction industry" AND COVID-19.

As the occurrence of COVID-19 is new and scientific production has manifested itself in different forms, all types of documents and forms of research have been included, and the whole period from the first report on this virus is considered to guarantee the integrity of the information. From these databases, and with the search terms determined, 256 publications were collected and stored in the Mendeley library management software. In addition, 16 publications were added to the publications collection considered most relevant to the topic of this article. The keywords mentioned for searching were applied in the "title/abstract/keyword fields".

2.2 Screening

The exclusion criteria were applied in three steps. First, articles or papers that were included in more than one database were removed. Then the search fields far from the subject were dropped. At this point a total of 192 is obtained. Next, a reading campaign of titles, abstracts and keywords was carried out. This step resulted in the exclusion of 57 articles. Finally, the third step consisted of a complete reading of the retained articles. 34 were excluded. At the end of the process, 101 articles were retained to form the basis for analysis and the results that will be presented in the succeeding sections.

2.3 Data Analysis

The database of articles obtained was examined using, scientometric analysis and thematic method.

2.4 Scientometric Analysis

Scientometrics is an essential part of science's general science and a influential tool in research and innovation strategy [35]. To this end, the scientometric approach is favoured to bypass a research area [36]. With its ability to visualise trends and patterns in a large body of literature, this approach allows knowledge to be mapped [37]. It uses mathematical and statistical methods to quantify and evaluate knowledge development around a specific topic by analysing a large body of scientific output [38]. Its performance allows the detection of researcher's capacity, leading payrolls, institutions, and different types of journals and documents specific to the topic under investigation [39]. The benefits of scientometric approaches help researchers to uncover new aspects, original ideas, and research gaps for further study [40]. The potential of these approaches lies in creating an interconnected, readable, and decision-supporting network.

In contrast to the literature review, which runs the risk of having ideas unnoticed and unaddressed [41]. This analysis involves the co-occurrence of several parameters, namely keywords, co-citation of documents and their authors and others. Thanks to its performance, several studies have been established, and many fields have been explored [42]. Nevertheless, it has some limitations, especially in data acquisition and analysis, as well as multifactorial dependence, permanent rearrangements of factors, the subjectivity of quantity results, non-additivity of empirical data, obtainability of two types of variables – indicators and latent variables and theoretical position of empirical parameters [43]. To mitigate the limitations and disadvantages of this qualitative approach [44], Estrela S recommendations, such as careful and attentive selection of keywords and respect for their vocabulary, were considered in the elaboration of this chapter [45]. In the absence of its limitations, we have chosen to include the different types of documents and the existing databases and to use the various keywords in the literature to designate the AEC. We have also exploited the navigation and search features offered by the databases, such as the enhanced list of organisations and affiliations, to get around all the publications and critical aspects related to the AEC fight against COVID-19 pandemics. Therefore, scientometric analysis was chosen as an appropriate method to gauge a research field's developing areas and essential points [46]. VOSViewer, BibExcel, CiteSpace, CoPalRed and HistCite are the most well-known software packages for analysing and visualising scientific trends in a specific research area [47, 48]. For this study, we chose the VOSViewer software. This tool pays special attention to the graphical representation of bibliometric maps. It offers the functionality to display large bibliometric maps in an easy-to-interpret way [49]. The latest version, 1.6.18 of VOSViewer, containing new features, was released on 24 January 2022 [50]. The data export from the databases was done in the form of quotes acquired by the CVS format and read into the VOSViewer.

Three basic scientometric techniques were practical in this chapter. These are co-author analysis, co-word analysis and co-citation analysis. The co-author's examination comprises a network of countries/regions and a list of productive organisations. Co-word analysis uses co-occurrences of the search term. The third technique involves the creation of a network of journal, document and author co-citations and keywords. The deployment of these three techniques was as follows. First, each journal's published studies and citations were analysed. Then, the studies were analysed based on the number of sources received. After this database was built, the co-occurrence of the article's keywords was investigated, as well as the authors and co-authors. Other data were examined, such as the regions and countries of the AEC industry that showed resilience during the fight against COVID-19. With the help of graphical representation based on colour categories, the scientometric analysis allowed for an understanding of the different relationships between the specific data of the AEC industry during the COVID-19 fight.

2.5 Thematic Analysis

Based on Fig. 1, the process of this study must go through the analysis of themes. To do this, a thematic analysis is conducted. It is an approach based on a process of identification, analysis, and reporting of data in the form of a qualitative database. This method is based on the conversion of scattered and varied data into fruitful and detailed data. In the first instance, we went through each article and for each one the overall theme is identified. Secondly, the categorisation and ranking of the themes covered is based on an examination of the body of the text. At the end of this section, the case studies, tools, and frameworks of great importance in the fight against COVID-19 have been revealed.

In the last part of this section, a gap analysis was conducted to discover future research directions. According to Sandberg and Alvesson there are three modes of gap analysis, namely confusion, neglect, and enforcement. Confusion gap is the identification of some form of confusion in the existing body of knowledge which is the focus of this strategy. The neglect analysis considers three versions of identifying a neglected area, an under-researched area, and a lack of empirical support. The application gap is an area of the existing body of knowledge where the lack of an accurate theory or distinct perspective in a particular research area is targeted [51].

3 Results of Scientometric Analysis

This section will analyse several bibliometric properties of the collected article base to highlight good experiences in the AEC industry during COVID-19.

3.1 Number of Publications and Citations

As soon as COVID-19 appeared, the number and type of publications related to this topic evolved between 2020 and August 2022. This evolution by year and by type of publication is presented in Fig. 3.

There has been a remarkable increase in research associated with this topic. From the date of the appearance of COVID-19, the publications of all types have increased. The maximum number of publications is identified in 2022 with 127, even if the data is collected until August. At this point, it is worth noting that the subject of COVID-19 represents an effective rate in the overall publications produced between 2021 and 2022 in the AEC [52]. For this reason, the documents considered for this chapter are topical. In this period of COVID-19, most of the publications are journal articles. In 2022. This can indicate that the information collected and analysed is reliable, which increases the quality of the study conducted. The total number of citations between 2020 and 2022 has experienced a visible increase of 1027 citations (Fig. 4). The year 2022 experienced the maximum number of citations. According to the Springer database, the number of books and chapter books has significantly increased in 2022, with more scheduled for 2023. This corroborates the previous hypothesis that defending the AEC industry against COVID-19 is a topic of great interest, especially in late 2022, where capitalisation of data, studies, frameworks, and approaches makes sense.

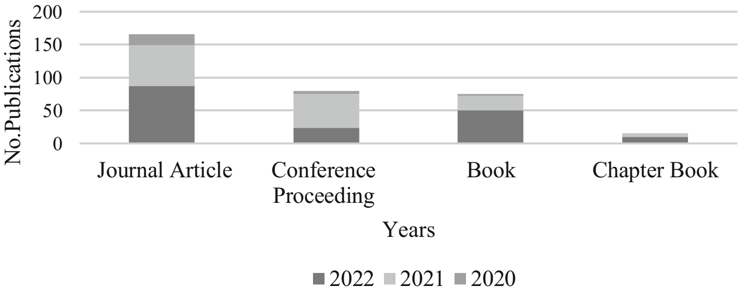


Fig. 3 Evolution of number and type of publications

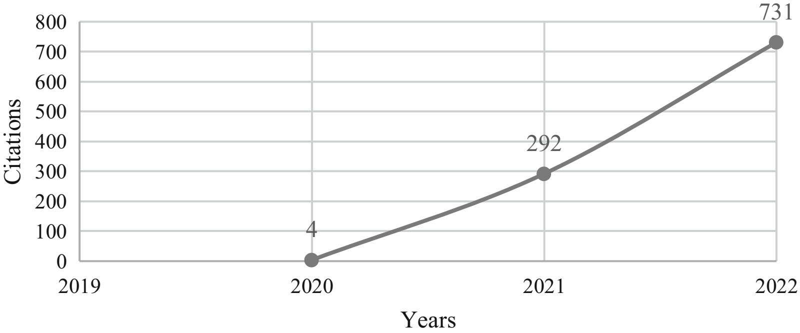


Fig. 4 Evolution number of citations

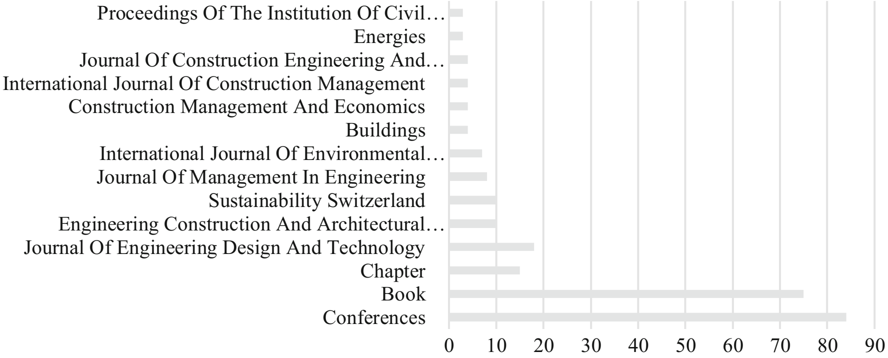


Fig. 5 Publication sources

3.2 *Publication Source*

I was looking at the sources of publications. This topic was addressed through journal articles, conference papers, books, and chapters. A total of 166 journals, 84 conference papers, 75 books, and 15 book chapters were identified.

Figure 5 illustrates the several types of publication sources. Because the number of journals is large, it only includes journals hosting at least three articles.

The Journal of Engineering Design and Technology reports first place with 18 publications, followed by Engineering Construction and Architectural Management with ten publications and 8 for Sustainability Switzerland. The IOP Conference Series Earth and Environmental Science and the International Conference on Construction and Real Estate Management (ICCREM) are at the top. These journals, conferences, and books are all indexed and published by famous publishing houses such as Elsevier, Emerald, ASCE Library, Taylor Francis, and MDPI. It is found that 51 conferences based on 84 were published in 2021.

3.3 Origin of Publications

The effect of COVID-19 is widespread on a global scale. To understand the response of countries' AECs to this pandemic, the identified publications were linked to their countries represented by the institution of the corresponding author. A total of 62 countries with academic structures participated. Forty-four of these specified countries has at least two publications.

The USA, the United Kingdom, and China are the leading countries in research on this topic. It is remarkable that in addition to these developed countries, other developing countries such as South Africa, Nigeria, and Chile have paid attention to this topic. Therefore, the interest in this AEC fight is international. Consequently, the resilience of the AEC industry is different from country to country, and the development of countries contributed massively during this fight. The distribution of documents by country is schematized on a world map in Fig. 6.

3.4 Keywords Analysis

In scientometric studies, keywords represent the central element indicating the topics that have been addressed in a specific field. The minimum occurrence of a keyword was set at 5 to reveal the main keywords that appeared during this fight. Initially, 25 out of 764 keywords reached the defined threshold, and elements with the same semantic meaning were eliminated. Finally, we obtained 20 keywords. These are mapped in Fig. 7 using the VOSViewer software, creating a keyword co-

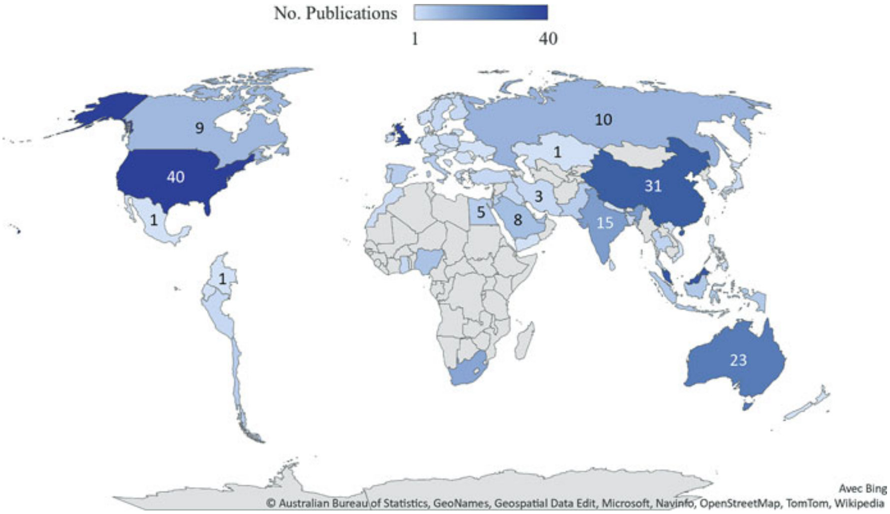


Fig. 6 Origins of publication

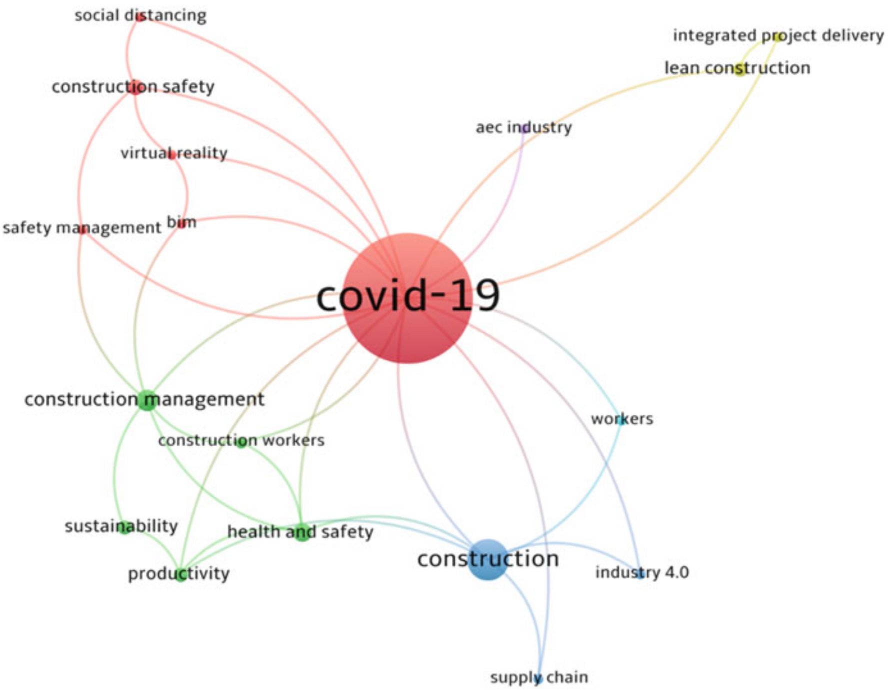


Fig. 7 Top keywords

occurrence network. This network visually represents the number of occurrences of a keyword based on the size of the node and the degree of co-occurrence between the keywords by the thickness of the link.

According to the results obtained, "Construction management," "Construction safety," "Health and safety," "Lean construction," and "Sustainability" are the most used keywords during this period. This shows that safely managing construction sites was a critical challenge. The occurrence of the keywords does not specify the nature of the constructions; however, the qualitative analysis conducted shows that in addition to the projects launched before COVID-19, the construction of hospitals was faced with the same challenge but also with the timeframe, which is tight due to the rapid evolution of suspect cases [52]. It is evident from the figure that managerial approaches such as "Lean Construction" and other technological processes such as "Building Information Modelling (BIM)" and "Virtual Reality" take place in the top 20 keywords. According to the mapped links, BIM is being exploited in construction management in the pandemic phase. The LC is directly linked to integrated project management. It follows from the links created between the keywords that virtual reality is deployed for the benefit of social distancing and by creating a framework with BIM for construction management. At this stage, it can be concluded that these are approaches deployed to arm the AEC industry against COVID-19. These keywords represent relevant aspects containing information to be identified and

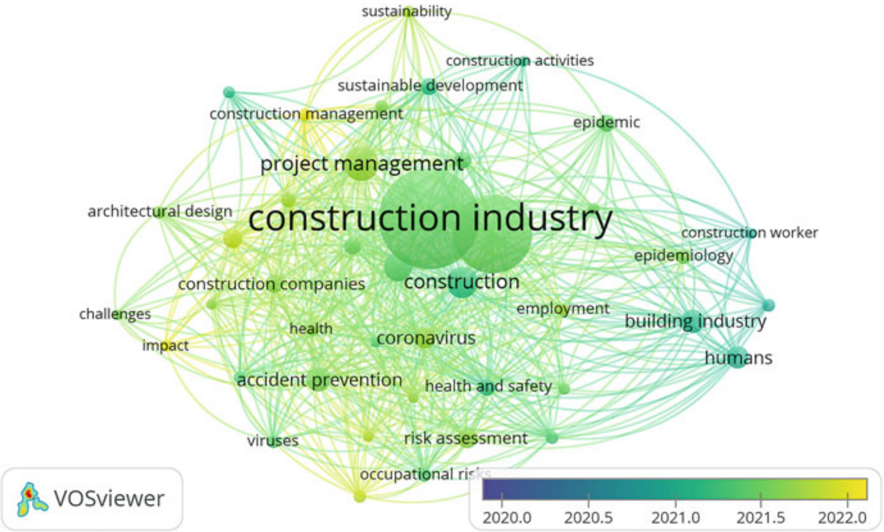


Fig. 8 Keyword co-occurrence network

analysed later. A quick look at the years of publications reveals a growing interest and a concentration of keywords meeting the threshold in 2022.

3.5 *Co-occurrence of Keywords Analysis*

The chronological view of the keyword co-occurrence network presented in Fig. 8. highlights the developing and newly emerging keywords in the field. In addition to identifying these keywords, this figure shows the new links recently created and their development over time. “Architectural design,” with 11 occurrences, is one of the keywords that has attracted the interest of researchers. The architectural and engineering design appeared unable to cope with the changes brought about by COVID-19, especially when all professional and academic activities became remote. “Developing countries,” “Built environment research,” “Energy efficiency,” and “Construction resilience” are also newly emerging research areas. If we take the interaction of these terms with the main keywords, these recently introduced areas may be the future trends. The common factor between these words mentioned in this figure is that they include multidisciplinary topics and represent new challenges for the AEC industry and its trades.

3.6 *Author Co-citation Network*

Co-citation is the frequency with which other documents cite research. Co-citation analysis is a technique for studying the cognitive structure of science [53]. Papers cited in other recent publications tend to have relevant topics, so co-citation analysis can help identify hidden patterns and research topics in the field under investigation [54]. Analysis of the journal co-citation network, the author and paper co-citation network, and one of the avenues for identifying the data.

In scientific research, collaboration ensures a considerable improvement in the productivity and quality of scientific papers. Knowledge in each field is transferred by authors when they are cited. The authors' co-citation network makes it possible to visualise and map the intellectual skeleton of knowledge by showing the frequency with which two authors are cited together [55]. This analysis identifies collaborative issues between researchers to unveil influential authors and even evaluate the research community. To analyse co-authorship and given that this period is short and many recent articles, we include authors with at least two publications without any condition on the number of citations. We set the maximum number of authors per article to 10. The author citation network is illustrated in Fig. 9. As mentioned in this figure, each node represents an author, and each line describes his interaction and collaboration with others. The size of the nodes represents the number of co-citations. Therefore, out of a total of 838, 13 authors are selected based on this threshold. The colours of the links change from blue to green to yellow, indicating the year of link creation between 2020 and 2022. The authors mentioned are divided into three categories, three of which contain two authors and six include only one author. Based on the results obtained, the maximum number of documents published in this period is six recorded by Rahman r.a. with a total of 43 citations. The maximum number of citations is registered in the name of Araya f., with 71 citations and three articles. In the second place, we find Fauzi m.a. with four publications, followed by the other authors with three publications. The relevant link between the author and the one established between Rahman r.a. and Fauzi m.a.

Following this network (Fig. 9), the five most cited authors are respectively: Araya f. (Frequency = 71, Chile), el Adaway i.h. (Frequency = 59, United Kingdom), Kermanshachi s. (Frequency = 53, USA), Amoah c. (Frequency = 45, South Africa) and Simpeh f. (Frequency = 45, South Africa).

The first five most cited authors are of different origins. Remarkably, they come from other continents: Europe, the two Americas, and Africa. However, authors from different countries join the list as the list continues. This diversity in countries shows that the exploration of the AEC industry during COVID-19 was global. The burst intervals of these authors are concentrated between mid-2021 and early 2022, which shows that their influences in this and other areas continue in the coming years.

3.7 Active Countries

As mentioned above, the subject matter has an international dimension, attracting the attention of several authors from different continents. This section aims to identify the responsiveness of the countries participating in the research. The

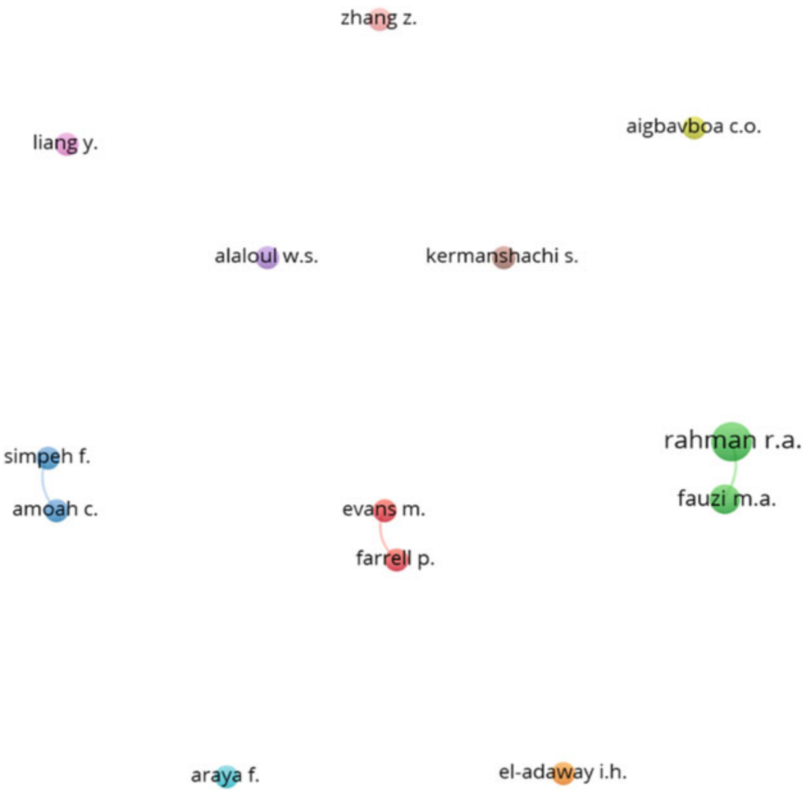


Fig. 9 Science mapping of the authorship

Table 1 Countries cluster analysis

Cluster	Countries
1	Chile – Italy – Pakistan – South Africa – Spain – United Arab Emirates
2	Canada – Egypt – Hong Kong – United Kingdom – USA
3	India – Indonesia – Malaysia – Saudi Arabia
4	Australia – Nigeria – Singapore – South Africa
5	China – Russia

thresholds for inclusion are at least three papers for each country without any condition on the number of citations. The threshold set resulted in a total of 21 countries out of 67. The UK, USA, Malaysia, and China are the most productive countries with a total output of 41, 40, 33, and 32 documents, respectively.

Regarding citations, South Africa, Chile, and Australia join the list of top-cited countries. The United Kingdom stands out as the country with strong collaborative links. It is remarkable that once again, the topic is addressed by several countries from different continents. The countries are divided into 5 clusters, as summarised in the Table 1.

Table 2 Most-cited publications

Order	Citations	Title	Corresponding author	Institution
1	85	Early impacts of the COVID-19 pandemic on the United States construction industry	Alsharef et al. [56]	North Carolina State University [USA]
2	55	Modelling the spread of COVID-19 on construction workers: An agent-based approach	Araya [57]	The Technical University Federico Santa María [Chili]
3	53	Ultra-rapid delivery of specialty field hospitals to combat COVID-19: Lessons learned from the Leishenshan Hospital project in Wuhan	Luo et al. [58]	Huazhong University of Science and Technology [China]
3	53	Digital twin and web-based virtual gaming technologies for online education: A case of construction management and engineering	Sepasgozar, S. [59]	UNSW Sydney, [Australia]
4	50	Guidelines for Responding to COVID-19 Pandemic: Best Practices, Impacts, and Future Research Directions	Assaad and El-Adaway [60]	New Jersey Institute of Technology [USA]
5	40	COVID-19 recovery for the Nigerian construction sites: The role of the fourth industrial revolution technologies	Ebekozien and Aigbavboa [61]	University of Johannesburg

3.8 Most-Cited Publications

In scientometric analyses, the number of citations is a critical element that indicates the true impact of a paper. Generally, the topics covered in high-citation documents tend to reveal the research aspects that have attracted academic interest. The Top 5 most cited articles are summarised in Table 2. The data was extracted from the databases mentioned above. According to the table, Alsharef et al. [56], and Araya, F. [57] received maximum citations.

Furthermore, comparing the most mentioned papers in this Table with the authors’ co-citation network listed above, we find that only three authors are found in both rankings: Araya Felipe and Islam H. El-Adaway, and Aigbavboa Clinton. Only the first one is designated as the corresponding author. It can be concluded that there is a strong correlation between citation and publications. The authors’ co-citation network is based on the frequency with which two authors are cited together. In contrast, the analysis of the most-cited publications is based on the individual performance of each researcher and their research area. Remarkably, only one publication in the top 5 cited dates from 2020, while the others date from 2021.

Looking now at the bottom of the top 5 publications, Alsharef et al. [56] map the significant impacts of the pandemic on the construction industry and the good practices and opportunities provided. Araya [57], on the other hand, explored how COVID-19 influences activity at construction sites and consequently deduced corrective actions to minimise the risks. On a different note, Luo et al. [58] summarise the technological and managerial lessons and approaches deployed to build the famous Wuhan record hospitals. In the same vein, a review of best practices and emerging tools for dealing with the pandemic has been analysed in the paper by Assaad and El-Adaway [60]. The AEC industry's revival during the health crisis circumstances was the subject of the study by Ebekozien and Aigbavboa [61]. These authors propose revolutionary technologies in the construction industry to keep construction services running smoothly while respecting health measures and making construction sites intelligent and integrated. As mentioned above, as many articles appeared in 2022, and despite the short duration, they received a considerable number of citations, such as the article by Agyekum, K. et al. [62], and King, S.S. [27], which received 20 and 13 citations respectively. It makes sense at this point to cite the content of the papers of the author with the highest number of documents. Rahman, R.A. totals six papers with a cumulative 43 citations. In his participation with Zamani, S.H. [63], they listed strategies to reduce the impact of COVID-19. With Rani, H.A. et al. [64], a bypass of the critical impacts of the pandemic was made, which are a total of 5. Again, King, S.S. et al. [65], brought the scientific community the suitable approaches to improve the government policies and strategies to push the entrepreneurs to manage the impacts of COVID-19. Their strategy, effectiveness, and interrelationships with all sizes of businesses were validated and evaluated in the paper by Zamani, S.H. et al. [66]. In the same year, 2022, with Radzi, A. R. et al. [67], the relationship between COVID-19 impacts and response strategies was modelled as structural equations [67].

Therefore, when looking at the most cited articles, overcoming impacts based on revolutionary strategies, approaches, and technology tools is the primary concern of the authors of these articles. By linking the results of the keyword mapping with the document co-citation, we can conclude that one of the issues of concern to researchers is how to equip the AEC industry with the tools necessary to be resilient to the COVID-19 pandemic. Looking at the new papers, we find that many are focused on proposing management approaches [68], technological tools [69], frameworks [70], and synthesising the real lessons from this exceptional experience [66]. Other scientific work has pushed the scientific community to follow the achievements of hospitals and infrastructures to support COVID-19 cases. In addition to the professional environment and construction constraints, several researchers have focused on improving web-based learning and flipped learning in academic settings in architecture, engineering, and construction [71]. In the same academic stream, Fang Y. et al. [72] explored the critical factors for the success of scientific conferences with the new distance mode. While [73], valuated the influence of social networks as learning environments on the academic teaching operation of AEC. The situation of this sector after COVID-19 has also taken its place in the scientific discussion. Many approaches to capitalise on have been proposed, such as Building Information Modelling [74], and Lean construction [75]. Remarkably, the scientific focus during the pandemic has shifted from general topics to more detailed, specific topics oriented towards the capitalisation of experience and potential tools for a robust post-Covid-19 recovery. The following section will be dedicated to exploring these categories of subjects.

4 Results of Thematic Analysis

To reinforce the mapping results and answer the research questions posed during this study, we adopt an in-depth analysis of the issues raised during this period. This analysis will investigate the approaches, tools, and frameworks deployed to combat the coronavirus. From the scientometric analysis and the previous citations, we note that the most raised research areas that have concerned the scientific community are technological tools and managerial approaches to keep up the pace of work and pilot strategies for the revival of this industry. These research areas will be the focus of the remainder of the chapter.

4.1 Technology Solutions for COVID-19

This theme category represents all the technology-related elements deployed in this context. The construction sector is an area of great economic contribution, yet it suffers from weak research and development [76]. This situation has influenced the response of the construction industry during COVID-19, especially in the face of lock-in measures [77]. In such a situation research and development in the built environment and its dependencies is imperative [78]. The outcomes of the research allow the identification of innovative strategies and practices to increase construction productivity during the pandemic [79]. In line with this philosophy, the survey conducted by Ravina-Ripoll, R et al., shows that companies with a positive background in adopting digital technologies experience less disruption than those relying on traditional, manual methods [80]. According to [81], the resilience of the construction sector to epidemics and other types of disruption is linked by digital autonomy as a key issue in strategies to adopt and this through the deployment of programming technologies, intelligent services, and front and back-office solutions. The blow of this biological disaster, which is unique in this sense, was too hard, as it did not allow for a perception of the risks, especially in the absence of a history and an institutional repository or manual of pandemic management [82]. Add to this the disruption in human resources. In fact, the response and level of resilience differed between workers according to their gender, familiar situations [83], psychological and mental health, especially with feelings of uncertainty, anxiety, and depression during this phase [84].

As many studies have categorised the most critical challenges as “the requirement of COVID-19 protocols”, “restriction of travel,” and “use of additional safety equipment” [85, 86], and others have cited the critical impacts as “reduction of foreign investment in the construction sector,” “reduction in demand for construction work,” “disruption of the supply chain” and “reduction in the number of public projects” [87]. Despite this disadvantageous situation, this period reveals opportunities of enormous potential, such as “hygiene programmes,” “effective use of technological tools,” and “BIM-based construction” [88]. The levels of digital communication and process automation have again addressed the challenges of the emergence of technology, especially in small and medium-sized enterprises [89]. According to the Romanian experience presented in [90], on-site organisations suffer from low utilisation at the worksite level and quite well during the design and engineering phases. According to the survey conducted during the article, the pandemic context has accelerated the digitalisation of processes and information technology such as 3D modelling and BIM. As a digitised process to provide added value throughout the life cycle of a construction [91]. BIM has helped construction professionals to comply with pandemic rules and measures such as social distancing through pre-simulation of site activities using drone surveillance and 360° videos [92]. In the same sense, the fourth dimension (BIM 4D), a connection of temporal analysis to the 3D digital model, is used as a solution for managing workspaces and integrating physical distancing in 4D planning [93]. Surprisingly, COVID-19 and labour constraints have impeded the digitisation of the construction industry [94].

Among the technologies that have shown significant effect during this crisis reported by Elrefaey, O et al. is artificial intelligence (AI) and Radio frequency identification (RFID) which have been deployed to compensate for the absence of human resources, tracking equipment, supply chain materials by quickly reporting information to the manager [92]. AI has helped monitor and control visitors’ fever and temperature to work sites using Bluetooth Low Energy and cloud coordination [95]. RFID creates frameworks for use with other technologies such as drones, especially in the data acquisition phase and real-time monitoring of construction sites to plan interventions and adjust deadlines [96]. As well as with BIM. Indeed, the outputs of drones and RFID constitute one of the main inputs for creating digital models by BIM software [97]. Underpinning the Global Positioning System (GPS) deployed in this context, the effect of the technology goes beyond the positive impact on collaboration to the remote control of worksites as a safety measure to embody both collaboration and risk reduction during the pandemic [98]. Rapid response codes are also widely used for site access control, easy tracking of cases, potential contacts, travel history, individual health status, and preventing virus spread on construction sites [99]. Construction automation and robotics have also been used for installations, speeding up construction, catching up on lost time, and autonomous operation of sites [100].

Its technologies have proven to be effective in tracking the spread of the pandemic in the workplace. Recognising their positive effects on armament and creating an opportunity for adaptation of the AEC industry, Yang Y et al. named these technologies mentioned above as health and safety (H&S) technologies [101]. Through the benefits of the technologies. In this context of synthesising good practice, it is worth noting that the pandemic demonstrated the failings of the sector in health and safety, such as the provision of personal protective equipment (PPE) [102]. This was in addition to the other challenges of ignorance of COVID-19, implementation of safety measures following the COVID-19 safety protocol at project sites, and adherence to social distancing rules [103]. Despite the design, implementation of SMS prevention and awareness interventions for construction operators [104], the deployment of machine learning and mixed reality to predict COVID-19 impacts and violations on monthly employment, and the use of stochastic simulation to predict spread within work sites [105], the number of Occupational Safety and Health Administration (OSHA) citations are unfortunately decreasing in an increase of monthly employment and productivity [60, 106].

The impact of COVID-19 has disrupted all actors, all the life cycle of construction, and all trades. Moreover, even some measures of the sanitary protocol, such as work reorganisation and disinfection, have been shown to harm the economic performance of construction projects [107]. For example, they are looking at the trade of quantity surveyors, which plays a crucial role during the whole life cycle, from pre-construction to post-construction. The criticality of the work implies periodic visits to construction sites [108], hence the positive impact of specific technologies such as video inspection [109]. According to [110], contractors have estimated a decline in business due to pandemic prevention and predict that a better recovery depends on increased knowledge of construction management and internal monitoring [111]. To this end, technology will be essential in driving this recovery and coping during this or similar delicate situations [112]. No one can deny that the owner's work is too critical but has been too disrupted during this phase. This crisis has caused some project owners to postpone the award of contracts or tenders because of the imbalances in the prices and budgets allocated [113]. As mentioned above, the technology with the various tools has given a new lease of life to the AEC industry to combat COVID-19. However, Ling, FYY, et al. question the ability of project owners to increase project budgets, especially in the presence of many of the economic impacts of COVID-19, to allow companies to have margins to acquire the expensive technologies [114]. It is important to remember that the financial challenge was one of the most critical concerns of the scientific and professional community [115]. As mentioned earlier, the construction life cycle has become too blurred, and the pandemic occurs when construction projects reach different phases. Projects in the delivery and acceptance phase were not far from this situation. In this respect, virtual factory acceptance testing replaced physical testing [116]. This testing is done remotely with the highest quality assurance based on communication, connection, and technology [117]. A vFAT process was developed by Peiris S and De Silva, N to adapt to construction project acceptance and create an opportunity for construction practitioners to save time, comply with safety protocol, and ensure smooth validation testing of ready-built structures [118].

Technology was not only a means to ensure the continuity of all phases of construction and to guarantee health and safety at work, as mentioned above, or comfort in private and professional life, workers' welfare, and promising career management [119]. But also, a catalyst and a weapon for countries to strengthen hospital infrastructure. To hinder the spread, the challenge before governments is to ensure the availability of isolation spaces and facilities for treating coronavirus cases [120]. Among the solutions chosen to strengthen isolation spaces are the refurbishment of existing hospitals [121], isolation in temporary cabins [122], and the construction of new hospital infrastructure [123]. The success of these seclusion solutions has been conditioned by the availability and proficiency in technological tools, as well as the efficiency of communication and information sharing processes and, of course, the use of collaborative tools from information technology such as BIM, cloud, and mobile computing [124]. It is imperative to shed light and deduce good practices from the fantastic experience of the ultra-fast construction of hospitals in Wuhan. An array of technology-creating frameworks with other construction methods were modelled to deliver two hospitals in record time [125]. BIM for design, virtual reality simulation, mobile BIM, BIM cloud, 5G, edge computing, a product, organization, and process (POP) modelling, prefabrication, and production technology all were brought together to be used in the creation of an isolation space under the name of Leishenshan Hospital of about 80,000 square meters [58].

4.2 Management Frameworks for Health Technology

To align with the requirements of COVID-19, the companies' managerial organisation and practices were shaped, with the underlying measures put in place including restricted and irregular access to the site, the provision of office and site staff support, improved hygiene, and social distancing protocol, investigation, and mitigation of contractual risks, self-isolation, and enhanced site security [126]. One of the new practices in work organisation is remote working [127]. Increased awareness has proved necessary for the whole value chain and life cycle, especially regarding productivity management, health, and safety, and not forgetting the objectives of sustainable development [128]. The construction management process has proven unable to cope with pandemic disruption and environmental change [129]. In this context, the study conducted by Rokooei S. et al. highlights the need to improve the preparedness of entities and the perceptions of construction professionals over time to manage the concerns raised [130]. Any improvement must be articulated on workforce qualification, administrative support, education, and training without forgetting safety and technology deployment as shown and to successfully work remotely [131]. However, the effect of the pandemic on the organisation differs according to the size of the company [132]. Underpinning this distinction is that government pandemic response strategies differ from small to medium-sized enterprises. In their paper, Zamani et al. report on potential governance strategies for different sizes of CEA firms. For the first category, diversification of the existing supply chain and allocation of support to the digitalisation of construction projects. For the second category, the same article reports that enterprise capacity management and information and labour management are effective strategies [133]. In this sense, Tisha Meriam Cherian has highlighted the linkage and positivity that agility creates as a mode of management and collaboration with supply chain resilience and information technology to ensure product performance [134].

However, some companies deployed actions to remain productive during the COVID-19 phase, but most faced difficulties in controlling and mitigating the impacts. In this regard, Raoufi and Aminah Robinson identify a non-exhaustive and prioritised list of actions affecting the construction organization during this and similar pandemics [135]. One of the organisational solutions opted for, especially at the level of human resources management, is adopting a strategy derived from the manufacturing industry and the Lean 6 sigma tools. This is shift work [136]. The human resources were distributed as work teams to accomplish the tasks at the sites and mitigate the spread of COVID-19 [137]. Because of the nature of the production flow for construction projects, allocating labour requires remarkable attention. To this end, Wang et al. [138] propose a model for optimal, sustainable labour allocation consistent with pandemic prevention and control policies. The development of the model took into consideration alternative work schedules, the availability of construction crews, and the overall priority of the project [138].

The managerial component was not only restricted to breathing new life into the organisation of AEC enterprises and the good management of teams and the supply chain, but also good practices and managerial approaches were deployed for the reinforcement of hospital infrastructure and the creation of isolation units to accommodate COVID-19 contaminated cases. Despite the obstacles that hinder its development in the market, the limitations of use, the weakness of the adoption mechanisms, the prefabrication technology has been able to attract considerable attention from professionals and researchers worldwide, due to its decisive role in the construction during the pandemic and the fight against its spread [139]. In addition to the reduction of construction time, the possibility of conducting controls, quality assurance, noise reduction and the respect of environmental and sustainable aspects, the production and manufacture of prefabricated construction create added value [140]. As the prefabricated elements are assembled in the verified environment of the factory, designers can hunt for any problems before entering the construction site [141]. The modular structure, as it is called, promotes mutual respect and consistency between design and construction, as the flow of communication and coordination is improved by information technology [142], and the growth in the field of industrialisation in terms of eliminating waste and meeting the triptych of cost, quality and time through Lean tools and its derivatives [143]. As mentioned by Navaratnam et al., that despite the restrictions and limitations of transportation and travel, pre-construction was not affected by the pandemic and in addition it preserved the future and growth of construction [144]. Off-site prefabrication and modularisation were suggested in the context of COVID-19, to both scale up the productivity of residential, commercial, and patient care buildings. The phenomenal construction of Wuhan Leishenshan hospital was based on this technique by creating industrialised modular composites [145]. Notably, on a global scale the modular structure was present in the emergency plans of many countries. In addition to China, modular units and companion hospitals and other temporary facilities have been installed in Italy [146], UK [147], USA [148], Australia [149], Georgia [150], Canada [151], Romania [152], Morocco [153]. Given the potential offered by modular construction much research has been conducted into the development of new units and forms. Lightweight modular units with cold-formed steel frames are proposed [154], to reinforce the variants usually used [155].

The mapping during this study revealed the circulation of an approach considered by the scientific community as a managerial, organisational, and sustainable revolution in construction projects. This is Lean Construction (LC). The deployment of this approach was on two main levels. The first level is focused on mitigating the critical impacts of the pandemic revealed above by developing workforce and supply chain management frameworks. The second level collaborates with other approaches to accelerate the construction and delivery of isolation cabinets during the COVID-19 phase. In the face of the exponential spread of the pandemic, no one can deny that the role of the workforce and its commitment to adhering to health protocol and aging on the proper execution of tasks at the construction sites is indispensable. To this end, Jiang et al. [156] proposes an LC-based workforce management framework to regulate mobility and on-site transport and consequently improve productivity and resource efficiency. The study also proposes and includes the implementation of new extensions of LC, which are the “Worker’s Home:” and “Lean Work Package” [156]. According to the growing literature on LC, this philosophy, which originates from the Japanese Toyota Production System (TPS) culture, is deployed throughout the life cycle of construction, from engineering to demolition [157].

One of the critical steps in the primary construction phase is supply chain management. According to the study by Le et al. [158], LC tools such as Virtual Construction Design (VDC) and Last Planner System have enabled the construction site to be equipped with operational and efficient tactics for the proper management of the seven aspects of the supply chain which are lean supply chain management (SCM), supply chain integration (SC), SC standardisation, SC problem solving, SC information sharing, SC flexibility and SC sustainability [158]. The second level of LC integration was a framework between this approach and prefabrication technology to improve production, assembly, and monitoring work [159]. Remarkably, LC offers collaborative links with several approaches. This was clear in the literature that emerged during COVID-19. Organisational links are with integrated project delivery (IPD) and global integrated delivery (GID) [160]. In addition, the coherence and alignment between LC culture and BIM.

The organisational aspect is not restricted to managerial approaches and reforms or the financial and commercial part but also affects the competence and behaviour of the contractor. COVID-19 has emphasised the need for critical competencies in the contractor to manage such situations. In this regard, Deep et al. and other researchers analyse and summarise the most vital competencies, including site security management, leadership skills, technical skills, and supply chain disruption management [161]. A sense of collaboration was a requirement and a critical factor in the success of any response. The successful cooperation includes the Wuhan pandemic prevention and control, characterised by arrangements, facilities, and flexibility for all government and non-government stakeholders [162]. In this sense, we note the added value of information technology in promoting and facilitating collaboration and exchange among stakeholders.

4.3 Educational Technology

Like the professional world, training, teaching, and academic activity, in general, have been disrupted by COVID-19. The continuity of school and scientific events has overtaxed governments, universities, and schools and forced them to switch to virtual and remote activity. The role of technology has been decisive in saving the activities of students, teachers, and researchers. In this sense, the database of scientific production identified for this study contains a total of 4 documents divided into three articles and one conference paper dealing with the added value of information technology and other good practices to mitigate the impacts of COVID-19 on academic activity related to the AEC industry. The summary of these papers is given in Table 3.

Table 3 Education technologies papers

No	Author	Brief overview	Year
1	Fang et al. [72]	As are essential for industrial and academic development, successful virtual conferences are necessary. An analysis is made of one of the most famous conferences in the AEC industry’ the International Group for Lean Construction. The key factors critical to the success of this conference are information and communication technology and process design and control. The option of virtual reality was also proposed.	2021
2	Boton [163]	This article explores the experience of teaching the BIM module online. Technology deployment as a medium has made the flow of information effective, namely video clips, clouds, and collaborative platforms.	2022
3	Sengupta et al. [164]	This paper presents a deployment of an internet-based virtual classroom based on virtual reality. Virtual construction site management is used as a pedagogical and knowledge transfer tool.	2021
4	Ogunseiju et al. [165]	This study shows the pedagogical value of mixed reality in a learning environment for sensing technologies in engineering and management of the construction industry.	2021

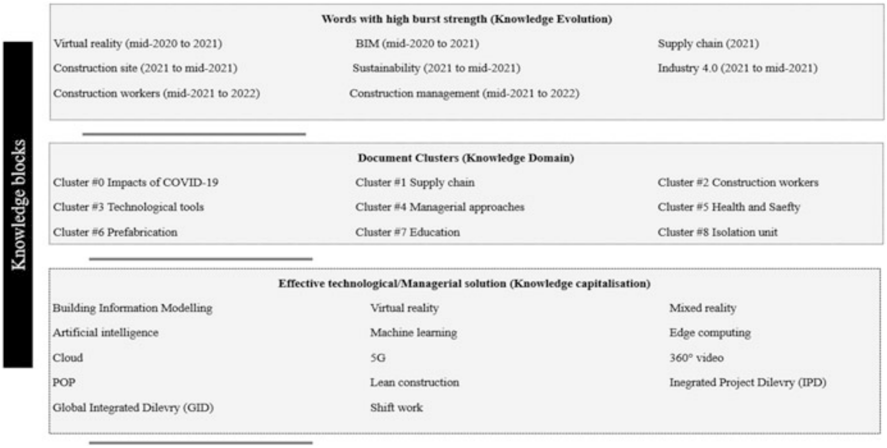
Distance learning has been complicated, especially in a field known for its low technology use. Fortunately, the deployment of some technologies has saved the situation. According to the table, communication and information technologies, virtual reality, cloud, and mixed reality are the tools adopted in the academic and scientific environment during COVID-19.

5 Discussion

The comparison of the results shows that the Journal of Engineering, Design, and Technology had the highest number of publications. While the most cited publication is in the "International Journal of Environmental Research and Public Health." The co-authorship analysis shows that Alsharef et al. [56] had the highest number of citations and Rahman, R.A. won more publications in this topic and during this phase. As this is the only systematic literature review, we do not have a way to compare the results with previous ones. There are no broad categories identified in the keywords. COVID-19, AEC industry, and Project management are the most used keywords in related works, which confirms the need to address this topic and conduct this summary. The added value of this study is also to investigate the technological trends that will accelerate the digital transformation of this sector. This study can be used to identify the most important lessons, the leading countries, and the most effective tools to strengthen the sector's resilience to the future pandemic.

This study's results reveal a global awareness of the role of technology and its impact, especially during the COVID-19 health crisis. These results justify the need to address the research question of identifying direct and indirect solutions deployed by the AEC industry to combat COVID-19. These solutions have been shown to fall into two broad families: those arising from information technology and the industrial revolution 4.0 and others organisational and managerial. In several contexts of use, the technological tools reinforce the latter by creating frameworks. The thematic analysis has identified three aspects of adoption of its solutions: the first aspect is to maintain the continuity of the engineering and construction processes and mitigate the impacts of COVID-19 on the production chain. The second aspect is integrating these solutions to design, reorganise and build new hospitals for isolation and reception units for infected cases. The third component is the introduction of the technologies into academic and scientific research activities.

The keywords are significant indicators of the topics that interest researchers. The scientometric analysis shows the hot critical keywords of concern to researchers in the construction industry in the distinct phases of the fight against COVID-19. This analysis argues from the occurrences found the effect of the technology at different scales. The outputs of the keyword co-occurrence analysis and the documents, in addition to the themes resulting from the thematic analysis, are exploited, and ordered to build blocks and levels of knowledge. This knowledge base, which is the result of this study, is composed of three blocks. The first concerns the



Knowledge blocks

Words with high burst strength (Knowledge Evolution)

Virtual reality (mid-2020 to 2021)	BIM (mid-2020 to 2021)	Supply chain (2021)
Construction site (2021 to mid-2021)	Sustainability (2021 to mid-2021)	Industry 4.0 (2021 to mid-2021)
Construction workers (mid-2021 to 2022)	Construction management (mid-2021 to 2022)	

Document Clusters (Knowledge Domain)

Cluster #0 Impacts of COVID-19	Cluster #1 Supply chain	Cluster #2 Construction workers
Cluster #3 Technological tools	Cluster #4 Managerial approaches	Cluster #5 Health and Saefty
Cluster #6 Prefabrication	Cluster #7 Education	Cluster #8 Isolation unit

Effective technological/Managerial solution (Knowledge capitalisation)

Building Information Modelling	Virtual reality	Mixed reality
Artificial intelligence	Machine learning	Edge computing
Cloud	5G	360° video
POP	Lean construction	Inegrated Project Dilevry (IPD)
Global Integrated Dilevry (GID)	Shift work	

Fig. 10 Knowledge blocks on AEC industry solutions to combat COVID-19

evolution of knowledge indicated by the most cited words, "Knowledge Evolution (KE)" The second block contains the documentary results creating the "Knowledge domain (KD)." The third block comprises the foundation of the "Knowledge capitalisation" block through grouping practices and solutions that have promoted the AEC industry in this pandemic context. The knowledge blocks are grouped in Fig. 10.

The first block highlighted the keywords that received more bursts with their active periods. From this block, it follows that the researchers' concerns are around the implementation of Industry 4.0 technology and tools to manage construction in such a way as to ensure sustainability by acting on the workforce and the supply chain. In the second block, the knowledge areas are structured into 8 clusters. These clusters summarise the interventions made by the researchers to address the concerns listed in the first block. The efforts of the AEC industry during this COVID-19 period have highlighted the potential of several technologies and management approaches that can be used alone or in linkage to help the sector cope with the impact of this pandemic. Capitalising on these solutions is essential for future resilience (see block 3 of Fig. 10). Identifying and exploring the knowledge base, areas, and best solutions adopted during this hard struggle helps to understand past and recent scientific interventions and to map out those to come.

In this regard, the period after COVID-19 should be explored in two phases. Firstly, there is a need to capitalise on this experience and standardise actions, tools, and good practices to deal with it in the future. Secondly, the search for mechanisms to ensure a good recovery in the post-COVID-19 period. In this sense, some studies have considered the recovery of the AEC industry and the mechanisms for recovery. As mentioned during the development of this article, among the parts that the uncertainties of COVID-19 have impacted is the supply chain, which requires a more mature level of resilience. In this post-pandemic perspective, Osunsanmi et al. focused their work on modelling a resilient supply chain from the adoption of Construction 4.0 technologies [166]. The construction-related Sustainable Development Goals (SDGs) were threatened during COVID-19. The period after this virus is critical and requires a specific redesign [167]. Again, Industrial Revolution 4.0 technologies are proposed to help achieve the SDGs in the intersection with the construction sector at this time of recovery [168]. From the perspective of Nassereddine et al., the resilience of the AEC industry is equivalent to the decentralisation of the workforce and the integration of data in a process that goes through eleven steps deploying technology through BIM, as well as LC that provides flexibility, agility, and visual and effective communication between stakeholders [169].

6 Conclusion

In this context of declining cases of covid-19 and the resumption of most activities and economies, there is a need to understand, explore and capitalise on the experiences gained during the fight against this virus. The AEC is one of the most critical industries with an important place in national economies. This study presents a detailed mapping, and thematic analysis of the issues and solutions deployed by this sector since the first case of COVID-19 was registered internationally. 101 documents from 272 published between 2020 and August 2022 formed the documentary base for conducting the scientometric analysis. This search highlighted the lead countries and institutions, the keywords and hot topics, the most productive authors, and the most cited journals. Knowledge structuring is derived from the results found in the form of three knowledge blocks: knowledge domains, knowledge evolution, and knowledge capitalisation. This last block summarises the solutions chosen to deal with the virus. These are primarily technological solutions resulting from the technological revolution with managerial solutions. This package of approaches and tools is robust because they can be deployed in linkage to cross the impact set and produce integrated, sustainable, quality constructions.

The review also identified avenues for further research into the AEC industry to strengthen the economic position of this sector to make it more resilient to a pandemic or similar disruptions. Although some research has examined the issue of post-COVID-19 resilience, there is a solid need to capitalise and carry out more synthesis studies, strategy development, and even rethinking current modes of providing construction with the necessary means to be more rigid and resilient in the future. Similarly, longitudinal research and case studies on country categories, specific experiences, and solutions can provide reliable and more tailored guidance for contingency planning and sequencing of construction productivity despite the disruptions that other pandemics might bring.

Researchers and practitioners can further explore AEC industry practices and performance measures in the context of emergencies and other situations. As well as further explore the tools and promising approaches identified in this study. The implications of this study are exploitable even in the normal case and are in line with global efforts to digitalise and position the AEC industry in the Industrial Revolution 4.0. Although this work has extended the coverage of the databases used (Scopus, Wos, and Springer), it has limitations. The results depend entirely on the contributions provided in scientific papers, whereas in such an emergency, countries' experiences would also appear in official documents and media. Despite these limitations, this research expands the body of knowledge on the AEC industry's expertise with COVID-19. Therefore, it will be a valuable reference and guide for academics interested in the construction industry's improvement, performance, and resilience.

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Deep Learning for Combating COVID-19 Pandemic in Internet of Medical Things (IoMT) Networks: A Comprehensive Review

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1 Introduction

The rapidly advancing communication and sensing technologies enable the IoT network to interconnect several physical objects, leading to the emergence of numerous IoT applications such as smart home, smart healthcare, smart transportation, and smart environment monitoring, among others [45]. On the IoT network, satisfying the latency, traffic reduction, privacy, and bandwidth requirements of IoT applications is a significant issue posed by the IoT applications' quick response to data [5, 98]. For instance, the smart healthcare application requires solid security and privacy for patient data, rapid response to the emergency status, and high bandwidth for uploading the enormous amount of daily sensed patient data across the IoT network [40]. These needs cannot be met by the current IoT network because to bandwidth limitations, inevitable delays, and the high cost of the massive amount of uploaded data [47]. These issues prompted Cisco to develop fog computing. Fog computing is an extension of cloud computing that uses edge devices to do computation, storage, and analysis locally between smart end devices and cloud data centers. It delivers intelligence and processing near to the data source. Therefore, Consequently, decision making at the fog computing layer can create a quick response from smart end devices instead of data transmitted to the cloud platform for decision that will takes a long time especially for real time applications [43].

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Adapted machine learning (ML) techniques were utilized to identify infected individuals based on their unique traits. Tumor detection uses machine learning algorithms such as multilayer perceptron and Naive Bayes [82]. The photos are initially preprocessed with preprocessing techniques. Then, extraction of features is conducted using a gray level cooccurrence matrix (GLCM). Finally, images have been classified using the multilayer perceptron and Naive Bayes methods. Support vector machines [7], multivariate logistic regression [39], and artificial neural networks [34] have been used in the classification of Parkinson's disease. All of these techniques have achieved disease classification accuracies greater than 90%. Due to the availability of a large number of rapid devices for the collection, analysis, and storage of enormous amounts of data, machine learning approaches have been widely utilized in experimental diagnosis. ML approaches can be applied efficiently in numerous healthcare applications, including as disease discovery, recognition, diagnosis, drug production, medical picture analysis, and intelligent record administration [17]. As machine learning is used for disease diagnosis and prognosis, it can potentially uncover disease trends [85]. Support vector machine, regression, random forest, and k-means have been used to tackle the global pandemic. Though ML has shown usefulness in categorizing health records, identifying a disease, collecting data, etc., some systematic approaches have not yet been implemented due to irregular data, diversity, absence of recognizing tools, temporal dependence, not using entire medical datasets, etc. To mitigate these constraints, feature engineering is approached by leveraging human creativity. However, these flaws have been exacerbated by a number of health principles utilized in information simplification. In rare instances, pharmaceutical works may need to be conveyed in unusual ways. This difficulty can be determined using an improvised example of the health composition. Nevertheless, supervised models cannot predict the most recent models. Nonetheless, representation learning can be used without difficulty to extract required data while creating predictors. Among the various approaches of representation learning, a deep learning (DL) method plays a crucial role, has been demonstrated to be a simple strategy, and is composed of numerous nonlinear variations. A deep architectural design makes DL approaches the superior accurate models for driving massive health datasets, such as classification and processing medical images [72]. DL approaches are an effective and popular methods due to great performance, human-free characteristic mining, and no engineering gains. DL, a well-known AI research area, offers end-to-end algorithms to reach guaranteed outputs with input data without manual feature extraction [63]. DL is increasing prominence in image and video recognition. DL is used in NLP and speech recognition. DL's structural architecture can be used in computer vision and image processing to store permanent learning systems and complex data with shared features. DL can construct attribute representations from raw pictures. DL increases a health organization's ability to detect superior outcomes, expand the reach of an infection, and apply substantial rapid medical images [68]. The NCOV-19 DL forecast plays an essential function. Several researchers have ap-plied DL to clinical diagnostics with improved results. Examples of DL approaches include tumor categorization recognition, prostate segmentation, nodule classification, etc.

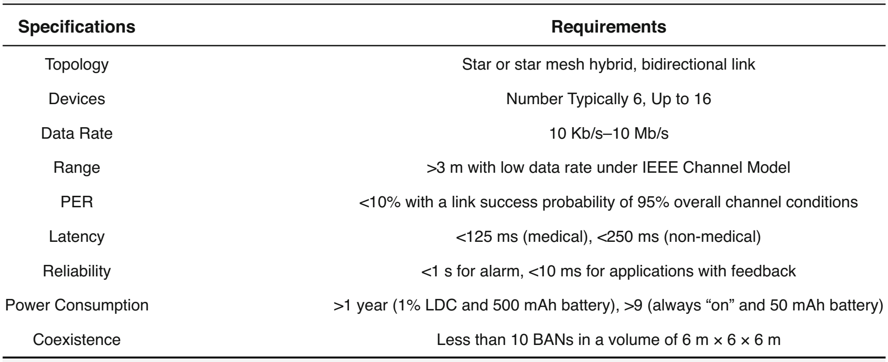
In addition to skin cancer classification [22], brain disease classification [89], lung segmentation [86], breast cancer detection [18], arrhythmia detection [100], and fundus image segmentation [90], DL techniques have been used successfully to solve numerous problems. Numerous studies demonstrated that DL approaches have been applied to the categorization and investigation of fatal diseases on radiography. For the prediction of many types of disease, the DL approaches are more competent and well-liked because to their distinguishing characteristics, which include superior performance, the absence of human involvement in quality extraction, and detection. As intelligent computing technologies have been deployed extensively in preventing the spread of diseases, the present Covid-19 pandemic seeks the assistance of intelligent computing approaches in the development of more accurate forecasting and prediction models to control the spread of the virus. Rapid expansion of the Covid-19 epidemic has necessitated understanding in this area. This has heightened interest in improving AI-based automated recognition systems. Due to the insufficiency of radiologists, it is difficult to afford skilled physicians for each institution. Therefore, AI strategies that are simple, accurate, and effective may be utilized to combat this issue and provide appropriate aid to patients [72]. This paper is structured as follows.

(1) We introduced a comprehensive review about using deep Learning for combating COVID-19 pandemic in IoMT Networks. An effort has been made to conduct a comprehensive study of alternative deep learning approaches for Covid-19.
(2) In addition to the techniques, the IoMT, remote patient monitoring, and decision making to combat Covid-19 have been thoroughly examined. To the best of our knowledge, this is the first work to survey the state-of-the-art deep learning techniques on Covid-19 based on IoMT networks.

This chapter is structured as follows: The Wireless Body Sensor Networks (WBSNs) are presented in the next section. Section 3 introduces the architecture of WBSN. The WBSN applications are illustrated in Sect. 4. The main challenges of WBSNs are shown in Sect. 5. The Health monitoring system is introduced in Sect. 6. Section 7 presents the data gathering and fusion in WBSNs.The Covid-19 pandemic is presented in Sect. 8. Telemedicine, remote patient monitoring, and decision making are investigated in Sect. 9. Section 10 explores the deep learning methods for Covid-19. Section 11 introduces a discussion about the presented work. Finally, the conclusions are indicated in Sect. 12.

2 Wireless Body Sensor Networks

The WBSNs had implemented the following cost-effective approach for the continuous monitoring of physiological and physical patient body parameters: A great deal of research has been conducted and is still being conducted on the design of medically accurate invasive and noninvasive sensors and the design of wearable

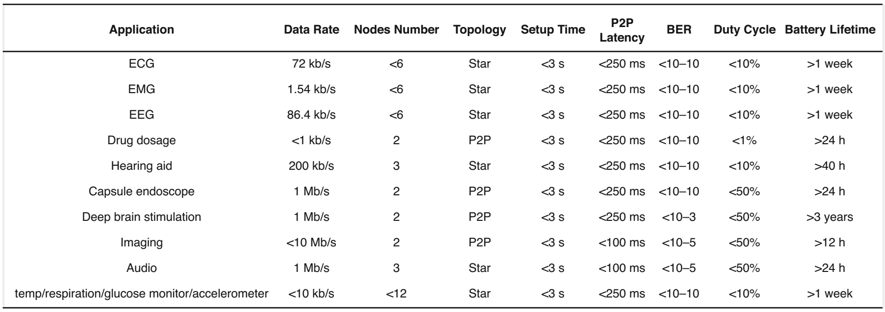


Specifications	Requirements
Topology	Star or star mesh hybrid, bidirectional link
Devices	Number Typically 6, Up to 16
Data Rate	10 Kb/s–10 Mb/s
Range	>3 m with low data rate under IEEE Channel Model
PER	<10% with a link success probability of 95% overall channel conditions
Latency	<125 ms (medical), <250 ms (non-medical)
Reliability	<1 s for alarm, <10 ms for applications with feedback
Power Consumption	>1 year (1% LDC and 500 mAh battery), >9 (always "on" and 50 mAh battery)
Coexistence	Less than 10 BANs in a volume of 6 m × 6 × 6 m

Fig. 1 The main specifications for WBAN systems

health monitoring systems that are both comfortable and accurate. Initially, the most typically used sensors in WBSNs are examined. Capture physiological parameters, such as vital signs and physiological signals, in addition to physical parameters associated with body movement. In addition to the explanation of the distinctions between various commercially available wearable sensor nodes [49]: Continuous collection of health-related data results in a variety of body sensor network (BSN) applications. Since healthcare applications are the primary subject of this chapter, they are given special consideration. Depending on the monitoring phenomenon of interest, all demographic groups, from infants to the elderly, can benefit from BSN healthcare solutions. In addition, numerous monitoring tasks, such as event detection, prediction, diagnosis, etc., can be accomplished. Thus, a description and illustration of these activities are provided based on three distinct dimensions: the type of user, the type of processing, and the monitoring location. Figure 1 shows the main specifications for WBAN systems [102].

BSN healthcare applications must meet a set of requirements in order to achieve user satisfaction, perform as desired, have an impact on people's lives, and ensure continuity, given that WBSNs have limited resources, are susceptible to interference and faulty measurements, and deal with sensitive medical data [83]. In the preceding years, the world has faced an increasing number of patients and diseases. Moreover, the relationships between humans and animals resulted in the introduction and spread of unknown viruses and diseases, such as coved-19. Consequently, this will raise the difficulty of health observation and evaluation for hospitals and medical personnel. In addition, connected health-care applications are overcoming significant obstacles such as maintaining the power of biosensor devices to ensure as much monitoring time as possible for patients and expediting the discovery of the patient's condition and sending it to a medical expert so they can reach the correct conclusion [10]. Figure 2 shows the technical requirements of WBSN applications [102].



Application	Data Rate	Nodes Number	Topology	Setup Time	P2P Latency	BER	Duty Cycle	Battery Lifetime
ECG	72 kb/s	<6	Star	<3 s	<250 ms	<10–10	<10%	>1 week
EMG	1.54 kb/s	<6	Star	<3 s	<250 ms	<10–10	<10%	>1 week
EEG	86.4 kb/s	<6	Star	<3 s	<250 ms	<10–10	<10%	>1 week
Drug dosage	<1 kb/s	2	P2P	<3 s	<250 ms	<10–10	<1%	>24 h
Hearing aid	200 kb/s	3	Star	<3 s	<250 ms	<10–10	<10%	>40 h
Capsule endoscope	1 Mb/s	2	P2P	<3 s	<250 ms	<10–10	<50%	>24 h
Deep brain stimulation	1 Mb/s	2	P2P	<3 s	<250 ms	<10–3	<50%	>3 years
Imaging	<10 Mb/s	2	P2P	<3 s	<100 ms	<10–5	<50%	>12 h
Audio	1 Mb/s	3	Star	<3 s	<100 ms	<10–5	<50%	>24 h
temp/respiration/glucose monitor/accelerometer	<10 kb/s	<12	Star	<3 s	<250 ms	<10–10	<10%	>1 week

Fig. 2 The technical requirements of WBSN applications

3 The WBSN Architecture

A WBSN consists of biosensor nodes and a coordinator. The biosensor nodes are implanted into a person's body. They may be implanted into or placed on the human body. They continuously detect physio-logical signals, such as vital signs; physiological signals include ECG, EEG, and PPG, among others [6]. In contrast, vital indicators include the respiratory rate (RR), heart rate (HR), temperature, blood pressure (BP), and oxygen saturation, among others. Periodically, the gathered data is wirelessly transferred to the network coordinator. This refers to any portable device close to a person's body, such as a smartphone or PDA. It is responsible for managing the network and fusing the acquired data. Thus, the coordinator may ensure that emergencies, abnormal events, and continual monitoring of the person's health state are addressed. In addition, it can provide ad-vise and reminders, as well as take action in emergency cases, such as calling the doctor. The coordinator sends the collected data and the findings of the fusion procedure to the medical center (healthcare professionals, doctors) for further processing [5]. The primary reasons for using the WBSN are (1) reducing the energy consumed by biosensor devices to ensure the patient receives the longest possible monitoring and (2) detecting the patient's urgency quickly and sending that information to medical professionals so they can make the best life-saving decision. (3) keeping track of the patient's condition at any time and from any location, the patient can provide experts remote access to his medical records [49]. Figure 3 shows the WBSN architecture.

Biosensors are miniature, lightweight, low power, limited-resources and intelligent sensor nodes that sense, process and transmit human physiological parameters such as the ECG, the heart rate, the body temperature, the body movement etc. Figure 4 illustrates the components of a wireless biosensor node. It is composed of three units powered by a battery: the sensing, the processing and the transmission units. All three units require power for performing tasks. However, the transmission has been viewed as the most power-hungry of tasks [33, 41]. The unit of sensing includes a sensor and an ADC, converting the analog signal that is sensed with a certain frequency (Nyquist-Shannon), to a digital signal. The latter is given to

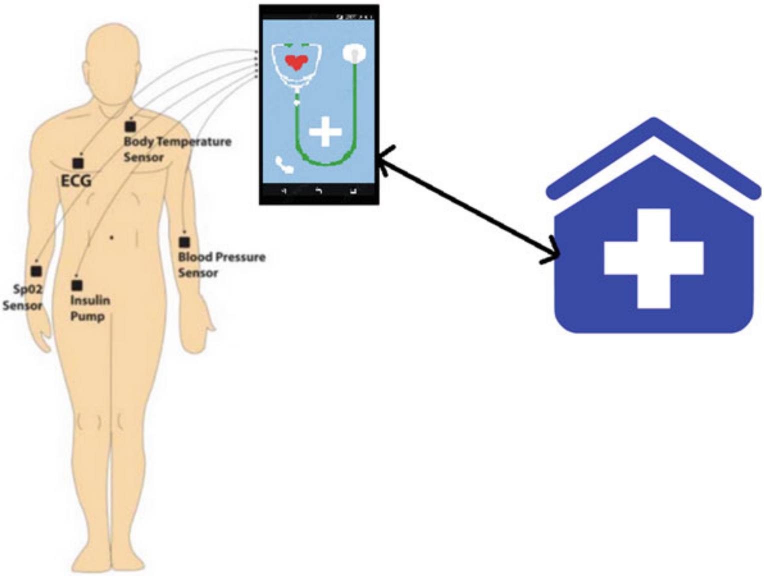


Fig. 3 WBSN architecture

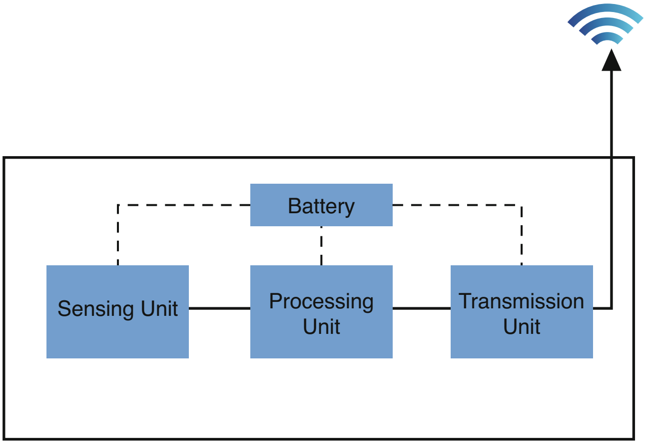


Fig. 4 The components of a biosensor node

processing unit (memory and processor) where the algorithms of processing are run. In addition to that, the processor regulates the transmission and sensing units and it changes and/or activates their status based on applications and utilized protocols [78].

Biosensors are small, lightweight, low-power, limited-resource, intelligent sensor nodes that detect, process, and communicate human physiological characteristics such as the ECG, heart rate, body temperature, etc. Figure 4 depicts the constituent parts of a wireless biosensor node. It consists of three battery-powered units: the sensing, processing, and transmission units. All three devices require power for operation. However, transmission has been considered the most energy-intensive task. The unit of sensing consists of a sensor and an ADC, which converts the analog signal sensed at a particular frequency (Nyquist-Shannon) into a digital signal [42]. The latter is provided to the processing unit (memory and processor) where processing algorithms are executed. In addition, the processor controls the trans-mission and sensing units and modifies and/or activates their status dependent on the applications and protocols in use [78].

4 WBSN Applications

These applications are comprehensive for numerous fields, including health care, help for the aged, and emergency case response [9, 50, 56, 99]. In this section, an outline of prospective medical uses will be provided.

4.1 Telemedicine and Remote Patient Monitoring

The rising expense of medical treatment and the aging of the global population result in a significant expansion of the telemedicine net-work for the provision of numerous medical services. Using an integrated medical system and current communication tools, telemedicine enables the delivery of a remote patient care service and gives health professionals such as physicians, scientists, and others the opportunity to care for more patients. In this situation, the patient can remain under the doctor's constant observation in normal physiological parameters, with minimal impact on everyday activities and at the lowest cost. WBSNs are able to provide continuous monitoring of biological parameters, failure detection in medical devices, and early detection of medical emergencies. These patient monitoring technologies will be safer, more compatible, and more affordable.

4.2 Rehabilitation and Therapy

Rehabilitation software's purpose is to allow patients to recover their functional abilities and return to normal state after leaving the hospital through the use of convenient therapy. Rehabilitation is a dynamic process intended to repair any inappropriate behavior by utilizing available resources to achieve the best condition.

4.3 Biofeedback

Biofeedback refers to the possibility of measuring biomedical activity and prospective medical parameters and returning them to the user so that he can adjust and control his biological activity in order to improve his health.

4.4 Assisted Living Technologies

The aging of the global population, the high cost of formal healthcare institutions, and the propensity of some individuals to live autonomously have all contributed to the proliferation of novel living strategies for independent and safe aging. These apps leverage home automation to improve living conditions and retain independence. In fact, supported living strategies have been employed as an option for seniors, individuals with special needs, and people with disabilities who cannot live independent but do not require constant health care.

5 Main Challenges of WBSNs

This section introduces the main challenges in WBSNs that can be summerized as follows [15].

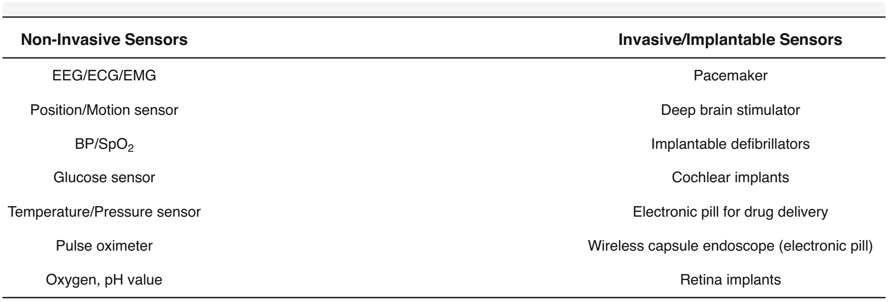
1. Reliably—The primary challenge is ensuring that information reaches its intended recipient reliably. Multiple variables con-tribute to the dependability of a wireless body sensor network, such as robust software programming, durable wireless communications between sensor nodes, and efficient processing in each sensor node.
2. Biocompatibility—For sensor nodes that interface directly with the patient's body, size, shape, and materials are restrict-ed. The idea is to encase the sensor in materials that are bio-compatible.
3. Portably—Whether they are placed on or swallowed, the sensors node used in a wireless physiology measurement device must be small and lightweight.
4. Privacy and security—Principal security risks include eaves-dropping, identity forgery, and the leaking of personal information to unauthorized parties. It is feasible to strengthen security by intercepting data, but confidential information must be protected from unauthorized access. Important aspects of designing software or hardware solutions include consented data gathering, correct data storage, secure transfers, data integrity, and allowed data access.
5. Lightweight wireless communication protocols must support self-organizing networks (including security features) in addition to data collection and routing.
6. Energy-aware communication nodes must transmit at the maximum permissible power level. To allow the nodes to negotiate a reduction in their transmission power, an emergent protocol is necessary.

6 Health Surveillance System

The surveillance system remotely monitors patients' physiological parameters using body-worn sensors that feed data to a viewing or processing device through cables or wirelessly. Surveillance and diagnosing helps provide important diagnosis and support remotely, without hospitalization. It employs numerous sensors to monitor the patient's vital signs, including EEG, ECG, body temperature, heart rate, breathing, and blood pressure, among others. In addition, people with certain conditions, such as cardiovascular and diabetes, require constant monitoring throughout the day. Where previous systems would require them to carry multiple gadgets and connections. Because patients are always coming and going, there is a chance of getting wrong information and also of losing information. Using the mobility and wireless communication properties of the wireless body area network (WBAN), the WBAN-based health monitoring system is able to effectively treat these side effects [88]. There are three main parts to WBAN-based health monitoring systems: biosensor devices, a gateway, and a back-end component. These constituents are detailed in full below [27].

6.1 *Biosensor Devices*

They are wearable or implantable devices that sense the patient's physical condition to collect medical or vital data, such as location, temperature, blood pressure, ECG, EEG, and EMG, before communicating it to the gateway node through Wi-Fi, Bluetooth, 6LoWPAN, or ZigBee. Figure 5 shows non-invasive and invasive sensors [102].



Non-Invasive Sensors	Invasive/Implantable Sensors
EEG/ECG/EMG	Pacemaker
Position/Motion sensor	Deep brain stimulator
BP/SpO_2	Implantable defibrillators
Glucose sensor	Cochlear implants
Temperature/Pressure sensor	Electronic pill for drug delivery
Pulse oximeter	Wireless capsule endoscope (electronic pill)
Oxygen, pH value	Retina implants

Fig. 5 The non-invasive and invasive sensors

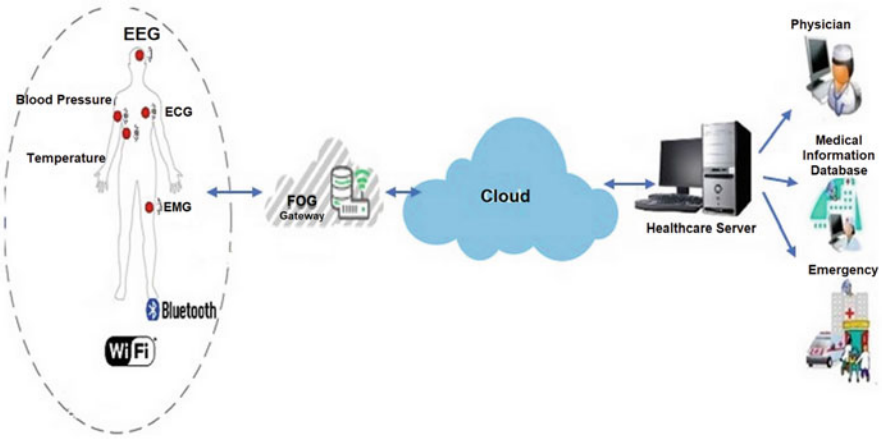


Fig. 6 The design of the IoT health monitoring system

6.2 *Gateway Device*

The gateway is the heart of the healthcare system since it connects many sensors to the cloud. When a gateway bottlenecks or malfunctions, the health system suffers. Therefore, it’s impossible to access the patient’s cloud server information in time to take action.

6.3 *Back-End Component*

It includes a cloud server and health care servers (back-end services), which differ per system and service. The cloud server charge of collecting patient data from gateway devices, storage, computing, and sending to health care servers for analyzing medical data and monitoring patient existing situation so a decision can be taken based on the patient’s situations. The IoT health monitoring system is shown in Fig. 6.

7 Data Gathering and Fusion

Data collection is the process of obtaining and measuring information from many sources in order to provide answers to pertinent queries [8]. Data collection is the process of acquiring, measuring, and evaluating the proper information for the study using approved, established procedures [45]. Using the collected data, a research might evaluate the hypothesis. Regardless of the area of study, data gathering is often the first and most significant step in the research process [46]. Depending on the type of information required for dialysis, several data gathering techniques are applied in various academic disciplines [44]. The most important objective of data collection is to collect information-rich and accurate data for statistical analyses, so that study conclusions can be based on data. There are two types of data collection: primary data and secondary data. Primary data are initially collected, unprocessed information. The secondary data comprise previously collected and tested information [40]. The scientific community is currently interested in the development of intelligent algorithms for a variety of healthcare applications. Consequently, the treatment and processing of the gathered data is a crucial part of WBSNs. For instance, data fusion in WBSNs enables the combination, correlation, and association of physiological data and medical information originating from a single or several biosensor nodes in order to generate precise situation assessments of the monitored individual. Particularly, multisensor fusion is attracting significant interest due to its ability to provide a unified picture of the patient's health condition [49]. WBSNs face a number of obstacles, including the fact that the acquired data is susceptible to noise, interference, and erroneous measurements, resulting in the fusion of imprecise and inconsistent data. Moreover, real-time fusion and high accuracy, two important elements of healthcare applications, should be met by multisensor fusion techniques. Data fusion is a multilevel operation that deals with associations, correlations, and the combination of data and information from multiple as well as single sources for the purpose of achieving identity estimations, refined positions, and complete, timely evaluations of situations, threats, and their relevance [57]. By merging information from multiple sources, the following definition for Multisensor fusion permits the creation of a unified image and a globalized view of the system [2]. Based on the processing architecture, three distinct data fusion methodologies are identified: distributed, centralized, and hybrid. The centralized method is reliant on a fusion center where all processing oc-curs. A distributed technique is utilized when the sensor nodes independently process the captured data and transmit the results to a fusion node. In this instance, the fusion node runs a global analysis based on all the sensor nodes' sent data [4]. Lastly, hybrid fusion refers to distributed systems in which sensor nodes execute just preprocessing and/or partial lightweight computation on acquired data, while a central node combines the obtained data and performs high-level fusion [30].

8 The Covid-19 Pandemic

The emergence of the novel coronavirus (Covid-19) in 2019, for which there is neither a treatment nor a vaccination, created a sense of urgency for the development of new drugs. The pandemic of novel coronavirus-19 has been designated by the World Health Organization as a public health emergency of global concern [74]. Researchers from all around the world are utilizing diverse pandemic models for Covid-19 in order to gather experience assessments and implement significant control measures. Researchers are most concerned with epidemiological and simple statistical techniques among the usual methods for Covid-19 worldwide outbreak prediction. Insufficiency and inadequacy of health tests for identifying remedies has become a significant obstacle in preventing the development of Covid-19. Deep learning has emerged as a new approach among a dozen machine learning techniques to address this issue. In medical applications, deep learning has achieved superior performance. Deep learning is able to identify patterns in huge, complicated datasets [87]. They are recognized as a suitable tool for analyzing Covid-19-affected patients. Some disease identification systems focus entirely on enhancing predictions or classifications, excluding uncertainty from decision-making. Recognizing computer-based health analysis trust is key to gaining clinicians' trust and developing therapy. Covid-19 diseases are the biggest global health threat. X-rays must detect Covid-19 for diagnosis, therapy, and assessment. Nonetheless, radiologists are faced with a challenging yet predictable task when analyzing ambiguity in a report [72].

9 Telemedicine, Remote Patient Monitoring, and Decision Making

In clinical applications, various devices are put on patients' bodies to monitor their vital signs. These devices continuously communicate every detected signal to the Gateway. Periodically, the gateway collects huge amounts of observed data. Therefore, each device must de-crease the data before sending it to the gateway. Data cleansing at the sensor device level can lower system costs and extend its lifespan. In addition, it can reduce the amount of data rereceived at the Edge gateway, making it simpler to analyze and provide an accurate evaluation of the patient's condition [60]. According to New Early Warning System (NEWS) [91], the devices only transmit measurements with outcomes greater than 0 to healthcare professionals. Normal patient data will not have been transmitted to the gateway. Clearly, less time will be spent frequently monitoring the patient's state and transmitting data to the gateway. This issue can be rectified by establishing the relationships between the observed data per interval and then transmit-ting them to the gateway. After collecting the data of the biosensor nodes running the emergency detection algorithm, the Edge gateway fuses the readings of the biosensor nodes in order to offer meaningful information about the patient 's condition. This patient's health state is used to assess the patient's health risk and subsequently to make the proper decision. The Edge gateway delivers the made the decision and the gathered data to the healthcare specialists [13]. The Edge gateway gathers the initial readings of biosensor nodes at the start of each period, and each time t re-receives a reading from a suitable biosensor k, it updates its US score. Lastly, the Edge gateway computes the total score AS for all biosensor nodes by averaging their updated scores. For instance, if the Edge gateway only receives the scores of the biosensor nodes HR, respiration rate (RESP), and ABPsys at time t, it updates their scores. Then, it takes the most recent score saved for the two remaining biosensor nodes, blood temperature (BLOODT) and oxygen saturation (SpO2). Consequently, the overall score is computed [56]. Some decision-level fusion techniques for predicting the health of COVID-19 patients are proposed in [26, 31, 62].

10 Covid-19 Pandemic Combating: Deep Learning Approaches

In this part, several deep learning techniques used to solve Covid-19 problems are described [12, 77]. Recurrent neural network (RNN) [11], convolutional neural network (CNN) [32], generative adversarial network (GAN) [101], long short-term memory (LSTM) [64], and autoencoder-decoder [14]. Several types of deep learning techniques for overcoming Covid-19 difficulties such as multiple CNN [16], inception residual CNN (IRCNN), and modified CNN [36] have been applied successfully. In addition, numerous additional DL techniques, such as DenseNet [25], MobileNet [92], ResidualNet (Res-Net) [21], and SqueezeNet [94] have been employed to solve different Covid-19 difficulties, such as diagnosis and categorisation, etc.

10.1 Convolutional Neural Network (CNN)

Figure 4 depicts a convolutional neural network (ConvNet), which employs the mathematical approach of convolution. In this sense, “convolution” refers to the simultaneous processing of many convolutional applications. It is a special linear transformation operation on its levels that replaces matrix multiplication with convolution. According to TheConvNet, the first parameter is termed the input, the second parameter is called the kernel, and the output is called the fea-ture map [54, 61]. Whereas the input is a matrix of data, the kernel is an array of varia-bles. These two matrices are referred to as tensors since the input and kernel components must be kept separate. ConvNet is primarily moti-vated by sparse interactions, parameter sharing, and equivariant repre-sentation. Due to sparse interaction, the kernel is less than the input, and parameter sharing is utilized in a model. Equivariant representa-tions suggest that if the input is altered, the output will also be altered [29]. The ConvNet components are separated into left and right layers. The left layer consists of a small number of complex layers, each with nu-merous steps. These stages are also referred to as the input stage, out-put stage, and several hidden stages, the most frequent of which are the convolutional, pooling, completely linked, and normalizing hidden layers. Three stages comprise a pooling layer: First, a sequence of convolutions are performed sequentially to generate a collection of

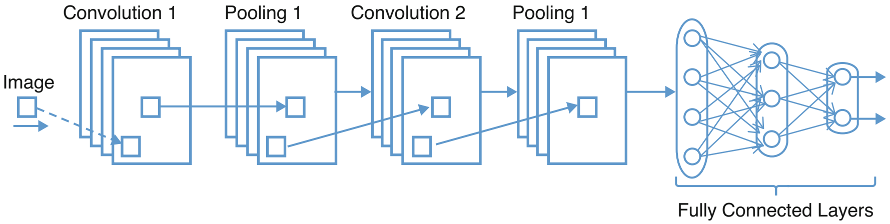


Fig. 7 The CNN

linear activations. In the second phase, each linear activation is con-ducted out using the activation function. In the third stage, the pooling function is utilized to influence the output of the subsequent layer. Pooling improves the network's computational and statistical efficacy while reducing the amount of storage required to hold parameters due to the possibility of employing fewer pooling units than detector units [29] (Fig. 7).

Using CNN, Rajaraman et al. [80] have developed a method for identifying NCOV-19 in chest X-rays. The authors eval-uated datasets including the RSNA pediatric Chest X-Rays (CXR) dataset [53], and Twitter Covid-19 CXR dataset. As performance metrics, we use accuracy, sensitivity, and precision, among others.In [97], The authors presented a Residual Network34 (ResNet34) deep CNN model for COVID-19 diagnosis in CT scan images. ResNet34 was tested using CT scans from 99 patients (55 patients with typical viral pneumonia and 44 patients with COVID-19). Simulations show ResNet34 has 73.10% accuracy, 67% specificity, and 74% sensitivity. In [71], scientists used three pre-trained methods: ResNet50, InceptionV3, and InceptionResNetV2. Normal, COVID-19, bacterial, and viral pneumonia were studied. The studies show ResNet50's great precision across three datasets. Wang et al. applied eight deep learning (DL) algorithms for COVID-19 detection: FCN-8 s, UNet, VNet, 3D UNet++, DPN-92, Inceptionv3, ResNet50, and Attention ResNet50. Using 1136 CT images from five hospitals, the models' effectiveness was tested (723 with COVID-19 and 413 normal). 3D UNet++ outperformed other CNN models in simulations [96]. Chen et al. used UNet++ to identify COVID-19 in CT scans. 106 CT scan pictures were used to train UNet++. UNet++ has a 95.24% accuracy, 100% sensitivity, and 93.555% specificity per patient, according to simulations. Accuracy was 98.85% per image, sensitivity was 94.34% per image, and specificity was 99.16% per image [19]. Toraman et al. developed the CAPSNET CNN model for COVID-19 diagnosis. CAPSNET was evaluated with 2100 and 13,150 cases. In the first dataset (1050 with COVID-19 and 1050 without), CAPSNET had an accuracy, precision, sensitivity, and specificity of 97.23, 97.08, 97.42, 97.04, and 97.24. In the second dataset (1050 cases with COVID-19, 1050 cases with no results, and 1050 cases with pneumonia), CAPSNET displayed improved accuracy, precision, sensitivity, and specificity [93]. In [35], they evaluated six deep CNN models for COVID-19 filtering and recognition (ResNet34, ResNet50, DenseNet169, VGG19, InceptionResNetV2, and

RNN-LSTM). 5863 (Normal and Pneumonia) X-Ray images of children were utilized to evaluate the procedures. DenseNet169 has an accuracy of 95.72 % based on simulations.Toaçar et al. combined CNN models (MobileNetV2 and SqueezeNet) with SVM for COVID-19 detection. The suggested models were evaluated using a dataset of normal, COVID-19, and pneumonia X-rays. Their accuracy is 99.27% [92]. Ahuja et al. provided ResNet18, ResNet50, ResNet101, and SqueezeNet for automatic COVID-19 early diagnosis [3]. Oh et al. introduced a ResNet18-based patch-based convolutional neural network [73].

10.2 Recurrent Neural Network (RNN))

The network is efficient and delivers a succession of learning [38]. RNNs are state-structured temporal dynamical systems. They are utilized in a number of temporal processing situations and digital appli-cations, and are quite potent. Common RNN models include the Hop-field and Cohen Gross-berg models, each of which uses a kinetic basic feature to contain data and serves as an associative memory for storing knowledge and solving optimization issues, respectively. There are two forms of RNN: global and local. Local RNN feed forward connec-tions are organized using dynamic neuron models, whereas global RNN uses feed forward connections between neurons. There are two static time models for RNNs: time-delayed and simultaneous. The first is taught to minimise prediction error, and the second is taught to develop wide approximation function skills [1]. Unlike the shallow RNN, the deep RNN contains multiple hidden layers (see Fig. 8).

The work in [11] has anticipated a novel technique for the identification of NCOV-19 and Covid-19 by utilizing recurrent NNs (RNNs). The datasets in both [70] and [23] are with Xray and CT images, respectively. The authors have evaluated a variety of performance indicators, including TP, FP, and accuracy rate. The suggested method achieves accuracy rates of 84.67% for CT pictures and 98.78% for X-ray images, respectively. In [79], the authors have presented a strategy for pandemic analysis using DL approaches. The writers have evaluated the Johns Hopkins University dashboard data. The RNN (recurrent neural network), DNN (Deep neural network)), polynomial regression (PR), and support vector regression (SVR) are some of the techniques that the authors employ. It accepts time series information as input. The authors have determined, through experimentation, that the PR model is superior to other models in terms of root-mean-square error (RMSE).

10.3 LSTM (Long Short-Term Memory)

Long short-term memory is a form of RNN that permits the construction of deep RNNs without compromising the load-updating pitches [37]. Data patterns can

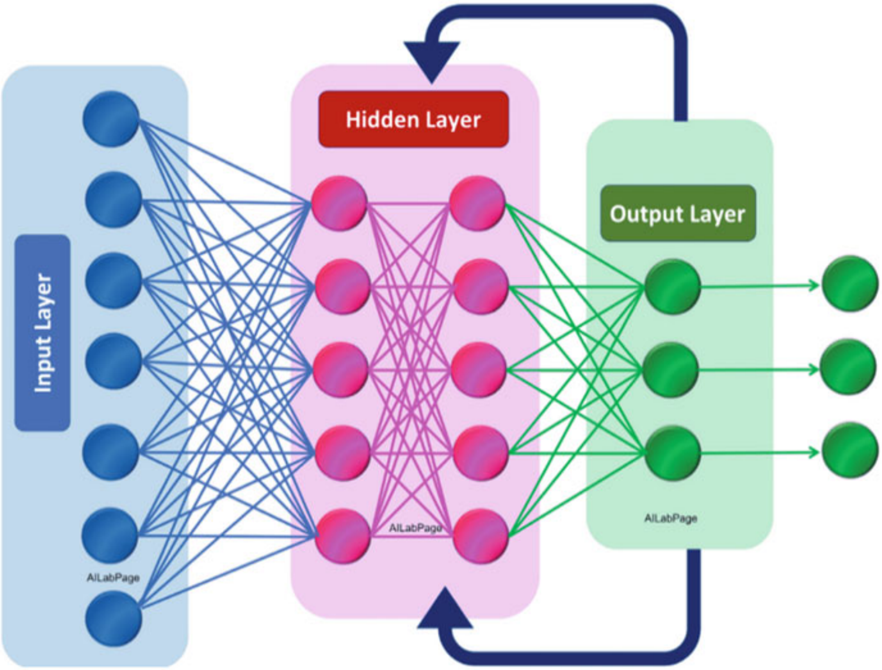


Fig. 8 The deep RNN

be retained in memory indefinitely, with the flexibility to selectively review or delete data. It utilises backpropagation but is able to learn information grouping by employing memory squares connected in layers as opposed to neurons. As data is processed via the levels, the architecture might include, remove, or adjust variation in the data. LSTM is one of the most effective algorithms for diagnosis and detection based on temporal organization data, producing outstanding results for a variety of situations [84]. These allow data scientists to create sophisticated models leveraging large stacked systems and tackle succession problems in ML more efficiently. Jelodar et al. suggested a novel approach for COVID-19 case classification based on LSTM and natural language processing (NLP). The effectiveness of the proposed model was evaluated using a dataset of 563,079 COVID-19-related comments obtained from the Kaggle website (between January 20, 2020 and March 19, 2020), and the findings demonstrated its efficiency and robustness on this problem area for guiding decisions [52]. These permit data scientists to develop sophisticated models leveraging large stacked techniques and tackle succession problems in ML more efficiently. Jelodar et al. suggested classifying COVID-19 cases using LSTM and NLP (NLP). The suggested model was evaluated using a dataset of 563,079 COVID-19-related comments from Kaggle (between January 20, 2020 and March 19, 2020), and the findings proved its efficiency and robustness for directing [52]. Patankar has suggested an unique medication development technique to solve Covid-19 by

2020. The author employed fingerprint data to test LSTM-performance. RNN's The recommended technique increased drug discovery [76]. Bandyopadhyay and Dutta established an innovative method for forecasting Covid-19 using text data. The authors propose LSTM-based, GRU-based, and LSTM-GRU-RNN for Covid-19 forecasting. LSTM-GRU-RNN beat the competitors in experiments [24]. Pal et al. [75] developed an LSTM-based NN strategy for forecasting Covid-19 using text data. Employing the suggested approach produced a high rate of accurate forecasts. Chimmula et al. predicted COVID-19 cases in Canada using LSTM. Johns Hopkins University and the Canadian Health Authority used confirmed instances to test LSTM's efficacy. LSTM outperformed other predicting systems, according to [20]. Mohammed et al. suggested an LSTM with ResNext+ and a slice attention module. The model was trained using 302 CT volumes (20 with verified COVID19 and 282 normal). The proposed strategy has an accuracy of 77.60%, precision of 81.90%, sensitivity of 85.50%, specificity of 79.30%, and F1-score of 81.40% [69]. Islam et al. developed a hybrid LSTM/CNN technique for automatic COVID-19 diagnosis. 4575 X-rays verified the hybrid model's usefulness (1525 images with COVID-19, 1525 with viral pneumonia, and 1525 normal). The hybrid model's accuracy, sensitivity, specificity, and F1-score were 99.20%, 99.30%, 99.20%, and 98.90%, respectively [48].

10.4 GAN

Generative adversarial networks are one of the unsupervised deep learning techniques [28]. GAN automatically detects data patterns in training datasets to produce fresh data through self-learning. Minimal differences imitate any dataset. Due to its adversarial network topology, GAN is so-called. They use a generator and a discriminator to create new instances of data and identify real data from fraudulent data. Repeated action strengthens them. GANs can store and replicate dissimilarities, generate visuals, and provide fine data. Loey et al. introduced a GAN-related deep transfer learning model to recognize NCOV-19 without standard datasets. AlexNet, VGGNet16, VGGNet19, GoogleNet, and ResNet50 were used. GAN was the most common method for analyzing chest CT images. They examined 307 images from four classes: bacterial, COVID-19, normal, and viral pneumonia. GAN's overfitting fixes have strengthened the approach's robustness. Despite a lack of datasets, the proposed technique detected NCOV-19 with 100% accuracy. Loey et al. [67] introduced a GAN-related deep transfer learning model to recognize NCOV-19 without standard datasets. AlexNet, VGGNet16, VGGNet19, GoogleNet, and ResNet50 were used. GAN was the most common method for analyzing chest CT images. They examined 307 images from four classes: bacterial, COVID-19, normal, and viral pneumonia. GAN's overfitting fixes have strengthened the approach's robustness. The proposed method discovered NCOV-19 despite a lack of datasets with 100% accuracy [67]. Waheed et al. developed a technique to detect COVID-19. The authors constructed GAN and evaluated its performance using

CXR pictures. GAN improves precision [95]. Khalifa et al. suggested a technique for identifying a pneumonia chest X-ray using modified deep transfer learning. The authors constructed ResNet18 and GAN. GAN is great for producing CT images from X-rays. 5.863 chest X-rays were analyzed. The AlexNet,ResNet50VGGNet16, and GoogleNet were used to identify CT images [55]. As classification metrics, sensitivity, accuracy, precision, etc. are taken into consideration. The model's 98% accuracy beats experimental results. Loey et al. used CGAN and deep transfer learning to detect NCOV-19 in CT images [66]. Their experiments showed 82.9% accuracy and good performance in ResNet50. Jamshidi et al. used GAN, ELM, RNN, and LSTM to diagnose and treat COVID'19 [51]. Sedik et al. proposed a GAN, CNN, and ConvLSTM hybrid model for COVID'19 detection. The simulation used two datasets of X-ray and CT images, and the results confirmed the combined model's efficacy and performance with 99.9% accuracy, 97.70% precision, 100% sensitivity, 97.80% specificity, and 99.9% F1-score [81].

10.5 Auto-Encoder-Decoder

Auto-encoders are instantaneous allocation neural networks that reestablish the contribution at the output [59]. Inside they have a hidden layer, which may be a model-representative code. It is envisaged that they will not be able to perfectly recreate the yield contribution. Typically, they are restricted to the portion of the code or penalised for implementation within the code. Due to coding errors, the information is restored with errors; however, in order to reduce them, the network must look for bowed selections of the most relevant highlights. Amyar et al. [14] have developed a contemporary deep learning method for classifying and segmenting Covid-19 in CT images. For segmentation purposes, the authors have proposed an encoder with 10 convolutional layers and two decoders with 10 convolution-al layers. MLP (multi-layered perceptron) has also been applied for classification purposes. Consideration has been given to a dataset containing 1044 patient records in order to analyze performance. A stacked autoencoder detector model is presented to significantly enhance the performance of detection models, including precision rate and recall rate. Four autoencoders are produced as the first four layers of a stacked autoencoder detector model that is being developed to extract improved CT image characteristics. The model is constructed by cascading four autoencoders and connecting them to the dense layer and the softmax classifier. To improve the model's detection accuracy, a new classification loss function is developed by superimposing reconstruction loss [65]. In [58], the authors developed DL to identify Covid-19. The CT CXR images were used to verify the suggested encoder-decoder design.

11 Discussions

According to the majority of studies, DL methods have also been applied well in the forecasting and analysis of Covid-19. Popular techniques utilized in the identification and forecasting of the pandemic include DL methods. DL is gaining popularity due to its advantage in terms of accuracy when trained with a massive amount of data. DL is a subset of ML that gets flexibility and strength through the learning process. DL techniques are the most precise ways for handling medicinal datasets, including classification of various tumors, harmful microbes, brain disorders, and segmentation of biomedical images, respectively. Due to the rapid expansion of practical advancements, DL models offer fresh opportunities in biomedicine. Additional properties of DL, including accurate performance, the ability to handle difficulties, an end-to-end training technique with mutual feature learning, and several others, made it the most suitable model for the healthcare industry. Therefore, the most of scientists have conducted Covid-19 diagnosis study employing DL advancements. According to a comprehensive analysis, deep learning approaches presented in this chapter are the most often used DL algorithms for pandemic identification. Numerous scientists have widely employed each of these DL methods for predicting Covid-19. Due to characteristics such as the absence of human engagement of quality extraction and recognition, high performance, and the absence of engineering benefits in the learning phase, DL approaches are more prevalent than ML methods. The majority of statisticians note that the prediction algorithms used to estimate the amount of Covid-19 deaths do not align with reality. Due to the lack of precise data, all forecasting methodologies have uncovered a wide variety of computation discrepancies. A lack of solid data is one of the primary causes of the differences in forecasts. Similarly, predicting future outcomes based on knowledge from proven cases is another cause of difference in predictions. In addition to disease transmission, demography, basic health conditions, environmental variables, and social distance, there are numerous other elements to consider, including inadequate immunity, chronic disease, hypertension, and disability, to name a few. The goal underlying the forecasting models developed by numerous researchers failed to produce precisely accurate outcomes. In order to create more accurate forecasts in the future, more research must be devoted to creating techniques and equipment for prediction on the vast bulk of biological data.

In spite of these achievements, there are still hurdles to implementing DL to combat COVID-19. In reality, the management of new datasets generated in real time presents a number of challenges that limit the efficacy of the outcomes. In fact, a great deal of the proposed methods are founded on small data sets. In most instances, they are incomplete, noisy, ambiguous, and contain a high proportion of missing patterns. Due to the large variation and error rate of the test set, the training is inefficient and the risk of overfitting is significant. Consequently, the necessity to construct big databases becomes inevitable. However, it is not enough. In fact, it is difficult to determine which strategy yields the best results without a thorough and standardized dataset. To solve this, extensive work is required to merge existing datasets and clean them up by deleting / imputing missing data and eliminating redundancy.

12 Conclusions

The rapid development of the Internet of Things (IoT) has led to increasing advancements in the healthcare industry. The development of the hardware platform, as well as the underlying software, led to the emerging Internet of Medical Things (IoMT). The demand for remote healthcare continuous monitoring systems using limited resources and biosensors has increased. This study suggests a detailed assessment of IoMTs based wireless medical biosensor networks. The main goal is to present a fundamental introduction of WMBNs and to highlight recent advances, with a focus on remote patient monitoring for the elderly and chronically ill. To fulfil the scientific idea of WMBN, a detailed investigation of WBSN architecture, healthcare applications, and the main challenges. The data collection, fusion, telemedicine and remote patient monitoring, and decision making are presented. The Covid-19 is explained. It also gives an overview of Deep machine learning techniques and its importance in taking decisions are investigated. This chapter provides a concise summary of the application of DL for Covid-19. The DL technique is suitable for estimating the impact of Covid-19 on multiple domains, which could aid the government in implementing the most effective methods to combat the financial crisis. Given the state of the art and the number of suggested methodologies, research must now concentrate on the quality and harmonization of the data employed. In fact, up to this point, the research conducted have been based on diverse types and amounts of datasets. Consequently, it is vital to build benchmarks using real-world datasets for training future models.

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Part II
Machine Learning and COVID-19 Pandemic

Machine Learning Algorithms for Classification of COVID-19 Using Chest X-Ray Images

Shah Hussain Badshah, Muhammad Imad, Irfan Ullah Khan, and Muhammad Abul Hassan

1 Introduction

The covid-19 pandemic continues to alert the situation for the global health outbreak of the virus. Coronavirus is the type of virus newly identified outbreak of respiratory illness during the early December 2019 investigation in Wuhan, China. It's a large family of viruses that spread from colds such as Middle East Respiratory Syndrome (MERS-CoV) and severe acute respiratory syndrome (SARS-CoV). The COVID-19 epidemic has spread to over 185 countries, infecting over 7,145,800 people and causing 407,067 fatalities by June 9, 2020. To address this global novel pandemic, WHO, scientists, and clinicians in the medical industry are looking for new technology to screen infected patients at various stages, find the best clinical trials, control the spread of this virus, develop a vaccine for curing infected patients, and track infected patients' contacts [1]. According to recent studies, Machine Learning and Artificial Intelligence are promising technologies used by many healthcare providers since they result in greater scale-up, faster processing power, reliability, and even outperform humans in particular healthcare jobs. The infection of the virus becomes a rapidly dangerous worldwide number of patients confirmed across the countries [2]. Machine learning classification algorithms is an important role in covid-19 probe prediction and determining the discrimination affected patients. In this paper, analyze the covid-19 data classification and identify the performance of various classifier accurate results on the corona dataset. The selected classification algorithms will be applying and evaluating their classification performance in terms of precision, sensitivity, accuracy, false-positive rate, as well

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as F-measures. Comparison classification algorithms performance on coronavirus dataset to achieve optimal results through machine learning algorithms [3]. The classifiers reduce the computational time, are overfitted, and improve the accuracy of real-world data problems. The statistical analysis removes the difficulties from the covid-19 data through the algorithms naïve bayes, decision tree, KNN, Logistic regression, as well as ANN classifiers. Machine learning proposed the distribution of the diseases data curve and forecast covid healthcare system to control the future epidemics cases. The performance of the models is compared taken the average mean value and errors percentage during the implementation of the results. Results represent that decision tree is high accuracy performance is 100%, KNN classifiers achieved 99%, ANN gained 98%, Logistic Regression accuracy 95%, Naïve Bayes 90% accuracy based on confusion matrix the accurately. World health organization arranging researchers conference to track collaborating solution of the new outbreaks of coronavirus. The coronavirus dataset was taken from the Kaggle. Moreover, we declared that to obtain the best accuracy classification for the coronavirus patient. Last month researchers suggested on the basis of genetic analysis, that the scaly, ant-eating pangolin was the prime suspect. Still, scientists have now examined the data to identify actual mystery in far from solved [4]. The Chines researchers struggle to identify the mystery source of coronavirus causing study deeply about the virus to find the optimal solution. The performance evaluation I depicted is based on a confusion matrix and it shows the ways in which the classification model is confused when it makes predictions. Aimed to establish an early screening model to distinguish COVID-19 pneumonia from Influenza-A viral pneumonia and healthy cases with pulmonary CT images using deep learning techniques.

The aim of study to achieve high accuracy and rank the algorithm performance on various X-ray Covid-19 datasets. The objectives of this work are;

- To optimize algorithm for optimal feature X-ray to select informative features out of many features in a dataset.
- To improve the accuracy and reduce the chances of overfitting of the machine-learning model.
- To check the performance of different machine learning techniques with a given dataset.

2 Literature Review

The pandemic of covid-19 disease growing firstly in throughout the world. Machine learning is an important role how to deal with covid-19 disease and deeply investigating the performance of various algorithms. Coronavirus is a disease spread from person to person who is in close contact with one another. The problem is that, will identifying or comparison classification algorithms performance on coronavirus dataset to achieve best results [1]. The authors, emphasis on the healthcare system to improve the efficient diagnosis of coronavirus system enables quick and mitigate the burden decreased. However, we selected those algorithms which are more suitable for the coronavirus dataset and find out the highest accuracy of machine learning techniques. The models combine some necessary features prediction can help us to detect and estimate the risky infection that has been developed [2]. Serkan Ball studied machine learning methods analysis the covid-19 pandemic data for the forecasting and cumulative time serious approach for short-term. Furthermore, almost any reasonable definition of pandemic, there's no evidence of it happening part of the difficulty for the WHO is that the impact of a pandemic declaration in previous disease outbreaks is hard to access [3]. Scientists and clinicians firstly worked to stop or slow down the corona pandemic while also struggling to learn the new technologies for covid. The numerous advantages of machine learning and artificial can be a help to improve the overcrowding epidemics tackle of the covid-19 outbreak. The comparative study of transmission and forecasting with the help of machine learning techniques performances investigated deeply in deep learning methods as well as Hybrid convolutional neural networks long and short-term memory (LSTM-CNN) [4]. The hybrid machine learning algorithms strictly impose and analyze the performance regulations of a covid-19 outbreak. The forecasting methods determined the number of corona cases and predict the model show the hybridized techniques among the machine learning and fuzzy inference system improve the overall performance of the model [5]. Covid-19 virus vaccine is still in the process unpredictable for throughout the world. Most of the researcher's emphasis is to test various prediction models training and testing to gain the optimal results of the performance to be computed and evaluated [6]. The affliction of covid-19 is spreading concerns throughout the world. The social networks speedily awareness among the people to protect and safe in the home. A realistic assessment of the circumstance is needed to optimal appropriate resources of the corona. In this study, selected classification algorithms will be applied to the coronavirus dataset for evaluating their classification performance in terms of precision, sensitivity, accuracy, false-positive rate, recall, as well as F-measures [7]. The worldwide scientists placed a massive burden on limited knowledge of covid developing nations. WHO organization informed the world covid is a very serious disease and also spreading firstly become dangerous for the human life. Some models have a strong relationship to test and evaluate the performance of the help to achieve accuracy [8]. The infection of SARS-Cov-2 rapidly risen global pandemic managing without controlling the volume of the cases. The objective is clearly to determine the greatest risk and prognostic mortality with the help of the machine learning model. Models have the ability to identify the impact of each feature highlighting the patterns of laboratory values outcomes of SARS infection [9]. Machine learning algorithms create facilities for the medical history data and create the predictions confirmed the covid-19 cases. The improvement of the performance through practitioners and predict the results through machine learning model [10]. This study detects the mask through the hybrid model and machine learning approaches. The feature extraction methods used Resnet50, SMV, and other algorithms were performing. It's a classical protection technique warning

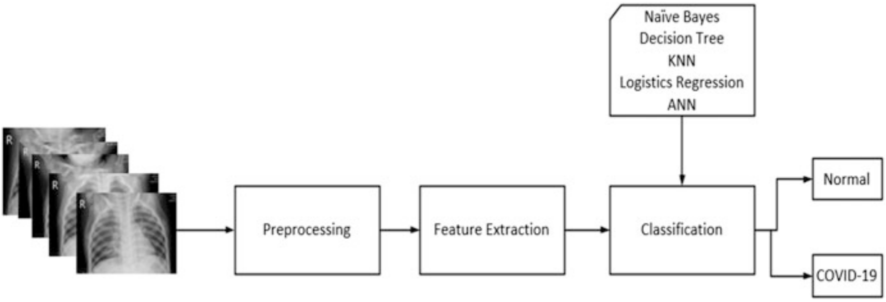

Fig. 1 Flowchart of the proposed algorithms

face masks in cities according to WHO [5]. The surveyed are conducted to predict the covid-19 treatment status and represents the pandemic highly contagious vaccine development conflict of MERS and SARS virus infection [11] (Table 1).

3 Methodology

This section discussed the detail of a proposed methodology (preprocessing, feature extraction, and classification) as shown in Fig. 1.

3.1 Pre-processing

In the pre-processing, we improve the contrast enhancement and remove unnecessary noise without the smoothing effect by applying a median filter. The Median filter is a non-linear method that is used to remove salter and pepper noise, sort all the pixels in the images, and replace them with the neighborhood pixels' median [16].

3.2 Feature Extraction

The Histogram of oriented gradient (HOG) technique automatically extracts the important feature from the X-Ray dataset and further provides these features for classification techniques [17, 18].

Table 1 Machine learning techniques, contribution and limitations using COVID-19 datasets

Authors	Year of Paper	Algorithm/models applied	Purpose	Contribution	Weakness and limitation
Ameer Sardar Kwekha-Rashid et al. [25]	2021	Supervised learning, Unsupervised learning, Linear regression, K-Means, KNN (K-nearest neighbors), and Naive Bayes	Classification, regression, clustering	Improve the accuracy	Poor accuracy unsupervised algorithm
Yazeed Zoabi et al. [6]	2021	Artificial neural networks and gradient-boosting machines, decision-tree	Validation, evaluation of the model	To identify the principal features driving model prediction, SHAP values were calculated	To prioritize testing for COVID-19 when testing resources are limited
Serkan Ballı et al. [7]	2021	LSTM, GAN-GRU, LSTM-CNN, RBM, GAN-DNN, CNN	Overall, we compared three hybrid models (LSTM-CNN, GAN-DNN, and GAN-GRU)	Improved the accuracy	Datasets of limited size
Abdelkader Dairi et al. [8]	2021	BAS algorithm, CESBAS metaheuristics, hybridized algorithm, adaptive neuro-fuzzy inference system (ANFIS)	Simulation results and comparative analysis	Improve the current time-series prediction (forecasting)	Additional modifications and improvements of the original BAS algorithm
Miodrag Zivkovic et al. [9]	2020	SVM, KNN+NCA, decision tree classifier, Gaussian Naïve Bayesian classifier, Multilinear regression, logistic regression and XGBoost classifier	Correlation matrices	Machine learning algorithms and their performances are computed and evaluated	ML classifiers and regressors are evaluated on the evolving COVID-19 datasets
Kolla Bhanu Prakash et al. [10]	2020	Linear regression, multi-layer perceptron, random forest and support vector machines (SVM) machine learning	Comparative, forecasting, validation, formal analysis	Compared according to the RMSE, APE, MAPE criteria	Poor results on the large dataset

(continued)

Table 1 (continued)

Authors	Year of Paper	Algorithm/models applied	Purpose	Contribution	Weakness and limitation
Furqan Rustam et al. [5]	2020	LSTM, Naïve Bayes, RF, XGBoost, ETC, DT, SVC	Feature extraction techniques, evaluation parameters	Compare the model performance	Improve their performance on small datasets
L. J. Muhammad et al. [11]	2020	Logistic regression, decision tree, support vector machine, naive Bayes, and artificial neutral network, decision tree, Naïve Bayes	Correlation coefficient analysis	Improve the performance evaluation	Limited healthcare systems
Adam L. Booth et al. [12]	2020	SVM, prognostic model	Feature selection, confusion matrix	Impact of each feature and feature combination in light of different model predictions	Further needed accuracy
Amir Ahmad et al. [13]	2020	Epidemiological models, susceptible-infectious-recovered models	Deep learning regression, traditional machine learning regression	Accurate prediction of the number of confirmed cases of Covid-19 using machine learning approach	Models in one country cannot be applied to other countries easily as they have different factors
Mohamed Loey et al. [14]	2020	Resnet50, decision trees, Support Vector Machine (SVM), and ensemble algorithm, K-nearest neighbors algorithm (k-NN)	Feature extraction, ensemble methods, validation, testing accuracy, and performance metrics	Hybrid model using deep and classical machine learning for face mask detection	Classical machine learning methods to get lowest consume time and highest accuracy
Edison Ong et al. [15]	2020	XGB model, logistics regression, SVM, KNN	Classification, phylogenetic analysis, immunogenicity analysis	Survey	Poor results on large data

3.3 Classification Techniques

3.3.1 Naïve Baye Classifier

NB probabilistic algorithm based on Bayes theorem with an accepted of predictors independent. Naïve Bayes algorithm expected the availability of a particular feature has not belonged to other any feature. Bayes model is impressive work on large data and highly useful classification techniques. However, theorem to calculate the posterior probability to solve the problem with the help of formula [19].

3.3.2 Decision Tree Classifier

Supervised learning classifiers solved both classification and regression problems connected with family. The purpose of algorithms is clearly defined to create the model and predict the optimal values or target variable. The final stage is to choose the correct and optimal decision according to classify problems [20].

3.3.3 KNN Classifier

KNN is used for classification and regression problems while efficiently implementing a supervised ML algorithm. Now briefly specified supervised machine learning algorithm worked on labeled input data function to create the output of unlabeled data. KNN classifiers determine that similar thing are close to a data point. The similarity is related to proximity, closeness, and calculating the distance among the points [21].

3.3.4 Logistic Regression

LG described predicting the probability of the optimal and target values solved the classification problem in a supervised learning algorithm. Most of the researchers select the target value; when any variable crosses the target, then is selected for improving the accuracy of the algorithm. The application of logistic regression is useful and impressive in real-world problems like cancer detection, spam detection, and diabetes prediction [17].

3.3.5 ANN Classifier

ANN is a complex patterns model used to process brain connectivity to develop classifiers and predict real-world problems. The human brain consists of billions of cells that process neurons' information. ANN algorithm takes the input and processing information at various stages inside of the neural network to provide the correct output with the help of the dendrites of the neuron cell. Depending on the signal strength, two main possibilism's reject or accept [22, 23].

4 Result and Discussion

This section provides a brief discussion of a dataset, Performance Matrix, and result analysis.

4.1 Dataset Description

The COVID-19 dataset is available online via the Kaggle repository [24]. The dataset consists of COVID-19 images and is normal. 80% of the data were used for training purposes, while 20% were used for testing. The dataset released by University of Montreal to improve the COVID-19 detection from chest X-rays images (Fig. 2).

4.2 Performance Matrix

The Machine Learning techniques are considered for performance evaluation based on accuracy, sensitivity, precision, specificity, and F1-Score. The performance evaluation is based on a confusion matrix TP, TN, FP, and FN presented in Eqs. 1, 2, 3, and 4, respectively.

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \tag{1}$$

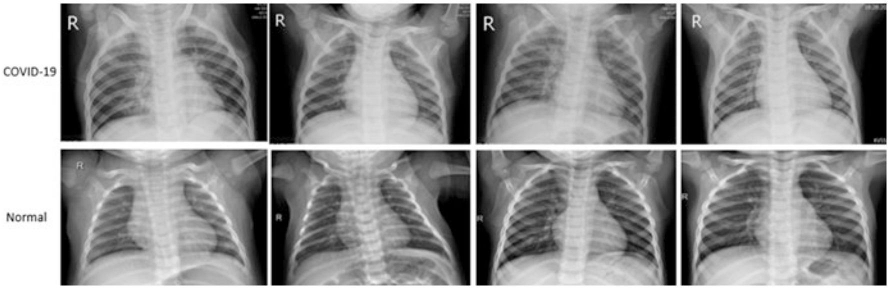

Fig. 2 Sample of COVID-19 and normal images

Table 2 Performance evaluation of classification techniques

Classification techniques	Classification report			
	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)
Naive Baye classifier	90	90	90	90
Decision tree classifier	100	100	100	100
KNN classifier	99	99	99	99
Logistic regression	95	95	95	95
ANN classifier	98	98	98	98

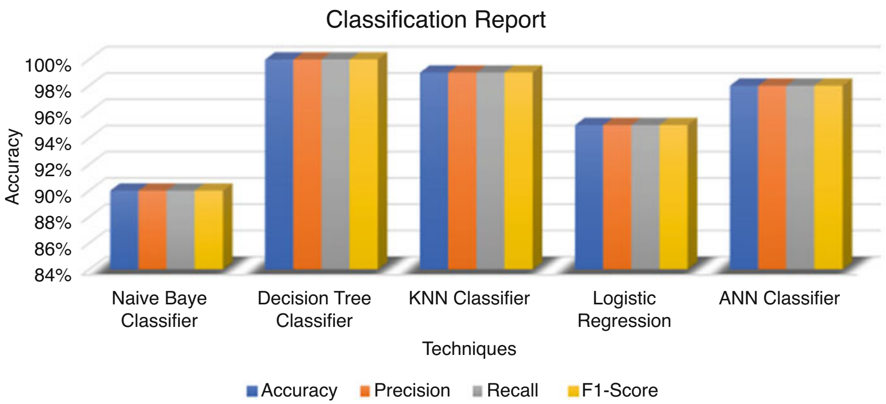

Fig. 3 Performance of classification in terms of accuracy of precision, recall and F1-Score

$$Precision = \frac{TP}{TP + FP} \tag{2}$$

$$Recall = \frac{TP}{TP + FN} \tag{3}$$

$$F1 - Score = 2 * \frac{Precision * Recall}{Precision + Recall} \tag{4}$$

Table 2 and Fig. 3, show various classifiers' performance from the confusion matrix in terms of accuracy, recall, precision, specificity, and F1-Score, which is the accuracy of algorithms, respectively. Illustrates that the results of naïve Bayes obtained from the confusion matrix represent that the accuracy performance is 90% while decision tree accuracy is 100%, KNN 99%, Logistic Regression 95%, and ANN 98%. The results clearly determine that decision tree accuracy is higher than other classifiers.

The performance of the Naïve Bayes algorithm is good and not bad results. The result analysis from the confusion matrix represents that the Naïve Bayes algorithm's highest accuracy is 90% among five different performance results in their precision, recall, specificity, and f1score. Decision Tree performance is impressive results as compared to other algorithms which are evaluated from the confusion matrix. The result analysis shows that the highest accuracy of the Decision Tree is 100%.

The KNN represents the performance evaluation of K-Nearest Neighbors, which is obtained from the confusion matrix. The result analysis shows that the highest accuracy of K-Nearest Neighbors is 99%, and their Precision, Recall, Specificity, and F1-score, respectively. If we compare the LR classifier, accuracy is high naïve Bayes obtained from the confusion matrix. The above graph shows that LR accuracy is 95% while Naïve Baye's 90% accuracy. The graph describes that the accuracy of ANN is highest from naïve Bayes, logistic regression-based of the confusion matrix. ANN is the third algorithm that has more good accuracy than others.

5 Overall Performance Accuracy

All the classifiers result involves various accuracy score achieved from the confusion matrix. Five different machine learning techniques are used: K-Nearest Neighbor, Naïve Bayes, and Decision Tree, Logistic Regression, and ANN, which is trained and tested on a dataset. The result analysis shows the Decision tree achieved the highest accuracy of 100% among the other classification techniques (KNN is 99%, Naïve Bayes is 90%, ANN is 98%). The lowest performance accuracy in the classification techniques is 90% of the Naïve Bayes algorithm.

6 Conclusions

The pandemic of Covid-19 appears the diseases including AIDs Tuberculosis, Hepatitis, and Measles worldwide leading World Health Organization (WHO) declared the emergency for human health will be affected badly. Machine learning algorithms can be helpful to reduce the huge burden on WHO as well as, researchers and scientists. The infection determination was developed with the help of Decision Tree, Naïve Bayes, Logistic Regression, KNN, and ANN training and tested the labeled data to improve the accuracy based on sensitivity and specificity respectively. We analyze each feature from the dataset to remove the unnecessary and irrelevant data to improve the performance of accuracy SARS-CoV-2 infection. As a result, applied various stages preprocessing of the data, feature extraction, and classification on coronavirus pandemic. The covid data was split into training and testing phase while 20% data for the testing and 80% data for training using the confusion matrix such as Precision, Recall, and F1-Score. The limitation or weakness that appears on a large dataset is not properly working while the accuracy on small data is impressive results. If we compare the whole results show that the decision tree is highest accuracy performance is 100%, KNN classifiers achieved 99%, ANN gained 98%, Logistic Regression accuracy 95%, Naïve Bayes 90% accuracy based on confusion matrix the accurately. Finally, we know that the accuracy of the Decision Tree is impressive and has incredible results.

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Forecasting of COVID-19 Cases Using AI and Real-Time DataSet

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1 Introduction

Wuhan, China, has become the centre of a pneumonia outbreak of uncertain cause in December 2019, eventually termed coronavirus disease 2019 (COVID19), sometimes known as SARS-CoV-2, and formally named COVID-19 by the World Health Organization (WHO) [22] which drew widespread attention not just in China but also abroad [14]. According to WHO announcement, the COVID-19 outbreak resulted in 559,694 deaths worldwide and 10,509,505 confirmed cases on July 9, 2020. The COVID-19 epidemic and its future unfolding trends are currently a hot topic of research due to its prevalence and potential damage.

Consequently, research on the COVID-19 pandemic and its progress trends is an important topic at present. The COVID-19 outbreak is causing panic in the community due to financial problems and governments' inability to make critical decisions. In attempt to reduce the infection from spreading, many governments have implemented social distancing, maintaining 1 m distances between people, refraining from hugging and handshakes, isolating the infected, putting them on quarantine, and closing schools and malls. There has been a reduction in the spread of the disease due to these measures [12].

As a response to COVID-19's global emergency in the research community, researchers in artificial intelligence (AI) used Deep Learning (DL) and Machine Learning (ML) methodologies to a wide range of COVID-19-related applications, including detecting and classifying the cases, predicting outbreaks, tracking transmission patterns, developing effective medications, predicting mortality rates,

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assessing the severity of the disease, and predicting COVID19 prevalence. AI mimics the intellectual processes of humans in a wide range of environments.

As part of AI, ML uses statistical models for forecasting future outcomes using data samples (also known as instances) without the need to know prior details or to develop explicit programs [23]. In DL, artificial neural networks are used to classify or detect raw data by analyzing the raw data in a defined array of possibilities and then shaping that raw data in a useful way. In light of the COVID-19 pandemic, DL has important implications for medical research. Policy makers, scientists, and researchers are interested in COVID-19 forecasting as it could be utilized to implement effective preventive actions and create effective plans to head off the dissemination of COVID-19 [1]. AI has the potential to be a panacea and is crucial in detecting early Corona virus infections. The goal of this research is to build a COVID-19 prediction model based on DL techniques in order to contribute to the present humanitarian situation. For the next 7 days, a prediction is made for the COVID-19's four most significant variables: the number of new confirmed, death, recovered, active cases. The prominent features of the methodology are summarized in terms of highlights as follows:

1. The model utilized a real-time dataset provided by Johns Hopkins.
2. The algorithm is a DL: LSTM, which proposed to predict the COVID-19 confirmed, deaths, recovered, and active cases for two countries.
3. Performance of the model is assessed using four performance measurement: RMSE, MAE, MAPE and MSE.

The remainder of the article is arranged as follows: Sect. 2 outlining the literature review, Sect. 3 discussing the materials and methods used in the research like dataset and the evaluation metrics, Sect. 4 explaining the employed methodology to forecast the next week's confirmed, 51 deaths, recovered, and active cases of coronavirus, Finally, the result will be discussed, and conclusion is shared in Sect. 5 and Sect. 6 respectively.

2 Literature Review

COVID-19 cases are increasing continuously globally, so the health care system in countries is being burdened by it. Several mathematical and statistical methods have been employed to forecast additional resources to prevent the epidemic. To predict COVID-19 outbreaks, the majority of statistical techniques rely on autoregressive integrated moving average (ARIMA) models [5].

In the field of health care systems, there are also common statistical versions that utilize artificial intelligence (AI) as the basis for learning and educating the COVID-19 dataset of Hubei Province, China in order to forecast epidemic trends and peaks [24]. These methods can often fail to adequately fit the real data and their accuracy in predicting the spread of COVID-19 is very low.

To improve the performance of statistical methods, machine learning(ML) models have been used throughout many fields of study, such as power technology [20], psychology [9], energy engineering, technology [25], psychology [25], and is used for early forecasting and real-time data distribution. As in this study [6] they pretend that ML is best known for its forecasting capabilities. Additionally, there was a latest proposal for an ML approach comply with a classification group called Infection Size Recognizing Aware Random Forest (iSARF) that highlights lung fields and infection size.

In recent years, ML techniques have been used in predicting a variety of diseases, such as coronary artery disease [13], cardiovascular disease prediction [2], and breast cancer prediction [3].

Specifically, on the use of ML on COVID-19, this study [15] concentrates on forecasting confirmed COVID-19 cases live, while the other study [8] specializes in tracking COVID-19 outbreaks and early response.

As well, this study [17] also shows how machine-learning models can forecast the number of recently infected cases, mortality rates, and recovery rates over the following 10 days, which is currently thought to be a potential threat to civilization. In particular, the least absolute shrinkage and selection operator (LASSO), linear regression (LR), the support vector machine (SVM), and the exponential smoothing (ES)forecasting techniques were used. ES has the best performance among the models used, followed by LR and LASSO, while SVM has the lowest performance. The study's findings indicate that these techniques offer a potential approach to employ in the present COVID-19 pandemic scenario.

Similar findings were found in the [21], where the least square support vector machine (LS-SVM) model outperformed the autoregressive integrated moving average (ARIMA) model in terms of accuracy. This result focuses on the five countries with the highest incidence of this disease to model and predicts confirmed cases one month in advance.

Furthermore, to ML, the application of DL algorithms is crucial for the study and forecasting of massive epidemic data patterns [16]. As COVID-19 being a time series data and having dynamic behavior, it should be dealt by using sequential models such DL models. As in this research [10] they estimate COVID-19 cumulative confirmed cases using DL based convolutional neural network (CNN) model. As well in [4] they analyze the prediction of COVID-19 confirmed, released negative, and death cases utilizing long short-term memory (LSTM) and a gated recurrent neural network (GRU).

Additionally, the study [19], forecasted COVID-19 time-series data in 10 countries disrupted by COVID-19 using SVR (support vector regression), LSTM, BiLSTM, and GRU (Gated recurrent units). According on COVID19 data that is accessible until June 27, 2020, BiLSTM offers improved performance.

In addition, this research [11] attempted to predict COVID-19 occurrences for the upcoming week using four models (ANN, ARIMA, CNN and LSTM). It has been determined that deep learning outperforms ARIMA by a wide error margin. Nevertheless, 1-dimensional CNN slightly outperforms the other two deep learning models, then the ANN, and LSTM comes in third with superior results compared to ARIMA.

On other hand of the utilized technique, the majority of recent studies focus on a single nation rather than doing comparative study across many areas, as mentioned in [7]. Therefore, the authors in [7] instead of concentrating on just one nation, the study dealt with the forecasting of the COVID-19 outbreak across Afghanistan, Pakistan, Bangladesh, and India. The prediction model was used to anticipate the number of COVID19 cases in the upcoming 10 days using deep learning techniques including RNN, GRU, and LSTM. The predictive performance of the utilized deep learning model demonstrated by July 1, 2020 is greater than 90% accurate, demonstrating its effectiveness.

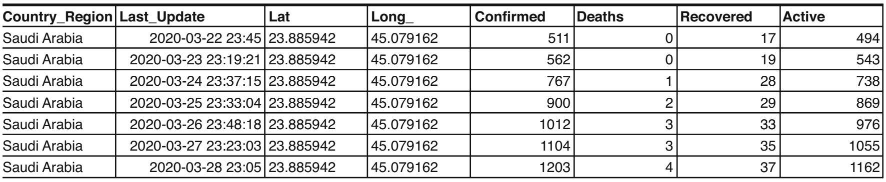
3 Materials and Methods

The following section including the novel coronavirus dataset employed, the deep learning algorithm used, and the evaluation metrics utilized in this research.

3.1 DATASET

Due of its “real-time” availability and accessibility on a variety of platforms, the COVID-19 dataset is collected from the Johns Hopkins University Center for Systems Science and Engineering [27]. The study applied to two countries which are Egypt and Saudi Arabia. The collected COVID-19 confirmed, deaths, recovery, and active cases dataset ranges from 22 March 2020 until the current time which is 26 September 2021. And for training and testing purposes, 80%–20% utilized respectively.

The single country file contains 550 samples of confirmed and death cases in Saudi Arabia. The COVID-19 confirmed, death, recovered, and active cases dataset sample used to COVID-19 forecasting is presented in Fig. 1.



Country_Region	Last_Update	Lat	Long_	Confirmed	Deaths	Recovered	Active
Saudi Arabia	2020-03-22 23:45	23.885942	45.079162	511	0	17	494
Saudi Arabia	2020-03-23 23:19:21	23.885942	45.079162	562	0	19	543
Saudi Arabia	2020-03-24 23:37:15	23.885942	45.079162	767	1	28	738
Saudi Arabia	2020-03-25 23:33:04	23.885942	45.079162	900	2	29	869
Saudi Arabia	2020-03-26 23:48:18	23.885942	45.079162	1012	3	33	976
Saudi Arabia	2020-03-27 23:23:03	23.885942	45.079162	1104	3	35	1055
Saudi Arabia	2020-03-28 23:05	23.885942	45.079162	1203	4	37	1162

Fig. 1 A sample of the prediction model dataset

3.2 Deep Learning Algorithms:LSTM

Recurrent Neural Networks (RNNs) are appropriate since COVID-19 cases fall within time series models. Nevertheless, regardless their benefits, Vanishing gradients is an issue that affects RNNs. Hochreiter and Schmidhuber [18] introduced LSTM as an advanced version of RNN that uses memory cells in the hidden layer to overcome RNN's limitations. The input, output, and forget gates are the gates that control memory cells which store network temporal state and control its self-connections [26]. The hidden state and cell state and are used to gather data and send it to the following state. A forget gate, an output, and an input are all used to determine whether data can pass through or not, based on the priority of the data. The equations from 1 to 5 explains how to solve the vanishing gradient problem.

$$i = \sigma\left(X_t W_i + h_{t-1}\, U_i\right) \tag{1}$$

$$f = \sigma\left(X_t W_f + h_{t-1} U_f\right) \tag{2}$$

$$o = \sigma\left(X_t W_o + h_{t-1} U_o\right) \tag{3}$$

$$c_t = \left(c_{t-1} \times f\right) + \left(i \times \sigma\left(x_t W_c + h_{t-1} U_c\right)\right) \tag{4}$$

$$ht = \sigma(ct) \times o \tag{5}$$

Where the input gate is (i), the forget gate is (f), the output gate is (o), the cell state is (c), the hidden state is (h), the activation function is (sigma), the weight matrix is (W, U), and the time is (t).

3.3 Evaluation Metrics

The research evaluates the performance of a DL algorithm which is LSTM using MSE, MAE, RMSE, and MAPE.

1. **MSE** is calculated by multiplying the square of the difference among the actual and estimated values. Below is the MSE equation in Eq. 6:

$$\mathrm{MSE} = \frac{1}{N}\sum\nolimits_{i=1}^{N}\left(\mathrm{Yi} - \mathrm{Y\hat{}}\,\right)^2 \tag{6}$$

2. **MAE** Without taking into account their direction, the MAE calculates the average amount of predicted errors. It evaluates precision for continuous variables.

The MAE equation is shown in the form of Eq. 7 below:

$$\mathrm{MAE} = \frac{1}{N}\sum\nolimits_{i=1}^{N} \mathrm{Yi} - \mathrm{y}'' \tag{7}$$

3. **RMSE** The standard deviation of the residuals is known as RMSE (prediction errors). The distance between the data points and the regression line is measured by residuals, and the spread of these residuals is measured by RMSE. Particularly, it provides information on how tightly the data is clustered around the best fitting line. In forecasting, climatology, and regression analysis, root mean square error is frequently used to validate results of the experiment. The RMSE equation is given in the following format Eq. 8:

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum\nolimits_{i=1}^{N}\left(\mathrm{Yi} - \mathrm{Y}\hat{}\right)^2} \tag{8}$$

4. MAPE is a method to assess how precise a prediction model is. An absolute percent error can be calculated by subtraction of actual values from actual values divided by actual values over each period of time. The MAPE formula is shown in the following Eq. 9:

$$\mathrm{MAPE} = \frac{1}{N}\sum_{t=1}^{N}\frac{}{\left(-\mathrm{A}-\mathrm{t}'' - \mathrm{F}-\mathrm{t}''''-\mathrm{A}-\mathrm{t}''''\right)} \tag{9}$$

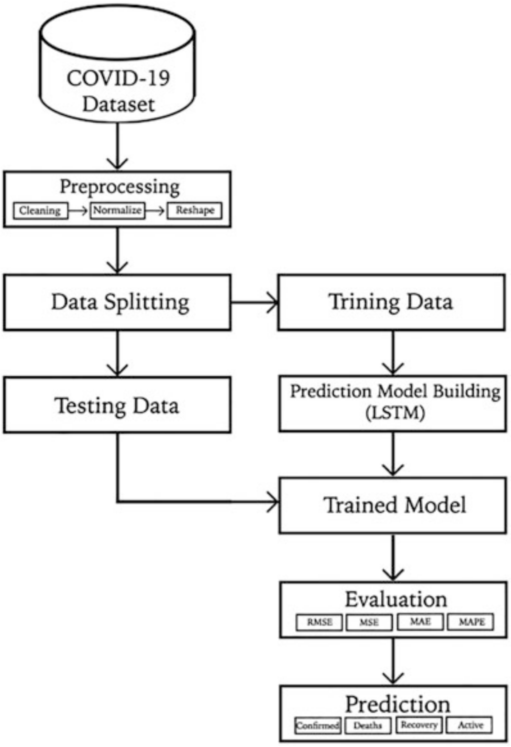
4 Methodology

In this section, the proposed methodology to build the LSTM model of COVID19 prediction for both Saudi and Egypt will be discussed. The following section describes the work done as shown in Fig. 2 to build the proposed COVID-19 prediction model to forecast the confirmed, death active, and recovery cases for the upcoming week. In the first section, the dataset configuration is described.

4.1 Dataset Pre-processing

Initially, COVID-19's real-time data were collected for both Saudi and Egypt. Datasets that have been gathered include daily time series data on active, deaths, confirmed, and recovery cases for Saudi Arabia and Egypt. Several preprocessing techniques were applied to both datasets to build a COVID-19 prediction model. Initially, cleaning of the both dataset was applied such as removing irrelevant values

Fig. 2 The proposed real-time prediction model



and taking care of missing values. In addition, as the datasets consists of a wide range in its value the normalization technique was applied. In the end, as DL models need data to be in a specific form to fit, the both datasets were converted to a multidimensional shape.

4.2 Model Configuration

A DL-based model was created to predict the COVID-19 cases, called an LSTM, which is appropriate for time-series data for both Saudi and Egypt.

The LSTM prediction model was applied to real-time COVID-19 data for one year and half, i.e., from March 23, 2020, to October 10, 2021, using the selected features which are the confirmed, active, deaths, and recovery cases for both Saudi and Egypt. Figure 3 demonstrates the LSTM's employed structure to develop the COVID-19 prediction model for Saudi and Egypt.

The same LSTM COVID-19 prediction model used for Saudi and Egypt. For the structure of the model as shown in Fig. 3, there are three layers: an input layer, two hidden layers, and an output layer. Depending on the type of model that will

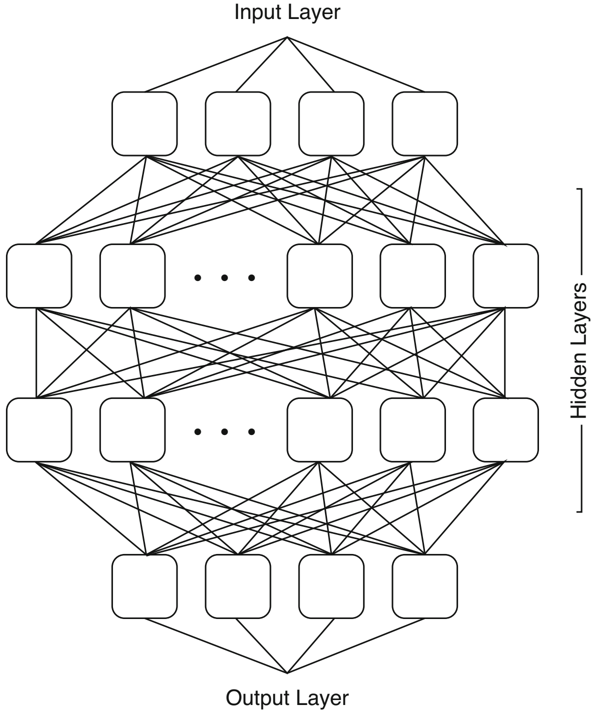


Fig. 3 The structure of LSTM model

forecast four different cases, the input and the output layer of the LSTM consist of four features.

The difference was on the number of neurons for each model. Two hidden layers were used for both models with 64 neurons and 1000 neurons for each layer in Eygpt model. On other hand for Saudi prediction model, the first layer has 259 while the other has 1000 neurons.

To reduce overfitting, a regularization function has been added for each hidden layer for both models. Dropouts were used as the regularization function, which drops a random unit of the model. The weights were optimized using the Adam algorithm.

The train/test split was the applied method in the training and testing phases, where 80% of the records were utilized for training, and the remaining 20% was used for testing.

Python was used to program the model along with libraries like Keras, Scikit-learn, NumPy, and Pandas. In order to build the model, the Keras and the Scikit-learn libraries utilized. In addition, data preprocessing was conducted using the NumPy and Pandas libraries. To accelerate the training time, the Colab graphics processing unit (GPU) was used.

5 Result and Discussion

This section includes the result of the proposed LSTM prediction model to predict COVID-19 Saudi and Egypt cases using a real-time dataset will be discussed in detail using the DL measurement techniques and the difference between the actual and predicted cases.

First, the model performance was revealed in terms of DL measurement techniques as displayed in Tables 1 and 2. Tables 1 and 2 demonstrate the COVID-19 training and testing prediction model results for Saudi Arabia and Egypt. As shown in Tables 1 and 2, the utilized DL measurement technique was MAE, MSE, RMSE, and MAPE measurement techniques. Egypt outperformed Saudi Arabia in both training and testing phases in model error rate. Specifically, it achieved in training an MAE of 0.0016664, an MSE of 0.000007, an RMSE of 0.002651. And in the testing phase, it achieved an MAE of 0.0092198, an MSE of 0.0002092, and RMSE of 0.014464. In terms of model accuracy of an LSTM algorithm on a particular dataset(MAPE), the LSTM model using the Egypt dataset is better fitting than Saudi Arabia since the MAPE in the training phase equals 4.9376978 and in testing is 3.2615096 unlike the LSTM model using the Saudi Arabia dataset is worse in testing these values.

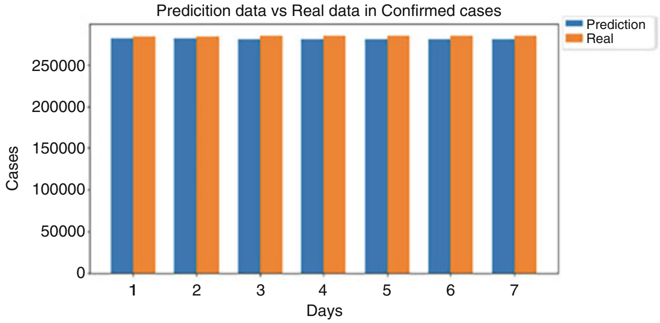
The next phase of revealing the model performance is to visualize the model predicted cases values with actual cases values as shown in Figs. 5 and 4. Figures 5 and 4 show the cases of Saudi Arabia and Egypt, which are the confirmed (a), deaths (b), active (c), and recovered (d) cases respectively. The x-axis represents the number of cases in accordance with a specific day which appears as the y-axis. The blue bar represents the LSTM model case predicted value on a specific day. Whereas, the orange bar represents the real/actual case value on a specific day. As shown in the Egypt prediction model in Fig. 4, the model behaves well in all cases there is no obvious variation, especially in confirmed and deaths cases. The model achieved the best point, in death case value where the difference between the actual and predicted 75 cases as shown in Fig. 4b where the predicted was 288,587 and actual was 288,637 cases. While in saudi prediction cases as in Fig. 5b, the model gets the best prediction on death case on day 3 & 4 it was 8553 and 8561 compare with a real of 8237 and 8249 respectively. In both egypt and saudi prediction model the active prediction was the worst.

Table 1 Prediction of the training sets

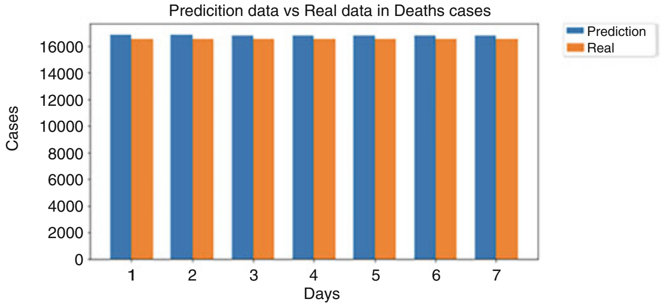
Country	RMSE	MSE	MAE	MAPE
Saudi Arabia	0.007901	0.0000609	0.0058633	6.3280
Egypt	0.002651	0.000007	0.0016664	4.9376978

Table 2 Prediction of the testing sets

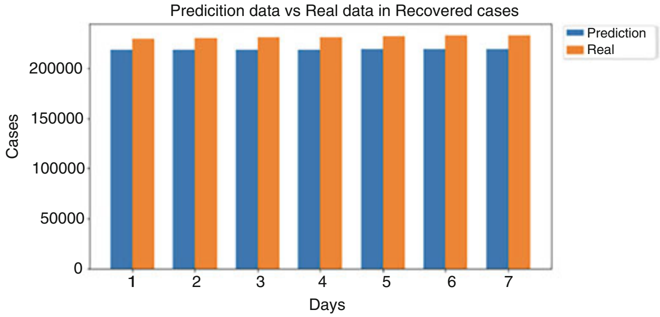
Country	RMSE	MSE	MAE	MAPE
Saudi Arabia	0.017013	0.0002894	0.0150114	5.0553147
Egypt	0.014464	0.0002092	0.0092198	3.2615096



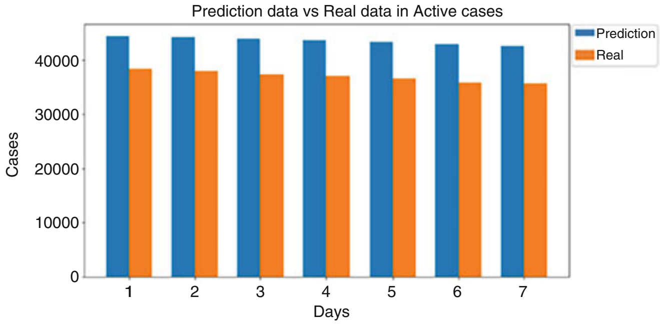
(a) Confirmed Cases



(b) Deaths Cases

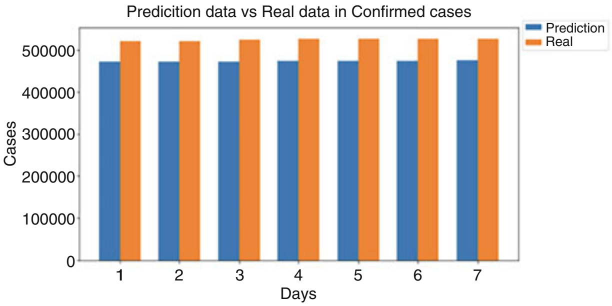


(c) Recovered Cases

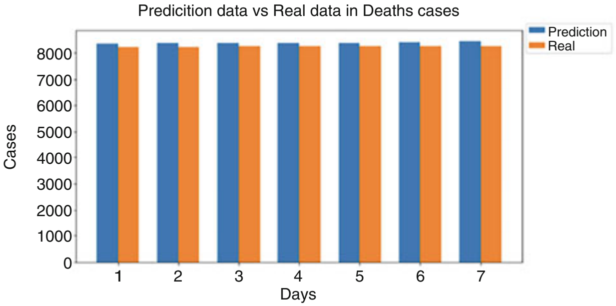


(d) Active Cases

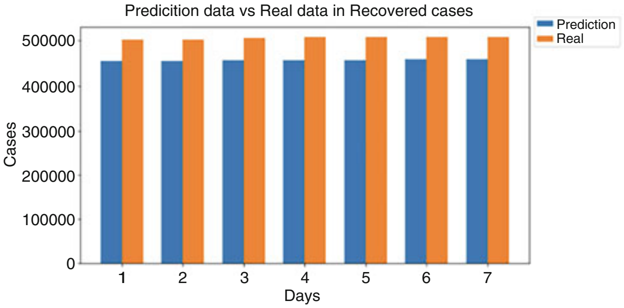
Fig. 4 Egypt predicting confirmed (**a**), deaths (**b**), recovered (**c**), and active (**d**) cases from 22 Mar 2020 until 26 Sep 2021



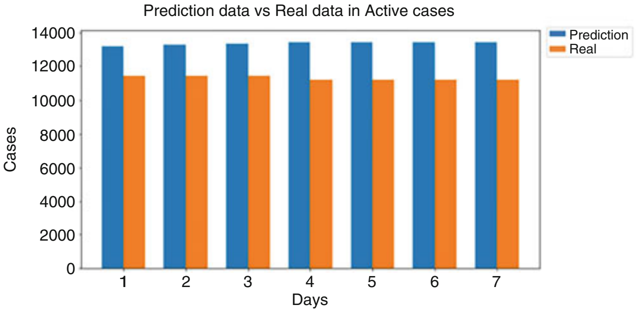
(a) Confirmed Cases



(b) Deaths Cases



(c) Recovered Cases



(d) Active Cases

Fig. 5 Saudi Arabia predicting confirmed (**a**), deaths (**b**), recovered (**c**), and active (**d**) cases from 22 Mar 2020 until 26 Sep 2021

6 Conclusion and Contribution

COVID-19 is a global threat that can ignite a massive global crisis. Regardless of the inaccuracies related to medical forecasts, COVID-19 cases number forecasts are still valuable in helping us fully recognize the present situation and prepare for the future. To contribute to controlling the COVID-19 pandemic, this study performed future forecasting on daily COVID-19 confirmed, deaths, active and recovered cases in the upcoming 7 days in Egypt and Saudi Arabia. The model was initially built using the real-time dataset found at Johns Hopkins University's Center for Systems Science and Engineering. The study employed an 80%–20% approach to train and test the model respectively. Different preprocessing techniques were employed such as cleaning and transforming data. A specific configuration to the DL algorithm which is LSTM was applied to produce an accurate prediction result of COVID-19 cases. Moreover, the model performance was revealed in terms of DL measurement techniques and computes the difference between predicted and real values. Finally, in both the training and testing phases, Egypt outperformed Saudi Arabia. The MAE, MSE and RMSE for training were 0.0016664, 0.000007, and 0.002651, accordingly. A MAE of 0.0092198, MSE of 0.0002092, and RMSE of 0.014464 were achieved during the testing phase. The LSTM model based on the Egypt dataset is more accurate in terms of model accuracy on a particular dataset (MAPE) since the MAPE in the training phase is 4.9376978 and in testing is 3.2615096, unlike the LSTM model used with the Saudi Arabia dataset which performs worse in testing. As a result of this research, policymakers will be able to make more informed decisions about the epidemic depending on realistic estimates of its volume. Nevertheless, the research will continue to be enhanced by using the updated dataset and applying the most appropriate machine learning techniques to forecast the future. The real-time dataset will also be expanded to include more countries in the future. Further, one of our main future priorities will be real-time forecasting.

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Predicting Covid-19 Using Cough Audio Recordings

Nursen Keleş and Mete Yağanoğlu

1 Introduction

The new virus (COVID-2019), which emerged in China in December 2019, spread rapidly all over the world and became a pandemic. It had great negative effects on daily life and global economies [1]. COVID-19, which affected the whole world in 2020, has been declared a pandemic by the World Health Organization (WHO). As of June 20, 2021, around 180 million people were infected with this epidemic, and it was seen that there was a death rate of around 3 million. The virus spread rapidly in most parts of the world, causing a pandemic, according to the WHO [1].

It is an undeniable fact that the rate of patients is high even these days, although vaccine studies continue to increase. The most common respiratory symptoms of COVID-19 disease are shortness of breath, cough, and fever. In more severe progressive variants, pneumonia, severe respiratory failure, renal failure, and death may develop [2].

One of the methods used in the detection of COVID-19; although it is seen in many studies that rapid tests are wrong, PCR tests are also a time-consuming method that requires high fees and an expert team. This shows that especially Artificial Intelligence (AI) based technological developments are needed for early diagnosis and rapid detection of the disease [3].

Studies have shown that dry cough, which is one of the most prominent conditions of the disease, has a characteristic sound coming from the upper respiratory tract [4]. Based on all these observations, putting together a large dataset of breathing and coughing sounds and performing the analysis and classification using Machine Learning (ML) can help diagnose COVID-19 [5]. The aim of this

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study is to support the existing test cases with a cost-effective, faster and simpler technique for the reasons stated, using AI methods.

The COVID-19 patient presents with fever, fatigue, and dry cough. In the work of doctors, clinical analysis of chest CT scan images, various breath sounds, and blood test results observed result showed us that it is possible to fight this disease by using various action and detection methods. It was envisaged that ML approaches could offer fundamental methods for rapidly identifying individuals at high risk for COVID-19 and understanding key symptoms.

To identify potential Covid-19 carriers, different breath sounds, including cough sounds, were investigated in studies conducted simultaneously with ours. Cough sound classification has been successful in diagnosing many respiratory diseases, and ML and Deep Learning (DL) have been used more in studies conducted for this purpose. At the same time, healthcare professionals have not been able to prevent the increase in Covid-19 cases and have not fully resolved the clinical phenotype of the virus. At this point, all countries started to work to control COVID-19. For this reason, it is of great importance to detect the spreading virus early and reduce its spread. Early diagnosis of individuals who are especially positive reduces the number of people around the patient who are at risk of becoming ill and also allows the person to be treated early. This reduces the death rate. And life can return to normal sooner. Rapid and cost-effective testing methods that can be used to detect the COVID-19 virus are needed to reduce the infection rate and prevent clinics from being overloaded. Existing approaches to detecting COVID-19 require expensive face-to-face kits that are not always readily available, which is only possible with costly and time-consuming tests such as PCR (Polymerase Chain Reaction). In addition to this method, thanks to the applications that can be used easily, speed and cost savings are achieved, and at the same time, it can limit the transmission by recommending isolation to the patients as soon as possible.

We hope this article will enable the use of fast, cost-effective, and convenient pre-screening tools to detect diseases automatically. Based on previous work on cough-based diagnosis of respiratory diseases, we propose an AI-based cough-sound prediction model.

2 Related Work

Andreu-Perez et al. [6] used Mel-frequency Cepstral Coefficients (MFCC), which is one of the feature extraction methods, and CNN for classification. As a result, true positive 97.18% and true negative 96.64% accuracy were obtained in the ROC curve.

Bagad et al. [7] offer a CNN-based triage tool. They used the ResNet-18 model, the backbone of the CNN model. The prediction layer used to predict whether it is COVID-19 is used after the dropout and ReLU layers. They have achieved 95% accuracy. Brown et al. [8] developed a dual COVID-19 prediction model on a worldwide dataset of cough and breath sounds. Han et al. [9] analyzed speech recordings from COVID-19 patients, and datasets were created to automatically categorize patients' health status. Gokcen et al. [10] used an open source dataset to detect cough using artificial intelligence (AI) data, and the AI model trained on cough detection achieved 80%. Sharma et al. [5] aimed to diagnose the COVID-19 disease by using respiratory sounds using machine learning techniques, and for this, they created a database consisting of respiratory sounds, namely cough, breath, and voice. Pahar et al. [3] found an accuracy of 92.91% by ML-based COVID-19 cough classifier that can distinguish between COVID-19 positive coughs recorded on a smartphone from both negative and healthy coughs. Chaudhari et al. [11] said rapid and cost-effective testing methods are needed to both reduce infection rates and prevent overfilling of medical facilities. Existing methods for detecting COVID-19 required face-to-face testing with expensive kits that were often not readily available. In the study of Chaudhari et al. [11], cough sound samples recorded and acquired on smartphones predicted COVID-19 infection with a ROC-AUC of 77.1.

In this study, a cheap and fast detection method has been developed against the expensive and time-consuming methods of COVID-19, which is a big problem and has become a pandemic today. While testing the method, a dataset containing voice recordings of 750 subjects from different age ranges and gender was created. While the MFCC method was frequently used in the extraction of the sound feature in previous studies in the literature, in addition to this study, Spectrogram, Zero Crossing Ratio, Spectral Decay, Spectral Center of Gravity, Tone, Square Root Average MFCC (16 types) methods were used. Comparison matrices and accuracy rates of the results obtained by considering all the methods used separately were compared, so the feature method that gave the highest accuracy rate was found. In addition, traditional methods (K-Nearest Neighbors (KNN), Support Vector Machine(SVM), Random Forest, Naive Bayes) and Deep Neural Networks (DNN), which is a deep learning algorithm, were used in the analysis of the data, and the accuracy rates were compared, and a great accuracy rate of 98.48% was found with the DNN algorithm.

3 Material and Method

The data set created within the scope of this study, signal processing, and feature extraction methods, classification methods used to find the highest accuracy are discussed.

In the flow chart given in Fig. 1, the processing processes of the sounds taken from the data set are shown step by step. Cough sound data collected with voice recorders were divided into simultaneous sound particles, and a data set consisting of pre-processed and uniform data was obtained. After the data set was prepared, 80% of it was divided into training and 20% as a test. By processing the audio signals, their features were determined by using feature extraction methods and made ready for classification in this direction. The classification was made by creating traditional ML methods and DL models.

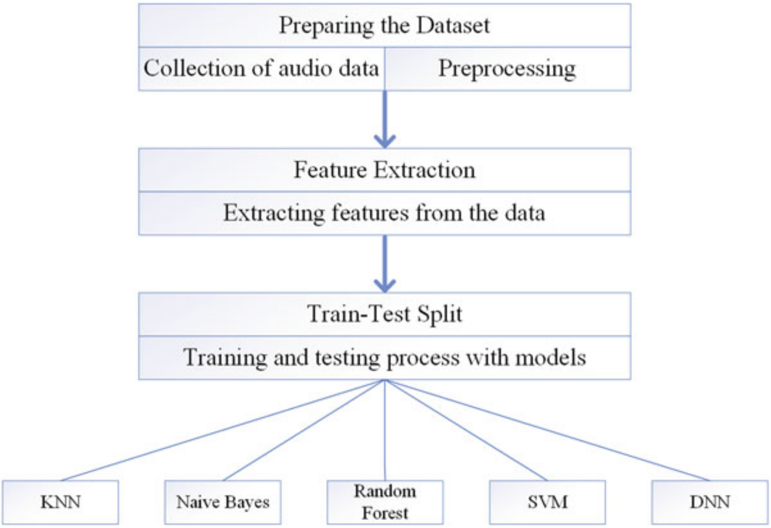


Fig. 1 Model flow chart

3.1 Dataset

Erzurum Atatürk University Faculty of Medicine obtained ethics Committee approval (No. B.30.2.ATA.0.01.00/533) for the collection of the dataset used in this study. The data in the dataset were obtained from individuals who were examined at Atatürk University Faculty of Medicine and gave PCR tests.

The data set consists of cough voice recordings of 375 individuals with positive COVID-19 PCR test results, males and females between the ages of 18–65, and cough voice recordings of 375 individuals with negative COVID-19 PCR test results, and voice recordings of 750 individuals. Voice recordings were collected from people whose PCR test results were known by recording cough sounds via smartphones. An example of our data is shown in the Table 1. The database contains the patient's Covid-19 status(clinically approved), age and gender.

3.2 Methods

In Fig. 2, there is a flow chart showing the steps of the project. The coughing sound obtained with voice recording devices such as smartphones is first preprocessed, divided into 1-second lengths, and data meat consisting of 750 data is obtained, then 80% of this data set is used as train, and 20% as test data, and the most used features in sound processing are extracted. And finally, high accuracy rates are obtained by using classification methods.

Table 1 Dataset description

Patient	Result of PCR	Gender	Age
Patient 1	Positive	Male	39
Patient 2	Positive	Female	43
Patient 3	Negative	Male	65
Patient 4	Negative	Male	26
Patient 5	Positive	Female	24
Patient 6	Negative	Female	31
Patient 7	Positive	Female	23
Patient 8	Negative	Male	40
Patient 9	Negative	Female	20
Patient 10	Positive	Male	55

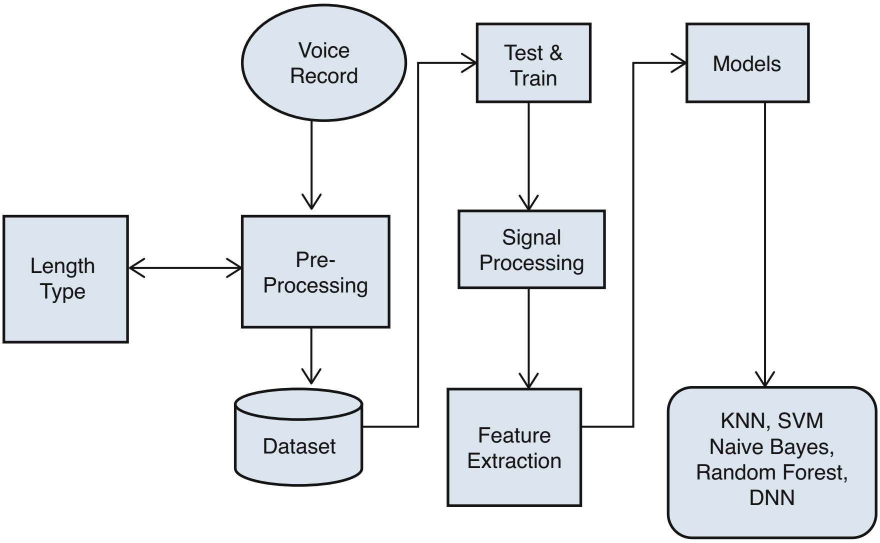


Fig. 2 Methods used in the model

In this study, audio data were collected. This audio data is 750 voice data collected from 75 patients and 100 healthy samples (18–65 years old) via smart devices. It has been collected in opus, wav, ogg, mp3 formats. The collected audio data at different lengths were divided into 1-second lengths, and then all audio data were converted to a single format (.wav), and the data set was created.

Our dataset consists of cough voice data of male and female individuals obtained from the hospital. It includes 75 patients, 100 healthy samples, the results of which were clinically confirmed by PCR testing. Our data was pre-processed, and we created a large dataset containing 375 patients and 375 healthy data for 1 second with the .wav extension. Test and train data were separated. After the collected data set was divided into uniform parts, the sample numbers were equalized for patients and healthy individuals. The healthy and sick samples in the data set were divided into 20% test and 80% train.

The quality of the features obtained from the data set significantly affects the success rate in classification. In order to find the best and correct result, it is necessary to choose the most accurate features. Here, we used the most used features in sound classification problems based on previous studies.

The most used features for sound processing (MFCC, Zero Crossing Rate, Spectral Centroid, Spectral Rolloff, Chroma, Root Mean Square, Pitches) were determined. Inferences were made with the determined features, and the results were recorded. The training was completed using different algorithms. With the extracted features values, training was made using different algorithms (SVM, Naive Bayes, KNN, DNN, Random Forest). The classification algorithm with the highest accuracy was found.

3.3 Data Preprocessing

For classification problems, the data is processed and divided into classes. Data types (ogg, mp3, opus, wav) are converted to the same format type since it is important for the evaluation to have the same type of data collected. After this stage, it is necessary to look at the change of each sound in a fixed time. Because if a numerical analysis and graphical drawing of the changes over time are made, an approximate value can be found, and it has been seen that the sound analyzes of the disease give more accurate results.

Preprocessing is applied to increase the quality of the data obtained while creating the data set and to obtain optimum results. Operations frequently used in data preprocessing; data cleaning, data reduction, data merging, discretization to remove noise in the data.

Pandas, one of Python's libraries, has provided great convenience in doing all these operations in this study and in many studies in the literature. It is one of the most important libraries of the Python programming language. With Pandas, data reading, data preprocessing and data cleaning stages in a data analysis project can be done. In data preprocessing, Python's Pandas library provides convenience in many ways, so it is frequently used in studies in the literature. While analyzing data with the help of the Pandas library, as in this study, it enables to perform operations such as filtering the raw data, filling the gaps in the data as it will affect the predictive value negatively; while doing these, it often uses the Numpy library for numerical calculations and the Matplotlib library to visualize the data. After the data is preprocessed, its features are extracted in order to be able to analyze its features before classification and, in this direction, to know which class the data belongs to.

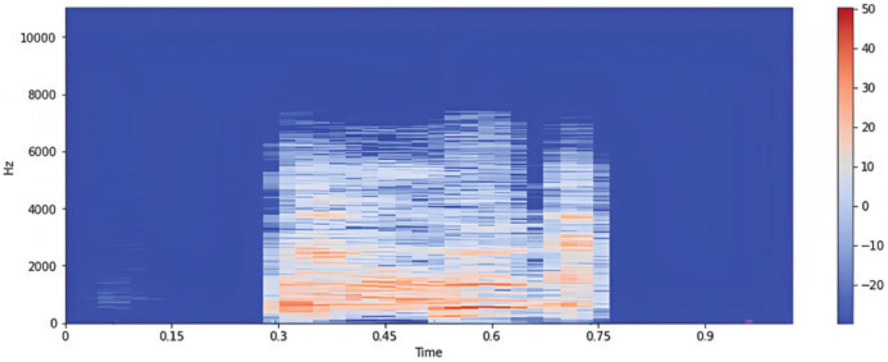


Fig. 3 Spectrogram obtained from cough sounds

3.4 Feature Extraction

Features are descriptive values derived from the values of the data. With these descriptive values, it is aimed to evaluate the data. In feature extraction, as in many studies in the literature, methods belonging to the Librosa library, which is a library of Python, were used in this study.

3.4.1 Librosa

It is a Python library used for audio and music analysis. It provides the necessary building blocks for building audio information retrieval systems.

3.4.2 Spectrogram

A spectrogram is expressed as a visual representation of the frequency spectrum of a time-varying signal. Spectrograms are sometimes called sonography, audio tracks, or voicemails and are widely used in music, radar, speech processing, and other fields. In addition, sound spectrograms can be used to phonetically identify spoken words or analyze various calls of animals. Figure 3 shows a visual representation of the spectrum of a sample frequency obtained from cough sounds in our dataset.

3.4.3 Zero Crossing Rate

It is the rate of significant change that continues throughout a signal. It is also known as the rate of change that occurs in the generated signal. It is often used to extract

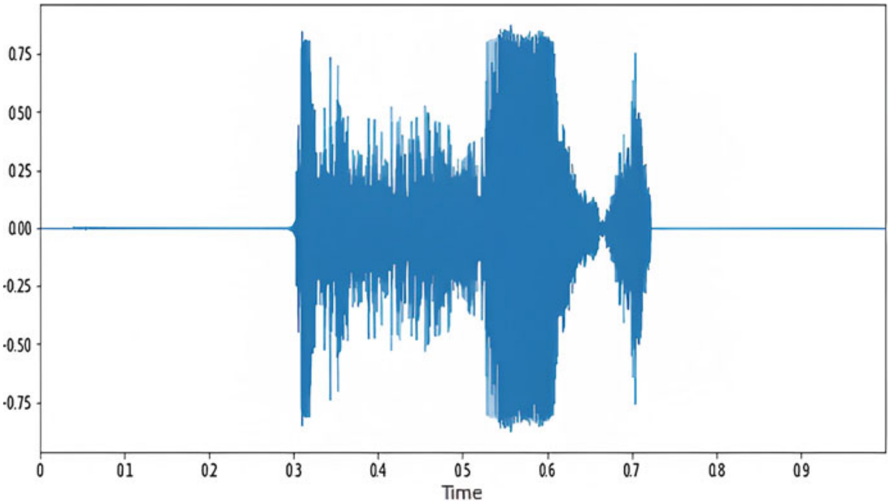


Fig. 4 Zero crossing rate obtained from cough sounds

information from audio data. It is used to classify percussive sounds, both in speech recognition and in the retrieval of musical information. Figure 4 shows the signal change rate of a sampling frequency obtained from the cough sounds in our dataset, which continues throughout the signal.

3.4.4 Spectral Centroid

The spectral centroid is used in digital signal processing to characterize the spectrum. The center of mass of the spectrum is found by this method. Calculates the center of gravity of the sound and shows where it is. Figure 5 shows where the center of mass of a sampling frequency obtained from cough sounds in our dataset is.

3.4.5 Spectral Rolloff

Spectral Rolloff is the frequency at which a certain percentage of the total spectral energy remains below, e.g. 89% lies. It can also be used to approximate the maximum (or minimum) frequency. Spectral Rolloff is a feature extractor that subtracts the Rounding Point below 85%. This is a measure of the right skewness of the power spectrum. Figure 6 shows a measure of the correct skewness of the power spectrum for a sampling frequency from cough sounds in our dataset.

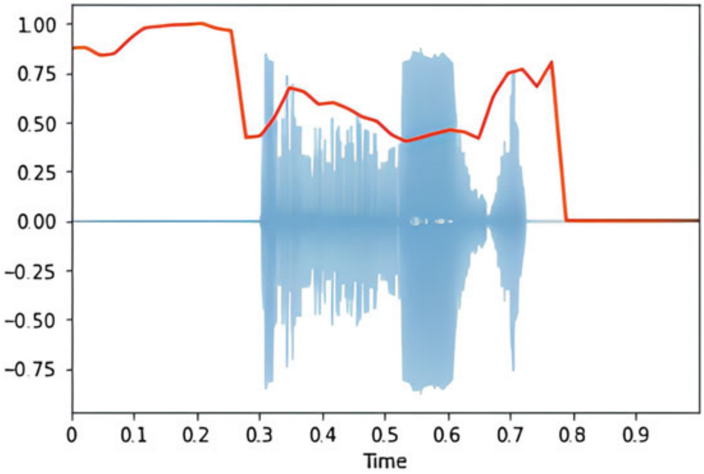


Fig. 5 Spectral centroid obtained from cough sounds

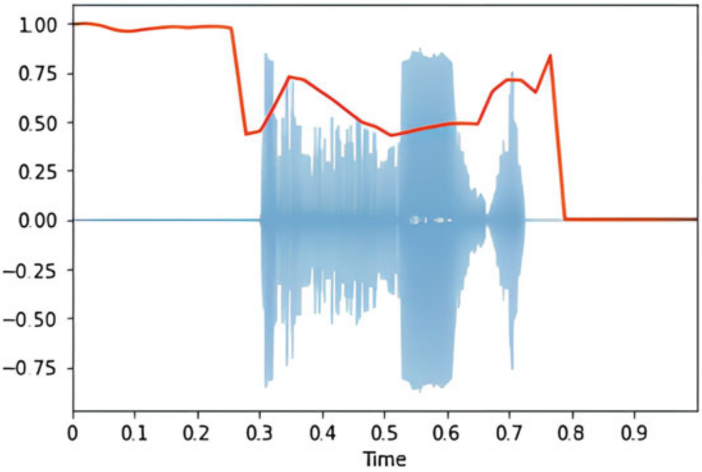


Fig. 6 Spectral rolloff obtained from cough sounds

3.4.6 Mel-Frequency Cepstral Coefficients

MFCC is one of the most generally used properties in sound processing. An attribute that processes perceptual sound, MFCC is a representation of the short-range power spectrum of sound based on a linear cosine transform of the power spectrum on a non-linear Mel frequency scale. Acting on the basis of detection, MFCC imitates the human ear in this sense and performs a numerical analysis using fast fourier transform. In addition, MFCC is little affected by changes in sound fluctuations in the ear.

Fig. 7 MFCC obtained from cough sounds

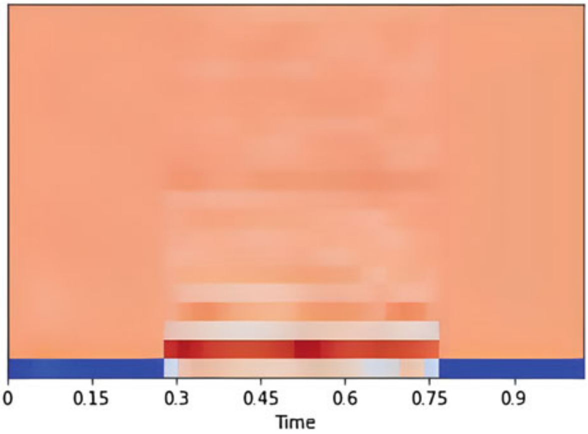


Fig. 8 MFCC algorithm

This feature is one of the important methods for extracting audio signal features. Used when working on audio signals. The MFCC coefficients of the signal show the overall shape of a spectral envelope.

Figure 7 shows the MFCC attribute output of a sample audio signal obtained in this study. The number of usable frames can be obtained with the calculated number of MFCCs. Figure 8 shows the steps of the algorithm to obtain the MFCC coefficients when processing a sound.

3.4.7 Chroma

The colour feature is an identifier of an audio signal that represents the tonal content in condensed form. For this reason, colour properties can be considered an important prerequisite for high-level semantic analysis of the sound, such as chord recognition or harmonic similarity estimation, as seen in Fig. 9. The better the quality of the extracted chroma feature, the better results are obtained in these high-level tasks.

3.4.8 Root Mean Square

It is used to calculate the energy on behalf of each square Root Mean Square (RMS) from sound samples or a spectrogram. The extracted data becomes ready for training and the confusion matrix is extracted by observing the accuracy value. RMS is the root mean square value of a signal and represents the average power of the signal.

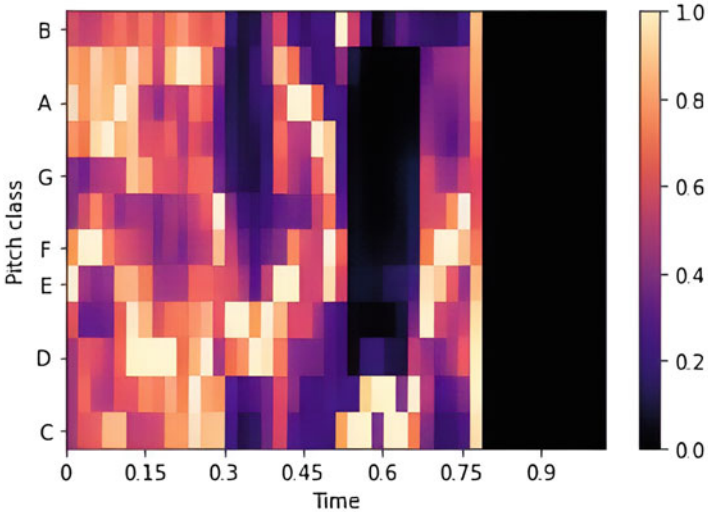


Fig. 9 Chroma obtained from cough sounds

The RMS value for a digitized signal is calculated by squaring each value, then finding the arithmetic mean and taking the square root.

The feature extraction methods and signal images used in this study are given in Fig. 10. Other methods used in addition to frequently used methods such as MFCC have increased the accuracy rate.

3.5 *Classification*

3.5.1 Support Vector Machine

SVM is a ML algorithm that can be used for classification problems. It is often used on medium or small datasets for classification problems.

Each data is plotted as a point in x-dimensional space where the value of each feature is the value of a particular coordinate (x: number of features). Then the hyperplane that best distinguishes between the two classes is found and the classification is concluded. Support Vectors are the coordinates of the observation made. The SVM is the boundary separating the two classes with the best result [12].

Even if at the SVM, data is not linear, the result accuracy can be increased by changing the kernel selection. For a linear dataset, we can choose ‘linear’, for other cases ‘rbf’ and ‘polynomial’. If the nonlinear kernel is chosen, the data is mapped to a higher dimension, which makes it easier to plot the hyperplane.

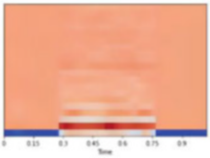
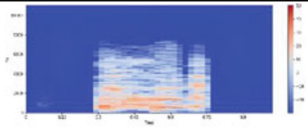
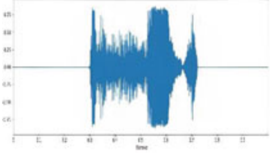
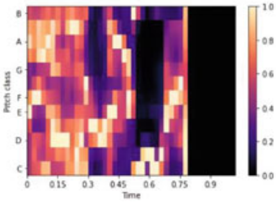
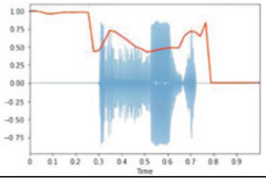
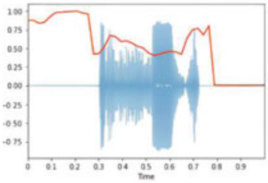
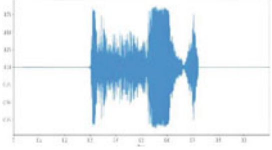
Methods	Features	Result
MFCC	The spectral characteristics of the audio signal.	
Spectrogram	A visualization of the frequency spectrum of the time-varying audio signal	
Zero-Crossing Rate	It gives the rate of change in the audio signal over time.	
Chroma	Enabled to obtain the content of the tone of the audio signal.	
Spektral Rolloff	It gave the minimum or maximum frequency of the audio signal.	
Spektral Centroid	It indicates where the center of mass of the spectrum is located.	
RMS	It gave an account of the root mean square energy in a spectrogram obtained from the sound sample.	

Fig. 10 Feature extaction methods

3.5.2 Naive Bayes

It works with Supervised Learning in machine learning. It is used for categorization. The Naive Bayes Classifier is based on the Bayes theorem. It is one of the learning algorithms. If we look at the working logic of the algorithm, it calculates the probability of the whole situation for each element in the class and performs the classification process according to the highest probability value. If a value in the test set cannot be observed in the training set, it returns 0 as a probability value, meaning that a prediction cannot be made. This condition is often referred to as the 0 frequency. Various remediation techniques can be used to resolve this issue [13].

3.5.3 Random Forest

Random Forest is one of the widely used ML methods because it can give good results without using hyperparameters and can be applied to both regression and classification problems.

A Random Forest classifier is a supervised learning algorithm. It can be used for regression as well as classification. The algorithm has an easy-to-use structure. This algorithm creates decision trees on randomly selected data, makes predictions in each decision tree it creates and chooses the best solution as a result of the estimation scores [13].

3.5.4 K-Nearest Neighbors

With its basic definition, the KNN algorithm is based on estimating the class of the newly added value, which is to be estimated to be included in which class, based on the information in which class the nearest neighbors of the vector consisting of independent variables are dense. In other words, it is an algorithm that makes classification based on the proximity relationship.

3.5.5 Deep Neural Network

Deep learning is the ability of a machine to learn desired information, provided there is sufficient data. DNN is a multi-layered structure of an algorithm designed for data recognition, called a neural network (NN), layered like human neural network circuits.

DNN consists of a multilayer feedforward sensor network constructor between input and output layers. Since it is very difficult to train the entire network using discriminant training, a pre-training step is applied to train one layer at a time. After the pre-training phase, the entire network is completed cross-layer training using a back propagation process. The more layers need to be processed to solve the problem, the deeper the network is considered [14].

DNN layers are made up of nerve nodes called neurons, these nodes are small parts of the system and are like neurons of the human brain. When a stimulus hits them, a propagation process takes place in these nodes. Each neuron has a separate weight for each of its inputs. Each weight is multiplied by each of the inputs going into the neuron, which is then summed up and fed with an activation function to form the output from the neuron. The missing function used for training networks for classification is cross-entropy. Cross-entropy provides a loss based on guessing the correct class and how confident you are that the guess is correct. This means a value of 1 applies if the training instance belongs to a class, and 0 if the training instance does not belong to that class [14].

3.6 Evaluation Criteria

We used a confusion matrix to evaluate the results. The confusion matrix is a table used to describe the performance of a classification model on a set of test data for which the true values are known. Accuracy, Precision, Recall, F1 Score values were obtained using the confusion matrix

4 Results

The COVID-19 pandemic has become a major problem of our time. Although health workers are mobilized to solve this problem, which started in China and spread all over the world, the problem continues and no solution has been found. In addition, the tests used for the diagnosis of the virus are costly and time-consuming but require an expert team. For all these reasons, alternative solutions are sought. A high-accuracy, inexpensive, and non-technical testing mechanism would be a great strength against the epidemic.

Based on all these reasons, within the scope of this thesis, in order to find a solution to all this probing, sound analysis and Classical Methods (Naive Bayes, SVM, Random Forest, KNN) and Deep Learning. Information about the effectiveness of DNN algorithms on the classification problem is given.

When the studies in the literature are examined, since the problem of predicting COVID-19 from the cough sound is a very new problem, the studies and the data sets obtained are very few. This requires a reliable and highly accurate data set. A data set containing 750 samples from 375 healthy and 375 patients clinically confirmed by PCR laboratory molecular testing was created.

First, a data series consisting of 750 data was created and the obtained data set was processed and the most frequently used features were extracted and finally, accuracy analysis was performed using deep neural network algorithms and the results shown in Table 2 were obtained. As the best solution, DNN was the method

Table 2 Result of feature extraction methods

Features	Result		
	Precision	F1 score	Accuracy
MFCC	0.92	0.94	0.94
Chroma Stft	0.56	0.54	0.53
RMSE	0.62	0.58	0.56
Centroid	0.48	0.53	0.65
Spectral bandwidth	0.62	0.57	0.65
Rolloff	0.58	0.62	0.65
Zero crossing rate	0.6	0.61	0.62

Table 3 Result of feature classification methods

Model	Precision	Recall	F1 score	Accuracy
SVM	0.3372	0.9354	0.4957	0.6402
KNN	0.6923	0.6176	0.6528	0.6598
Random Forest	0.9705	0.9705	0.9705	0.9697
DNN	0.9718	1	0.9857	0.9848

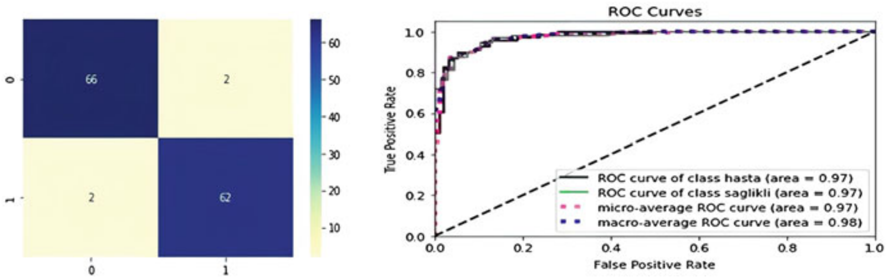


Fig. 11 Random forest confusion matrix and ROC

with the highest accuracy with a success rate of 98.48%.We have shared the accuracy results in Table 2.

The accuracy values are shown in Table 3. MFCC, Centroid, Spectral Bandwidth and Rolloff are the features that has most accuracy rate of the table.

ROC and confusion matrix results are shown in the Figs. 11 and 12 for the Random Forest and DNN.

When the confusion matrix values seen in Fig. 12 are examined, 100% of the processed data whose results are positive and correctly classified are classified correctly, while 96.82% of those that are negative and correctly classified are classified correctly. ROC (Receiver Operating Characteristic) curve; In cases where the threshold value used for binary classification, such as patient, healthy, differs, it is calculated as the ratio of sensitivity to precision. As the curve approaches the upper left corner of the graph, the overall accuracy of the test increases.

In this study, a cheap and fast detection method has been developed against the expensive and time-consuming methods of COVID-19, which is a big problem and has become a pandemic today. More feature extraction was used than studies in

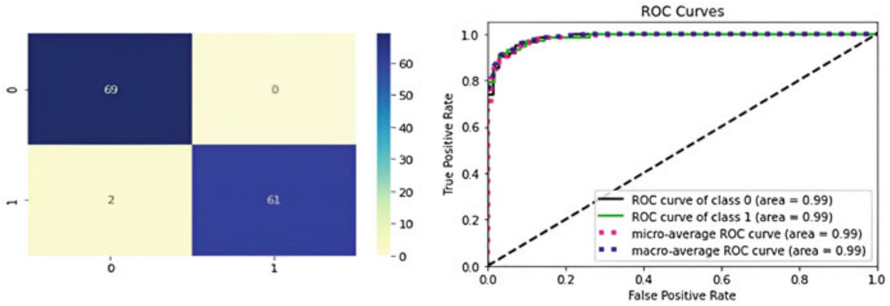


Fig. 12 DNN confusion matrix and ROC

the literature. In addition, classical methods (KNN, SVM, Random Forest, Naive Bayes) were also used in the analysis of the data and their accuracy rates were compared. Features used Specktogram, Spectral Centroid, Zero Crossing Rate, Spectral Rolloff, Color Its Brightness(Chroma), Root Mean Square Deviation(RMSE), Pitch, MFCC(16 features) are KNN 65.98%, SVM Cross 64.02%, Naive Bayes 83.68%, Naive Bayes Cross 85.36% , Random Forest 96.97%, DNN resulted in 98.48

5 Discussion and Conclusion

Comparison of the studies done is as seen in Table 4. Imran et al. [15] developed an AI-assisted screening method for cough-based diagnosis of respiratory diseases. The application called AI4COVID-19 is software that records and sends three 3-second cough sounds from the patient to an AI engine running in the cloud and returns results within two minutes. Its overall accuracy was 92.64%. According to Bagad et al. [7] AUC 0.72 and achieved 95% accuracy. They used ReLU layers and the CNN ResNet-18 model. Fakhry et al. [16] collected a dataset. They included information such as age, gender, geographic region in their datasets. They found an AUC of 0.99 for positively labeled sounds. Sharma et al. [5] created a database of breathing sounds called Coswara. Audio samples were collected using a website application. They used Random Forest method for voice analysis. It was aimed to group the sound recordings according to 9 categories. They extracted features from the collected records. They separated and trained the test set and stated that the accuracy of the test data was 66.74%. Mohammed et al. [17] used two open datasets of crowdsourced cough recordings. They used CNN and pre-trained CNN models and obtained 80% sensitivity. They used chroma, mel spectrum, MFCC, powerspec, raw, spec and tonal as features. We have reached higher accuracy with different features and our own dataset. Brown et al. [8], in their study, it reaches an AUC of over 80%. They used two different types of traits: handcrafted traits and those acquired through transfer learning. They released Handmade Features and leveraged the librosa library. Ritwik et al. [18] represented as supervectors of short-term Mel

Table 4 Comparison with previous studies

Previous studies	Classification methods	Results
Andreu-Perez et al. [6]	DNN	96.43% sensitivity, 96.20% specificity
Bagad, P et al. [7]	CNN	0.72 AUC
Fakhry et al. [16]	CNN, DNN	0.99 AUC
Sharma et al. [5]	ML	66.74%
Mohammed et al. [17]	CNN	0.75 F1-score
Zoabi et al. [19]	ML	87.30% sensitivity, 79.18% specificity
Hassan et al. [20]	RNN	97%
Brown et al. [8]	SVM	80% AUC
Ritwik et al. [18]	SVM	88.6%
Schuller et al. [21]	CNN	80.7% AUC
Imran et al. [15]	ML	92.64%
Barry et al. [22]	Probabilistic NN	80% sensitivity, 96% specificity
Jyothi [23]	ML	87%
Han et al. [9]	SVM	0.79 AUC
Mouawad et al. [24]	ML	97–99%
This study	DNN	98.48%

filterbank properties for each phoneme. These features used a two-class classifier to separate COVID-19 speech from normal.

In our study, besides MFCC, seven features that increase the accuracy rate such as zero crossing ratio, chroma and spectrogram were used. ML and DNN were used and compared in classification methods. In this study, we developed an inexpensive and rapid detection method against expensive and time-consuming methods of COVID-19, which is a big problem and has become a pandemic today. We used more features extraction than the studies in the literature. In addition, classical methods (KNN, SVM, Random Forest, Naive Bayes) were also used in the analysis of the data, and the accuracy rates were compared. In addition, our data set consisting of cough sounds obtained from 75 patients aged (between 18 and 65) and 100 healthy individuals was used. The features used are Spectrogram, Spectral Centroid, Zero Crossing Rate, Spectral Rolloff, Chroma, RMSE, Pitch, MFCC (16 types) and accuracy rate is KNN 65.98%, SVM Cross 64.02%, Naive Bayes 83.68%, Naive Bayes Cross 85.36%, Random Forest 96.97%, DNN resulted in 98.48%.

In future studies, more detailed studies can be carried out by developing our data set by using the cough sounds of individuals with diseases such as asthma and bronchitis with similar symptoms. In future studies, a richer data set can be created by adding disease data such as asthma, bronchitis, and sars, which contain similar symptoms to Covid-19. In this way, studies can be performed with higher accuracy and a lower margin of error.

Declarations

Local ethics committee of the Atatürk University Medical School approved this study with an approval number of B.30.2.ATA.0.01.00/533. This study was presented in summary at the International Congress on Scientific Advances.

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Computational Linguistics Techniques in Measuring Genetic Distance of Living Organisms

Iskander Akhmetov and Dilyara Akhmetova

1 Introduction

In the modern world, genetic research has taken a special place. It is constantly developing and climbing higher in the stages of development. Genetic analysis can be used in different areas, including the disease diagnosis and therapy of any organism, genetic engineering, different species' features identification, and others. Thus, genetic analysis can help in aspects of human beings, fauna, and flora equally. According to the National Cancer Institute (n.d.), genetic analysis is "The study of a sample of DNA to look for mutations (changes) that may increase risk of disease or affect the way a person responds to treatment". Moreover, genetic analysis is considered to be the center of the investigations on viruses with complex ecosystems. It means that the viruses can be studied from the perspective of the history of evolution and their molecular epidemiology [20]. Then the inheritance pattern, which can illustrate the linked diseases, is distinguished.

Viruses are everywhere; paradoxically, there are more viruses on the globe in terms of biomass than other organisms combined. When scientists began to study seawater using deep sequencing and metagenomic analysis, it turned out that there is a considerable amount of viruses that we did not suspect in every milliliter of water. There is not a single organism in which there would be no viruses. Many viruses coexist peacefully with humans and perform the most crucial function in our general evolution and physiology. However, some viruses cause various diseases, which, along with the ability of many viruses to mutate rapidly, highlights the need for suitable and rapid diagnostic measures.

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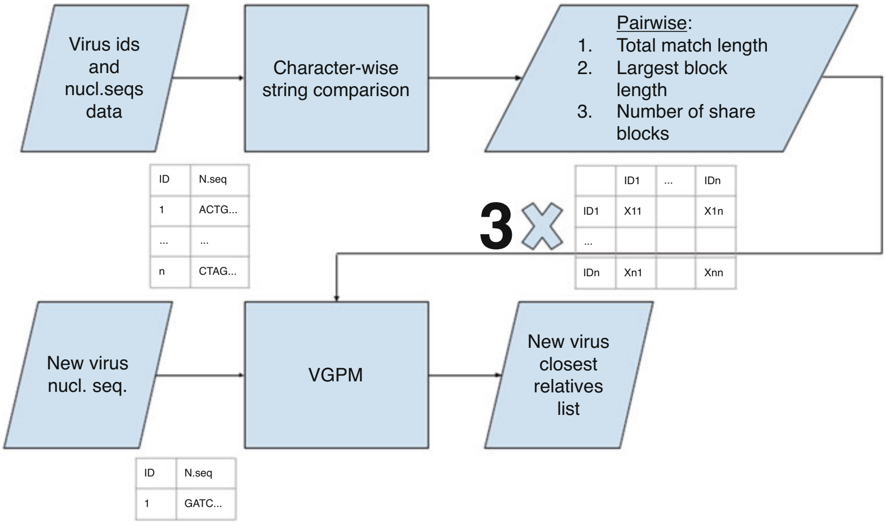
Viral infections are among the most common diseases worldwide. Tragically famous coronavirus 2019-nCoV caused the 2019–2021 pandemic, posing great menaces to public health security globally. However, timely detection of the causal pathogens of viral infections is substantial to save people’s lives by prescribing effective treatment and avoiding excessive use of antibiotics.

Zolyan S. investigated the semiotic-informational approach to the genome nucleotide sequences; see Definition 1. Its essence boils down to the similarity between language and genetic information processing, where genes and the genome can be considered text or language. In other words, the genome is a textual way of storing information, which is its fundamental property. Such an approach can be a helpful tool for explaining the underlying mechanisms of genetic information. Genetic information processing can be considered as certain operations for reading, writing, and editing text or as the interaction of vocabulary and grammar, showing its internal logic and systemic meaning. According to the author, the genetic code grammar is an optimal recursive system capable of creating an infinite set of information objects structured hierarchically [30].

Definition 1 **Nucleotides** are nucleoside and phosphate-containing organic molecules, serving constituent parts of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). Nucleotides can be obtained from the digested food or synthesized in the liver [28].

Our work aims to develop a model to find the closest relatives of any newly appearing virus strain to reduce the time to compile treatment protocol by using those used for the already known viruses. Our approach consists of; see Fig. 1:



ID	N.seq
1	ACTG...
...	...
n	CTAG...

	ID1	...	IDn
ID1	X11		X1n
...			
IDn	Xn1		Xnn

ID	N.seq
1	GATC...

Fig. 1 Virus Genetic Proximity Model (VGPM) approach

1. Creating three pairwise nucleotide sequences comparison matrices of known viruses:
    - Total match number.
    - Largest match block length.
    - Number of shared blocks.
2. Compare a nucleotide sequence of a newly appeared virus to existing ones.
3. Provide a list of the new virus's closest relatives among those compared in Step 1.

The limitation of the approach is in its speed, as we know that the pairwise string comparison might be slow. Therefore, we have room to optimize the algorithm to work with massive data. Another practical drawback of the method is that in case of a completely new virus that is not a strain of any known one, the closest relative might not be the best choice for selecting the treatment protocol. Thus, we need to establish a proximity threshold for the performance excellence of the proposed method.

The main contributions of our work include (1) Applications of methods from Natural Language Processing (NLP) and Computational Linguistics (CL) in the area of Bioinformatics, (2) Dataset with cleansed original viruses data, pairwise comparison data, adjacency matrices[1] [1], (3) Virus Genetic Proximity Model (VGPM) to assess the genetic relationship level of newly appearing virus strain to its predecessor.

Further, in our article we go through an overview of the related works in Sect. 2, describe our data and methods in Sects. 3 and 4, explain the experimental setup in Sect. 5, discuss the obtained results and draw out the conclusions in Sects. 6 and 7.

2 Related Work

Starting slowly from the early 1980 and booming in the late couple of decades machine learning has been used in medicine attracting more and more researchers to the field. Thus, currently we can observe exponential growth of both the medical data and publications in the area of Bioinformatics and Digital Healthcare [13].

In this research, we explored the adjacency matrix calculations to determine the genetic distance between viruses, assuming each virus has a genetic match with other viruses. However, before the experiment, it is essential to understand the subject better and analyze previous studies. Their limitations could be investigated deeply, which may help avoid further experiments.

Starting from the genetic distance itself, it is "the degree of gene difference (genomic difference) between species or populations that are measured by some numerical method" [6]. Of course, the development of technologies has significant

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[1] https://data.mendeley.com/datasets/swy5rzbmrd.

input in investigating genes. However, there is rapid growth in evolutionary biology, which requires accurate and double-quick methods for its investigations. Therefore, the new distance measures should vary and test different approaches. For example, Joly, S. et al. [8] have used such flexible methods as match states, genpofad, most common recent ancestor, and Nei's genetic distance.

Souza, L. R. et al. [23] depicted an ML method capable of identifying amino acids co-occurrence patterns in the protein sequences. The approach included protein chains mapping onto co-occurrence matrix disclosing patterns in amino acid sequences.

The support vector machine (SVM) can also be used to distinguish regulatory sequences and classify DNA sequences and classify DNA sequences by analyzing hyperparameters and ways for optimizing them [3, 4].

The method we propose is based on an algorithm whose first step is to compare strings. Then, python string comparison lexicographically is performed by applying the symbols in both strings, which are compared one by one. Using an algorithm for sequence comparisons, authors [10] create the suit of coincidences between two compared texts. Character errors, classified as substitutions, insertions, or deletions, are received by analyzing the coincidences and applying a weighting coefficient. Other researchers [25] presented an algorithm for automated analysis of free text entries for symbol-level errors. They also introduced new symbol-level metrics, which can help refine text input methodology.

M.A. Khan [9] suggests a code transformation purposed to increase the efficiency of the string-matching algorithms, including comparing buffers of symbols, by optimizing buffer comparison operations, heavily used and required by the algorithms.

A Pivot table is a conversational way to summarize large quantities of data quickly. It can be used to analyze numerical data amply and search for answers to unforeseen questions about data. Pivot Based Language Model (PBLM) approach [29] explores the synergy of Pivot tables and Artificial Neural Networks to account for the structure of the data. The approach can also be effectively used with LSTM and CNN architectures. Ben-David, E. et al. [5] proposed a representation learning model called Pivot-based Encoder Representation of Language (PERL), fine-tuning a pre-trained deep contextualized model, such as BERT, using a pivot-based Masked Language Modeling (MLM) training objective.

The next step is text vectorization, which can be described as transforming text into numerical representation to use in model parameter training. After vectorization, we can extract features, and data can be used to find word semantics/similarities or word predictions. X. Yang et al. [26] proposed a novel text vectorization method combining transfer learning with topic modeling. The text data is vectorized, and the similarity of texts is calculated by measuring the cosine distance. After comparative experiments, the method proved to show higher results when calculating the resemblance between text pairs. Singh, A. K., and Shashi, M. [18] compared different vectorization methods (TF-IDF, Word2Vec, and Doc2Vec) to identify the most effective way of solving the problem of Hybrid Summarization and Identification of news articles, by clustering text documents with the K-means algorithm. Finally, a solution to the problem of effective detection of fake articles by proposing a new statistical method for generating feature vectors for a document description was considered by Mersinias, M. et al. [12]. The new vectorization approach, called class label frequency distance (CLFD), was suggested and experimentally shown that the approach elevates the efficiency of machine learning methods.

The Vector Space Model (VSM) is established on the concept of resemblance. The model presumes that the document-query relevance approximately peers to the query-document similarity [15]. The concepts of soft cosine measure and soft similarity were proposed in [17], which are calculated taking into account the resemblance of features. New features were added to the VSM by calculating the similarity of each pair of already existing features. In other words, a similarity matrix was built and then used for each pair of features. However, if the features are similar only to themselves, these equations are equal to the traditional cosine similarity equation.

3 Data

In our research, we used the "SARS CORONAVIRUS ACCESSION"[2] dataset by BioTech researchers, which they utilized to explore the mutations of the SARS coronavirus complete genome and to find similarities in different variations of viruses from the COVID-19 group. The dataset contains accession data researched by BLAST, strategy: RNA and protein analysis with geographical location info, date [27].

The data contains genetic sequences of the following types of viruses:

- 2019-nCov
- COVID-19
- COVID-19 virus
- SARS-CoV-2 (genbank)
- SARS2
- Wuhan coronavirus
- Wuhan seafood market pneumonia virus

Using Biopython [2] module, we extracted data from the dataset in the format shown in Table 1, where *ID* is an Identification number of a genetic material sample, *Name* is a name of a virus, *Length* is a length of a nucleotide sequence, and the final column is a nucleotide sequence itself as the name implies.

After data cleansing procedures the final version of the dataset contained 81 unique records with nucleotide sequence length maximum of 30,256, median of 29,767 and minimum of 29,350; see Fig. 2 and Table 2 for distribution and statistical description information.

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[2] https://www.kaggle.com/datasets/jamzing/sars-coronavirus-accession.

Table 1 "SARS CORONAVIRUS ACCESSION" dataset excerpt

ID	Name	Length	Nucleotide seq.
MN985325.1	Wuhan seafood market pneumonia virus isolate ...	29,882	ATTAAAGGTT...
MN975262.1	Wuhan seafood market pneumonia virus isolate ...	29,891	ATTAAAGGTT...
LC522974.1	Wuhan seafood market pneumonia virus 2019-nCo...	29,878	AAAGGTTTAT...
MT049951.1	Severe acute respiratory syndrome coronavirus...	29,903	ATTAAAGGTT...
MN908947.3	Wuhan seafood market pneumonia virus isolate ...	29,903	ATTAAAGGTT...
...	...	...	...
AY502928.1	SARS coronavirus TW5, complete genome	29,729	TAAACGAACA...
AY714217.1	SARS Coronavirus CDC#200301157, complete genome	29,727	TTGTGAGATT...
DQ898174.1	SARS coronavirus strain CV7, complete genome	29,751	AGGTTTTTAC...
AY283796.1	SARS coronavirus Sin2679, complete genome	29,711	CCCAGG–AA–...
AY282752.2	SARS coronavirus CUHK-Su10, complete genome	29,736	CTACCCAGG–...

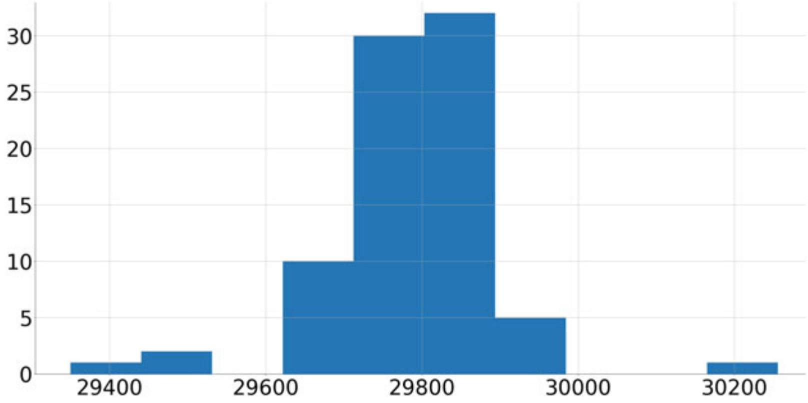


Fig. 2 Samples nucleotide sequence length distribution

4 Methodology

Our research methodology consists of various string character-wise comparisons, pivot table building to obtain vectors, and vector space modeling.

Table 2 Samples nucleotide sequence length statistical description

Parameter	Length
Count	81
Mean	29,790.82
Standard deviation	113.95
Minimum	29,350.00
25th percentile	29,729.00
50th percentile	29,767.00
75th percentile	29,878.00
Maximum	30,256.00

4.1 String Character-Wise Comparison

We used the string character-wise comparison method to compare a pair of nucleotide sequences for total positional match length, longest match block length, and the number of shared blocks; see Appendix 1 for the code listing of the Compare function in Python. The method is similar to what is performed by genetic genealogists when they compare human genetic samples to find the relationship they could have. However, the unit of measurement they use is centimorgan (cM); see Definition 2, and we use a single nucleotide instead. In addition, before comparing the sequences, we truncate them to the length of the shortest sequence in the pair.

Definition 2 **Centimorgan (cM)**, also known as a map unit (m.u.), is a measure of genetic linkage or recombination frequency. One centimorgan is a 1% chance for a marker at a specific genetic locus to be separated from a marker at another locus during the crossing-over process in a single generation [22]. The centimorgan unit was named in honor of a famous geneticist Thomas H. Morgan by J. B. S. Haldane [7].

4.2 Pivot Table

Pivot tables found their applications in many fields of Computer Science research, including Natural Language Processing (NLP) and Computer Vision (CV). The method consists of constructing a matrix to show aggregate values (ex., sum, average, min, or max) grouped by one or more categories [24]. We used the realization of Pivot Table functionality in Python Pandas module [11].

4.3 Vector Space Model

The method comprises a set of techniques to represent objects in general as vectors to apply general Linear Algebra operations to compute the proximity (cosine or Euclidean distance measures) of one object to another and get corresponding intuition on their interrelation and its degree [16].

Definition 3 **Cosine distance** is a similarity measure of two vectors characterized by the cosine of the angle between them and is closely related to the term of cosine Similarity; see Eqs. 1 and 2 [19].

$$\text{cosine similarity} = \cos(\theta) = \frac{\mathbf{A} \cdot \mathbf{B}}{\|\mathbf{A}\| \|\mathbf{B}\|} = \frac{\sum_{i=1}^{n} A_i B_i}{\sqrt{\sum_{i=1}^{n} A_i^2} \sqrt{\sum_{i=1}^{n} B_i^2}}, \tag{1}$$

where A_i and B_i are components of vector A and B, respectively.

$$\text{cosine distance} = 1 - \text{cosine similarity}. \tag{2}$$

Definition 4 As the name implies, **Euclidean distance** is the distance between two points in Euclidean space, which can be computed using the points' Cartesian coordinates; see Eq. 3 [21].

$$d(p, q) = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2 + \cdots + (p_i - q_i)^2 + \cdots + (p_n - q_n)^2}, \tag{3}$$

where $p_1 \ldots p_n$ and $q_1 \ldots q_n$ are the dimensions of points p and q respectively.

Definition 5 **Objects** o_i are represented as vectors.

$$\begin{aligned} o_i &= (w_{1,i}, w_{2,i}, \ldots, w_{t,i}) \\ &\ldots \\ o_n &= (w_{1,n}, w_{2,n}, \ldots, w_{t,n}) \end{aligned} \tag{4}$$

Each vector dimension corresponds to an object's feature; in our case, they are the total match length, longest match block length, or the number of match blocks between a sequence of nucleotides of a virus and that of all other viruses in our dataset.

5 Experiments

We used the method and techniques described in Sect. 4 to compare nucleotide sequence strings of viruses we have in our dataset, which we have described in Sect. 3. Then, we built pivot tables, thus obtaining vector values for the viruses to represent them in vector space. Finally, we constructed a virus relationship graph and a model to help us predict which previously known viruses a new one might have the highest proximity to and quickly find the best cure for that virus.

5.1 Virus Nucleotide Sequence Pairwise Comparison

For each pair of virus nucleotide sequences we performed a comparison (see algorithm pseudo code in section "Character-Wise String Compare Algorithm Pseudocode" and flow chart in section "Character-Wise String Compare Algorithm Flowchart") to get total matches length, longest match block length, and a number of shared match blocks.

The comparison algorithm, given 81 unique viruses and 3240 unique virus pairs:

1. Take a pair of nucleotide sequence strings ($S1$, $S2$).
2. Get the minimum length value of the two strings ($minlen$).
3. Trim the strings to the length of $minlen$
4. For each of the positionally corresponding character pairs in the $S1, S2$: If characters match, increase the match counter ($mcnt$) by 1, else add counter value to the match list ($mlist$) and set $mcnt = 0$.
5. Return total match length as $sum(mlist)$, longest match block length as $max(mlist)$, and a number of match blocks as $|mlist|$.

5.2 Vectorization of Virus Objects and Vector Space Models

Since we calculated total match length, longest match block length, and the number of shared match blocks for all the unique virus pairs, we produced adjacency matrices (or Pivot tables; see Table 3) for each of the three values. Thus, a row in the matrices is a vector characterizing the virus by its nucleotide sequence matching other viruses in the dataset. We reduced the dimensionality of the adjacency matrices down to 3D from 81 features and visualized it using Plotly Python module [14].

Table 3 Adjacency matrix or Pivot table example

P1 \P2	AY278554.2	AY282752.2	...	MT066176.1
AY278554.2	−1	349	...	3433
AY282752.2	349	−1	...	358
...	...	...	...	...
MT066176.1	3433	358	...	−1

Attention We put a -1 value when comparing a virus instance with itself regarding total match length, longest match block length, and the number of shared match blocks. Because comparing a nucleotide sequence with itself would produce a perfect match, which would not be helpful for our analysis.

5.3 Virus Relationships Graph

After obtaining vectors for virus nucleotide sequences, we can build graph representations of the viruses using each of the three dimensions: total match length, largest match block length, and the number of shared match blocks. We performed the edge cut on the following conditions:

- Total matches $\geq$ 1814 or first quartile (Q1), leaving us with 1540 edges out of 3306 and 55 nodes out of 81.
- Largest match block length $\geq$ 9, to retain 3003 edges and 77 nodes.
- Number of shared match blocks $\geq$ 1039, to distill the edges down to 1225 and 49 nodes.

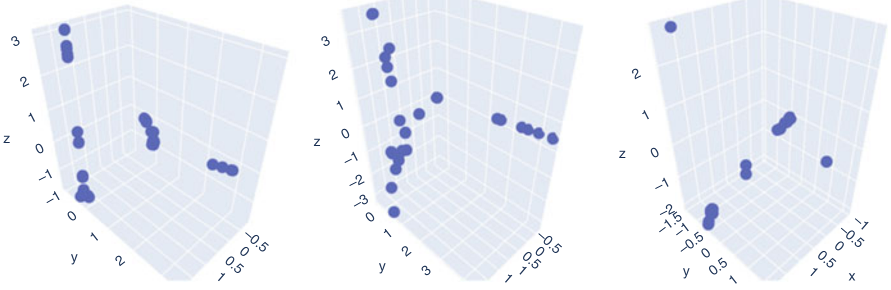
5.4 Virus Genetic Proximity Model (VGPM)

Given the viruses vector representations described in Sect. 5.2 we built a model (see algorithm pseudo code in section “VGPM Closest Function Algorithm Pseudocode” and flow chart in section “VGPM Closest Function Algorithm Flowchart”) which given a new virus nucleotide sequence and a number N of top closest virus matches:

1. Finds top N closest matches for the new virus in each of the adjacency matrices:
    - Total nucleotide positional match length.
    - Largest nucleotide match block.
    - Number of match blocks shared.
2. Collects the unique matches from all of the three matrices.
3. Returns the unique matches ids and names.

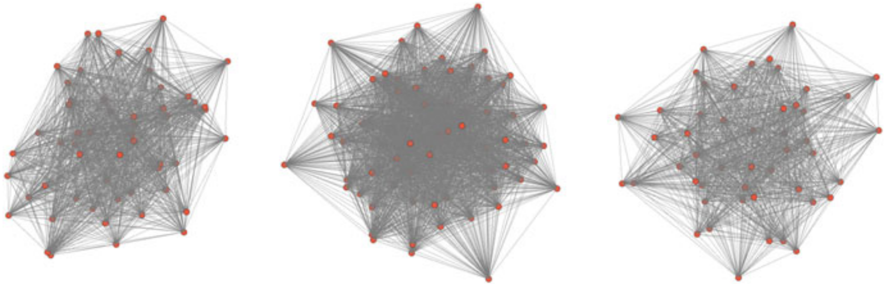
6 Results

We performed pairwise comparisons as described in Sect. 5.1 on all possible pairs of viruses nucleotide sequences in our dataset (refer to Sect. 3), and for each pair, we obtained three values: (1) total matches length, (2) largest match block length and



(a) (b) (c)

Fig. 3 The Vector Space Representations of the viruses. (**a**) Total nucleotide matches length. For interactive 3D chart please visit https://plotly.com/~isa_almaty/36/. (**b**) Largest nucleotide match block length. For interactive 3D chart please visit https://plotly.com/~isa_almaty/38/. (**c**) Number of match blocks shared. For interactive 3D chart please visit https://plotly.com/~isa_almaty/40/



(a) (b) (c)

Fig. 4 The graph representations of the viruses. (**a**) Total nucleotide matches length. For interactive 3D chart please visit https://plotly.com/~isa_almaty/44/. (**b**) Largest nucleotide match block length. For interactive 3D chart please visit https://plotly.com/~isa_almaty/50/. (**c**) Number of match blocks shared. For interactive 3D chart please visit https://plotly.com/~isa_almaty/53/

(3) the number of shared match blocks shared. Then for each of the three values, we built an adjacency matrix, thus obtaining the vector values of length 81 for the viruses. Reduced vector dimensionality to 3D, using the Principal Component Analysis (PCA) technique, and produced scatterplots; see Fig. 3.

We also visualized the relationship between the viruses in an alternative way, using the graph representations; see Fig. 4. In our graphs, nodes represent viruses, and edges characterize relations implied by the nucleotide sequence pairwise comparison results.

Figures 3 and 4 can be browsed in an interactive mode if you follow the URL links in the footnotes of the subfigure captions.

Finally, we have built a Virus Genetic Proximity Model (VPGM), which allows us to find the closest relative from our dataset for a new virus given its nucleotide sequence; see section "Virus Genetic Proximity Model (VGPM)" for the Python code, pseudo-code, and the flowchart of the model. Knowing the closest relative of a new virus allows for a faster treatment protocol composition, using techniques on top of those that worked well for the relative.

7 Conclusions

In conclusion, we want to emphasize our VGPM approach's ability to help find the cures for the newly appearing virus strains faster than before by identifying the closest relative of the new virus and using the treatment that worked for the relative the best as the starting point. Moreover, finding an effective treatment protocol is a crucial success factor in fighting pandemic outbreaks, which we faced in 2019–2020.

In our work, we applied some techniques peculiar to Natural Language Processing (NLP) and Computational Linguistics, such as string manipulation and comparison methods, adjacency matrix, Vector Space Model (VSM), and others in the Bioinformatics field. Thus, proving the potential usefulness of transferring the methods that proved their effectiveness in one field to another.

For future work, we plan:

- Use the approach on a much larger dataset to optimize the speed of the algorithms when working with BigData.
- Evaluate the inferred proximities using the phylogenetic information or family trees of the viruses.
- Implement our approach in diagnostic laboratories and Sanitary Epidemiological Service Department facilities on our city, province, and country levels.

Acknowledgments We gratefully acknowledge the financial support of the Ministry of Education and Sciences of the Republic of Kazakhstan under the grant #AP14871214 for the "Development of machine learning methods to increase the coherence of text in summaries produced by the Extractive Summarization Methods" project.

Appendix 1: Character-Wise String Compare Algorithm

Character-Wise String Compare Function Python Code

```
def nucl_seq_compare(s1, s2):
    min_len = min(len(s1), len(s2))

    match_cnt = 0
    shares = []
```

```
    for i in range(min_len):
        if s1[i] == s2[i]:
            match_cnt += 1
        else:
            if match_cnt > 0:
                shares.append(match_cnt)
            match_cnt = 0

    if len(shares) > 0:
        total = sum(shares)
        longest =  max(shares)
    else:
        total = 0
        longest = 0

    shares = len(shares)
    return total, longest, shares
```

Character-Wise String Compare Algorithm Pseudocode

```
DEFINE FUNCTION nucl_seq_compare(s1, s2):
    SET min_len TO min(len(s1), len(s2))

    SET match_cnt TO 0
    SET shares TO []
    FOR i IN range(min_len):
        IF s1[i] EQUALS s2[i]:
            match_cnt += 1
        ELSE:
            IF match_cnt > 0:
                shares.append(match_cnt)
            SET match_cnt TO 0

    IF len(shares) > 0:
        SET total TO sum(shares)
        SET longest TO  max(shares)
    ELSE:
        SET total TO 0
        SET longest TO 0

    SET shares TO len(shares)
    RETURN total, longest, shares
```

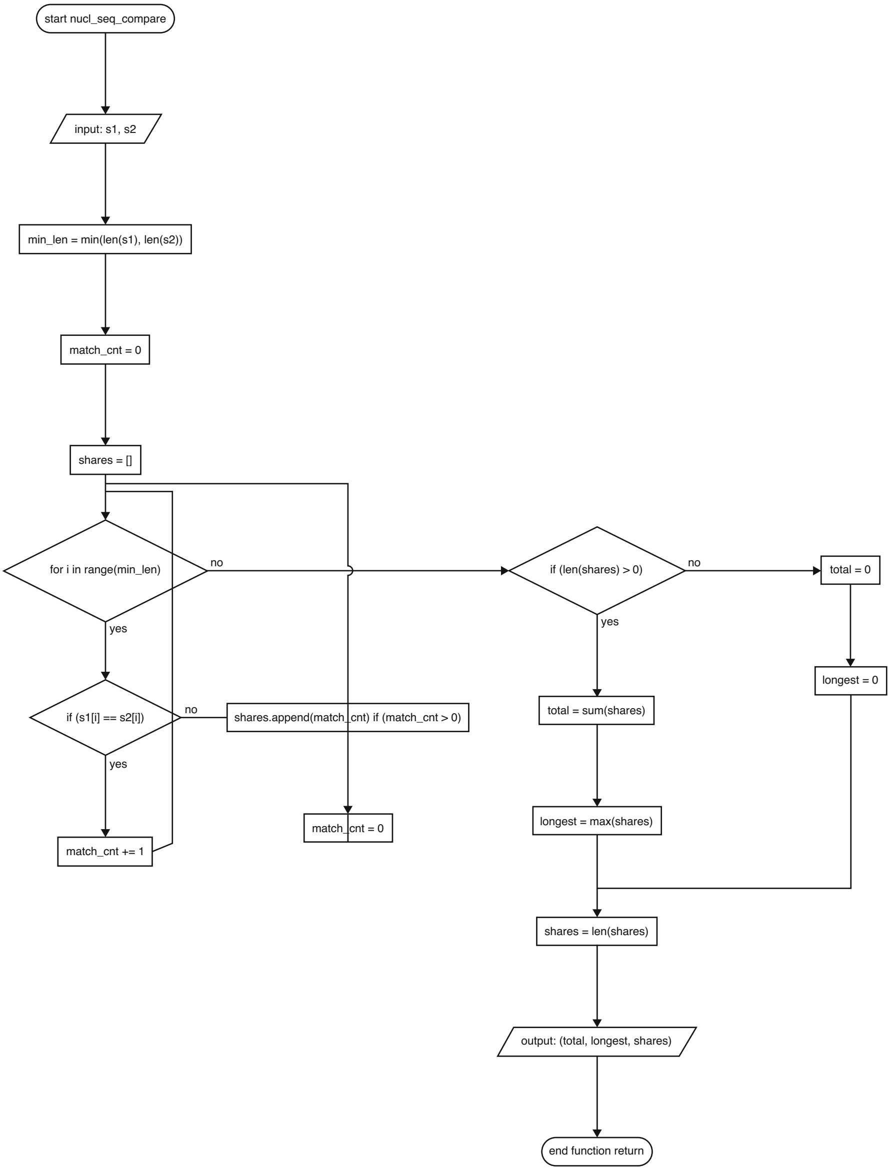


Fig. 5 Character-wise string compare algorithm flowchart

Character-Wise String Compare Algorithm Flowchart

See Fig. 5.

Virus Genetic Proximity Model (VGPM)

VGPM Function Python Code

```
from sklearn.metrics import pairwise_distances
import numpy as np
import pandas as pd

class VGPM:
    def __init__(self):
        self.total = pd.read_csv('total_matches.csv',
            ';')
        self.largest = pd.read_csv('largest_block.csv',
             ';')
        self.shares = pd.read_csv('shares.csv', ';')
        self.generic = pd.read_csv('Viruses_initial_ds.
            csv', ';')
        self.generic = self.generic.sort_values('id')

    def closest(self, seq, top_n=3, metric='euclidean')
        :
        #get the comparison data
        match_vals = []
        for s in self.generic.nucl_seq.values:
            vals = nucl_seq_compare(seq, s)
            match_vals.append(vals)

        #assemble vectors
        vecs = pd.DataFrame(match_vals).values
        total_vc = vecs[:,0]
        largest_vc = vecs[:,1]
        shares_vc = vecs[:,2]

        dists_total = pairwise_distances(total_vc.
            reshape(1, -1), self.total.values[:,1:],
            metric=metric)
        dists_largest = pairwise_distances(largest_vc.
            reshape(1, -1), self.largest.values[:,1:],
            metric=metric)
        dists_shares = pairwise_distances(shares_vc.
            reshape(1, -1), self.shares.values[:,1:],
            metric=metric)
```

```
        idx = list(set(list(np.argsort(dists_total)
            [0][:top_n]) + list(np.argsort(dists_largest
            )[0][:top_n]) + list(np.argsort(dists_shares
            )[0][:top_n])))

        return self.generic[['id','name']].values[idx]
```

VGPM Closest Function Algorithm Pseudocode

```
DEFINE FUNCTION closest(self, seq, top_n=3, metric
    ='euclidean'):
    #get the comparison data
    SET match_vals TO []
    FOR s IN self.generic.nucl_seq.values:
        SET vals TO nucl_seq_compare(seq, s)
        match_vals.append(vals)

    #assemble vectors
    SET vecs TO pd.DataFrame(match_vals).values
    SET total_vc TO vecs[:,0]
    SET largest_vc TO vecs[:,1]
    SET shares_vc TO vecs[:,2]

    SET dists_total TO pairwise_distances(total_vc.
        reshape(1, −1), self.total.values[:,1:],
        metric=metric)
    SET dists_largest TO pairwise_distances(
        largest_vc.reshape(1, −1), self.largest.
        values[:,1:], metric=metric)
    SET dists_shares TO pairwise_distances(
        shares_vc.reshape(1, −1), self.shares.values
        [:,1:], metric=metric)

    SET idx TO list(set(list(np.argsort(dists_total
        )[0][:top_n]) + list(np.argsort(
        dists_largest)[0][:top_n]) + list(np.argsort
        (dists_shares)[0][:top_n])))

    RETURN self.generic[['id','name']].values[idx]
```

VGPM Closest Function Algorithm Flowchart

See Fig. 6.

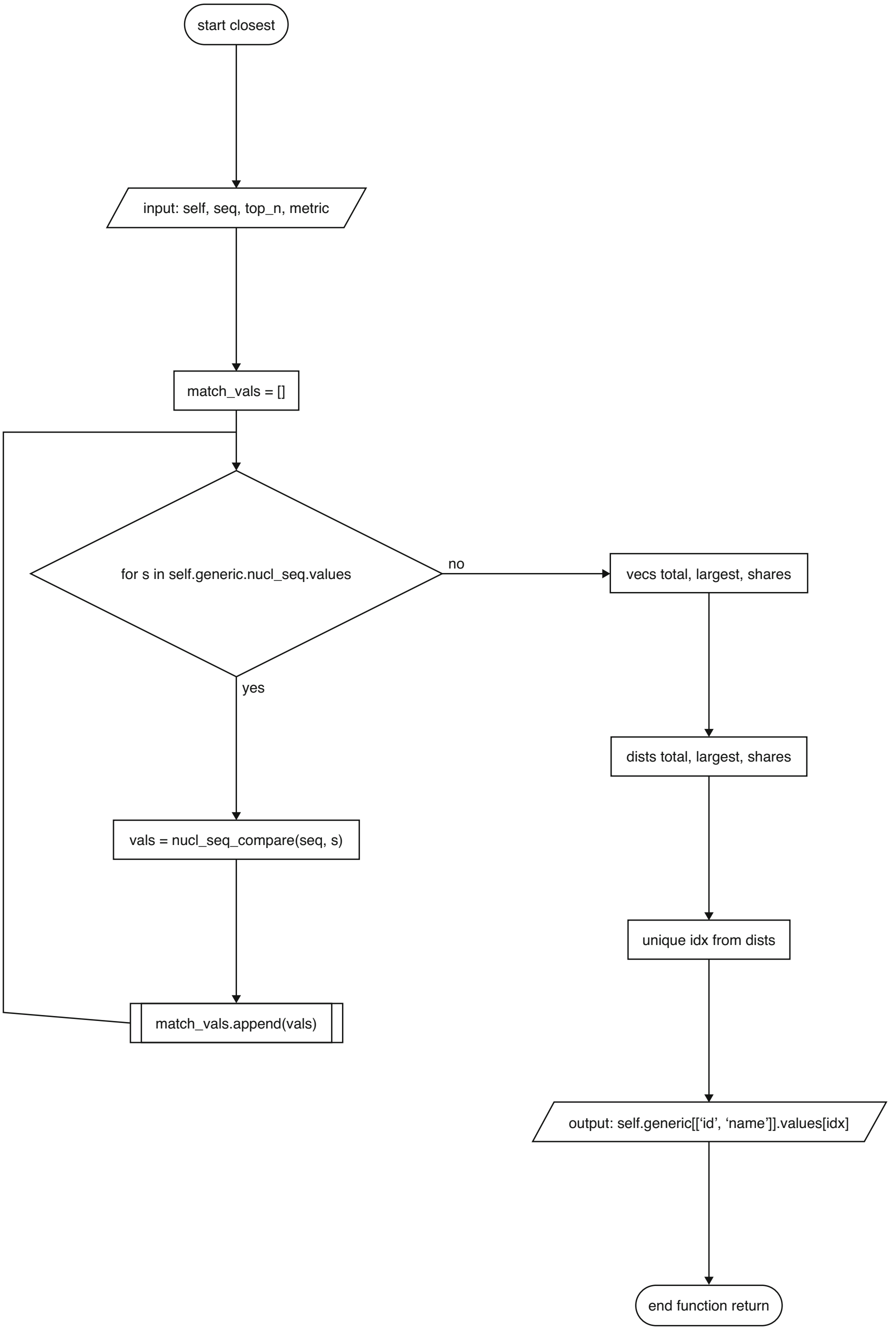


Fig. 6 VGPM closest function algorithm flowchart

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Explainable Artificial Intelligence (XAI) Based Analysis of Stress Among Tech Workers Amidst COVID-19 Pandemic

Jyoti Sekhar Banerjee, Arpita Chakraborty, Mufti Mahmud, Ujjwal Kar, Mohamed Lahby, and Gautam Saha

1 Introduction

The subject of stress [1] is presently receiving a lot of interest in both everyday life and research in general. Most people are aware of this phenomenon and its effects on different levels, such as social, psychological, physical and well-being. On the other hand, scientists from a wide range of fields are working on new ways to measure, track, and deal with stress that may not only be of interest to the public but also help us learn more about the problem [2–7].

Stress is the body's response to a difficult situation, which is characterized by intense worry or pressure. Eustress is a kind of stress that has good effects. It is a form of tension that a person experiences when they anticipate some exciting event occurring in their immediate area. High degree of worry or anxiety are signs of distress, a kind of stress that has harmful effects. Both short-term and long-term occurrences are possible. Distress's consequences might be seen as a drop in performance and a fogginess of the mind. Chronic or serious illnesses may also

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generate suffering that the body and brain find exceedingly difficult to tolerate, perhaps even resulting in depression and other problems with mental and physical health [8].

Again, when an employee's talents, resources, or requirements do not adequately meet the demands of their job, they may have detrimental emotional and physical reactions, known as work stress [9]. Everyone has to deal with stress at work, and it's being more recognised as a significant risk factor for both mental and physical disease [10], as well as a major contributor to subpar productivity and dissatisfaction in the workplace [11].

Although occupational stress has personal repercussions on people, there is particular concern about the impact on organisations, particularly their economic implications. The economic costs of work stress are widely acknowledged to be substantial, reaching to billions of dollars annually in the USA alone [12]. These losses are brought on by the rising cost of health insurance, the excessive strain on medical personnel and facilities, reduced efficiency, human mistakes, absence, and other factors [13].

Prior to the 2019 new corona virus disease (COVID-19) epidemic, the majority of organizations had not embraced the working from home (WFH) strategy. Each workday, employees had to report to their workplaces. To reduce the risk of infection during the COVID-19 pandemic, people have been and continue to be urged to maintain social distance [14, 15]. Some nations and localities even need to impose lockdown procedures to limit residents' activities in order to contain the problem [16]. However, many workers are unable to attend to their workplaces as normal due to social exclusion and lockdown procedures. Most businesses have reacted improvisatorily by creating new WFH arrangements to continue company operations, despite the fact that most of them have no expertise with such structures [17]. WFH should be a good method for addressing the COVID-19 problem since it can lower infection rates and is associated by the low economic expenses of confinement [18]. Furthermore, not everybody enjoys or can successfully do work remotely.

In fact, the compulsory house isolation amid lockdowns to regulate COVID-19 may have an impact on people's psychological health, raising their chance of having sleep problems and sleeplessness due to the stressful circumstances and shortage of stimulating factors. The correlation between lockdown and detrimental psychological effects, such as increased stress levels, has been supported by earlier research [19]. WFH's effect on employees' psychological wellbeing is yet unknown, however. Employees may experience more stress if they are required to participate in WFH but are not well equipped to do so [20].

Random Forest (RF) [5, 21, 22], SVM [5, 23, 24], and decision trees [22–25] were determined to be the most effective machine learning classifiers out of all those utilised in previous works owing to their superior results in stress detection [26–28]. This study used a relatively new subfield of AI called Explainable Artificial Intelligence (XAI) [29–31] to shed light on the inner workings of AI models and reveal how they arrive at their predictions. Explainable Artificial Intelligence (XAI) allows humans to understand AI. XAI provides an explanation for its decisions and actions. Humans may get insight into the reasoning process of automated systems. Concerns about the rising popularity of ML in everyday life, especially in the medical area, have been widely addressed. We need to have trust in these institutions if we are to rely on them.

Research in this chapter aims to propose and develop XAI strategies for the analysis of stress among Tech employees. The findings indicate promise in that both qualitative and quantitative visualisations may give the physician with additional information to help in their understanding and decision-making of the findings supplied by the smart XAI models.

The chapter is organized as follows. Section 2 addresses a state of art literature review of mental health amidst COVID-19 pandemic. Section 3 describes the system framework for stress analysis among Tech workers. In Sect. 4, the experimental results using Explainable Artificial Intelligence (XAI) are discussed. Lastly, some closing remarks are described.

2 Related Study

The sudden outburst of the COVID-19 pandemic and today's fast-paced digital lifestyle are causing depression, anxiety, and other socio-economic disorder, giving a massive rise in mental health issues. Even after the pandemic, mental health remains a major concern for humanity. Between 2010 and 2020, the number of people living with anxiety daily increased by 25–30%. Even more so, anxiety is particularly problematic in autistic patients. They can have severe anxiety attacks in many cases leading to self-harm. Now suicide is the third most often reported cause of death in the 15- to 29 age brackets worldwide, and in 2016, it was the second leading reason of death [32].

Natural disasters, global pandemic outbreaks, war conflicts, man-made tragedies, socioeconomic problems, and other large-scale human disasters may trigger major stress-related disorders in populations [33]. Furthermore, the worldwide economic deficit attributed to mental health conditions was estimated to be 16.3 trillion US dollars before the COVID-19 pandemic. Over the duration of 2010–2030, behavioural well-being will be the most costly aspect of the healthcare system globally [34]. The WHO generally estimates that 44.3 million individuals in Europe struggle from depression, with 37.3 million suffering from anxiety [35, 36].

While the complete magnitude of COVID-19's social and economic implications cannot be predicted at this time, the reality that numerous countries have imposed absolute or partial lockdowns can be intuitively grasped [37]. Leading industry magazines examine COVID-19's detrimental economic effects [38–41].

Several company closures and near-bankruptcies notwithstanding monetary and fiscal assistance are addressed in these papers, as is the increase in unemployment, as demonstrated by an extraordinary amount of over three million unemployment claims filed in the United States in a single week during the last week of March 2020. Similarly, science publications publish reviews of the global negative economic effects, such as [42], which predicts a global GDP loss of 0.42 per cent in Q1 2020 owing to the COVID-19 epidemic.

While the crucial challenges of viral prevention, medical treatment, and vaccine production are being resolved, it is therefore, critical to begin discussing the long-term consequences of destabilized world communities' mental well-being as quickly as possible. COVID-19 is widely acknowledged as posing a significant challenge to mental well-being worldwide, owing to public health and economic concerns; for example, a WHO strategic advisory notice [43] claimed as much.

Similar concerns have been raised elsewhere [44], namely that a COVID-19 pandemic might have many physical and mental health consequences, which might include: excessive uncertainty and fear; depressed looked health; undesirable societal reactions due to fear; skewed perceptions of danger, such as extreme fear and rage; and disrupted sleep (insomnia, fear, rage,) (PTSD, anxiety disorders, depression).

Additional studies, such as those on the coronavirus pandemic [45, 46] and the 2015 MERS epidemic [47], agree that healthcare professionals are at high risk for mental distress and recommend timely and ongoing evaluation of the clinical effects, as well as early tailored mental wellbeing services for this sensitive group.

To combat the outbreak of the COVID-19 pandemic, several countries across the world have briefly closed educational facilities. More than 91 per cent of the world's student population is affected by this national closing. Several other nations have introduced local closures, affecting millions of additional students [48]. UNESCO supports countries in reducing the direct effect of school closures, especially for the most vulnerable and deprived populations, and making distance learning more accessible to all [49].

In the elderly, mental health issues, especially depressed symptoms, are very common [50, 51]. Due to ongoing mass quarantines and public transportation restrictions [52], this age group appears to be disproportionately affected since mental health care has shifted to telemedicine in the COVID-19 era. Most elderly people not only have little access to or are unable to use smartphones and internet services, but are also unable to reach their outpatient clinics to obtain their monthly prescriptions. As a consequence, there is a sense of a shortage of medication and pre-existing psychological conditions are exacerbated. Apart from that, when hospitalisation is necessary, the stigma of social isolation is exacerbated since most hospitals in impacted areas do not admit visitors [53]. Similarly, aged people without pre-existing psychiatric diseases seem to be more vulnerable to developing mental health issues, as they are the age group most at risk for deadly complexities and expiry due to COVID-19, especially those with underlying health conditions, and are currently very concerned about becoming affected with the virus and not having the facility to proper care [54]. COVID-19 has been portrayed as an elderly disease in the media, resulting in age-based discrimination, social stigma, and negative stereotypes against aged people, with consequences ranging from prolonged confinement to demolition of their right to health and life on the same footing with others, generating further trouble not only to them but also to their family and caregivers [55].

3 System Framework

The rationale for utilizing Explainable AI and why it is superior to conventional AI and OSMI datasets for stress detection are covered in this section. XAI is portrayed as an AI system that explains the predictions' underlying assumptions. AI that humans can understand is simply referred to as explainable AI. XAI improves the AI approaches' accountability, fairness, dependability, and transparency. More users are starting to have doubts about the conclusions drawn by AI [57–59], which is the key factor pushing XAI. They want to know how the projections were made before relying on them and making decisions.

The block diagram of the Conventional and Explainable Artificial Intelligence (XAI) methodology is shown in Fig. 1. The same Explainable AI methodology underpins our suggested framework, which use the OSMI dataset and the SHAP interpretability model to identify mental stress.

3.1 Dataset Used

This dataset focuses on the perspectives on and experiences with mental health disorders among the employees in the technology sector. The original dataset comes from the Open Sourcing Mental Illness (OSMI) survey [56].

This dataset gives the details as following:

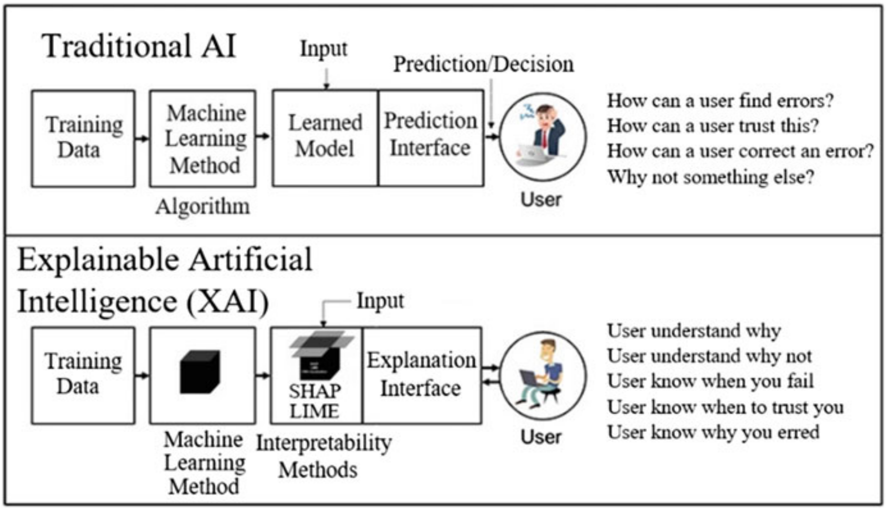
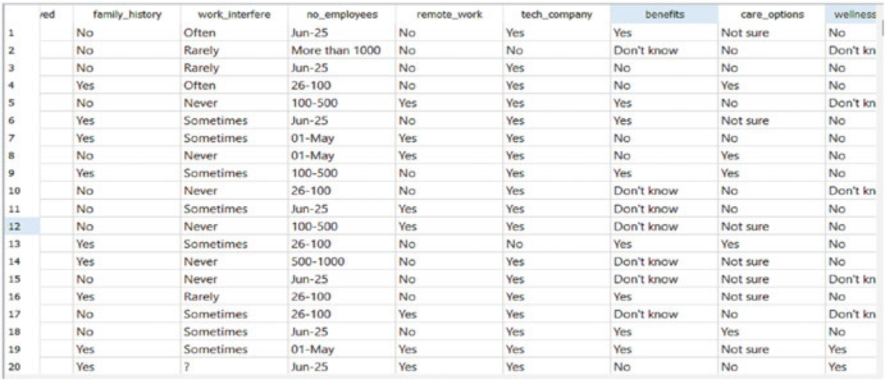


Fig. 1 The Block representation of the Conventional and Explainable Artificial Intelligence approach

- Timestamp
- Country
- Gender
- Age
- Self-employed: Do you work for yourself?
- State: Which Indian state or region do you reside in, if any?
- Treatment: Have you ever asked assistance for your mental health?
- Family_history: Is there a record of mental problems in your family?
- no_employees: How many people work for your organization or company? Remotely Job: Do you work remotely (from anywhere other than an office) at least half the time?
- Work_interferes: How much do you believe your mental illness prevents you from being productive at work?
- Benefits: Do you have access to mental health care at work?
- tech_company: Is the organization/company you work for predominantly a tech firm?
- wellness_program: Has your company ever included mental wellbeing as a part of a healthcare initiative for workers?
- care_options: Do you know what choices your workplace offers for mental health care?
- Anonymity: If you decide to utilise services for mental health or drug addiction therapy, will your privacy be protected?
- seek_help: Does your company provide any resources to help you to understand something about mental wellbeing and where to get assistance if you need it?
- mental*health*consequence: Do you fear repercussions if you tell your employer that you're dealing with mental health issues?
- Leave: How simple do you find it to request time off work due to a mental health issue?
- coworkers: In the workplace, would you feel comfortable talking about a mental health issue?
- phys*health*consequence: Do you believe talking to your employer about a medical emergency would be detrimental?
- mental*health*interview: In an interview, would you discuss a mental health condition with a prospective employer?
- Supervisor: If you were experiencing mental health problems, would you be open to talking to your supervisor(s)?
- obs_consequence: Have you seen or heard of any unfavourable outcomes for coworkers who are dealing with mental health issues?
- mental*vs*physical: To what extent do you believe your company prioritises mental health in addition to physical health?
- phys*health*interview: To what extent would you discuss a health problem with a prospective employer during the interview process?
- comments: Any further thoughts or observations



	ved	family_history	work_interfere	no_employees	remote_work	tech_company	benefits	care_options	wellness
1		No	Often	Jun-25	No	Yes	Yes	Not sure	No
2		No	Rarely	More than 1000	No	No	Don't know	No	Don't kn
3		No	Rarely	Jun-25	No	Yes	No	No	No
4		Yes	Often	26-100	No	Yes	No	Yes	No
5		No	Never	100-500	Yes	Yes	Yes	No	Don't kn
6		Yes	Sometimes	Jun-25	No	Yes	Yes	Not sure	No
7		Yes	Sometimes	01-May	Yes	Yes	No	No	No
8		No	Never	01-May	Yes	Yes	No	Yes	No
9		Yes	Sometimes	100-500	No	Yes	Yes	Yes	No
10		No	Never	26-100	No	Yes	Don't know	No	Don't kn
11		No	Sometimes	Jun-25	Yes	Yes	Don't know	No	No
12		No	Never	100-500	Yes	Yes	Don't know	Not sure	No
13		Yes	Sometimes	26-100	No	No	Yes	Yes	No
14		Yes	Never	500-1000	No	Yes	Don't know	Not sure	No
15		No	Never	Jun-25	No	Yes	Don't know	Not sure	Don't kn
16		Yes	Rarely	26-100	No	Yes	Yes	Not sure	No
17		No	Sometimes	26-100	Yes	Yes	Don't know	No	Don't kn
18		No	Sometimes	Jun-25	No	Yes	Yes	Yes	No
19		Yes	Sometimes	01-May	Yes	Yes	Yes	Not sure	Yes
20		Yes	?	Jun-25	Yes	Yes	No	No	Yes

Fig. 2 Screenshot of the data table being used

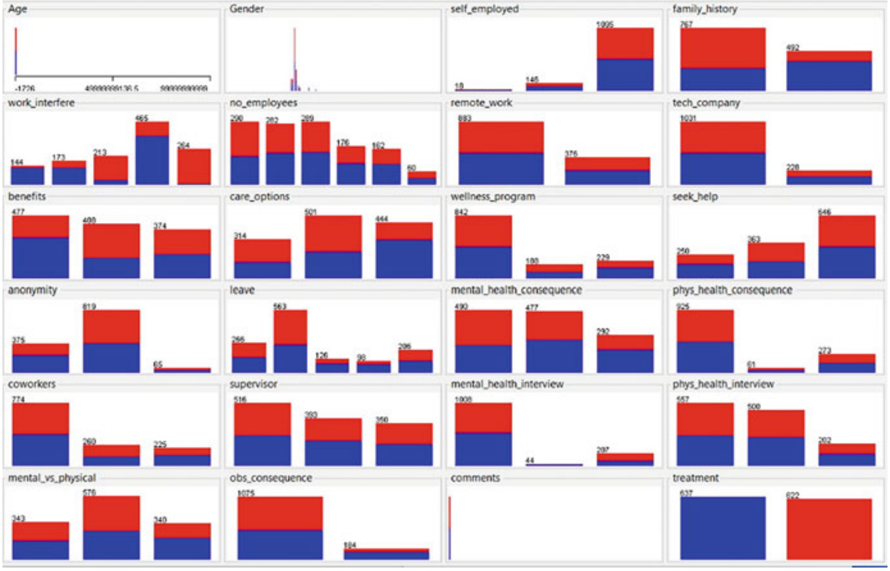


Fig. 3 Histogram plot of individual parameter of the dataset

Preview of the dataset is given in the Fig. 2. And histogram plot of the individual parameters been considered in the dataset are plotted in Fig. 3.

There are a total of 26 columns in the dataset. We see that except the age column, all the columns are of object data type. The comment column appears to have the highest percentage of null values (70%); this is expected given that it was a non-mandatory text box and most respondents likely left it blank. The timestamp field will be removed since it indicates the day, month, year, and time the participant took this survey, which is unimportant. There are several null values in the state column as well. We won't go any further into it. It would be very misleading to assume that just because the US makes up around 60% of the population, that nation has greater issues with the mental health of its workforce. Additionally, a majority of nations only have one responder. Thus, the nation column is no longer useful. We are also dropping this. From a brief scan of the states, we can see that it only applies to US-based locations, therefore we have removed it from consideration as well. To determine if any elements may influence an employee's decision to get treatment or not, this survey is being completed by respondents who work in IT businesses and have mental health illnesses (medically diagnosed or undiagnosed, even if it is only a feeling).

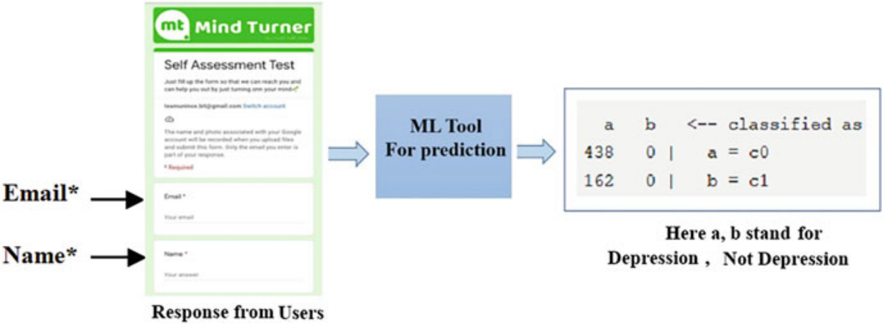
The dataset describing the distribution of values in the data—the minimum, maximum, mean and standard deviation are plotted in Fig. 3 through colored histogram. Depending on the characteristic selected as the class, color is coded in the histogram.

3.2 Stress Monitoring in Offices

Nowadays, the subject of stress is crucial to both study and social life in general. People are becoming more and more conscious of this issue and its effects on a variety of spheres, including health, social life, employment, quality of life, etc. As a consequence, the need for tools and applications that can assess and manage stress in real time has been increased significantly. The emergence of novel techniques and strategies has fueled this interest in recent technical and scientific advancements. In this paper, authors have examined one of the novel techniques for stress evaluation, paying particular attention to those that are appropriate for the workplace—one of the primary drivers of stress in modern society. As with other self-reporting systems, questionnaires are seen as a low-cost way to get a lot of data specially at workplace maintaining every one's privacy. They don't need a lot of work from the experimenter, who somehow benefits from the simplicity of data collection that comes from using a set of predetermined responses. These measures are very practical and may be administered by the researcher or anybody else remotely, if necessary, without compromising their validity or reliability.

3.3 Stress Prediction Through Questionnaires

Due to many reasons, it is seen that sometimes people are worried or distressed and do not realize their own mental condition. In this paper the authors have tried to predict work stress using Question-Answer based approach. Here, a set of questionnaires are kept which the users at office, have to give response to each and every question. Several machine learning algorithms are used to classifying different outputs and thus to detect mental stress. The following Fig. 4 explains the method.



```
   a     b    <-- classified as
 438     0 |    a = c0
 162     0 |    b = c1
```

Fig. 4 Question & Answers based stress prediction

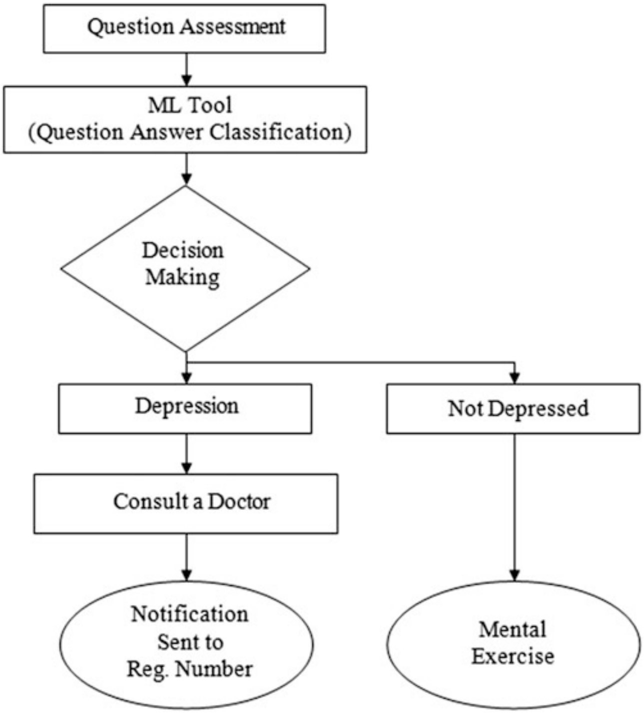


Fig. 5 Flow diagram of Question & Answers based mental stress prediction

In case a patient is found to be depressed, consultation with doctor is recommended. Further, a notification is also sent to the registered contact number of the patient. If the user is found to not be depressed, however, only mental exercises are advised to maintain mental health. The process is depicted through the flowchart (see Fig. 5).

4 Results & Discussion

Simulation findings have been provided here for the purpose of empirical results. Various development frameworks have been used for simulations to detect stress, such as Python and Orange. Like MATLAB, Orange is also professional software and specially designed for Machine Learning applications [60–71].

4.1 Performance Measures of Different ML Models

Experiments based on the above dataset were undertaken utilizing four multiclass classification algorithms: K-Nearest Neighbor (KNN), Random Forest, support-vector machines (SVM) and Neural Network (see Fig. 6).

The effectiveness metrics for the four classification methods are shown in Table 1, that are the results received from Orange.

Using Table 1, we can observe that the Random Forest classifier outperforms all other ML models in terms of efficiency.

Figure 7 shows the confusion matrix for the prediction results using Random Forest, SVM, KNN, and Decision Tree. Orange and Weka are the tech frameworks used to simulate these.

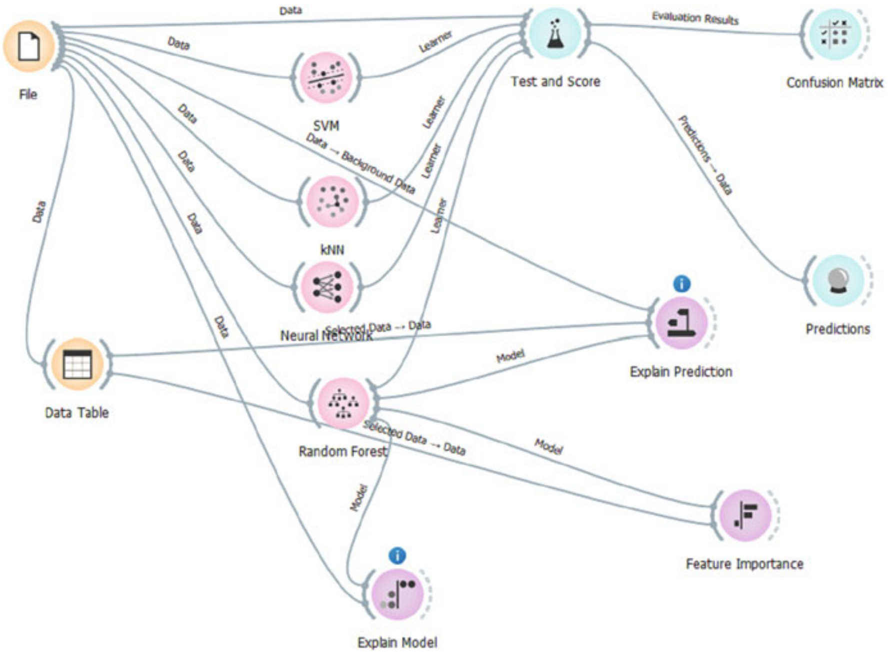


Fig. 6 Implementation of ML algorithms along with Explainable blocks using Orange

Table 1 Comparison of efficiency measures of the different ML algorithms

Model	AUC	CA	F1	Precision	Recall
KNN	0.712	0.651	0.648	0.656	0.651
SVM	0.710	0.653	0.646	0.663	0.653
Random Forest	0.881	0.813	0.813	0.816	0.813
Neural network	0.793	0.720	0.719	0.720	0.720

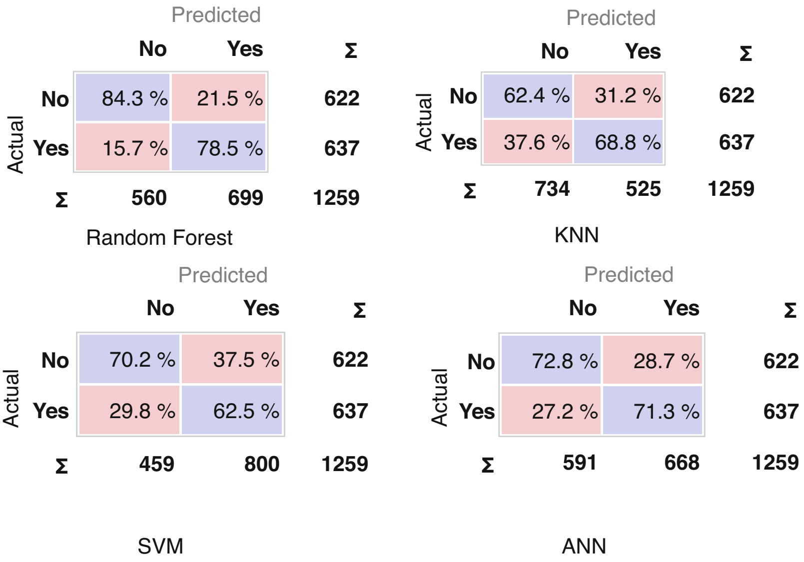


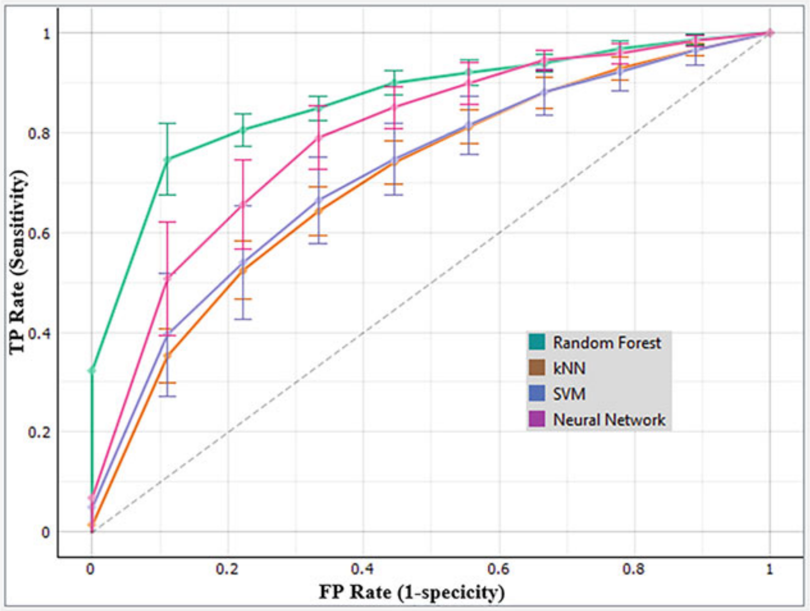
Fig. 7 Confusion matrix of the four different ML algorithms

Receiver Operational Characteristic (ROC) Analysis It is the graphical tool for evaluating the output of a classifier, of four ML algorithms, is shown in Fig. 8a and the Classification accuracy plot, i.e., the proportion of correctly classified observations is shown in Fig. 8b.

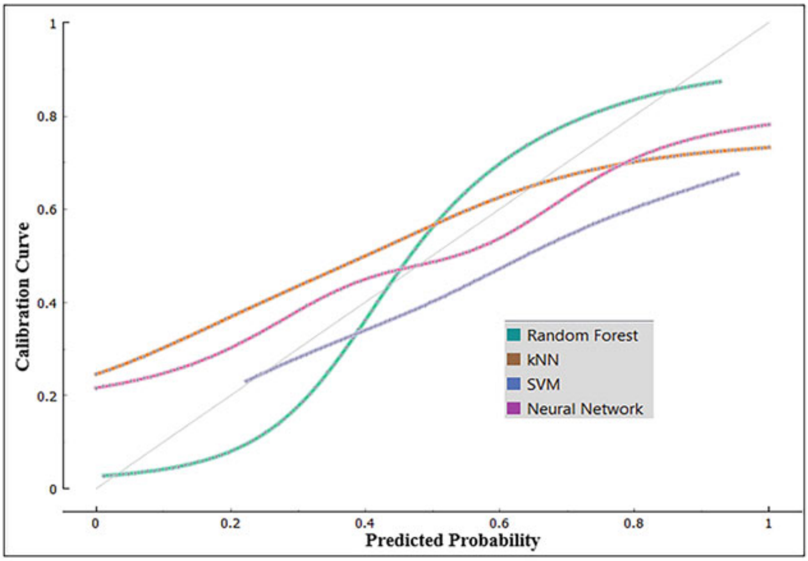
From Fig. 8b it is seen that the calibration curve of Random Forest algorithm is actually following the ideal curve with minimum deviation, throughout the range. Hence analyzing both figures, it is clear the Random Forest approach outperforms all other machine learning techniques in this given instance.

Hence, Random Forest has been considered here for mental stress prediction. When considered 600 instances, 73% (438) of them are correctly classified by it and 27% (162) are incorrectly classified. The output obtained is shown in the following Fig. 9a.

Hence, it is very much justified to adopt Random Forest algorithm for this specific case of work stress detection, as it predicts the output most reliably, i.e., with least error in comparison to other ML algorithms considered here (shown in Fig. 9b).

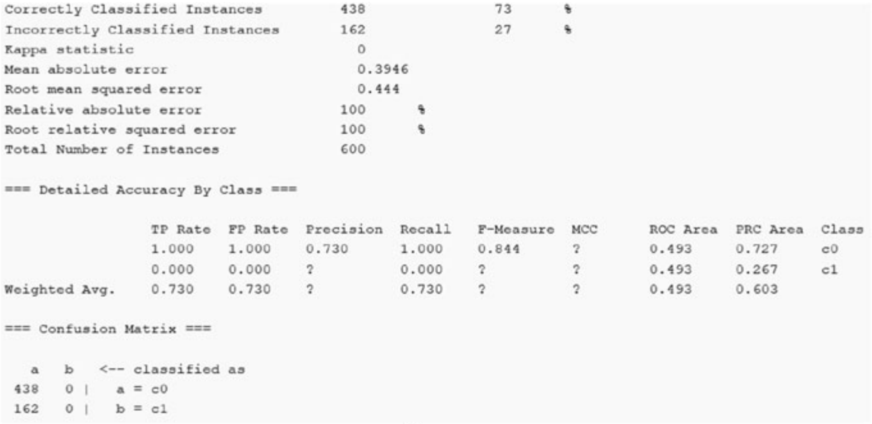


(a)



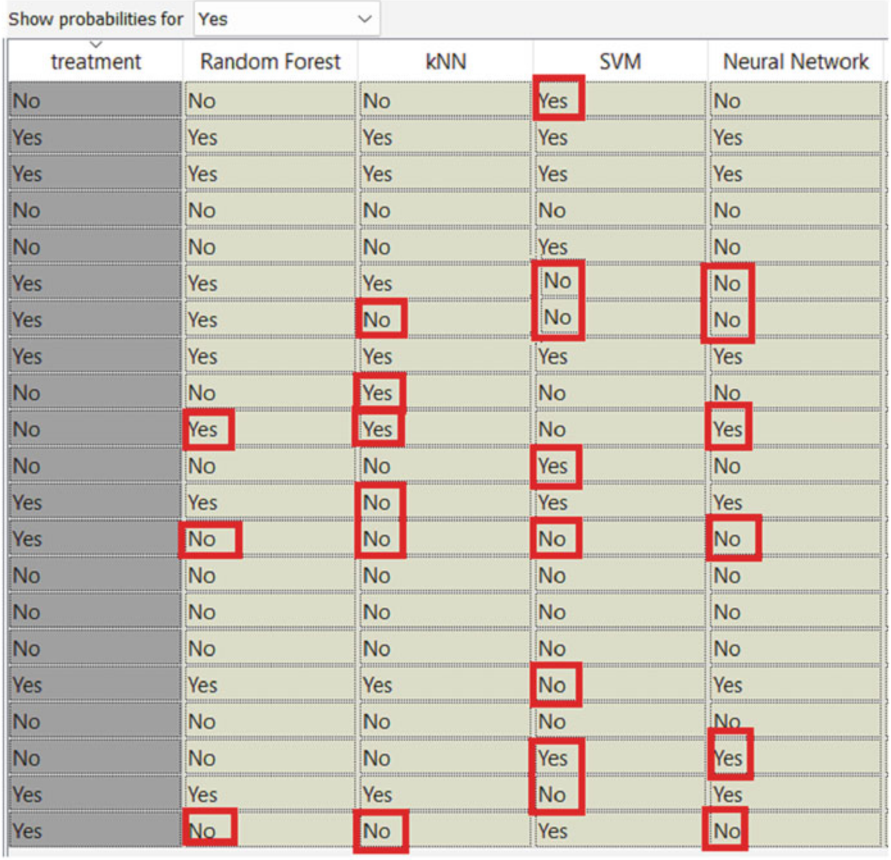
(b)

Fig. 8 (**a**) ROC analysis using RF, SVM, KNN & ANN algorithms. (**b**) Calibration plot of the different ML algorithms (for class 1)



```
Correctly Classified Instances         438               73      %
Incorrectly Classified Instances       162               27      %
Kappa statistic                          0
Mean absolute error                      0.3946
Root mean squared error                  0.444
Relative absolute error                100      %
Root relative squared error            100      %
Total Number of Instances              600

=== Detailed Accuracy By Class ===

                 TP Rate  FP Rate  Precision  Recall   F-Measure  MCC      ROC Area  PRC Area  Class
                 1.000    1.000    0.730      1.000    0.844      ?        0.493     0.727     c0
                 0.000    0.000    ?          0.000    ?          ?        0.493     0.267     c1
Weighted Avg.    0.730    0.730    ?          0.730    ?          ?        0.493     0.603

=== Confusion Matrix ===

   a   b   <-- classified as
 438   0 |   a = c0
 162   0 |   b = c1
```

(a)



Show probabilities for Yes

treatment	Random Forest	kNN	SVM	Neural Network
No	No	No	Yes	No
Yes	Yes	Yes	Yes	Yes
Yes	Yes	Yes	Yes	Yes
No	No	No	No	No
No	No	No	Yes	No
Yes	Yes	Yes	No	No
Yes	Yes	No	No	No
Yes	Yes	Yes	Yes	Yes
No	No	Yes	No	No
No	Yes	Yes	No	Yes
No	No	No	Yes	No
Yes	Yes	No	Yes	Yes
Yes	No	No	No	No
No	No	No	No	No
No	No	No	No	No
No	No	No	No	No
Yes	Yes	Yes	No	Yes
No	No	No	No	No
No	No	No	Yes	Yes
Yes	Yes	Yes	No	Yes
Yes	No	No	Yes	No

(b)

Fig. 9 (**a**) Determination of mental stress by Random Forest Algorithm with 600 instances. (**b**) Prediction of mental stress done by Random Forest Algorithm with least error

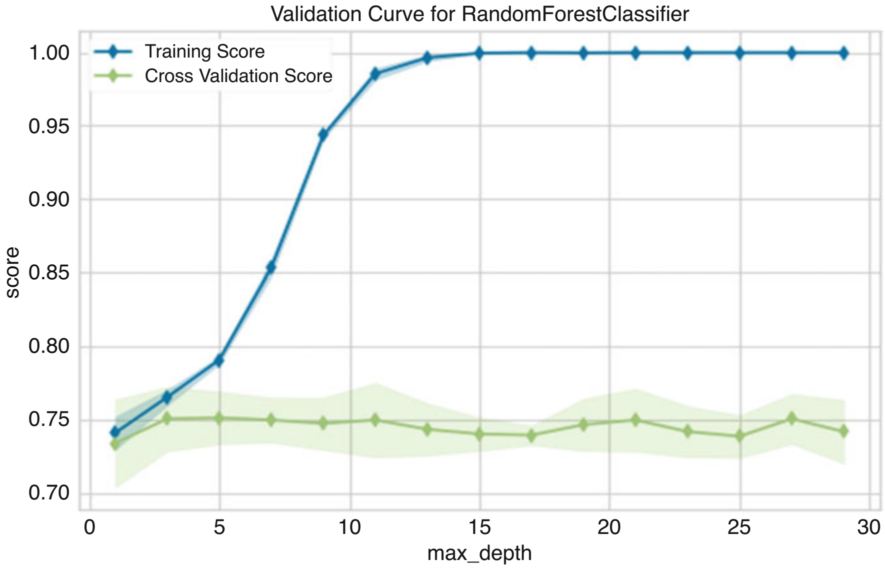


Fig. 10 Validation curve

Validation Curve Analysis

When validating a model, it is common practice to create a validation curve between certain model parameter and the score of the model. A validation curve has two curves: one that shows the cross-validation score and the other one shows the training set score. The validation curve and the training curve should ideally resemble each other as much as feasible. From the Fig. 10 following, it is very much understood, that both the curves are very close to each other, and are apart by small difference only. Hence, the appropriateness of the model been considered here, is justified.

The performance of the chosen algorithm (Random Forest) is investigated in the table below with a change in the number of trees.

It has been discovered that increasing the number of trees has a positive impact on the system's performance when there are a significant number of rows in the dataset. But for a fixed dataset, increase in the number of trees will not run the system better. From Table 2, it is clear that number of trees 60 is sufficient for this particular dataset and further increase of it neither improves 'Model Prediction', nor 'Classification accuracy'.

Table 2 Performance of Random forest with the variation of Number of Trees (#Trees)

Random forest						
# Trees	AUC	CA	F1	Precision	Recall	Model prediction
15	0.879	0.816	0.815	0.818	0.816	0.7
30	0.887	0.820	0.824	0.820	0.820	0.74
60	0.891	0.833	0.832	0.839	0.833	0.84
100	0.894	0.827	0.826	0.833	0.827	0.8
200	0.893	0.826	0.825	0.831	0.826	0.77
500	0.894	0.824	0.823	0.831	0.824	0.77

4.2 Explainable Artificial Intelligence (XAI) Based Model Predictions

4.2.1 SHAP Global Explainability

The computational complexity of random forest, SVM, AdaBoost, and XGBoost models makes it challenging for the common users to grasp how predictions are formed. A game theoretic post-hoc interpretation approach known as Kernel SHAP was used to increase model explainability for these types of models. For example, SHAP gives both a global explanation of the model's structure (global explainability) as well as a particular prediction (specific explainability or local explainability).

4.2.2 SHAP Feature Importance

Identifying the significance of the features is the primary objective of a model (see Figs. 11 and 12). It computes each feature's impact on the prediction using the supplied dataset. Importance or significance of the features is basically the mean as well as standard deviation of impurity reduction accumulated inside each tree. Characteristics having high absolute Shapely values are considered as the most important. By assessing the increase in the prediction error of the model following the permutation of the feature's values, individual feature's contribution can be measured. Here the feature importance is explained through Random Forest model. The features in the plot are arranged according to their importance. From the Fig. 11, it is seen that 'work_interference' is the most responsible parameter for mental stress in work stations. 'Family_history', 'benefits', 'care_options', 'age' are the next responsible parameters respectively to cause mental stress.

Features which are responsible to predict the output are plotted using two different software namely Orange and Python. Mean SHAP values of the features or in other words, feature importance may vary slightly. But the ruling parameters are vivid from the figures. Here, in this case 'family_history', 'work_interference' are the major impactful parameters towards predicting mental stress of a person.

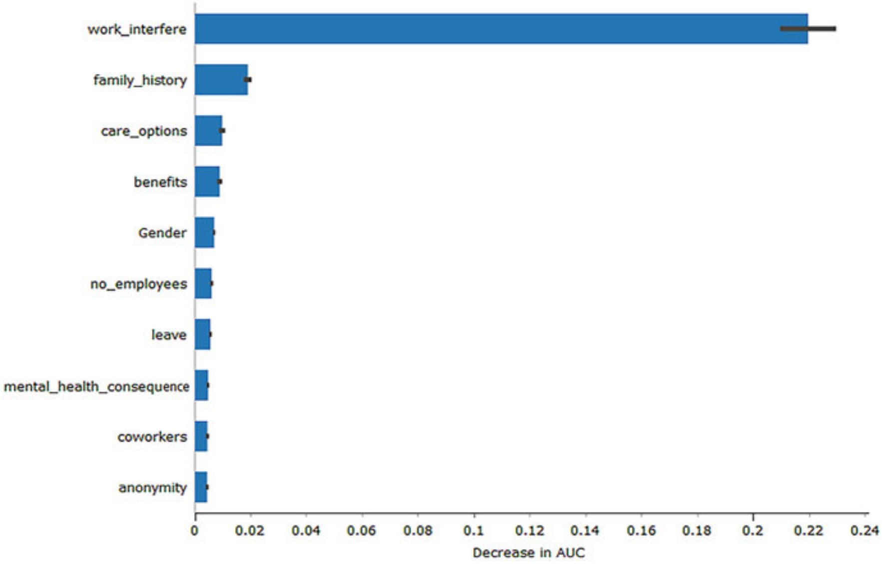


Fig. 11 Average impact on model output magnitude using Orange Software

4.2.3 SHAP Summary Plot/Explain Model

This graph (as shown in Fig. 13) illustrates which characteristics are the most important and how they affect a specific class's prediction. Here we have set the target class 'Yes', it means that we are looking for the features that are most indicative of a patient who needs medical treatment. The features in the plot are arranged in order of how closely they relate to the prediction. As we get to see from the Fig. 13, 'Work_interference' is the most important feature for the prediction in class 'Yes'. Higher instances of this feature (shown by the color red) have higher SHAP values, which mean they help with the prediction of class YES; while, lower values of this property (blue) work against this class's prediction. 'Family_history' is the second-most significant characteristic. The occurrence of these features to the patients, i.e., red color predicts class 'Yes' and the absence predicts against class 'Yes'. Blue color denotes a lower value while red color indicates a higher value. Based on every value for a feature in the dataset, the color range is established.

4.2.4 SHAP Force Plot/Explain Prediction

The Fig. 14a illustrates the most important and contributing parameters towards prediction for a particular instance depending on the model and the way they contribute. The score deviation from zero is higher for features that contribute more to prediction. Further, this Force plot is a way for inaccuracy assessment and

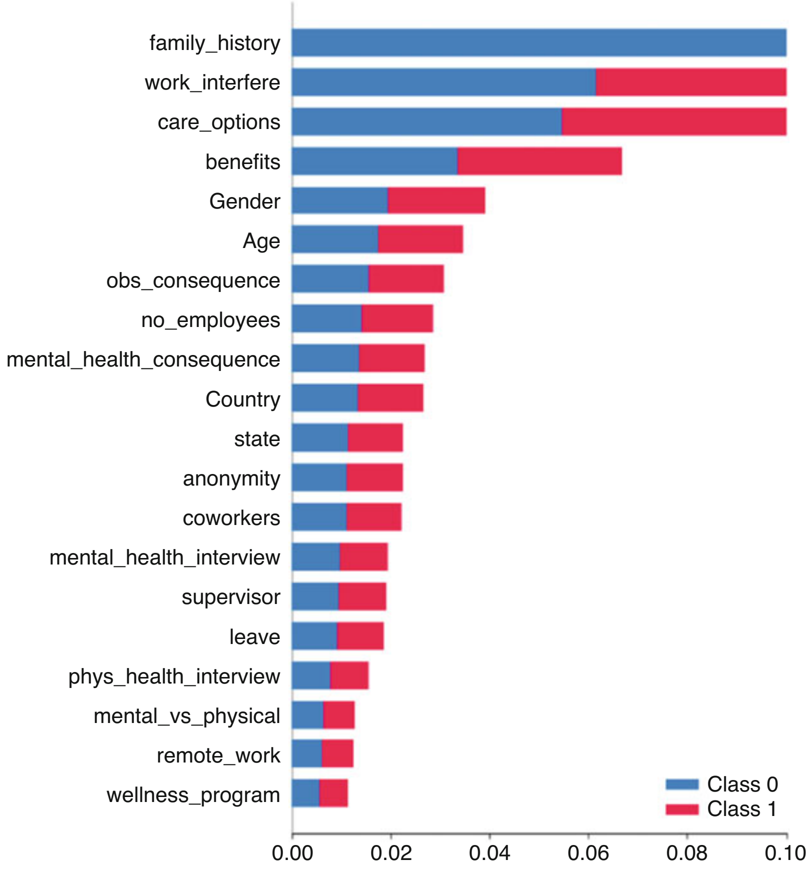


Fig. 12 Mean SHAP value (Average impact on model output magnitude) using Python

explanation of a particular case prediction; i.e., both the cases where the prediction is accurate and occasions where it is inaccurate can be analyzed. This also provides a notion of which features are driving to the incorrect forecast.

The computation of the explanation involves the removal of features, their replacement with many alternatives drawn from the background data, and monitoring how the forecast changes. The plot (Fig. 14a) demonstrates the effects of the features (those with longer tape lengths) that have the greatest influence on the forecast. While blue features lower the probability for a particular class, red features raise it. We can see the feature name and its value for the chosen instance on the right side of the tape.

Numbers in the grey boxes of the plot show that the selected class has a 0.99 probability of being predicted as ‘Yes’, using Random Forest Algorithm. And the average probability in the data i.e.- baseline probability is 0.20. From the Fig. 14b,

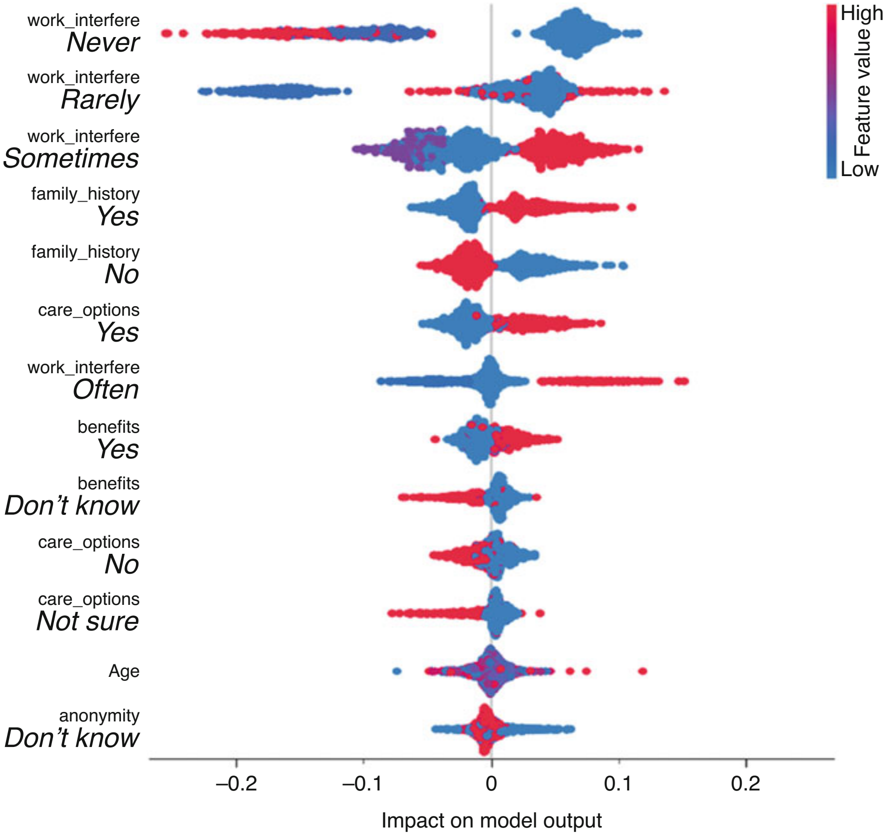


Fig. 13 Summary plot

which basically the zoomed version of Fig. 14a, is vividly observed that the highest impact on the prediction is with the feature ‘Work_interference’ with the maximum value 2.73.

4.2.5 SHAP Results Summary

The SHAP framework has been shown to be a major advancement in the area of interpreting AI models. SHAP integrates many existing methods to provide a technique to explaining model predictions that is both theoretically sound and accessible. With SHAP values, one can quantify the quantity and direction (positive or negative) of a feature’s influence on a prediction. Therefore, the significance of characteristics may be better described when using SHAP AI models.

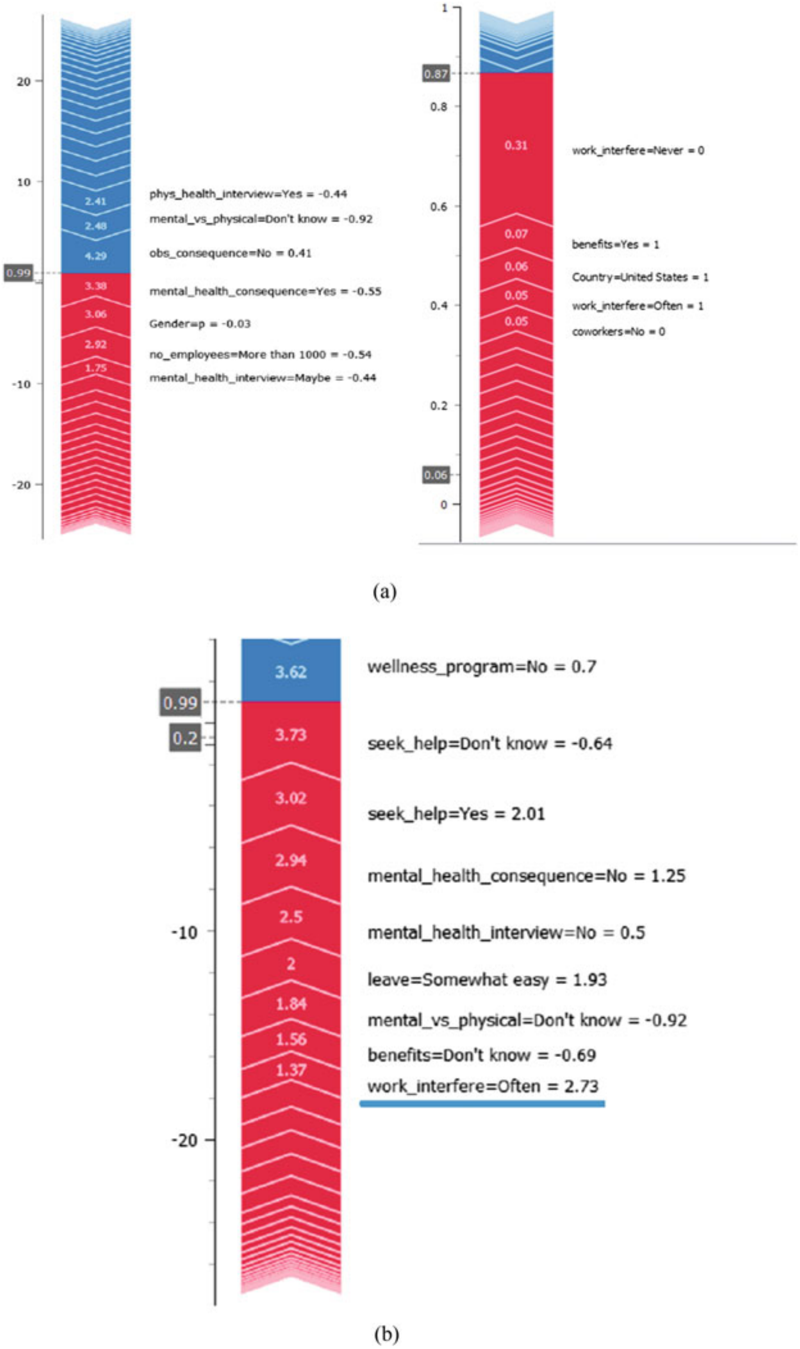


Fig. 14 (**a**) Prediction using RF Algorithm (left) and Prediction using ANN Algorithm (right). (**b**) Features playing significant role of causing mental stress (Red tape with higher values)

5 Conclusion

Explainable AI improves the AI systems to a greater extent. In this chapter, the authors used Open Sourcing Mental Illness (OSMI) survey dataset, which is basically Question-Answer based. Random Forest algorithm has been adopted here in this research, by observing a comparative study among a set of algorithms like SVM, KNN, ANN and Random Forest. The Random Forest algorithm outperforms all other models that were tested. Tech workers' stress amidst the COVID-19 pandemic is thus identified as Not Stressed or Stressed. Different software platforms have been experimented to explain the machine learning model, to understand the affecting reasons of stress of the users at the work station. Adoption of XAI blocks actually made interpretability improved.

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Part III
Deep Learning and COVID-19 Pandemic

COVID-19 Disease Detection Using Deep Learning Techniques in CT Scan Images

Mouna Afif, Riadh Ayachi, Said Yahia, and Mohamed Atri

1 Introduction

The corona-virus (COVID 19) has been present in Wuhan, China, since 2019. After that, the virus started to seriously affect people's health all across the world. Coronavirus 2 that causes severe acute respiratory syndrome is the source of the Covid 19 virus (sars-cov 2). It is a significant global cause of fatalities today. The increasing number of COVID-19 infected persons pose a serious problem for the researchers to be addressed. The number of COVID-19 infected and confirmed cases is getting increasing day by day.

A very famous technique used for COVID-19 diagnosis is the testing kit: reverse transiption polymerase chain reaction (RT-PCR). The widespread disease was initially unknown, but after laboratory examination using a polymerase chain reaction (PCR) test kit, this viral epidemic was identified and given the name COVID-19 per the World Health Organization's guidelines (WHO). This worldwide epidemic over a very short period has crossed the geographic boundaries and affected a huge number of persons around the world. Ensuring an early detection of COVID-19 is not only important and crucial for patients care, but it is essential for the public health by isolating the suspected and the confirmed cases and controlling the pandemic.

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Different ways have been adopted by researchers to fight this epidemic and to control its evolution. At first the diagnosis of COVID-19 is performed by using the RT-PCR method which is very time-consuming, complex, manual and very costly. Another drawback of this method is that it needs a laboratory kit which is very difficult in the under-developed countries. For this end, it is extremely important to develop new COVID-19 detection system that are more accurate, automatic, less complex and cheap to encounter the epidemic evolution. The RT-PCR method need expert laboratory technician to process the nasal and the throat mucosa which present a very painful method for the patients.

Compared to the RT-PCR, the CT scan based diagnosis system presented a higher sensitivity for early diagnosing and COVID-19 cases detection.

Up to day, the number of deaths is 6.29 million around the world and the total cases is 529 million. As COVID-19 infected cases keeps spreading, the medical products that are used to face this pandemic as: blood test will become scare due to the high demand and the insufficient logistic means. To address this problem, a new set of technologies used for COVID-19 diagnosis need to be developed. However, deep leaning-based techniques have been widely used for early diagnosis of COVID-19 which will widely help to solve medical problems and save a big number of infected cases. This fatal epidemic can be mortal due to the delayed diagnosis and progressive respiratory failure [1].

For this end, early and automatic diagnosis of COVID-19 using the most recent advances of artificial intelligence (AI) can widely assist the worldwide in facing and combatting the pandemic. After 2 years from the pandemic, neither tests nor numerous medical capabilities have really stopped this pandemic evolution.

In this vein, deep-learning based techniques presented an important breakthrough in the AI and computer vision fields. The early detection and diagnosis of COVID-19 with a low cost present one among the big challenges in the COVID-19 pandemic. The RT-PCR test presents the most known technique for diagnosing the COVID-19 but this technique is costly and very time consuming. A major drawback of this technique is that it needs a laboratory kit process which is very difficult for different countries during the epidemic crises. Various hospitals in the developed countries do not provide enough tests as they are very costly. To address this problem, various works have been proposed for COVID-19 images detection, classification and segmentation. The COVID-19 causes big troubles including myalgia, chest troubles, fever, dry cough and headache [2, 3]. Various imaging techniques are used to build new COVID-19 based deep learning techniques as: chest x-ray and chest CT- scan images, thorax computed tomography. CT scan images are widely used by the experts to detect COVID-19. Performing a diagnosis of COVID-19 based on CT scan images generally require a huge knowledge of radiology experts which is very time consuming. COVID-19 pandemic is rapidly spreading and it has rescued and claimed the life of huge number of person's around the world. The virus generally attacks the human lung and its early detection is increasingly important. As deep learning-based architecture require huge amount of data for the network training, medical imaging as x-ray and computed tomography (CT) are critical for disease diagnosis. To limit the number of deaths and to minimize the number of COVID-19 cases, it is increasingly important to develop new assistive technologies that come to assist the medical staff in combatting this pandemic. Deep learning-based models have demonstrated their competitive performances on classification, detection and segmentation of different tasks. These AI techniques are very suitable and robust to identify a set of illness related to COVID-19 disease accurately and in a fast way. Building an early warning system used for COVID-19 pandemic prediction is very important to save human lives around the world.

Deep learning-based architectures have shown big performances for different artificial intelligence tasks including: indoor objects detection [4], indoor scene recognition [5], pedestrian detection [6], traffic sign detection [7], traffic light detection [8], indoor wayfinding assistance [9] and medical imaging [10].

An early diagnosis system for COVID-19 using chest CT scan is proposed in this chapter. The COVID-19 detection system is developed by tacking advantages of deep neural networks. The developed system is able to detect and diagnosis accurately COVID-19 disease. The proposed COVID-19 detection system is developed based on HookNet [11] which present hybrid architecture that combine encoder-decoder convolutional neural networks. Different concentric patches under multiple resolutions fed different branches of HookNet and the intermediate representation are combined via a hoocking mechanism. The proposed work can widely help the medical staff and the radiology experts for early diagnosing and detection of COVID-19 and for combatting this worldwide pandemic based on the achieved very encouraging detection results that can contribute to combatting the epidemic by accurately diagnosing the COVID-19 presence.

The reminder of this chapter is the following: Section 2 will review the state-of-the-art works. Section 3 details the proposed method used for diagnosing COVID-19 disease. Section 4 will provide the experiments conducted and the results of this work and Sect. 5 will concludes the chapter.

2 Related Works

In the recent years, medical imaging techniques have been developed and used to solve different problems. This huge progress can be explained by the introduction of artificial intelligence (AI) technologies. It was widely used to solve classification, detection and segmentation problems. The artificial intelligence technique presents a very powerful technique as it provides powerful features representations [12].

Since the appearance of COVID-19 in Wuhan in China in 2019, different works has been proposed to address this worldwide pandemic. To this end, many works have been elaborated for lung COVID-19 infection detection in x-ray and CT scan recently [13]. By introducing these works, the COVID-19 disease can be early diagnosed and huge number of human lives can be saved.

Wong et al. [14], proposed a new deep convolutional neural network design named "COVID Net" which is used for the detection of COVID-19 infections in chest x-ray images. They also introduce a new benchmark dataset of chest x-ray images named COVID-x which count 13,975 images of 13,870 patient's cases. In [15], authors proposed to develop a new automated detection system of COVID-19 from lung CT scan slices using transfer deep learning techniques. They used three-phase detection models using stationary wavelets. They used three versions of ResNet to develop the proposed system: ResNet 18, 50 and 101.

In [16], authors proposed to develop a new neural network named "InefNet" to automatically detect the infected regions from CT slices. In this work, authors present a semi-supervised segmentation framework based on randomly selected propagation strategy. In this study, authors used a small dataset of 100 CT labeled images.

In [17] authors proposed to develop a new joint classification and segmentation (JCS) system used for COVID-19 chest CT diagnosis. To train the developed system, authors proposed to construct a new large scale COVID-19 chest CT images with 144.167 images. According to the experiments conducted authors have demonstrated the efficiency of their developed system. In [18], authors proposed a gray-scale spatial exploitation net. It uses a new methodology for constructing the dataset by web crawling. The developed system achieved competitive results compared to GoogleNet, VGGNet-19, ResNet 50 and AlexNet.

A new deep learning-based segmentation system is proposed in [19]. It can be used to quantify the infected regions of interest (ROIs) with COVID-19 and their volumetric ratios. A new quantification system for chest CT images of COVID-19 with deep learning is proposed in [20]. The experimental results have shown the high accuracy of severity prediction and infection delineation. An artificial intelligence system is developed to segment lung regions infected by COVID-19 in thick CI images chest sections are proposed in [21]. This system also shows its great capability on accurately identifying and quantifying the lung abnormalities and assesses the disease severity and its progression.

Deep learning based architecture have been widely used and successfully applied to reduce the negative impact of COVID-19 epidemic in X-ray images [30, 31]. In [32], authors present a decision-level fusion approach that integrates three well-calibrated ensemble classifiers: the random forest (RF), gradient boosting (GB), and extreme gradient boosting (XGB) techniques used for COVID-19 disease detection. A survey on the different innovation of deep learning techniques in medicine is proposed in [33].

In [22], authors survey the different deep learning-based techniques used for COVID-19 detection. They also present a cost effective evaluation of their method.

Different works have been elaborated to fight the worldwide epidemic, but few of them provide a good tradeoff between efficiency and segmentation performances.

3 Proposed Approach for COVID-19 CT Scan Images Segmentation

COVID-19 disease caused by SARS-COV-2 virus presents a serious problem that affects millions of persons around the world. Deep learning architectures have presented very promising results on early detection and prediction of COVID-19 presence in X-ray and CT scan images.

Recently, deep learning-based models have shown significant results for the COVID-19 detection and its early diagnosis in computed tomography CT scan images. The non-early detection of COVID-19 in early stage may affect the demographic situations of the infected cases and their surroundings. An early detection of COVID-19 is extremely important to control the virus spreading. The RT-PCR presents a low sensitivity and a time consuming process. To address this problem, building new alternative tools used for early and accurate diagnosis of COVID-19 is extremely important.

In order to build the proposed COVID-19 early detection system, transfer learning technique which consists of reusing a first task as a starting point for the neural network for a second task is applied. Transfer learning is a popular approach used in deep learning where a pretrained model is used as starting point for a new task totally different from the first task. It aims to adopt the pretrained model weights for the second task. Transfer learning technique enables the network to be generalizable on new datasets and tasks.

In the proposed work, we first retrained the HookNet model with its pretrained weights on the COVID-19 CT scan datasets. Generally, applying transfer learning techniques reduce the model training complexity as well as processing time.

Transfer learning application is not an easy process as it aims to identify which parts and aspects of the model knowledge need to be transferred and that can be relevant for the new task. This process employs to identify the sources and the target that are in common in the two tasks. Figure 1 present an illustration of the transfer learning approach.

Early diagnosis of COVID-19 is increasingly important for combatting the COVID-19 pandemic. In this context, we propose in the following a deep learning-based framework used for COVID-19 diagnosis for more specification the HookNet deep neural network is used. This deep neural network, which combines visual context and specifics via numerous branches, is a semantic segmentation neural network.

Semantic segmentation aims to separate concepts by grouping pixels belonging to the same concept or objects which highly contribute to simplify the image representation and understanding to fight the COVID-19 disease. It is necessary to perform lung-chest image segmentation in order to diagnosis patient's images situation.

The HookNet [11] network present a semantic segmentation neural network used for histopathology whole slide images that ensures a combination between contextual and image details. This architecture present a convolutional neural

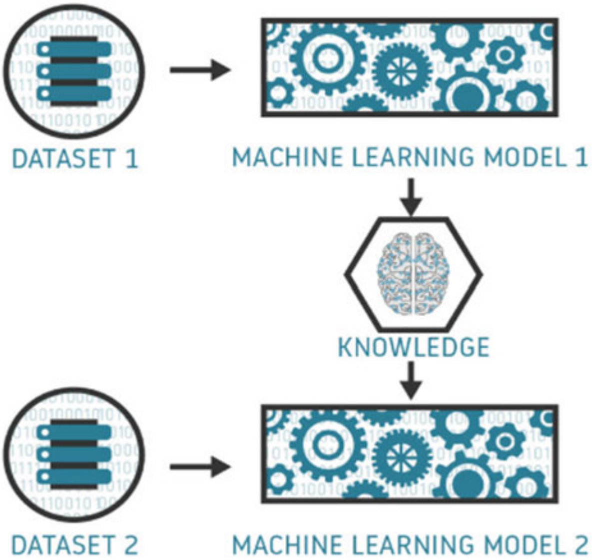

Fig. 1 Transfer learning technique

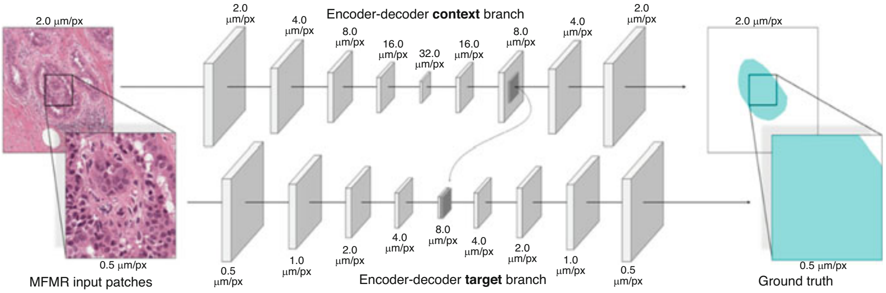

Fig. 2 HookNet architecture [11]

network based on an encoder-decoder block. In order to differentiate between objects, the HookNet architecture "look" at the global image composition and analyses the context of each object in the input image. It also zoom-in into each region of interest where the objects pixels are examined at a high resolution to obtain details about the objects. Also, HookNet model is characterized by its receptive field and field of view. The size of the receptive field depends on the filter size and the number of convolution and pooling layers, if this number increases the receptive field increase. All this allow the model to capture the best and the more valuable contextual information. Another aspect concerning the HookNet architecture is the field of view (FoV) which aims to ensure concentric patches at multiple image resolution with various Fov.

HookNet architecture is detailed in the Fig. 2.

It target to ensure semantic segmentation by combining information from low resolution patches with large field of view which provides the detailed and the fine-grained information. The HookNet architecture is composed of two main parts: (1) context branch which aims to extract features from input images that contain the contextual information, (2) target branch which extract fine-grained details from the high resolution patches.

The main contribution of this network is that the contextual and fine-grained information are combined through a feature map across branches concatenation; the HookNet architecture is composed of five main components:

Context and Target Branches The architecture of these two branches consists of an encoder-decoder based on U-Net [26] architecture.

Multi Field of View/Multi Resolution (MFMR) Input Patches For the context (c) and target (T) branches, respectively, the HookNet input is a pair (Pc, Pt) of (MxMx3) concentric patches that were recovered from various spatial resolu-tions Rc, Rt. The region with the dimensions (M Rt/Rc, M Rt/Rc, 3) is Pt′s field of view. HookNet makes a particular design decision to provide high-quality segmentation output. Because the features maps in the encoder block are all the same size before the pooling layer, M parameters should be used. An irregularly sized feature will result in a number of issues, including misalignments via skip-connections and across-branches, therefore this constraint needs to be thoroughly addressed.

Hooking Mechanism A hook-up information from the context branch is concatenated to the target branch via a feature map concatenation. The concatenation choice has been adopted as it allows to downstream the convolution layer to learn optimal operations for the features combination during the optimization parameters stage. The extracted feature map from context and target branches is concatenated after the bottleneck layer. By this, the semantic encoding will occurs separately. After various experiments, concatenation is the best done at the beginning of the target branch of the decoder. It allows an inherent up-sampling in the decoder block path. The concatenated features map will benefit from the skip connection in the target branch. All this contribute for the hooking concept.

Loss Function A separate loss function is calculated for each model branch. The equation (1) presents the HookNet loss function.

$$L = \lambda \, \mathrm{L}_{\mathrm{high}} + (1 - \lambda) \ \mathrm{L}_{\mathrm{low}} \tag{1}$$

where

$\mathrm{L}_{\mathrm{high}}$, $\mathrm{L}_{\mathrm{low}}$ are pixel wise cross entropy for the target and the context branches
λ: control the importance of each branch.

Pixel-Based Sampling Every class label is equally represented during the training phase thanks to a pixel-based sampling method. Patch sampling is done based on each class's accumulated ground truth for the succeeding mini-batches while patch sampling for the initial mini-batch is done at random. To make up for the underrepresented classes, the low pixel accumulation classes are sampled.

4 Experiments and Results

Building an early COVID-19 detection system is extremely important to fight the worldwide epidemic. The early diagnosis of COVID-19 is very important as it can contribute to control the disease and to save huge number of human lives. In the proposed work, the HookNet neural network is used to contribute for a COVID-19 segmentation system. In the proposed work we make use of HookNet which is the first time applied to CT scan images.

4.1 Data Augmentation and Training Details

Training and testing experiments were performed using SARS-COV2-CT-scan dataset [23] and COVID-x-CT dataset.SARS-COV2-CT-scan dataset contain 1252 CT scan images with positive SARS-COV-2 infection and 1230 CT scan images for non-infected patients. So, it presents 2482 CT scan images in total.

In the proposed work we have efficiently and comprehensively evaluated the efficiency and the robustness of HookNet when it was applied to two benchmark COVID-19 CT scan datasets. Extensive experiments have been performed in the proposed work which contributes to very competitive results in terms of precision and processing time. Figure 3 provides a data subset from the SARS-COV2-CT-scan

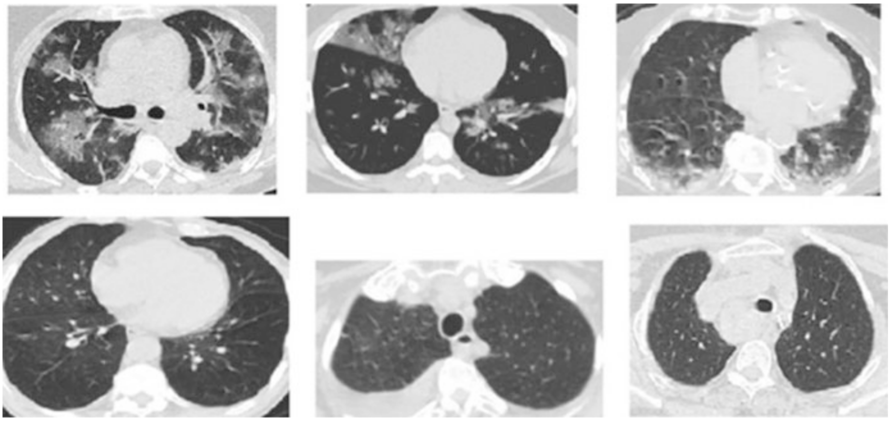

Fig. 3 Example of image from the SARS-COV2-CT-scan dataset

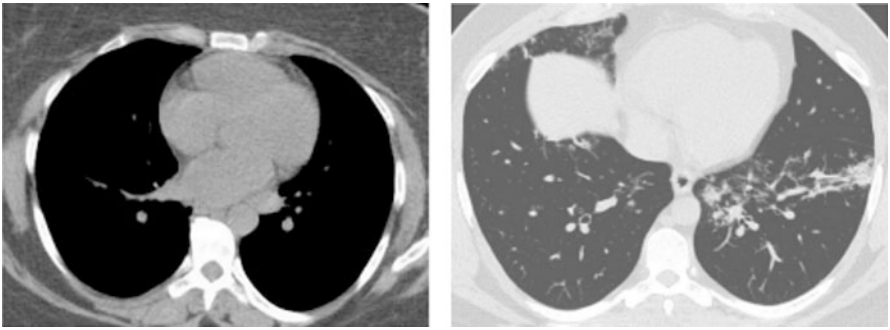

Fig. 4 Different images contrast

dataset. In the following, all the experiments conducted in the proposed work will be detailed.

This dataset present a very challenging data as it provides different conditions. The data has been collected from the hospital of Sao Paolo, Brazil. Also, this dataset do not provides a fixed image size (smallest image in the dataset is 104 × 153 and the largest image size is 484 × 416). The data provided in this dataset present different contrast as presented in Fig. 4.

In order to study the effectiveness of HookNet on COVID-19 early detection and diagnosis, we applied this network to a second COVID-CT dataset named "COVID-x -CT dataset". The dataset has been divided into 3 parts: train, validation and test. Over 60000 images were used for training, 21036 for validation and 21192 for testing the network. The validation set is used to study how much the network is able to understand the data as well as to avoid the overfitting problems. An example of images from the COVIDx CT dataset is presented in Fig. 5.

The most common problem that can influence the deep learning models is the class imbalance. In order to overcome this problem, data augmentation technique is applied. The data augmentation was applied using different techniques including: random cropping, image translation, rotation, brightness adjusting and horizontal flipping. Table 1 provides the experiments settings.

In order to evaluate the robustness of the proposed work, we trained HookNet using two different activation functions: RELU [24] and leaky RELU. The transfer learning technique by starting from the HookNet neural network and it was retrained for the proposed second task is applied. Performing a fine-tuning of a pre-trained neural network will reduce the amount of computation complexity as well as time consumption. This technique is very effective as it enables the reuse of already learned filters, parameters in other tasks and be reused for second task [25]. In the proposed work, we worked with a small dataset with few images which makes using transfer learning is imperative.

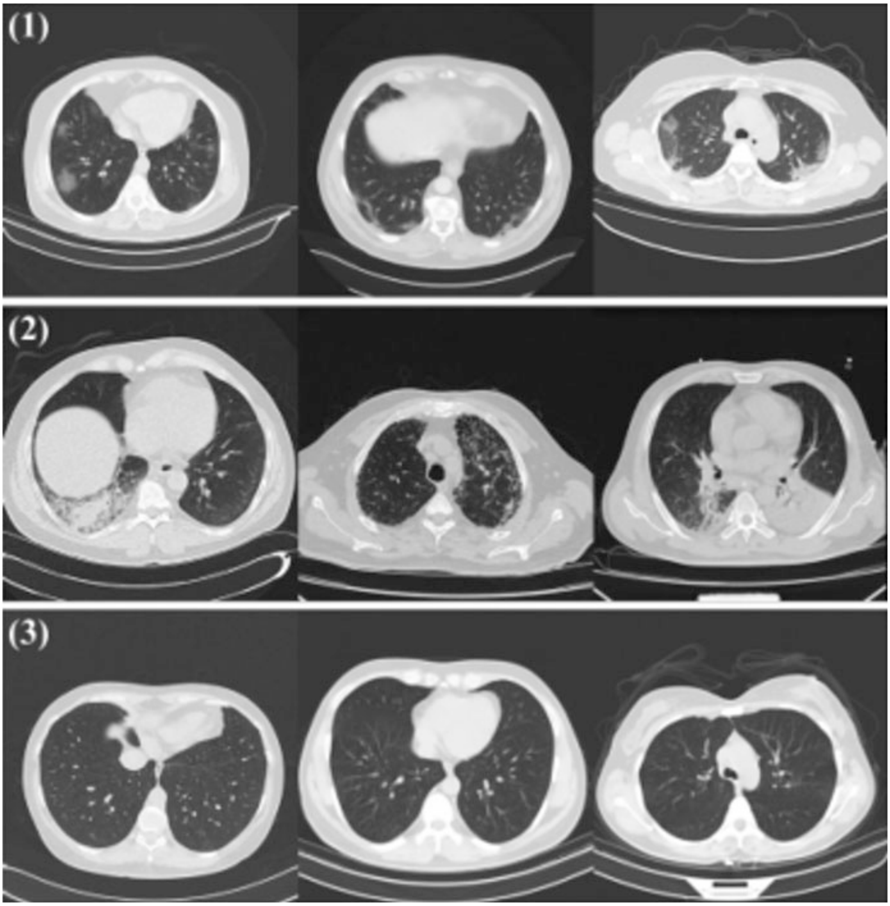

Fig. 5 Sample CT images from the COVIDx CT dataset, images (1) coronavirus pneumonia (NCP), (2) common pneumonia (CP), and (3) healthy lungs

Table 1 Experiments settings

Parameter	Value
Epochs	20
Activation function	RELU/leaky RELU
Learning rate	0.000005
Optimizer	ADAM
Iteration	10,000
Iterations	1000

4.2 Results and Discussions

Experiments were carried out using a tesla workstation equipped with Intel Xeon E5–2683 v4 processor and a tesla K40C graphic processing unit with 12 GB of graphic memory. The HookNet implementation was performed using tensorflow framework.

In this chapter, the advantages of deep learning models are applied in order to build a robust system used for COVID-19 image segmentation. In order to assess the model performances, the work is evaluated using different evaluation metrics, precision, recall and F1 score.

$$\mathrm{Precision} = \frac{\mathrm{TP}}{\mathrm{TP} + \mathrm{FP}}$$

$$\mathrm{Recall} = \frac{\mathrm{TP}}{\mathrm{TP} + \mathrm{FN}}$$

$$\mathrm{F1} - \mathrm{score} = 2 * \frac{\mathrm{Precision} * \mathrm{Recall}}{\mathrm{Precision} + \mathrm{Recall}}$$

where TP, TN, FN, and FP stand for the COVID-19 samples correctly classified, non-COVID-19 samples correctly classified, the COVID-19 samples classified as non-COVID-19, the non-COVID-19 classified as COVID-19.

In order to increase the effectiveness of the proposed work, two experiments with two different activation functions RELU and Leaky RELU are proposed. Table 2 provides the accuracies obtained for the two activation functions used. Evaluation metrics values are presented in Table 3.

As presented in Table 2, very competitive COVID-19 detection results are achieved. By using leaky RELU as an activation function, the model accuracy by is improved by around 1.5%. The proposed system has shown very effective evaluation performances as presented in Table 3.

Table 2 Obtained accuracies for SARS-COV2-CT

Activation function	Accuracy (%)
RELU	95.31
Leaky RELU	96.80

Table 3 Evaluation metrics

Precision	93.88
F1-score	94.79
Recall	95.34
Accuracy	96.80

Table 4 Obtained accuracies for COVIDx-CT dataset

Activation function	Accuracy (%)
RELU	96.45
Leaky RELU	97.58

Table 5 Evaluation metrics

Precision	94.12
F1-score	95.22
Recall	96.68
Accuracy	97.58

Table 6 Comparison of segmentation accuracies on COVIDx-CT dataset

Method	Accuracy (%)
Method in [27]	93.25
Method in [28]	95.64
Method in [29]	91.62
Proposed	96.12

Table 4 provides the accuracies obtained for the two activation functions used for the COVIDx-CT dataset. Evaluation metrics values used in the proposed experiments are presented in Table 5.

As presented in Table 4, the developed system demonstrated very competitive COVID-19 detection results. By using leaky RELU as an activation function, the model accuracy is increased by around 1%.

Table 6 provides a comparison with the state-of-the-art works used for lesion detection common pneumonia and COVID-19 segmentation on CT scan images.

As presented from Tables 2 and 4, very encouraging accuracies for the two datasets used in the proposed experiments has been obtained. Better results are achieved for the COVIDx-CT dataset as it present much more data for neural network training and evaluation.

As mentioned in Table 6, by using HookNet network for lesions segmentation for COVID-19 prediction, the proposed system achieved better results than those obtained by state-of-the-art works. The proposed system demonstrated better segmentation accuracies on the COVIDx-CT dataset compared to the work done on the same dataset and with the same training, testing and evaluation protocol. Based on the obtained results, the proposed work shows better competitive segmentation results which can helps the scientific community and especially doctors for early diagnosis and prediction of COVID-19 and saving more human lives around the world. The developed COVID-19 early detection system in CT scan images present a very powerful tool with much lower cost than the RT-PCR kit which can widely applied in the hospitals around the world.

5 Conclusion

In this study, a deep learning-based technique used for early diagnosis of COVID-19 using CT imaging is proposed. The developed system is proposed based on HookNet network. Quantitative results have demonstrated the effectiveness of the proposed work. Training and testing experiments have been conducted using two benchmark datasets: SARS-COV-2 CT-scan dataset and COVIDx-CT dataset. We highlight in this work the power and the performance of deep learning models on COVID-19 diagnosis. The developed system presents a very effective tool to help doctors and radiologists to diagnosis the suspected cases. Based on the experiments results, very encouraging accuracies for the two datasets used are obtained. In order to ensure more robustness for the developed work, two activation functions has been used. When using leaky RELU instead of using RELU, better performances has been achieved. The developed system achieved very promising results coming-up to 96.80% on SARS-COV-2 CT-scan dataset and 97.58% on COVIDx-CT dataset.

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Multimodal Diagnosis of COVID-19 Using Deep Wavelet Scattering Networks

Rami Zewail

1 Introduction

Since December 2019, the whole world has been fighting the COVID-19 pandemic. It is believed that COVID-19 has infected over 219 million individuals worldwide and caused the death of over 4.5 million [1]. Moreover, it is believed that the numbers in developing countries are even worse than the officially recorded cases. One of the most challenging aspects of the current pandemic is the early diagnosis and close monitoring of suspected cases. The Real-Time reverse-transcriptase-Polymerase Chain Reaction (RT-PCR) test has been widely accepted as the main diagnostic means for COVID-19 cases. However, studies have shown that the PCR test has highly variable false negative rates. This False negative rate is highest (up to 67%) during the first 4 days and lowest (around 21%) on the 8th day of exposure [2]. This is alerting since early diagnosis of the COVID-19 has been found to be crucial into increasing the patient's survival rate. In addition to the PCR test, chest radiographs (X-ray) and computed tomography scans (CT) scanning have been routinely used as well in the diagnosis and monitoring of COVID-19 *cases* [2, 3]. As the world continues to struggle through waves of the COVID-19 pandemic, there continues to be a growing interest in artificial intelligence-based diagnostic solutions. This is particularly true in developing countries and areas with limited resources. Yet, despite the research efforts, a recent study by the University of Cambridge has concluded that most of the published methods have barely any clinical relevance [4]. Moreover, majority of the research on this topic have focused on resource-hungry deep learning solutions that might be of limited benefit in settings with limited resources.

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2 Related Work

Throughout the past year, there has been a growing interest in the use of artificial intelligence for the diagnosis of COVID-19 in X-ray and CT scan images. The majority of the methods in the literature have focused on using Convolutional Neural Networks (CNN) and transfer learning approaches. Augmentation methods have also been suggested to tackle the problem of scarce training data. In [5], the authors presented an overview of various deep learning diagnosis methods with reported accuracies in the range of 80–98%. The authors concluded that most of the results have been reported on relatively small training and/or test datasets and that they are prone to overfitting. In another review study conducted by researchers from the University of Cambridge [4], the authors reviewed 2212 studies, among these only 62 studies made it through the initial and the quality screening phases. Out of these 62 studies, non were found of potential clinical relevance. The authors attributed this to several reasons such as a flaw in the methodology and underlying biases.

In [6], the author explored several ways to tackle the problem of scarce COVID-19 imaging data. Methods explored include transfer learning, data augmentation, and few-shot learning. A new few-shot learning approach using the Siamese network was proposed to detect COVID-19 in X-ray images. Average accuracy of 96.4% is reported. In [7], the authors proposed a CNN-based deep feature concatenation approach. Deep features extracted from X-ray and CT images are concatenated to form the classification descriptor. Using a train/test ratio of 70/30, the authors reported an accuracy of 96.13% with an F1-score of 95.69%. The accuracy was enhanced to 99.3% through feature concatenation and transfer learning from pre-trained networks. In [8], the authors proposed a method based on transfer learning using as AlexNet. The method was used to differentiate between COVID-19 and Healthy cases in X-ray images. An accuracy of 96.5% was reported with 98% sensitivity and 91% specificity. In [9], the authors presented a method for automated detection of COVID-19 from CT scan using transfer learning. The proposed model is based on VGG16 and ResNet50 networks. An average accuracy of 99% is reported for the two-class classification task (normal-vs-COVID-19). An average accuracy of 88.52% is reported in the three-class classification task (COVID-19 vs pneumonia vs Normal).

Apart from the CNN-based methods, some researchers have reported competitive results using different approaches. In [10], the authors presented a proof-of-concept study on the potential of texture analysis in the automated diagnosis of COVID-19 chest X-ray images. Experiments were limited to 106 images and an accuracy of 90.6% was reported. In [11], the authors presented a new machine learning system for the diagnosis of COVID-19 in chest X-ray images using local binary transform and Gabor filtering. Average accuracy of 94.43% was reported. Experiments were conducted on 105 X-ray images covering the cases of Healthy, COVID-19, and Non-COVID-19 pneumonia. In [12], the authors proposed a method for the identification of COVID-19 cases in CT scan images using Gabor filters in the Fourier domain.

Average accuracy of 95.37% was reported on a total of 470 CT-scan images with 275 positive cases and 195 negative cases.

Apart from applications of artificial intelligence for automated diagnosis of COVID-19, efforts have also been directed towards using machine learning in predicting of outbreaks. In [13], the authors proposed a method a machine learning-based diffusion model for prediction of COVID-19 outbreaks. The authors reported ability of proposed model in predicting number of confirmed cases, recovered cases, deaths and active cases within a four-week time frame window. In [14], the authors presented a comprehensive study on developing predictive models to forecast impact of COVID-19 pandemic on country-driven sectors.

A more thorough review on applications of Artificial intelligence in current COVID-19 pandemic can be found in [4, 5, 15–19].

3 Proposed Methodology

This section presents the details of the proposed method for multimodal COVID-19 diagnosis using light Deep Wavelet Scattering Networks (DWSN). Figure 1 shows the general architecture of the proposed method in both single-modal and multimodal diagnostic modes. Sections 3.1 and 3.2 presents the details of constructing the wavelet scattering network. Section 3.3 presents the details of the deep scattering features extraction process. The details of the subspace feature learning process is described in Sect. 3.4. Final classification step is described in Sect. 3.5.

3.1 Deep Wavelet Scattering Decomposition

Traditionally wavelets have found applications in numerous domains such as signal processing, compression, and image denoising. More recently, application of wavelets has also been extended to machine learning and deep learning domains. A thorough background of wavelets can be found in [20–22]. Deep Wavelet Scattering Network (DWSN) is a deep architecture that is capable of efficiently extracting deep low-variance features [23–26]. A wavelet scattering network shares several desirable properties with Convolutional Neural Networks (CNN). These desirable properties include multiscale representation, non-linearity, and sparse representation. On the other side, contrary to traditional CNNs, wavelet scattering networks use predefined wavelet and scaling filters. In its two-dimensional formulation, wavelet scattering networks are capable of extracting robust features that are insensitive to translation, deformations, and rotations [25, 26]. The appealing properties of this light deep learning network are of potential significance to tackle challenges related to scarce training data and high computational demands. These

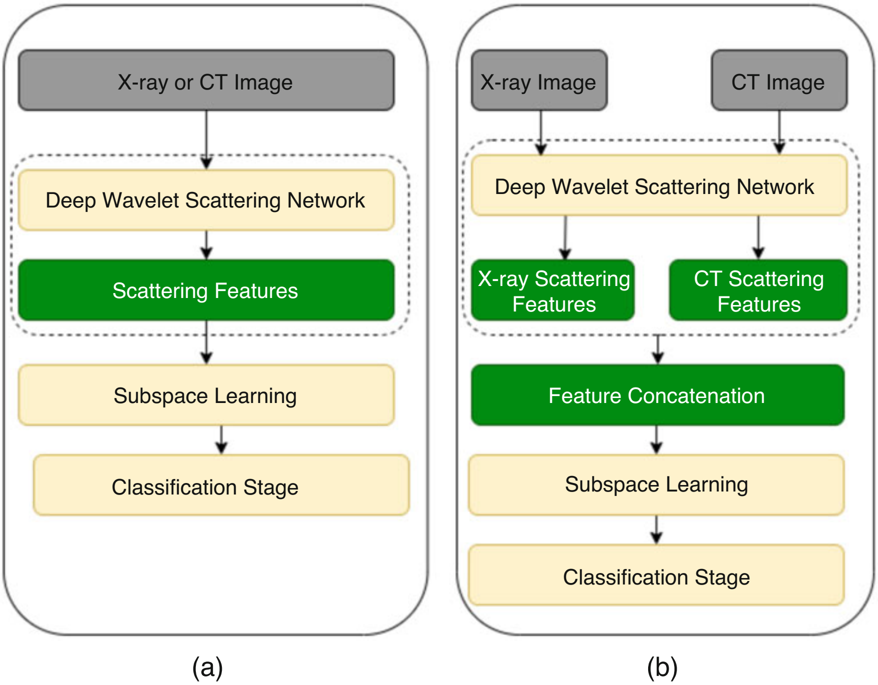

Fig. 1 General Architecture of the proposed COVID-19 Diagnosis framework. (**a**) Single modality diagnosis. (**b**) Multimodal diagnosis

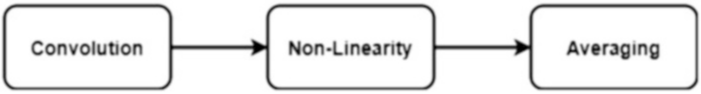

Fig. 2 Basic operations in a Deep Wavelet Scattering Network

challenges became prevailing in the current COVID-19 pandemic, especially in resource-limited environments.

A Deep Wavelet Scattering Network (DWSN) is constructed by iteratively repeating the basic operations shown in Fig. 2. These are namely: convolution with a wavelet filter, applying non-linearity operator, and averaging using the scaling function.

The wavelet scattering network is constructed using a complex Morlet wavelet as the wavelet function and Gaussian function as the low-pass scaling function. Morlet wavelets are composed by multiplying a complex exponential with a Gaussian envelope. The significance of Morlet wavelets relies on the fact that they provide optimal joint time-frequency localization and their analogy to the human visual and auditory models [27, 28]. A Morlet wavelet is defined as in Eq. (1)

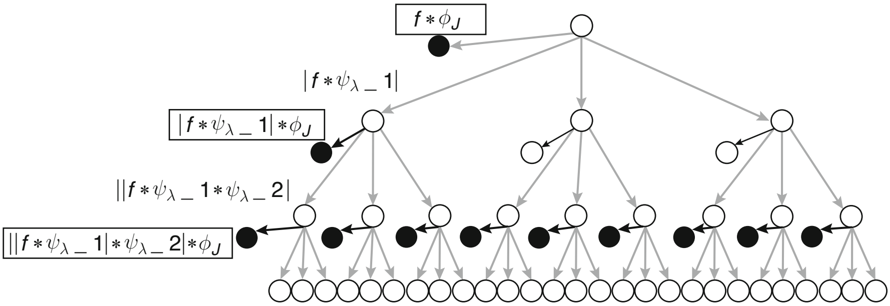

Fig. 3 General architecture a Deep Wavelet Scattering Network (DWSN)

$$\psi(u) = C1\ (\ e^{-i\xi u}\ -\ C2\ )\ e^{-\frac{|\,u\,|^2}{2\sigma^2}} \tag{1}$$

Where ξ is the frequency, σ is a measure for the support, and $C1$ and $C2$ are constants that are used to satisfy the wavelet admissibility conditions. For a 2D Morlet wavelet, u is the (x, y) spatial coordinates

The general architecture of the Deep Wavelet Scattering Network (DWSN) is given in Fig. 3. Let ψ and φ be the mother wavelet and the scaling function respectively. φ_J is a low-pass filter that provides translation invariance at scale J. Let $\{\psi_\lambda\}$ be the wavelet filter-bank constructed by dilating and rotating the mother wavelet.

$$\psi_\lambda(u)\ =\ 2^j\,\psi_\lambda(2^j\theta\ u) \tag{2}$$

Where θ is rotation matrix and $\lambda = (2^j,\ \theta)$.

Referring to Fig. 3, a scattering path is defined as the sequence of edges from the root to a node. Tree nodes are referred to as scalogram coefficients. Convolving the scalogram coefficients at each node with the scaling function results in the scattering coefficients.

The zero-order scattering coefficients are computed by averaging the input using the scaling function φ_J.

$$S_0\,f = f\ *\ \varphi_J \tag{3}$$

The first-order scattering coefficients are then obtained by doing the convolution with the wavelet function, taking the modulus, and applying the low-pass filtering.

$$S_1\,f\ =\ \left|\,f\ *\ \psi_{\lambda_1}\right|\ *\ \varphi_J \tag{4}$$

The second-order scattering coefficients are calculated as described in Eq. (5).

$$S_m\,f\ =\ \left|\ \left|\,f\ *\ \psi_{\lambda_1}\right|\ *\ \psi_{\lambda_2}\,\right|\ *\ \varphi_J \tag{5}$$

The process continues and the mth order scattering coefficients is then defined as in Eq. (6).

$$S_m f = \left| \; \left| f * \psi_{\lambda_1} \right| \ldots . * \; \psi_{\lambda_m} \right| * \varphi_J \tag{6}$$

The scattering and scalogram coefficients are critically down-sampled based on the bandwidth of the low-pass scaling filter for efficient implementation [23].

3.2 Constructing the Wavelet Scattering Network

A two-dimensional wavelet scattering network has only three hyperparameters. These are namely: the quality factor (number of wavelets per octave), number of rotations, and the invariance scale factor. The quality factor is responsible for discretizing the scale-space according to the number of wavelet filters used. Table 1 shows the parameters used to construct the scattering network. Figure 4 shows the predetermined filters used to construct the network.

Table 1 Configuration parameters for the Deep Wavelet Scattering Network (DWSN)

Parameter	Selection
Input image size	256 × 256
Number of levels	3
Invariance scale (pixels)	128
Quality factor (Q)	1
Number of orientations	8

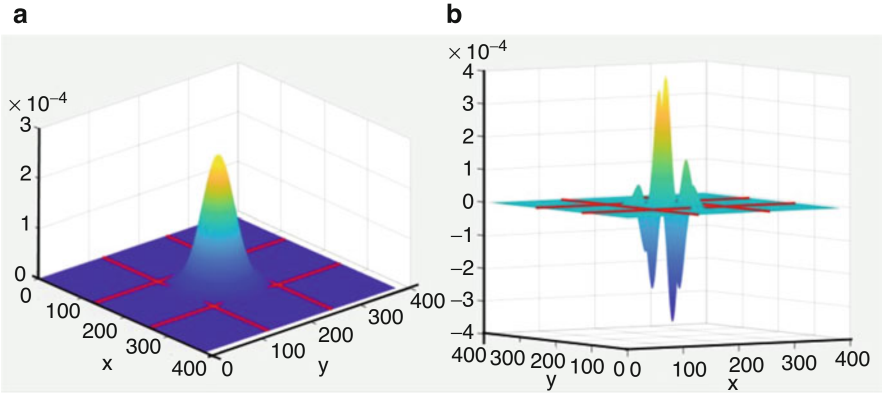

Fig. 4 Wavelet scattering network filters. (**a**) Scaling filter. (**b**) Morlet wavelet

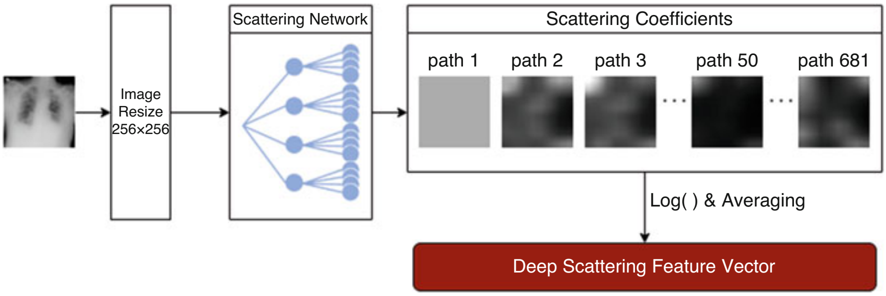

Fig. 5 Deep scattering feature extraction

3.3 *Deep Scattering Feature Extraction*

Figure 5 highlights the procedure for extracting the deep scattering features from the chest medical images. All input images are first resized to a fixed size of 256 × 256. This is meant to limit the training time and the power requirements of the developed model. Our end goal is to a develop a light learning engine for resource-constrained settings. The resized image is then passed through the wavelet scattering network with the parameters described in Table 1. The output is a feature matrix of size 681 × 8 × 8. This represents 681 scattering paths and each scattering coefficient image is 8 × 8. The final feature vector is obtained by taking the log and the average for each of the 8 × 8 coefficient image at each path. This outcome is a feature vector of size 681 × 1.

3.4 *Subspace Feature Learning*

The output from Sect. 3.3 is a low-variance deep feature vector for each image in the dataset. Given a training set of data, the following methods were explored for dimensionality reduction of the feature space.

3.4.1 Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is a well-established method for dimensionality reduction [29]. Given a training set of feature vectors, PCA projects the features in the direction of maximum variance. The resultant principal components are ordered in descending order from the most to the least variability in the feature space. Sub-space dimensionality reduction is achieved by selecting the components that capture 99% of the total variance in the training set.

3.4.2 Joint Best Scattering Non-linear Approximation (JBSC_NA)

This section presents another method for sub-space feature learning using joint non-linear approximation and Discrete Cosine transform (DCT). DCT is an approximation for Karhunen Loeve Transform (KL) (i.e. PCA) [29]. It is widely used in signal and image compression applications. While KL transform (PCA) computes its basis using the space represented in the training space, DCT uses a data-independent fixed cosine basis. The training set is just used to estimate the best jointly approximating basis.

Given a training set of M images, the original deep scattering feature vector, $\mathbf{Z_i}$, is first extracted for each image in the training set.

$$\mathbf{Z_i} = [z_{i1} \quad z_{i2} \quad z_{i3} \ \ldots\ldots z_{iN}\ ] \tag{7}$$

Where N is the original size of the deep scattering feature vector obtained in Sect. 3.3.

Discrete Cosine Transform (DCT) is then applied to $\mathbf{Z_i}$.

$$Y_{\mathbf{i}} \ = \ DCT\ (\ \mathbf{Z_i}\ ) \ = \ [\ y_{i1} \quad y_{i2} \ \ \ldots\ldots.. y_{iN}] \tag{8}$$

Using Eq. (9), we calculate the relative energy captured by each element in $\mathbf{Y_i}$ across the entire training dataset.

$$E_i \ = \ \frac{\sum_{j=1}^{M} \left| y_{ij} \right|^2}{\sum_{i=1}^{N} \sum_{j=1}^{M} \left| y_{ij} \right|^2} \tag{9}$$

The m-term joint best non-linear approximation is then defined as the m terms with the largest relative energy E_i Details about the experiment conducted to evaluate the subspace learning is presented in Sect. 4.3.5.

3.5 *Classification Stage*

The output of the subspace learning stage is then passed to the classification stage. Several classifiers have been evaluated [29] within the proposed framework.

- Support vector machine classifier (SVM): This is a supervised learning approach originally formulated in binary classification problems to construct the optimal hyperplane that best separates the two classes at hand. Kernel functions are used to expand the application of SVM to non-linear classification problems. Results reported in this chapter are based on a Quadratic Support Vector Machine (Q-SVM).

- Linear Discriminant Analysis Classifier (LDA): This is an easy classifier that establishes linear boundaries among classes.
- Subspace Discriminant Analysis Classifier (SDA): This is a memory-efficient classifier that is fast in training and predictions. An ensemble of K-nearest neighbors' classifiers is created using the random subspace algorithm. The number of learners used is equal to 30 and the subspace dimension is equal to 204.

4 Experiments and Results

This section presents the details of the experiments conducted to evaluate the proposed scattering-based multimodal COVID-19 diagnosis method.

4.1 Description of Datasets

Several publicly available datasets have been used throughout the evaluation process.

4.1.1 COVID-19 Radiology Dataset (XrayDB1)

This dataset is an open-source dataset [30–32]. The dataset was prepared by several international researchers and doctors from Qatar University, University of Dhaka, along with collaboration with medical doctors in Pakistan and Malaysia. The dataset is one of the most comprehensive COVID-19 open source datasets available. It is voted by the Kaggle community as the best COVID-19 dataset. It contains a large number of labeled chest X-ray images. The images in the dataset are labeled into four categories. These are namely: COVID-19, Healthy, Viral pneumonia, and Lung Opacity. The results reported in this chapter used a subset of this dataset with a total of 4000 images of balanced classes (1000 images per class). Samples of the classes in this dataset are shown in Fig. 6. Going forward, this dataset is referred to as XrayDB1.

4.1.2 Augmented X-ray and CT COVID-19 Dataset

This is an extensively augmented open-source dataset [1, 32, 33]. This dataset consists of COVID-19 and Non-COVID-19 cases for both X-ray and CT scan images. Experiments were conducted on 4600 X-ray images and 4600 CT scan images with balanced classes. Figure 7 shows examples of different classes in this

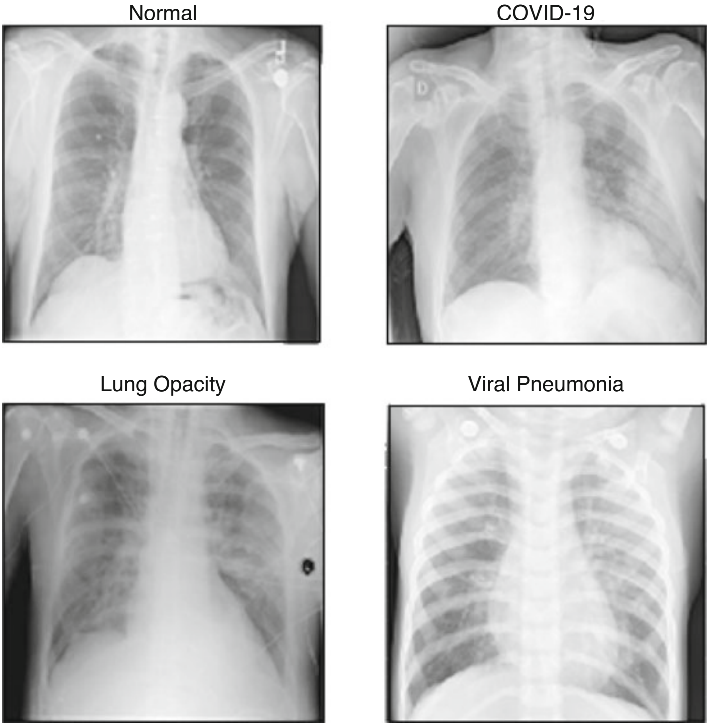

Fig. 6 Samples of the four classes of chest radiograph images in XrayDB1 dataset [32]

dataset. Going forward, the X-ray portion of the dataset is referred to as XrayDB2 and the CT scan portion of the dataset is referred to as CTDB1.

4.2 *Evaluation Protocol and Metrics*

The proposed method has been evaluated using repeated K-Fold cross-validation. N-repeated K-fold cross-validation is conducted by repeating the K-fold cross-validation experiment for N times and reporting the average as the overall performance. In our experiments, reported results are an average of threefold cross-validation that is repeated 10 times. The outcome of the repeated K-fold cross-validation was evaluated using standard classification metrics; namely: accuracy, specificity, sensitivity, F1-score, and Receiver Operating Characteristic (ROC) curve [29, 34].

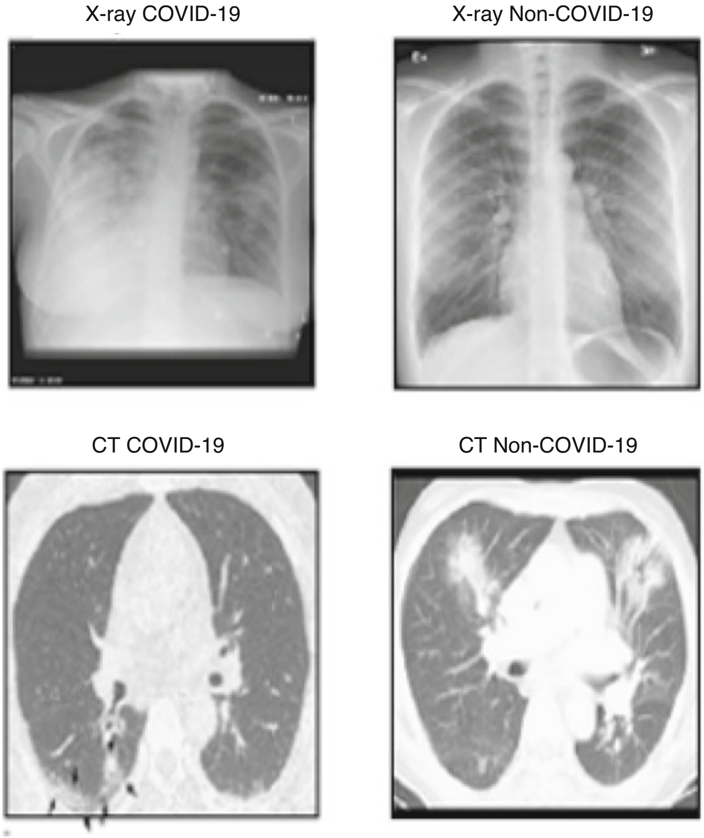

Fig. 7 Samples of the classes in the X-ray dataset (XrayDB2) and CT scan dataset (CTDB1) [33]

4.3 *Results*

This section presents details of the experiments conducted to evaluate the proposed scattering-based COVID-19 diagnosis method in single-modal and multimodal modes. Using the datasets described in Sect. 4.1, several classification tasks have been conducted as outlined in Table 2. In all experiments, classes have been balanced such that each class is equally represented in the undergoing classification task.

4.3.1 COVID-19 vs Non-COVID-19 Classification

Experiments were conducted to evaluate the ability of the proposed method to identify COVID-19 cases in chest radiograph images. Experiments were conducted

Table 2 Number of images used in the evaluation experiments

Experiment	Number of images
X-ray COVID-19 vs Non-COVID-19	XrayDB1:2000 XrayDB2:4600
CT scan COVID-19 vs Non-COVID-19	CTDB1: 4600
X-ray COVID-19 vs Healthy	XrayDB1:2000
COVID-19, Healthy, Viral Pneumonia, Lung Opacity	XrayDB1:4000
Mutlimodal COVID-19 vs Non-COVID-19 Classification (Xray + CT)	CTDB1:4600 XrayDB2: 4600

Table 3 COVID-19 identification in X-ray and CT images (COVID-19 vs NON-COVID-19)

Dataset	XrayDB1	XrayDB2	CTDB1
SVM classifier			
Accuracy	95.3%	97.61%	94.8%
Sensitivity	94.5%	98.12%	94.95%
Specificity	96.5%	97.10%	94.7%
F1-score	95.24%	97.62%	94.83%
LDA classifier			
Accuracy	93.5%	95.35%	91.2%
Sensitivity	91.4%	98.6%	91.9%
Specificity	95.5%	91.94%	91.4%
F1-score	93.31%	95.59%	91.16%
SDA classifier			
Accuracy	94.35%	95.9%	94.43%
Sensitivity	93.1%	98.2%	94.7%
Specificity	95.6%	93.6%	94.15%
F1-score	94.28%	96.13%	94.44%

using the two X-ray datasets described in Sect. 4.1. Results are summarized in Table 3. Throughout all experiments, the proposed DWSN-based method has demonstrated consistent capability in identifying COVID-19 cases in chest X-ray images. Among the three classifiers investigated, the Quadratic Support Vector Machines (QSVM) classifier has consistently achieved the highest performance. Results obtained using the augmented dataset XrayDB2 were slightly higher than those obtained using the dataset XrayDB1. Using the XrayDB1 dataset, the proposed method has achieved an average accuracy of 95.3%, with 94.1% sensitivity and 96.5% specificity. Using the XrayDB2 dataset, an average accuracy of 97.61% was achieved, with 98.12% sensitivity and 97.10% specificity. Over all the experiments, the proposed method has achieved an average F1-score of 96.43%.

Experiments were also conducted to evaluate the ability of the proposed method to identify COVID-19 cases in CT scan images. Experiments were conducted on a total of 4600 images. The Best results were achieved using the QSVM classifier. The proposed method has demonstrated an average accuracy of 94.8%, with 94.95% sensitivity, and 94.7% specificity.

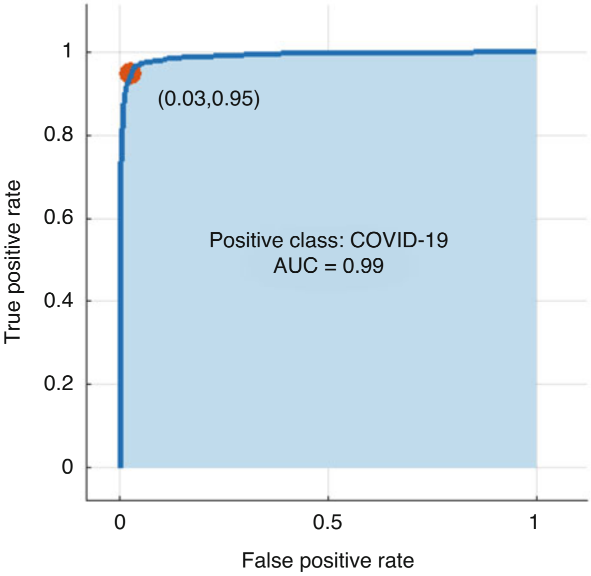

Fig. 8 ROC curve for COVID-19 vs Healthy Classification Task

4.3.2 X-ray COVID-19 vs Healthy Classification Task

Experiments were conducted to evaluate the ability of the proposed method to differentiate between COVID-19 cases and Healthy cases in chest X-ray images. Using the Quadratic Support Vector Machine classifier (Q-SVM), the proposed DWSN-based method has demonstrated an average accuracy of 96.1%, with a sensitivity of 95% and a specificity of 97.3%.The ROC curve in Fig. 8 shows an AUC of 0.99. A true positive rate of 95% is achieved with a false positive rate of 3%.

4.3.3 Four-Class Classification Task

Using the dataset XrayDB1, the proposed method was trained to classify chest X-ray images into one of four classes. These are namely: COVID-19, Healthy, Lung Opacity, and Viral Pneumonia. QSVM classifier was used throughout the experiment. Compared to other experiments, the four-class classification task is the most challenging. Nevertheless, the proposed DWSN-based method has achieved an average accuracy of 90.42%, with sensitivity of 90.43%, specificity of 96.64, and F1-score of 90.46%. The cross-validation matrix is given in Fig. 9.

Fig. 9 Cross validation matrix for four-class classification task: COVID-19 (0), Healthy (1), Lung Opacity (2), and Viral Pneumonia (3)

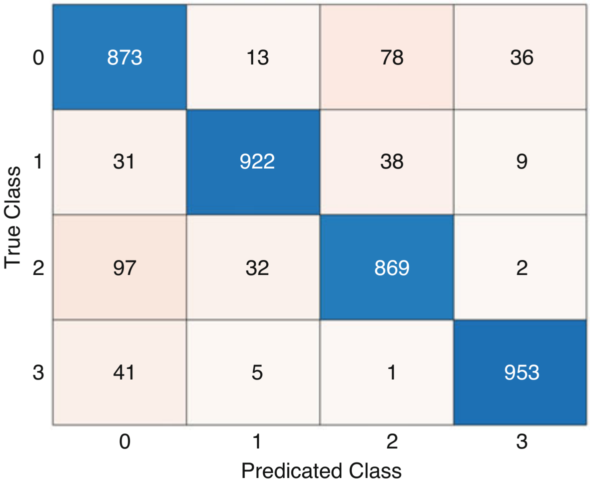

Table 4 Evaluation of subspace learning in deep wavelet scattering domain

Subspace learning	Reduction	Accuracy	F1-score
None	None	95.3%	95.24%
PCA	87.1%	94.9%	94.82%
JBSC_NA (99.9% energy retained)	44.2%	95.05%	94.9%
JBSC_NA (99% energy retained)	85.72%	94.95%	94.85%

4.3.4 Evaluation of Subspace Learning Method

The next set of experiments were conducted to evaluate the impact of the subspace learning method presented in Sect. 3.4. we evaluated the subspace learning method described in Sect. 3.4 within the COVID-19 vs Non-COVID-19 classification task. Experiments were conducted on total of 2000 images from the X-ray dataset XRayDB1, described in Sect. 4.1. Evaluation was conducted using the average threefold cross validation framework outlined in Sect. 4.2. Results are summarized in Table 4. Using Principal Component Analysis (PCA), a dimensionality reduction of 87.1% was achieved. This reduction was at the cost of a slight decrease in the overall system accuracy by 0.4% and in the F1-score by 0.42%.

Using the proposed joint best scattering non-linear approximation method (JBSC_NA), a dimensionality reduction ratio of 85.72% was achieved while preserving 99% of the energy. This was at the cost of a 0.25% reduction in the accuracy and a 0.39% reduction in the F1-score. Preserving 99.9% of the energy resulted in a dimensionality reduction of 44.2%. This reduction was at the cost of a 1.25% reduction in accuracy and 0.34% reduction in the F1-score.

These results demonstrate the ability of the proposed scattering-based joint non-linear approximation method (JBSC_NA) to achieve significant reduction in the feature space with minimal impact on the discriminating power of the

Table 5 Performance of the proposed DWSN-based multimodal COVID-19

Modality	Accuracy %	Sensitivity %	Specificity %
X-ray modality	97.61%	98.12%	97.10%
CT modality	94.8%	94.95%	94.7%
Multimodal (X-ray + CT)	98.77%	99.13%	98.41%

overall system. Also, it is important to highlight the computational advantage of the JBSC_NA subspace learning method over PCA since it does not involve eigenvectors calculation over the training set.

4.3.5 Multimodal COVID-19 Diagnosis

Experiments were also conducted to evaluate the performance of the proposed method in a multimodal COVID-19 diagnosis framework. Deep wavelet scattering features from both CT scan images and X-ray images were concatenated to form a new fused feature vector. The combined fused vector was used as input to the next classification stage. Experiments were conducted using XrayDB2 and CTDB2 datasets with a total of 4600 X-ray images and 4600 CT scan images. Results are summarized in Table 5. The fusion of multimodal deep scattering features resulted in a considerable improvement to the overall performance. The proposed scattering-based multimodal method achieved an accuracy of 98.77% with 99.13% sensitivity and 98.41% specificity. Table 5 highlights the relative advantage of multimodal diagnosis over single-modal diagnosis. A 1.16% increase in system accuracy was achieved compared to the X-ray-based single modality case. An increase of 2.81% in the accuracy was achieved compared to the CT-based single modality case.

4.3.6 Comparison to Related Work

In this section, we attempt to gain some insights into how the proposed method compares against related work in the literature. The majority of related work in the literature has focused on Convolutional Neural Networks (CNN) and transfer learning. CNN-based learning models are always challenged in settings with limited resources. On the contrary, the proposed method is based on Deep Wavelet Scattering Networks (DWSN) that tend to follow the architectural structure of CNN but without the need to learn the weights of the network. Consequently, the proposed diagnosis method is remarkably simple to train and update compared to traditional CNN-based approaches.

We evaluated the performance of the proposed method against several state-of-the-art deep learning approaches that were applied to the COVID-19 diagnosis problem in [7]. Our results were compared against results reported in [7] where the same X-ray and CT scan images dataset, [33], were used. Tables 6, 7, and 8

Table 6 Comparison between the proposed method and state of art methods, [7], for COVID-19 diagnosis in X-ray images

Method	Accuracy	Precision	Recall	F1-score
Proposed	97.6%	97.1%	98.1%	97.6%
CNN-based	92.3%	89.3%	92.89	91.1%
CNN+ResNet18+GoogleNet	99.3%	99.8%	98.8%	99.3%
ResNet101V2	79%	87%	87%	87%
ResNet-18	98.97%	98.2%	99.79	98.98%
GoogleNet	94.2%	89.7%	100%	94.55%
Xception	95%	92%	90%	90%
DenseNet201	84%	94%	94%	94%

Table 7 Comparison between the proposed method and state-of-the art methods, [7], for COVID-19 Diagnosis in CT-scan images

Method	Accuracy	Precision	Recall	F1-score
Proposed	97.6%	94.3%	94.95%	94.83%
CNN-based method	94.35%	96.61%	91.94%	94.21%
CNN+ResNet18+GoogleNet	98.9%	99.36%	98.5%	98.92%
ResNet101V2	88.92%	91.03%	91.19%	91.1%
ResNet-18	95.81%	96.6%	94.9%	95.77%
GoogleNet	92.1%	86.8%	9.24%	92.6%
Xception	94.8%	93.18%	90.72%	91.93%
DenseNet201	91.72%	90.61%	92.73%	91.65%

Table 8 Comparison between the proposed DWSN-based method and CNN-based method, [7], in multimodal COVID-19 Diagnosis

Method	Acc. %	Prec. %	Rec. %	F1-score
DWSN-based feature fusion (Our method)	98.8%	98.4%	99.1%	98.77
CNN-based feature fusion	96.1%	94.4%	97%	95.69

summarize the performance comparison in three different modalities. These are namely: X-ray-based single-modal diagnosis, CT-based single-modal diagnosis, and multimodal diagnosis (X-ray plus CT scan images).

Results for the X-ray COVID-19 versus Non-COVID-19 classification task are summarized in Table 6. Compared to the CNN-based method proposed in [7], our method has achieved an improvement in accuracy by 4.11%. In terms of F1-score, our proposed method has achieved 96.633% versus the 91.08% for the CNN-based method reported in [7]. Compared to other state-of-the-art approaches, our method has consistently demonstrated a higher performance against GoogleNet, Xception, and DenseNet201. Using the proposed DWSN-based method, an F1-score of 96.633% has been achieved, versus 94.55% for GoogleNet, 90% for Xception, and 94% for DensNet201. As shown in Table 6, the performance of the proposed method was only superseded by the ResNet-18 where a 1.36% increase in F1-score was reported in [7]. Also, the deep feature fusion method described in [7] has achieved a 1.68% increase in F1-score over our method.

Table 7 summarizes the evaluation results in the CT-based single-modal COVID-19 diagnosis task. Despite its computational simplicity, the proposed method has demonstrated a relative advantage against other state-of-art methods reported in [7]. In terms of F1-score, our method scored 0.62% higher than the CNN-based method proposed in [7], 3.73% higher than ResNet101V2, 2.23% higher than GoogleNet, 2.9% higher than Xception, and 3.18% higher than DenseNet201. The performance of our method was superseded by ResNet-18 and the deep feature fusion method proposed in [7] which also relies on ResNet-18 based features.

Table 8 compares the proposed DWSN-based method against the CNN-based method proposed in [7] in the multimodal COVID-19 diagnosis framework. The proposed method resulted in an improvement of 3.08% in the F1-score, a 2.09% improvement in the Recall (sensitivity), and a 2.6% improvement in precision.

4.4 Summary and Conclusion

The COVID-19 pandemic and its impact on healthcare systems worldwide has highlighted the escalating need for efficient AI-based diagnostic tools. This is particularly true for less-advantaged communities and countries. This chapter presented a novel method for identifying COVID-19 in chest X-ray and CT scan images using Deep Wavelet Scattering Networks and subspace learning. To the best of our knowledge, this is the first attempt to explore the potentials of wavelet scattering networks in COVID-19 medical image diagnosis as a light deep learning framework. Leveraging on the properties of wavelet scattering networks, a robust invariant representation is learned and used in several classification scenarios. Subspace learning in the scattering domain was achieved using a joint best non-linear approximation approach. Extensive experiments were conducted to evaluate the proposed method. Experiments were conducted on a total of 4600 CT scan images, and 8600 chest X-ray images. COVID-19 vs Non-COVID-19 classification was achieved with an average F1-score of 95.9% in chest X-ray images and an F1-score of 94.8% in CT scan images. Finally, multimodal diagnosis using the proposed method resulted in significant improvement over the single modality diagnosis.

Compared to relevant related work in the literature, the proposed method has demonstrated an exceptional performance despite its relative computational advantage. The results presented in this study open the door to more investigation on the significance of deep wavelet scattering networks in medical diagnosis applications. Wavelet scattering networks offer a deep learning framework without the complex hyper-parameter tuning required in CNN-based approaches. This is of particular significance in settings with limited resources. The future work of the presented research includes more extensive testing and the development of an end-to-end mobile-aware deep learning platform for computer-aided diagnosis of COVID-19.

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Development of Computer Aided Diagnosis System for Detection of COVID-19 Using Transfer Learning

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1 Introduction

Computer Aided Diagnosis (CAD) systems assist in the medical image interpretation by processing medical images features, marking conspicuous areas, and classifying the images [1]. CAD can detect abnormalities in images at the earliest stage and evaluate information quickly for accurate illness identification and diagnosis [2]. Applications of CAD include mammography, lung cancer, cervical cancer, brain cancer and coronary artery disease [4, 5]. The CAD system involves image acquisition, preprocessing, extracting characteristics, choosing and selecting features, segmenting and classifying features [3, 4]. Image acquisition is a method of obtaining images with medical imaging techniques [5]. Image preprocessing methods like denoising and enhancements are required for image quality improvement [6, 7].

To distinguish image malignancy stages, certain attributes from the image are extracted at the feature extraction stage, including textural features and random features [8]. To aid in decision-making during detection, feature selection gives images in their most basic form, improving learning precision and cutting down on computation period [9]. Image Segmentation is a technique for breaking up image into portions to make the image representation more meaningful [10]. The segmentation plays a significant part in detection by converting complicated images to simpler ones. The task of manually classifying medical images, which was

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traditionally the responsibility of radiologists, has been challenging since the images are impacted by noise, inter-observer variability, labor intensive, and subjective interpretation. To address these issues with the manual classification of medical images, CADs for image classification have been created [11]. Conventional methods of CAD for image classification involve the use of handmade features, the efficacy of the methods relies on the extracted and chosen features. Deep learning is a sub-division of machine learning where extraction and classification of image features are combined in a network [12]. The convolutional layer automatically extracts features. The elimination of the handcrafted features results in better classification performance.

The application of deep learning techniques for CAD development has newly gained attention [13]. Several deep learning models have been developed to classify medical into benign and malignant. Medical images have also been classified into multiple classes [14]. However, a deep learning network requires a lot of medical images [15]. The major problem in deep learning technique of classification is usually the lack of adequate labeled images. The available medical training images are usually scarce due to ethical and legal issues. Furthermore, labeling and annotation of medical images are time-consuming and require experienced radiologists. Transfer learning allows for the use of fewer training images since the learned data characteristics can be used in the present task [16]. This chapter aims at the following: (i) developing a CAD system with few images and good performance for COVID-19 detection (ii) evaluating the developed system using accuracy, true positive rate, and true negative rate. The procedures for modifying pre-trained Convolutional Neural Network (CNN) for medical image classification using transfer learning are presented. The chapter provides pilot insight into automatic classification of COVID-19 images into COVID-19, normal and pneumonia, which will be an aid to radiologists in the interpretation and evaluation of the COVID-19 images, and hence reduces false diagnosis. Data augmentation and dropout were applied to prevent overfitting of the network for better performance. Although there are several imaging techniques, this research only considered the X-ray images. The chapter's structures as follows: Section 2 describes the related works on the CAD detection of COVID-19. Section 3 describes transfer learning technique for image classification Sect. 4 explains the different types of *regularization techniques for modification of deep learning algorithms*. Section 5 presents the materials and the procedures for the COVID-19 identification with transfer learning. Section 6 gives the results and compare the proposed techniques with the existing ones. The conclusion as well as the future direction in the development of CAD system for medical images are presented in Sect. 7.

2 Literature Review

A branch of machine learning known as deep learning learns characteristics directly from data by making use of a neural network. It is different from other learning techniques in the sense that it can handle huge data and can precisely focus on the necessary features A deep neural network, which consists of many layer [17] have different kinds of deep neural network designs like deep belief networks and Recurrent Neural Network (RNN). Deep Belief Network (DBN) is unsupervised algorithm that consists of multi-layer latent variables (feature detectors) [18]. The first two layers are not directed unlike the bottom layers that are directed from top layers. The bottommost layer or the visible units accepts data while the hidden units acquires association features in the data. All unit for every layer is associated to each unit in every adjacent layer. Areas of application of DBN are Image recognition, Speech recognition, video sequences and Motion capture data [19]. RNN identifies the succession features of data and applied patterns to predict the results. The output relies on both the present RNN input and the initial step's neurons' state. RNN is popularly used in recognition of speech and handwriting recognition as well as language translation. Recurrent Neural Networks can have loop in their connections which allow them to develop short-term behavior gain accuracy in areas such as audio, and text [20].

A CNN is a popular network with several layer which performs significant role [21]. CNN captures an image, allocate weights for image segmentation [22] CNN can automatically learn filters. Unlike traditional methods which use filters are hand-made filters with adequate training images. The basic CNN layers are the Convolutional layers, Rectified Linear Unit, Pooling layers and Fully Connected layer [23]. Convolutional layers are made up of group of filters which extract characteristic input and learn image features to maintain the pixels spatial relationship [9].

Non-linearity Layer apply several activation functions which introduce nonlinearities that are useful for multi-layer networks. Both sigmoid and rectified linear unit (ReLU) are common activation function. ReLU are usually recommended because it allows for better and quicker training. Pooling layer operates downsampling (Spatial pooling) on activation map thereby reducing learning network parameter [24]. The Batch normalization layers help to achieve a simpler optimization task through activation normalization [25]. The convolutional and pooling layers output images exhibit advanced input image characteristics. The softmax activation function determine the probabilities of each label and used the results for classification of the images into different categories.

Ozturk et al. [26] created a network named DarkNet for the COVID-19 identification. The dataset used was dataset supplied by Dr. Joseph Cohen [27] and the Kaggle Chest X-ray images [28]. The dataset was divided into COVID, No-Findings as well as COVID, No-Findings and Pneumonia. Accuracy of 98.08% and 87.02% were achieved for two and three classes respectively. Alom et al. [29] developed a Recurrent CNN for COVID-19 detection and obtained a testing accuracy of 84.67%. Linda [30] developed a network called COVID-Net with good structural variety and a selective connection was presented. The model was experimented on COVID-19 dataset and pneumonia dataset and achieved a testing accuracy of 83.5%. Chavez et al. [31] developed COVIDX-NET and used it to identify COVID19 from Xray images and archived an accuracy of 90%.

Ioannis et al., [32] used 224 chest images of the verified Covid-19 disease, 700 images of the proven bacterial pneumonia, and non-affected images of up to 500 were used by to assess the effectiveness of VGG19 and the MobileNet in the identification of Covid-19. 96.78% accuracy and 96.46% true negative rate were obtained. Barstugan et al. [33] applied Grey-Level Size Zone Matrix (GLSZM) to extract the image characteristics. The Support Vector Machine (SVM) was applied to categorize the retrieved characteristics. GLSZM feature extractor obtained 98.77% accuracy. Farooq and Hafeez [34] created a deep neural network model with the ResNet-50, for COVID-19 identification. On a multiclass categorization of normal, bacterial infection pneumonia, and COVID-19, an accuracy of 96.23% was obtained. Narin et al. [35] proposed Inception ResNetV2, ResNet50, and InceptionV3 to classify X-ray images into COVID and non-COVID images. ResNet50 achieved the greatest accuracy of 98%. A deep anomaly detection model was created by Zhang et al., [36] for COVID-19 detection. The dataset consists of 30 chest images that are not COVID-19 and 70 COVID-19 images. The model had a 96% accuracy. Sethy and Behra [37] achieved an accuracy of 95.38% when they combined Resnet 50 and Support Vector Machine (SVM) to detect COVID-19 images.

Kumar et al. [38] applied a multimodal fusion to detect COVID-19 with an accuracy of 98.91%. Gumaei et al. [39] used a decision level fusion for COVID-19 detection with F1 score of 0.97. Fang et al. [40] applied multi-stage neural network [41] for COVID-19 detection to achieve an accuracy of 82.2%. Abbas et al. [42] applied network for COVID-19 detection from 80 and 105 normal and covid-19 samples respectively DeTraC, a deep CNN created, handles the anomalies in the image dataset. Their model successfully identified COVID- 19with an accuracy of 95.12%, a sensitivity of 97.91%, and a specificity of 91.8%. Their model's flaw is the small sample size that was used to create it. To determine the COVID-19 cases, Zhao et al. [43] created datasets for COVID-19 and applied a many learning method. The data set included 463 normal CT images in addition to 349 covid-19 CT. With supervised learning, 89% accuracy was obtained. Maghdid et al. [44] developed a detection for COVID-19 technique with X-ray and CT images using CNN. The dataset included 170 X-ray images and 361 CT images of covid-19 cases that were obtained from Radiopedia, GitHub, and Kaggle. The CNN model suggested resulted in an accuracy of 94.1% using the developed CNN. Luz et al. [45] suggested a Deep Learning model for detecting Covid-19 patterns using 13,800 X-ray images, broken down between COVID-19 pneumonia and normal, non-covid-19 pneumonia. Data collection came from three different places: (i) the RSNA Pneumonia dataset for the detection task, (ii) the COVID-19 image acquired from the COVIDx dataset, and (iii) 13,800 X-ray pictures were taken. The suggested model was trained using 13,569, while 231 was utilized for validation. Their model's general accuracy was found to be 95.9%.

The majority of authors employed few images when creating network for COVID 19 detection without decreasing the effect, which led to overfitting and negatively impacted the model's result. When the learning set size is too small in comparison to the complexity of the model, overfitting occurs. Some authors employed complex models [34, 35], which lengthen training periods and complicate implementation. To solve the problem of huge computation requirements and overfitting, which often affect the performance of the deep neural network, dropout and data augmentation are applied to the transfer learning network to avoid overfitting and thus result to better classification performance. Pooling layer is also utilized for network parameter reduction as well as the decrement in the amount of computation required of the network. The CAD system will aid correct interpretation of images and thus enhance early detection of the COVID-19 images.

3 Transfer Learning

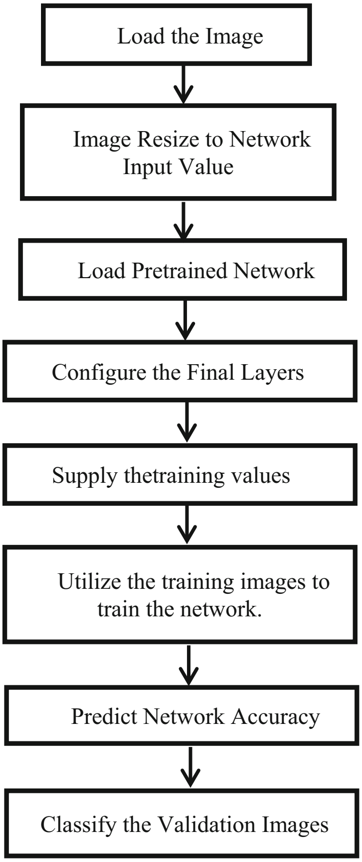
Transfer learning is a process by which deep neural network is fine-tuned for classification of new set of images [46]. Transfer learning is a method of applying a model that has been trained on a particular task to solve a related problem. Transfer learning gives good results when the learned characteristics from the previous work are general. Some or all of the model's parts can be modified to find solutions to the particular deep learning tasks. Transfer learning involves the use of pre-trained models is commonly employed because it results to simpler network training [47]. Common pre-trained models include LeNet-5, AlexNet, GoogLeNet, etc. LeNet-5 is among the simplest pretrained CNN [48]. Figure 1 shows the procedure for the development of the classification stage of the CAD system with transfer learning. The images are loaded and resized to the network input size. The pre-trained network is loaded and the final layers are reconfigured to the classes corresponding to the new image. The training options are selected after which the network is retrained with new images. The hyper-parameters values were adjusted to achieve the most suitable results [49]. Validation images are classified into the required classes.

4 Regularization in Deep Learning

Regularization technique is used to make slight modification to learning algorithm in order to make the deep learning model generalize better [50]. *Generalization* is the potential of the developed model to apply the learned features to solve new task.

Deep learning models need to generalize properly from dataset assigned for training data to predict well for the testing dataset. *Generalization* penalizes the nodes weight matrices. A high regularization coefficient, results to simpler network and little underfitting dataset used for training. The high value of the regularization coefficient value is not always important. Optimization of the regularization coefficient value is necessary in order to obtain a well-behaved model. An overfitting results whenever a model learns the details too well and learn the noise. This leads to low result for the testing data. Overfitting occurs when few datasets is used in

Fig. 1 Block diagram for image classification using transfer learning



relation to the number of model parameters. The problem is much common in deep neural networks with millions of parameters. Regularization reduces overfitting without increasing the bias significantly. There are many ways to regularize model in deep learning such as Weight Penalty L1 and L2, Dropout, Dataset Augmentation and Early Stopping [51]. Weight penalty assumes that a network with a small weight model is less complicated than a large weights model. The penalties maintain the weights zero or small except if there are large gradients to offset it for better interpretation of the model. Weight Penalties ensures the weights decay towards zero. L2 norm penalizes the weight square value and reduces all the weights to smaller values while L1 norm penalizes the weight absolute value and tend to pushmost weights to exactly zero, while some weights are permitted to have large value.

For L2 regularization [52],

$$\text{Cost function} = \text{Loss} + \frac{\lambda}{2m} * \Sigma \|w\|^2 \tag{1}$$

For L1 regularization,

$$\text{Cost function} = \text{Loss} + \frac{\lambda}{2m} * \Sigma \left\| w \right\| \tag{2}$$

A dropout layer - which is applied to either hidden layer or input layer, randomly eliminates part of the network nodes some [51]. The dropout makes network to be less sensitive to some weights of neurons resulting to an improved generalization and low probability of overfitting. An overfitting model can be improved by the using more training data. Synthetic data can be created by methods such as translation, rotation and scaling. In Early stopping, part of training set is separated for validation. The training model is ended when the result of the training on validation data is reducing.

5 Materials and Methods

5.1 Materials

The chest X-ray images used in this experiment consist of 401 COVID-19 images donated by Dr. Cohen, while 397 normal and 390 pneumonia-labeled images were offered via the Kaggle database. Dataset1 corresponds to the COVID-19 and normal while dataset 2 corresponds to COVID-19, normal, and pneumonia images. To avoid imbalanced dataset, data augmentation was used to equalize the number of chest X-ray images.

5.2 Methods

The developed systems were carried out in Matlab R2020a installed on laptop 2.9 GHz processor speed, 8 GB RAM. At the pre-processing stage, histogram equalization and adaptive filtering were applied for image contrast enhancement and adaptive filtering respectively. 60% of the acquired images applied for training, 20% for validation, and 20% for testing. The images for training were augmented by rotation and flipping to prevent overfitting. CNN was applied to classify dataset 1 (COVID-19 positive and Normal) dataset 2 (COVID-19 positive, Normal and Pneumonia). CNN assign biases and weights to various segments in the input image by using a pre-trained network. Transfer learning was applied to modify Googlenet, SqueezeNet, and Alexnet for image classification. The procedures for the development of CAD system with pretrained CNN is as follows

(i) Load the images
(ii) Split the data into training and validation dataset

(iii) Load pretrained network
(iv) Replace Final Layers
(v) Freeze the initial layers
(vi) Train network
(vii) Estimate and evaluate the network's accuracy
(viii) Identify the validation images' classes.

The final layer that can learn and the last classification layer employ extracted features by the convolutional layers to categorize the input image. To train a pretrained network again to classify new images. The layers are replaced with additional layers tailored to the new dataset. The output classes of the network are defined by the classification layer. Another layer without class labels should be added in place of the categorization layer.

5.2.1 Chest X-Ray Image Classification Using Modified GoogLeNet Transfer Learning Network

Szegedy et al. [53] created a CNN with twenty-two layers named as Googlenet. The CNN trained on ImageNet, was designed to classify images into 1000 classes. Googlenet consist of over 4 million parameters and 224-by-224 image input size. In order to modify Googlenet for COVID-19 classification. An image datastore function was used for loading images and the images resized were to GoogLenet input image size (224-by-22). The convolutional layers were freezed while the fully connected layer (lost classifier layer) was replaced with the layer that correspond to the numbers of filters equal to two classes for dataset 1 and three classes for dataset 2 while the classification layer (output layer), which was replaced with the one corresponding to the required classes. The fine-tuned network categorized the validation images and obtained the accuracy.

5.2.2 Chest X-Ray Image Classification Using Modified SqueezeNet Transfer Learning Network

SqueezeNet is a CNN developed with 18 layers and designed to work with fewer parameter than AlexNet [54]. The convolutional layers and the final classification layer extract image relevant features and classify the image respectively. In order to modify SqueezeNet to detect COVID-19, the training images were resized to 227-by-227-by-3, which is the SqueezeNet input image size. 'Conv10' and 'ClassificationLayer predictions' are the layers in SqueezeNet that has features combination information that is extracted by the network. The two layers were replaced with another layers adapted to the X-ray data set and the network trained with X-ray images.

5.2.3 Proposed Method (Modified Alexnet) for Classification of Chest X-Ray Image

A deep learning network was developed using modified Alexnet. Alexnet, which is a CNN designed by Krizhevsky et al., [55] was trained with images from imagenet database. The pre-trained CNN with 60 parameter an input size of 227-227 consists of 5 convolutional and 3 fully connected layers. The architecture of the proposed network for classification is depicted in Fig. 2. The final three Alexnet layers configured for 1000 classes can be fine-tuned to solve new problems. In order to modify Alexnet to classify the images, the acquired images were made to the size 227-227, and transformed from gray scale to RGB by concatenating the channel three times. To set the layers to classify chest X-ray images, the final fully connected layer was substituted with a new layer having three neurous for three classes classification and 2 neurous for binary classification. Softmax layer and classification output layer were added for determination of probability of each label and classification of the images respectively.

The softmax function is utilized to activate the output as expressed in Eq. (3)

$$y_r(x) = \frac{\exp\left(a_r(x)\right)}{\sum_{j=1}^{k}\left(a_j(x)\right)} \tag{3}$$

$$0 \le y_r \le 1 \text{ and } \sum_{j=1}^{k} y_j = 1$$

$$P\left(C_r|x,\theta\right) = \frac{P\left(x,\theta|C_r\right)P\left(C_r\right)}{\sum_{j=1}^{k} P\left(x,\theta|C_j\right)P\left(C_j\right)} = \frac{\exp\left(a_r\left(x,\theta\right)\right)}{\sum_{j=1}^{k}\exp\left(a_r\left(x,\theta\right)\right)} \tag{4}$$

$0 \le P(\mathrm{C_r} \mid x, \theta) \le 1$ and $\sum_{j=1}^{k} P\left(C_j|x,\theta\right) = 1$.
$a_r = \mathrm{In}(P(x, \theta \mid c_r)(P(c_r))$,
$P(x, \theta \mid c_r)$ is the probability of the group r, and $P(c_r)$ is the group prior probability

The Classification Layer is tagged classificationLayer. Following the softmax layer, there must be a classification output layer. TrainNetwork uses the results from the softmax function in the classification output layer.

$$\mathrm{E}\left(\theta\right) = -\sum_{i=1}^{n}\sum_{j=1}^{k} tij \ln yj\left(xi,\theta\right) \tag{5}$$

Following every convolution layer, A max pooling layer was applied for network size reduction while dropout was applied for overfitting prevention. Dropout was

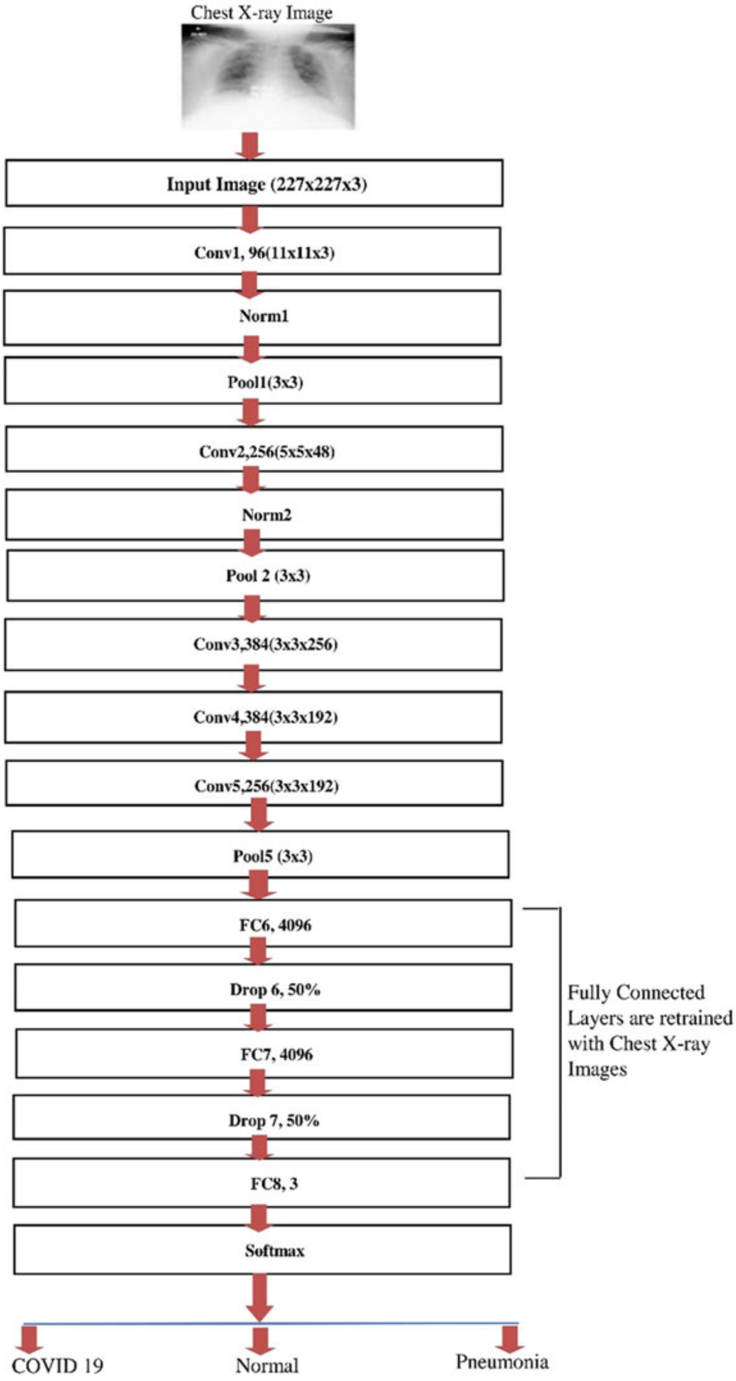


Fig. 2 The architecture of the proposed network for detection of COVID-19

applied by allocating zero to every neuron output, to eliminate unnecessary neurons. A dropout layer randomly retrains network nodes together with receiving and outgoing connections at each training iteration. The sensitivity of the network to the particular weights of neurons in the input units is reduced, which makes the network more generalizable and unlikely to overfit the training set.

6 Results and Analysis

The networks were trained at 0.0001 learning rate and for 6 epochs. The CNNs were compiled using Adam optimization method [56, 57]. The developed models were estimated using accuracy, True positive rate and True negative rate [58, 59] as shown in Eq. (1), (2) and (3) respectively

$$\text{Accuracy} = \frac{\text{True Positive (TP)} + \text{True Negative (TN)}}{\text{Total Number of Samples}} \tag{6}$$

$$\text{True positive rate} = \frac{\text{TP}}{\text{False Negative (FN)} + \text{TP}\big)} \tag{7}$$

$$\text{True negative rate} = \frac{\text{TN}}{\text{TN} + \text{False Positive (FP)}} \tag{8}$$

For N classes and N instances, the overall accuracy, average true positive rate and average true negative rate [26] are expressed in Eq. (4), (5) and (6) respectively

$$\text{Overall accuracy} = \frac{1}{N}\sum\nolimits_{i=1}^{c} TP_i \tag{9}$$

$$\text{Average Sesitivity} = \frac{1}{N}\sum\nolimits_{i=1}^{c} \frac{TP_i}{TP_i + FN_i} \tag{10}$$

$$\text{Average Specificity} = \frac{1}{N}\sum\nolimits_{i=1}^{c} \frac{TNi}{TN_i + FP_i} \tag{11}$$

6.1 Performance Comparison

The CNNs training graphs for Dataset 1 is as shown in Figure 3.1a-c. It can be deduced that the best validation accuracy was obtained by proposed modified Alexnet. The Modified Alexnet model increases validation accuracy faster than either Googlenet or Squeezenet and approaches 100%. Similarly, The CNNs training graphs for Dataset 2 is as shown in Figure 4.1a-c.

The performance of each model in classification of abnormalities in chest X-ray into two classes are depicted in Table 1a. Alexnet gave an accuracy of 100%, true positive rate of 100% and true negative rate of 100%. Similarly, Googlenet achieved an accuracy of 98.75%, true positive rate of 98.7% and true negative rate of 100% while SqueezeNet gave an accuracy of 97.48%, true positive rate of 97.5% and true negative rate of 97.5%. The results show that Alexnet outperforms Googlenet and Squeezenet in the classification of abnormalities in chest X-ray into two classes. Furthermore, the performance of each model in the classification of abnormalities in chest X-ray into three classes are shown in Table 1b. It can be observed that Alexnet identified abnormalities at higher average accuracy, true positive rate and true negative rate than either Googlenet and Squeezenet. The training time also indicates that the proposed Alexnet takes shortest time for training dataset 1 and dataset 2.

6.2 Analysis

The results show that Alexnet outperforms Googlenet and Squeezenet in the detection of abnormalities in chest X-rays for both two classes and three classes. It can be observed that the proposed Alexnet identified abnormalities at higher average accuracy, true positive rate, and true negative rate than either Googlenet or Squeezenet. The results also indicate that developed neural networks outperformed the techniques described in the literatures. In the proposed model, the dropout prevented overfitting by putting each hidden neuron's output to zero with a probability of 0.5. When the size of the learning set is too small for the complexity of the model, overfitting results in the system learning details from the learning set rather than structures. The model performed better because there was less overfitting as the training data has been increased. While Googlenet takes the smallest amount of time to train, Alexnet takes the longest for the two sets of the dataset. The number of convolutional layers and learning parameters determine how long training takes. The number of parameters the network must learn and the quantity of processing required in the network is both reduced by using a pooling layer.

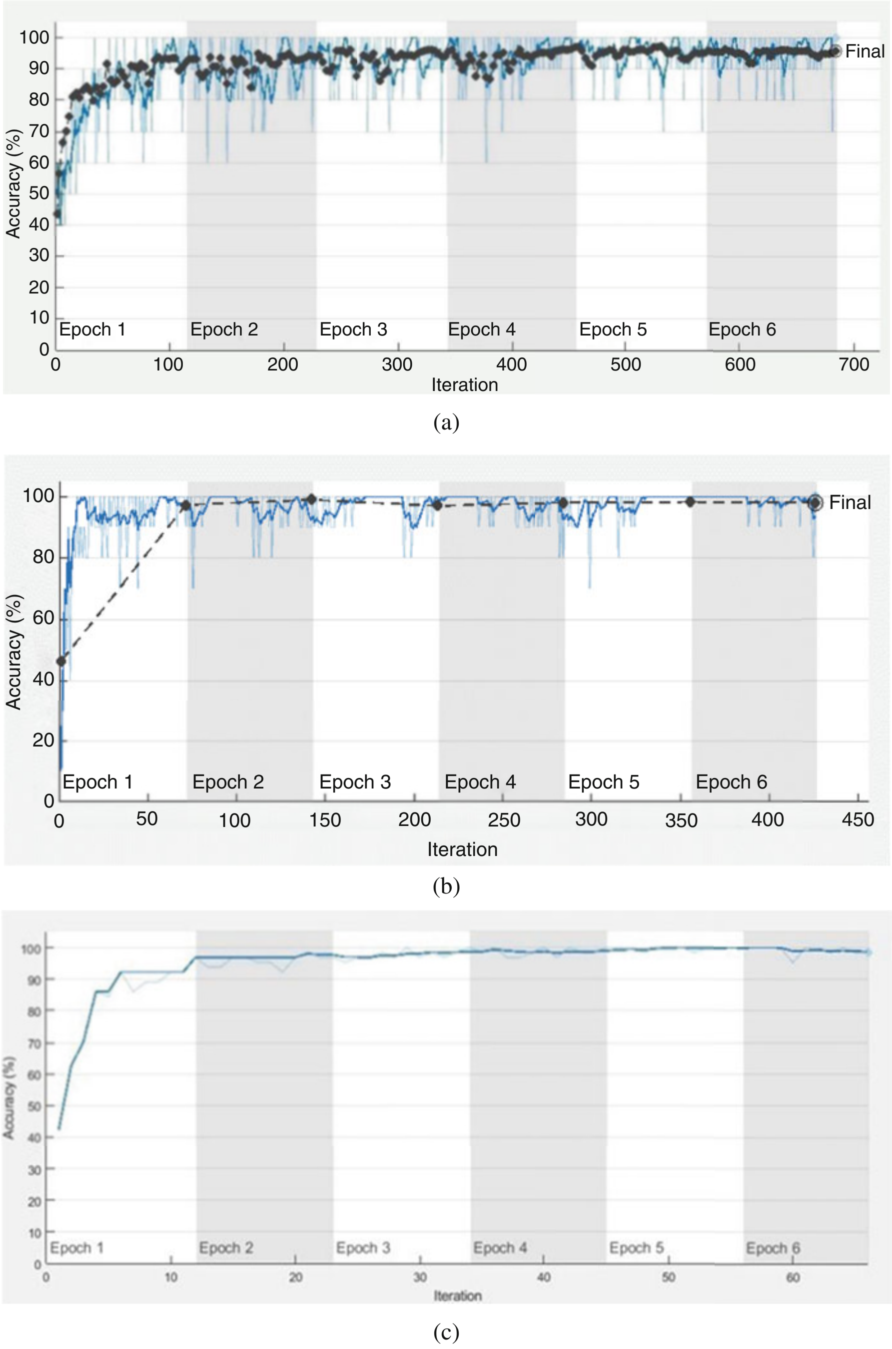
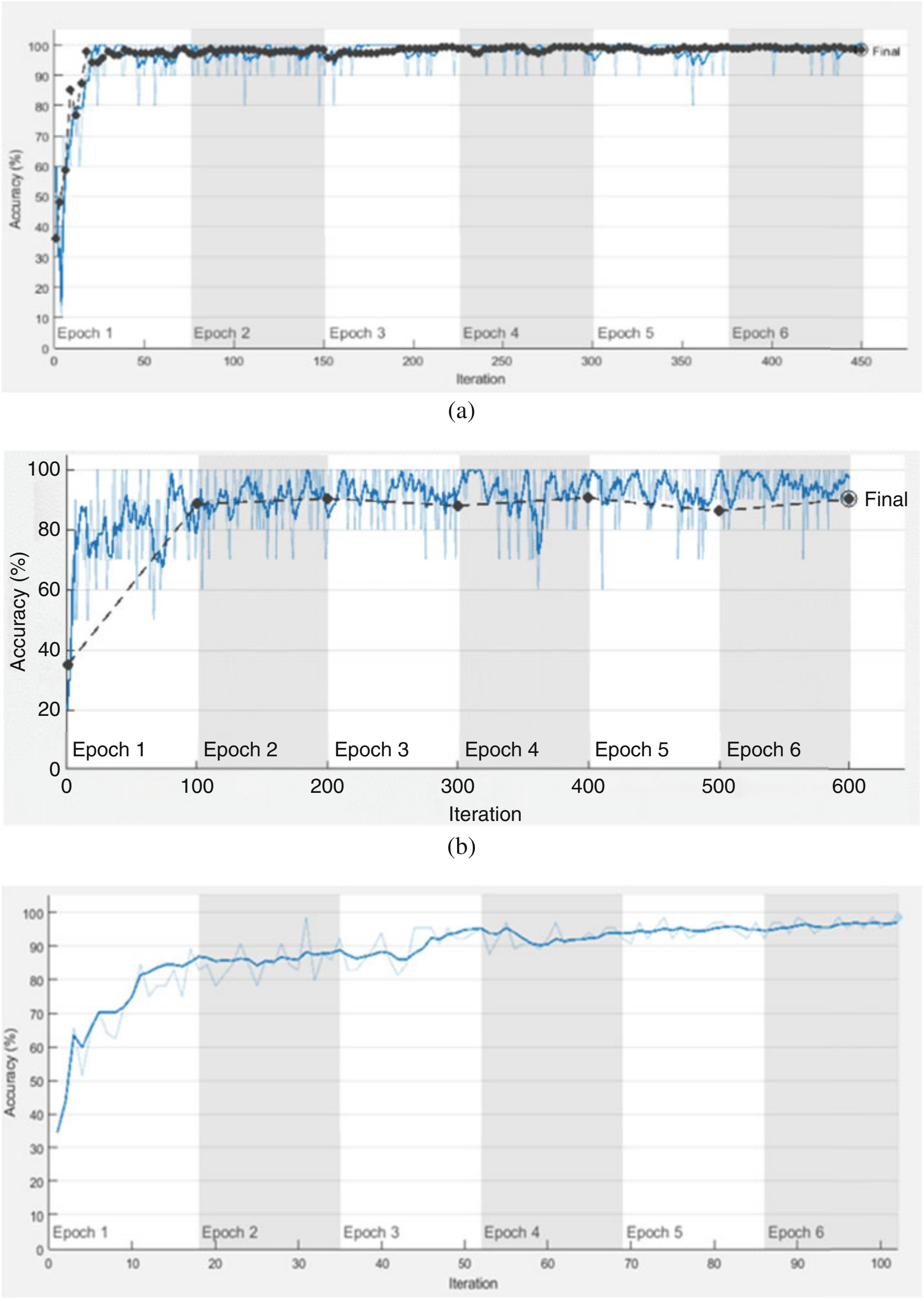


Fig. 3 (**a**) Training graph for detection of COVID-19 with Googlenet for Dataset 1. (**b**) Training graph for detection of COVID-19 with Squeezenet for Dataset 1. (**c**) Training graph for detection of COVID-19 with Alexnet for Dataset 1



(a)

(b)

(c)

Fig. 4 (**a**) Training graph for detection of COVID-19 with Googlenet for Dataset 2. (**b**) Training graph for detection of COVID-19 using Squeezenet for Dataset. (**c**) Training graph for detection of COVID-19 using Alexnet for Dataset 2

Table 1a Testing result of the evaluation of the CNN networks in the classification of abnormalities in chest X-ray into two classes

CNN Models	Accuracy	True positive rate	True negative rate	Training Time
Modified Alexnet	100	100	100	8:27
Googlenet	98.75	98.70	100	96:27
Squeezenet	97.48	97.50	97.50	14:44

Table 1b Testing result of the evaluation of the CNN networks in the classification of abnormalities in chest X-ray into three classes

CNN Models	Average Accuracy	Average True positive rate	Average True negative rate	Time
Alexnet	98.31	98.55	99.37	12:59
Googlenet	97.47	97.04	98.73	1056:18
Squeezenet	95.34	95.72	97.49	17:52

7 Conclusion and Future Scope

Application of Transfer learning to deep learning models allows the use of training images with fewer images by modifying the appropriate layers. Deep learning models trained faster with transfer learning since learned features are applied to classify new images using fewer training images. Transfer learning with CNN models has been applied to classify chest X-ray images into COVID-19 positive and Normal, then COVID-19 positive, Normal and Pneumonia. Dropout and data argumentation prevented overfitting resulting in better performance. The developed computer aided diagnosis system provides alternative opinion for detection and diagnosis of abnormalities in medical images and hence provides secured health system for diagnosis and management procedures. In this work, the deep learning hyper parameters values were manually selected until the optimum results were obtained. Further research can explore the automatic optimization of the hyperparameters for better performance. Furthermore, the effect of various generalization techniques on the detection and classification of medical images can be examined.

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Part IV
Internet of Health Things, Blockchain and COVID-19 Pandemic

COVID-19 Detection System in a Smart Hospital Setting Using Transfer Learning and IoT-Based Model

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1 Introduction

The majority are at great risk from COVID-19, notably in developing nations where the bulk of the populace uses non-sustainable energy sources and lives in extreme poverty [1]. Most sickness cases are officially certified by the World Health Organization, and many individuals have died, especially elderly folks and those with pre-existing conditions [2]. The most noticeable signs are dyspepsia, respiratory issues, coughing, and fever. When circumstances are challenging, the infection may cause multiple organ failure, severe respiratory syndromes, pneumonia, septic shock, and even death. Also, deaths among children aged 0–9 do happen [3]. Compared to healthy individuals, those with respiratory disorders are more vulnerable to COVID-19. Because of the aggressive expansion of healthcare units, the health system failed in many wealthy countries, including the USA [4]. The current failure of the public health system is caused because of the limited sensitivity of RT-PCR and the slow detection of COVID-19 patients, patients may not receive the necessary treatment time due to the spreading pandemic and inadequate medical

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resources. Additionally, because the virus is so contagious, a larger portion of the population is in danger. Serious issues arise from contamination brought on by the diseased patient. Nowadays, patients must wait for testing before receiving a diagnosis, which may make it difficult for them to receive a cure [5].

Healthcare is well represented through the services provided at hospitals. Different patient groups with varying demands are provided with a wide range of specialties and services [6]. Overcrowding is one of the issues facing hospitals today. This issue arises when there are more patients than the resources can handle, such as medical personnel, tools, or hospital environment. Whenever there is an inflow of patients to hospitals, patient wait times increase and healthcare workers' quality of treatment and efficiency suffer. Overcrowding is a worldwide problem [7] and a concern with public health that affects everyone, regardless of social class [8]. This issue's recurrence is ascribed to several elements, including patient inflow and outflow, patient wait times, healthcare practitioners' effectiveness, agglomerations, and the availability of resources [9]. Due to overpopulation, the level of service suffers, the danger of death rises, and social status comes to play [10]. McHugh [10] claims there is a strong connection between patient fatality rate and overcrowding. All of the aforementioned circumstances have been proven to be becoming worse as the COVID-19 virus spreads.

Therefore, the rising prevalence of COVID-19 offers a fresh problem for the health industry together with the anticipated daily service provision, where it is anticipated that the rate of death would be significant, and the diagnostic process will be time-consuming. Much research has been done on the usage of the IoT to promote health care, particularly during COVID-19. For instance, having a good monitoring system during quarantine is helpful. The Internet-based network makes it simple to monitor all high-risk individuals [11, 12]. Additionally, in COVID-19 situations, this method is employed to validate biometric measures of blood pressure, heart rate, and blood glucose levels. [13, 14]. Utilizing the cloud for data processing and storage is a component of IoT, making it available to and used by intelligent items linked to the cloud through the Internet [15]. IoT makes it possible to share and process data, allowing for the intelligent integration of objects made specifically to enhance the quality of life [6, 16]. The deployment of IoT in service systems is typically shown by smart hospitals that run on IoT technology; Using several application service vectors is necessary to build such a smart hospital. This type of hospital is recognized as a unique kind of hospital since it incorporates several functions, such as diagnosis, treatment, management, and decision-making. [17].

Additionally, the principles and insightful suggestions, of educational, and digital hospitals are combined to create smart hospitals [18]. Integrated hospitals accurately portray complex, detailed, and specific hospital descriptions. Building a digital environment-based application framework may be important while creating a smart hospital. People may quickly and properly receive important information about a service with a smart hospital. The standardization of administration, scientific decision-making, and the informationization of diagnostics are all made easier by this smart hospital system. Additionally, by combining application services in hospitals with advanced technology, information may be gathered and distributed inside the hospital. The improvement of the use of intelligent diagnosis, management, service, and therapy is the goal of this [18]. Molecular methods like quantitative real-time reverse transcription-polymerase chain reaction are commonly employed in detecting COVID-19 [19, 20] and various approaches, including viral throat swab testing and serologic assays [21, 22]. But prior research has shown that anomalies suggesting lung illness, such as COVID-19, may be accurately identified using X-rays [23] and CT images of the chest [24]. As the primary method of detection, CT scans can evaluate the results of X-ray examinations and the severity of COVID-19; these methods may also be utilized to forecast COVID-19 development and monitor the urgent cases of infected individuals [25].

However, due to the time constraints involved in such emergencies, manual diagnosis methods that are currently in use cannot be utilized [26]. A qualified doctor is needed for testing, reading, and interpreting the data since mistakes might lead to inaccurate results and inadequate therapy. This is because these processes are subject to human error. Due to a surge in COVID-19 transmission rates internationally, hospitals are overflowing with patients whose health is either getting better or becoming worse [27]. To save as many lives as possible, the patient test must be carried out quickly and efficiently [21]. Intelligent technologies are excellent tools for helping to diagnose and categorize the severity of COVID-19 [23]. Artificial intelligence (AI) is being used more and more in a variety of sectors, especially in the detection and diagnosis of diseases [28]. Because it makes it easier to provide reliable detection findings while lessening the stress on healthcare systems, AI is utilized extensively in several fields [29].

Additionally, compared to traditional approaches, AI can speed up decision-making throughout the detection process [30]. One of the important strategies for enhancing the prevention, prediction, and detection of future risks to global health is the development of AI in a way that makes it possible to recognize the dangers of epidemic illnesses [31]. Researchers have presented and evaluated multiple AI classifiers with different case studies and goals using the actual COVID-19 datasets [25]. Although AI approaches are useful for diagnosing and identifying COVID-19, choosing an AI methodology that is suited for producing accurate findings is still a challenging task [32, 33]. The complexity in deciding Which AI strategy is the most successful for detecting and categorizing COVID-19 is attributable to the broad variety of AI techniques that are available [34]. According to the study's findings [35], patients with COVID-19 may be diagnosed using ML models and laboratory tests. A dataset with 111 laboratory results from 5644 distinct people was filtered and balanced by certain authors, who subsequently presented their amazing contributions. Only 18 out of 111 test results among 600 individuals were determined to be significant, they discovered. The CNN-LSTM hybrid model produced the greatest accuracy of 92.3% when this dataset was examined using several deep learning algorithms. Arowolo et al. [36] suggested using hybridized ML techniques to anticipate COVID-19 instances. They conducted their experiment using MATLAB, and the results showed that L-SVM and SVM-RBF, respectively, had accuracy rates of 93% and 87%.

Even with this exceptional diagnostic precision, the accuracy of diagnosis can improve, but accurate ML models are still needed [37]. On a variety of parameter values and deep layers, deep learning models are constructed [38–41]; as a result, these models need a lot of resources, making it difficult to utilize them in real-time applications. So, the models are not lightweight designs. Thus, the hybrid model (CNN-LSTM) lacks the resources necessary for this kind of model in real-time applications due to its complexity. Additionally, from a medical perspective, taking into account previous research's recommendations, the same study implemented several selected features; however, from a technical standpoint, the authors ignored the method of feature selection based on the demands of the ML model, especially given the unpredictable nature of the quantity of COVID-19 patient data and the requirement for prompt medical care.

Given the need to create a thorough plan to support the COVID-19 pandemic defense, in this research, we present a performance comparison of four TL algorithms, InceptionV3, DenseNet169, ResNet50V2, and Xception, in identifying COVID-19. Each algorithm is used on the CT scan images to identify if a person has COVID-19 or not. The contributions of this research are as follows

(a) Development of four TL models based on the Internet of Things for reliable early COVID-19 detection and mass screening.
(b) Detecting COVID-19 cases using IoT dataset CT scan imaging techniques
(c) Assessing the suggested system's effectiveness in terms of the confusion matrix, precision, f1-score, recall, accuracy, and AUC.
(d) 5-fold cross-validation was used to avoid classification bias and improve training and validation performance.
(e) Contrasting the suggested approach with current best practices and highlighting the challenges involved in putting IoT-based AI models to use in actual healthcare settings.

The remaining portion of the essay is organized as follows: The materials and techniques utilized to implement this suggested system are presented in Sect. 2. The study results obtained from the implementation and Sect. 3 provide an interpretation of them. The study is concluded in Sect. 4 with future works being suggested.

2 Materials and Methods

PCR (Polymerase Chain Reaction) testing is presently the most reliable method to identify COVID-19. Every day, almost 240 thousand tests are conducted in the UAE alone [42] and over time, more people are involved. Researchers are attempting to decrease the number of PCR tests, especially those that can be identified through alternative methods like artificial intelligence. Consequently, the unneeded burden on the laboratories and hospitals might be decreased. On how to apply AI algorithms to identify COVID-19, there has been a lot of study in the literature. Four primary algorithms—InceptionV3, DenseNet169, ResNet50V2, and Xception—are employed in this study.

2.1 Image Pre-processing and Augmentation

The suggested approach is divided into the following three phases:

Pre-processing: In most machine learning (ML) and deep learning (DL) algorithms, a crucial step is data pre-processing. To provide excellent detections, ML and DL algorithms need high-quality datasets in a specified format. If there are missing values in the dataset, the algorithm will not utilize them. The algorithm's detection will be unreliable whenever the collection includes values that are erratic or noisy. To enhance the quality of the dataset, data pre-processing primarily consists of data cleaning, data reduction, and data transformation [43]. The dataset that was utilized was taken from the Kaggle database. Comparing several fine-tuned TL algorithms with image augmentation is the goal of this work. As a result, the following stages are included in the data pre-processing: Normalization of Data and Image Augmentation.

The CNN architecture is effective with a large number of datasets. We utilized the ImageDataGenerator, a Keras package, to create a huge dataset [44]. Some parameters are utilized for image augmentation, including Rotation range = 20, Shear Range = 0.3, Zoom range = 0.3, width shift range = 0.3, and Horizontal flip = 0.2. For speedier computation, all data images are transformed into NumPy arrays. The pictures were labeled using the LabelBinarizer() function, and the categorical cross-entropy was used to determine the losses for both models. The images were labeled using the LabelBinarizer() function, and the categorical cross-entropy was used to determine the losses for both models. Image augmentation was further developed to address the issue of model overfitting.

2.2 Dataset Collection

The SARS-CoV-2 CT scan dataset was used in this study. It is a COVID-19 dataset obtained from the Kaggle repository. It includes 1252 CT scans for people with COVID-19 illness and 1230 CT scans (Fig. 1) for those who are not COVID-19 afflicted, making a total of 2482 CT scans in the dataset. Real-world information gathered from hospital patients in Sao Paulo, Brazil, makes up the dataset. The URL to the Kaggle data set utilized in this study is https://www.kaggle.com/datasets/plameneduardo/sarscov2-ctscan-dataset [45, 46]. Both the COVID-19 and NON-COVID-19 CT scan dataset samples are shown in Fig. 2, whereas Fig. 1 shows the total number of the COVID-19 and NON-COVID-19 datasets.

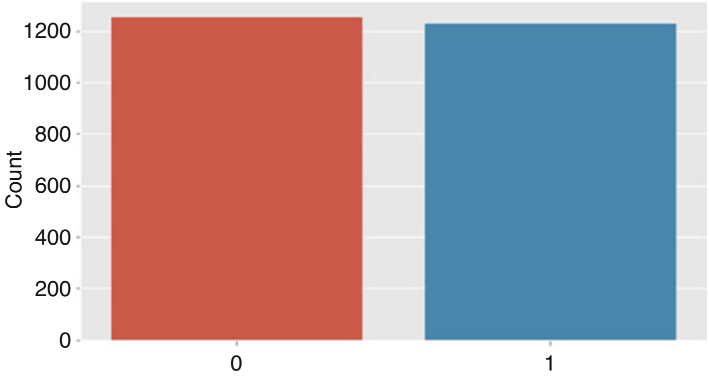


Fig. 1 Sum of CT scan COVID-19 dataset

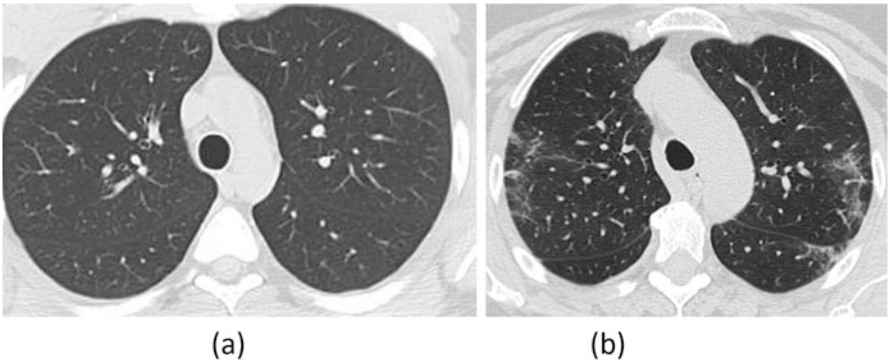
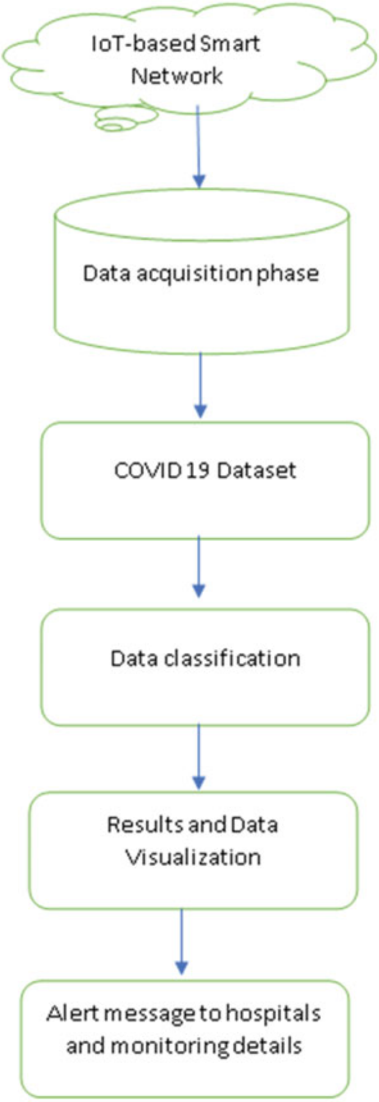


Fig. 2 (**a**) Negative and (**b**) Positive for CT scan dataset

2.3 Proposed Model

The benefits of IoT and deep learning (DL) technology for data analysis allow for the identification of COVID-19 spread. However, evaluating several strategies in real time is still a problem that has to be solved. Additionally, finding the best method for analyzing COVID-19 data is a crucial issue that has to be investigated. This section introduces and explores our proposed IoT-based system that might be used to quickly identify and classify probable coronavirus cases. The treatment response of reported instances and knowledge of the coronavirus's impact may be predicted using this significant structure. In particular, the provided methodology evaluates COVID-19 data using an IoT-based architecture. The real-time processing of data segments for the forecasting of disease transmission uses cloud computing as an intermediary. The visualization module is an add-on that shows the outcome to the appropriate medical professionals or carers. The layered perspective of the suggested methodology is shown in Fig. 3. With the use of our suggested detection model, which focuses on transfer learning models, doctors may monitor real-time uploads of questionable information and alert them on a possible disease. The physicians would therefore be able to react quickly to these suspicious situations by doing the additional clinical evaluation that is necessary to confirm the scenario. This will aid in the isolation of confirmed patients and the provision of appropriate medical care.

Fig. 3 Proposed IoT and transfer learning and IoT-based detection system



2.4 Performance Evaluation

The four TL models' performance was assessed using four performance metrics: accuracy, precision, recall, f1-score, AUC, and ROC curve. The confusion matrix approach was utilized to determine these measurements.

2.4.1 Confusion Matrix

By building a 2 by 2 matrix, using the confusion matrix, the results of a binary supervised learning problem were displayed. The instances in the actual class were displayed in each column of the matrix, while the examples in the anticipated class were displayed in each row of the matrix. The generated matrix had four values:

1. True positive (TP): All COVID-19 instances that have been projected to be positive and are currently positive are included here (utilizing the statistical model);
2. False positive (FP): This is the total number of COVID-19 instances that were statistically anticipated to be positive but turned out to be negative;
3. False negative (FN): This is the total number of COVID-19 instances that were expected to be negative but turned out to be positive;
4. True negative (TN): This relates to the total number of COVID-19 instances that were expected to be negative and turned out to be negative

2.4.2 Cross Validation

A mathematical method called cross-validation is used to assess how well learning and classification systems work. To do this, the available guided information instances are divided into k-folds. Both of those folds were employed, one for preparation and the other for study. In this study, five-fold cross-validation was used. There are 5 folds in the data instances. Eleven iterations of one-fold were employed for verification and 5 folds for preparation, in which testing was carried out during each iteration.

Accuracy The proportion of correctly detected COVID-19 instances among all COVID-19 cases can be used to gauge a model's accuracy.

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \tag{1}$$

F1-score: Integrating the results of the two accuracy and recall tests yielded the f1-score:

$$F1 - score = 2 \times \frac{Precision \times Recall}{Precision + Recall} \tag{2}$$

$$\text{Precision} = \frac{TP}{TP + FP} \tag{3}$$

$$\text{Recall} = \frac{TP}{TP + FN} \tag{4}$$

2.4.3 AUC ROC Curve

The Receiver Operating Characteristics (ROC) is a different method for computing a classifier's output. This was accomplished by comparing the real positive rate with the false positive rate in a plot. The accuracy of the classifier was then determined by making use of the area under the resultant ROC curve. The closer the region to 1, the better the classifier's accuracy. The AUC serves as the classifier's performance indicator, while the probability curve known as the ROC is produced by plotting the TP rate against the FP rate at various threshold values. The AUC value ranges from 0.5 to 1, where the value of a perfect classifier is 1, and a random classifier performs at a value of 0.5. Therefore, the classifier performs better the higher the AUC. To determine the region under the ROC curve, AUC was computed using trapezoidal integration [47].

$$\text{True Positive Rate (TPR)} = \frac{TP}{TP + FN} \tag{5}$$

and

$$\text{False Positive Rate (FPR)} = \frac{FP}{FP + FN} \tag{6}$$

3 Results of Implementation

Four transfer learning algorithms—InceptionV3, DenseNet169, ResNet50V2, and Xception—were used in our studies. TensorFlow, sklearn, Keras libraries, and other tools were used to conduct all of the experiments in Python. The simplicity and ready availability of the TL approach chosen for this study make it simple for a non-expert to utilize them in actual practice. We focus mainly on the accessible DL approaches because many medical practitioners lack an in-depth understanding of complex DL techniques. In addition, the data is not structured in a complex way and just contains a few features. InceptionV3, DenseNet169, ResNet50V2, and Xception are already extremely good approaches in their own right, there is no need to use unnecessarily complex models.

The already acquired benchmark dataset from Kaggle was utilized for model evaluation's training, validation, and testing. After a model has been trained, its accuracy is assessed using data from the test and validation sets. COVID-19 CT scan versions of the dataset are used in the experiments (55, 56). The dataset after being put produces an output of whether an individual is infected or not. The result is the conclusion of whether COVID-19 instances are Positive or Negative.

3.1 Transfer Learning Models

This study made use of four different transfer learning models and these are discussed as follows:

3.1.1 InceptionV3

One of the inception family's updated iterations is called InceptionV3, It incorporated improvements including Factorized 7×7 convolutions, LabelSmoothing, and the usage of an auxiliary classification network for propagating label information. Batch normalization is applied to the side-layers heads as well. It is mostly utilized for object recognition and image analysis. The base layer of the InceptionV3 architecture has initially been frozen in our research model. To do this, we first created a trainable layer upon the base layer using the command include top = false. Additionally, we sized all of our data images here into the (150, 150, and 3) ranges. In this case, the Relu Activation function has been used in conjunction with the stochastic gradient descent (SGD) algorithm for optimization. In our InceptionV3 architecture, the learning rate for backpropagation has been set to 0.01 [48]. Figure 4 illustrates the layered architecture in detail, while Table 1 provides a summary of the model's parameters.

3.1.2 DenseNet169

DenseNet-169 is one of the 169-layer DenseNet family designs, and it is frequently used for DL classification problems. Compared to alternative DenseNet architectures that have fewer layers, it has a significantly smaller number of trainable parameters. A reliable feature propagation technique is present in DenseNet-169 and the other DenseNet designs, they can avoid the vanishing gradient issue, have a few trainable parameters, and promote feature reuse, consequently, they form a class of very reliable DL architectures. DenseNet models are available in PyTorandes and Tensorflow (Keras). Fine-Tuned DenseNet-169 for Breast Cancer Metastasis Prediction Using FastAI and 1-Cycle Policy. Sensors, 22(8), 2988). Figure 5 depicts

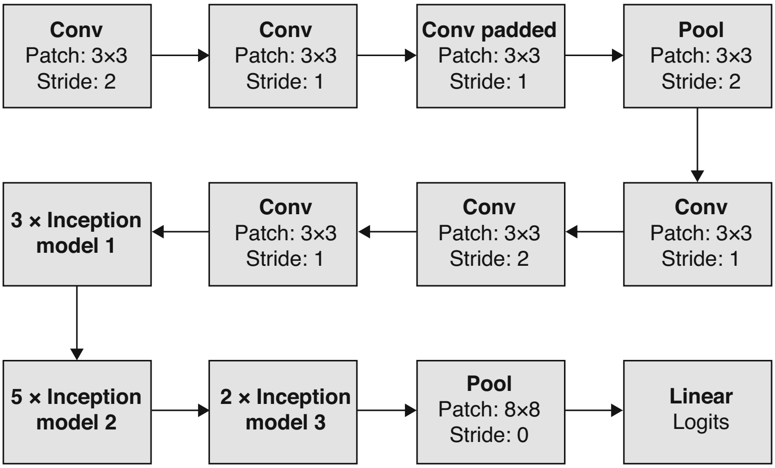


Fig. 4 TL model InceptionV3 architecture

Table 1 Summary of InceptionV3 model

Layer (type)	Output shape	Parameter
InceptionV3 (Functional)	(None, 3, 3, 2048)	21802784
Flatten (Flatten)	(None, 18432)	0
Dense (Dense)	(None, 128)	2359424
Dropout (Dropout)	(None, 128)	0
Dense_1 (Dense)	(None, 128)	16512
Dropout_1 (Dropout)	(None, 128)	0
Dense_2 (Dense)	(None, 2)	258
Total params **Trainable params** **Non-trainable params**		**24,178,9784,753,92219,425,056**

the layered structure of the DenseNet-169 employed in this investigation. The base model has 595 layers, and we freeze from layers 572 up and unfreeze from layers 572 down.

The architecture includes transition layers, dense layers, max pool layers, and convolutional layers. The model employs SoftMax activation for the final layer and ReLU activation for the rest of the architecture. The dimension of the inputs is reduced by the max pool layers while the convolutional layers extract the image's characteristics. The flattened layer is followed by the fully linked layers, which function as an artificial neural network using the flattened layer's single array input. Table 2 shows the specifications of the DenseNet169 layered design.

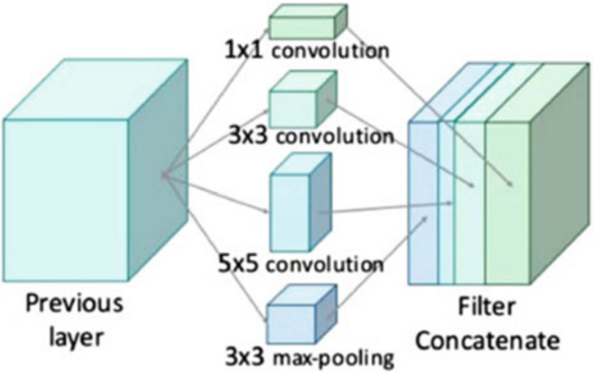


Fig. 5 TL model Xception architecture

Table 2 Summary of DenseNet169 model

Layer (type)	Output shape	Parameter
Densenet169 (Functional)	(None, 4, 4, 1664)	12642880
Flatten_1 (Flatten)	(None, 26624)	0
Dense_3 (Dense)	(None, 128)	3408000
Dropout_2 (Dropout)	(None, 128)	0
Dense_4 (Dense)	(None, 128)	16512
Dropout_3 (Dropout)	(None, 128)	0
Dense_5 (Dense)	(None, 2)	258
Total params **Trainable params** **Non-trainable params**		**16, 067, 6504, 163, 45811, 904, 192**

3.1.3 ResNet50V2

The Residual Networks architecture Resnet50V2 is a more advanced, faster-convergent convolutional network, more accurate, and compared to other deep convolutional neural networks, it is easier to train. It also addresses the issues of vanishing or exploding gradients by integrating “residual blocks” in the design. A residual network consists of many residual blocks placed on top of one another. Using shortcut connections that bypass one or more levels, each residual block is created [49]. Table 3 illustrates the ResNet50V2 layered design in detail.

3.1.4 Xception

This model was developed using ImageNet, which draws inspiration from Inception design. This design substitutes the inception module with depthwise separable convolutions operations, where the convolutions are performed both pointwise and depthwise. This model uses convolution layers with residual connections to improve

Table 3 Summary of ResNet50V2 model

Layer (type)	Output shape	Parameter
Resnet50V2 (Functional)	(None, 5, 5, 2048)	23564800
Flatten_1 (Flatten)	(None, 51200)	0
Dense_3 (Dense)	(None, 128)	6553728
Dropout_2 (Dropout)	(None, 128)	0
Dense_4 (Dense)	(None, 128)	16512
Dropout_3 (Dropout)	(None, 128)	0
Dense_5 (Dense)	(None, 2)	258
Total params **Trainable params** **Non-trainable params**		**30,135,29815,499,77814,635,520**

Table 4 Summary of Xception model

Layer (type)	Output shape	Parameter
Xception (Functional)	(None, 5, 5, 2048)	20861480
Flatten (Flatten)	(None, 51200)	0
Dense (Dense)	(None, 128)	6553728
Dropout (Dropout)	(None, 128)	0
Dense_1 (Dense)	(None, 128)	16512
Dropout_1 (Dropout)	(None, 128)	0
Dense_2 (Dense)	(None, 2)	258
Total params **Trainable params** **Non-trainable params**		**27,431,97814,434,86612,997,112**

classification performance and convergence speed [50]. A convolutional neural structure 71 layers deep are called Xception. A pre-trained version of the structure constructed using more than 1,000,000 images from the ImageNet data set may be combined. Figure 5 shows the layered design in more depth while Table 4 provides an overview of the model's parameters.

3.2 *Transfer Learning Classification Report*

A coronavirus strain known as severe acute respiratory syndrome coronavirus is responsible for the contagious illness COVID-19. In this study, we used 497 pictures as testing data. Using these images, we constructed our confusion matrix using the four TL models, and we subsequently estimated the precision, recall, and accuracy. The model can determine the primary class of a single image. 497 values (20% of the dataset) are used in the analysis to test the hypothesis. The result for all the TL models used is shown in the figures and table b. According to the outcome in the table, the models have an accuracy of 92% for InceptionV3 (InceptV3), 96% for DenseNet169 (DesN169), 94% for ResNet50V2 (ResN50V2), and 94%

for Xception (Xcep). This demonstrates that despite how similar each model is, the DenseNet169 model shows a better accuracy of 96% for detecting COVID-19 cases in the hospital setting. The overall analysis shows that DenseNet169 shows more accuracy on the testing dataset when compared with InceptionV3, ResNet50V2, and Xception models.

3.2.1 Confusion Matrix

The confusion matrices produced by using 5-fold cross-validation for the four selected TL classifiers can be seen in Figs. 6, 7, 8, and 9. Positive scores are represented by high values in the boxes at the upper-left and lower-right of these matrices. Poor results are represented by a large number of these matrices in the upper-right and lower-left boxes. Table 5 shows the Classification report for all four TL models used in this study.

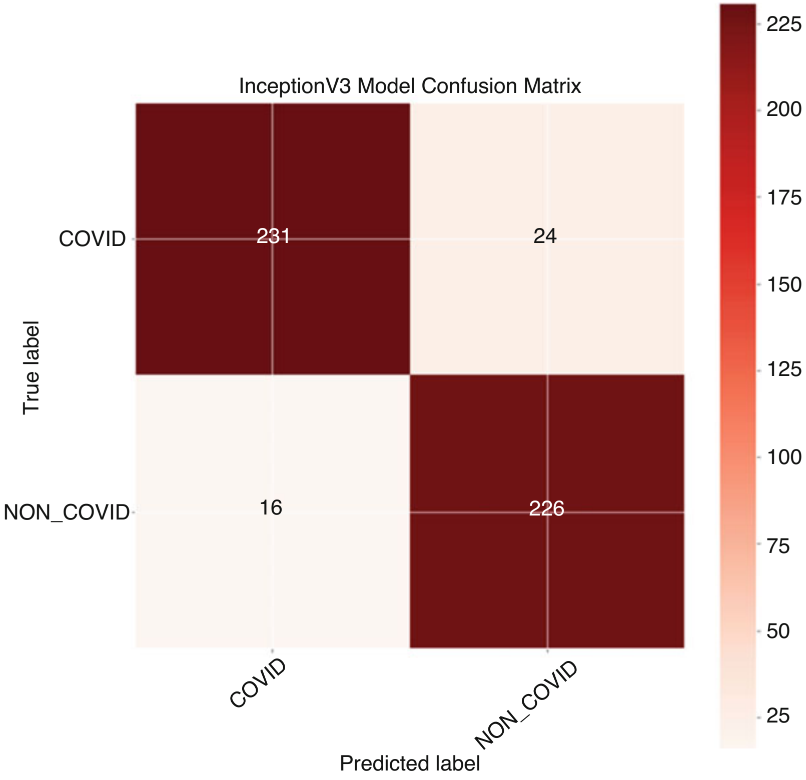


Fig. 6 InceptionV3 model Confusion matrix

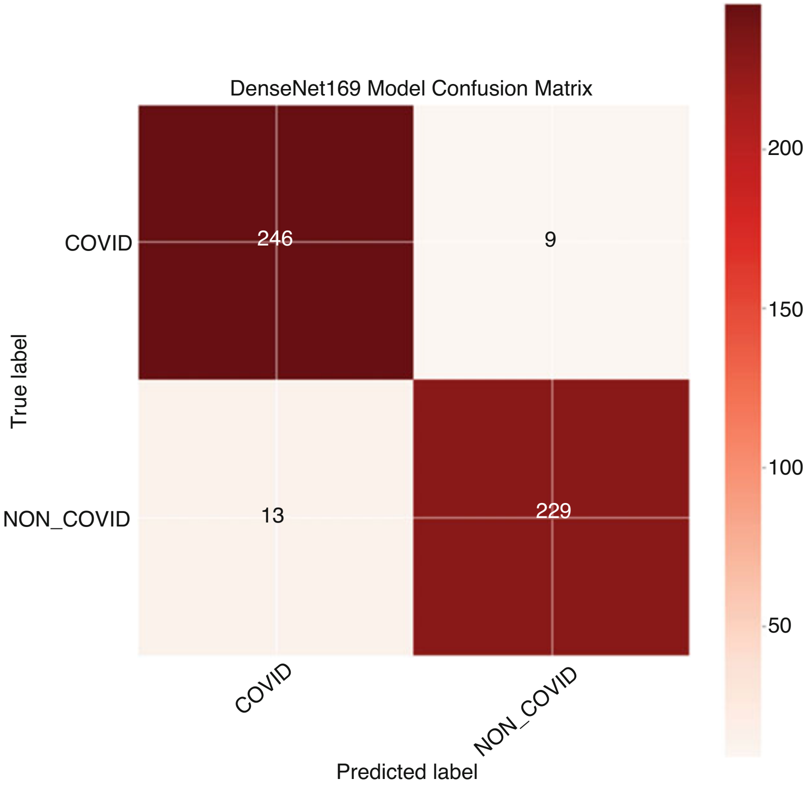


Fig. 7 DenseNet169 model Confusion matrix

3.2.2 TL Models Training and Validation

This sub-section shows the comparative evaluation of the suggested TL models concerning the training and validation in terms of accuracy and loss using the COVID-19 CT scan images while training and validating the dataset. The percentage of correctly categorized images in the current dataset is indicated by the training accuracy, whereas the validation accuracy displays the proportion of randomly chosen correctly classified images from a separate collection. The primary difference is that because the accuracy of training depends on the images that the network can learn, it can over-adapt to the noise in the data.

Table 6 lists the classification model parameters that were used in the experiment, and Table 7 lists the accuracy and loss measures for the models InceptionV3, DenseNet169, ResNet50V2, and Xception.

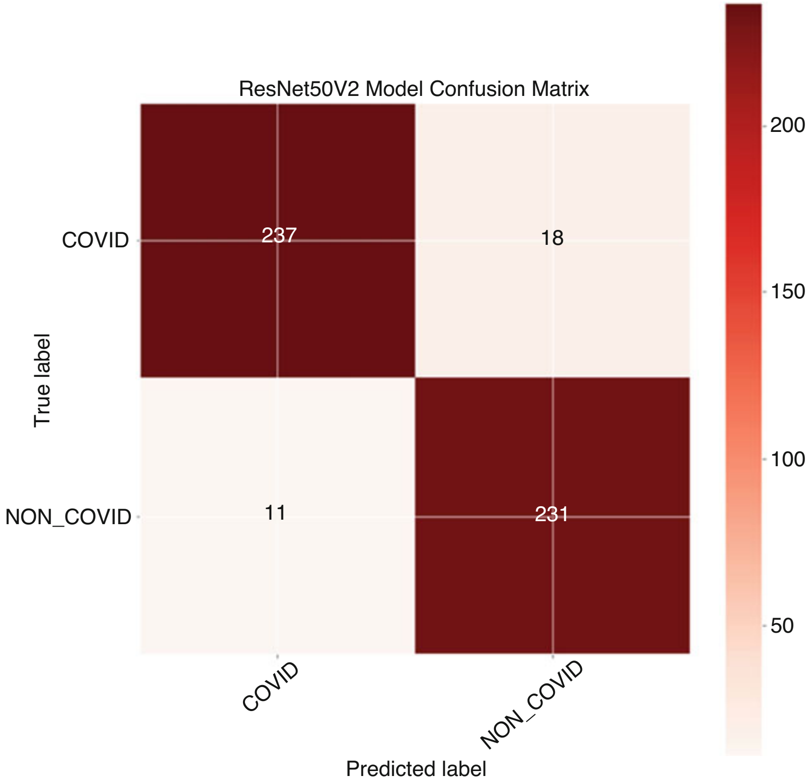


Fig. 8 ResNet50V2 model Confusion matrix

Training Loss The training loss of the TL models for COVID-19 are 0.0109, 0.0042, 0.0014, 0.0037 for the models InceptionV3, DenseNet169, ResNet50V2, and Xception respectively given in Table 7, and Figs. 10, 11, 12, and 13 illustrate the training loss for each epoch.

Validation Loss The validation loss of the TL models for the COVID-19 are 0.2918, 0.1947, 0.3207, 0.4197 for the models InceptionV3, DenseNet169, ResNet50V2, and Xception respectively as shown in Table 7. Figures 10, 11, 12, and 13 display the training and validation loss for each epoch.

Training Accuracy The training accuracy of the TL models for COVID-19 are 0.9981, 0.9994, 1.0000, 0.9994 for the models InceptionV3, DenseNet169, ResNet50V2, and Xception respectively as shown in Table 7. Training accuracy for each epoch is shown in Figs. 14, 15, 16, and 17.

Table 5 Classification report for the TL models

Models	InceptV3	DesN169	ResN 50V2	Xcep	InceptV3	DesN169	ResN 50V2	Xcep	InceptV3	DesN169	ResN 50V2	Xcep
COVID	0.94	0.95	0.96	0.98	0.91	0.96	0.93	0.91	0.92	0.96	0.94	0.94
NON_COVID	0.90	0.96	0.93	0.91	0.93	0.95	0.95	0.98	0.92	0.95	0.94	0.94
Accuracy									0.92	0.96	0.94	0.94
Macro Avg	0.92	0.96	0.94	0.94	0.92	0.96	0.94	0.94	0.92	0.96	0.94	0.94
Weighted Avg	0.92	0.96	0.94	0.94	0.92	0.96	0.94	0.94	0.92	0.96	0.94	0.94

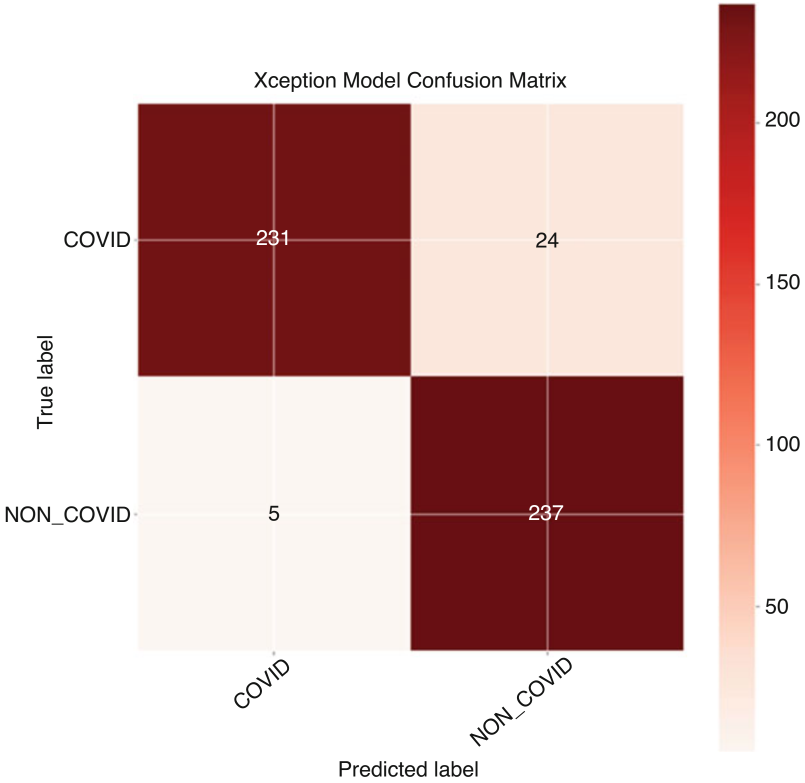


Fig. 9 Xception model Confusion matrix

Table 6 Classification models training, validation, and testing parameters

Training parameters	Classification model
Epochs	20
Learning rate	0.01
Monitor	Val_accuracy
Learning rate drop factor	0.70
Learning patience	7
Epochs stopping criteria	Verbose=1, patience=10
Optimizer	Stochastic gradient descent (SGD)

Table 7 Models performance evaluation

TL model	Training loss	Training accuracy	Validation loss	Validation accuracy
InceptionV3	0.0109	0.9981	0.2918	0.9295
DenseNet169	0.0042	0.9994	0.1947	0.9521
ResNet50V2	0.0014	1.0000	0.3207	0.9244
Xception	0.0037	0.9994	0.4197	0.9169

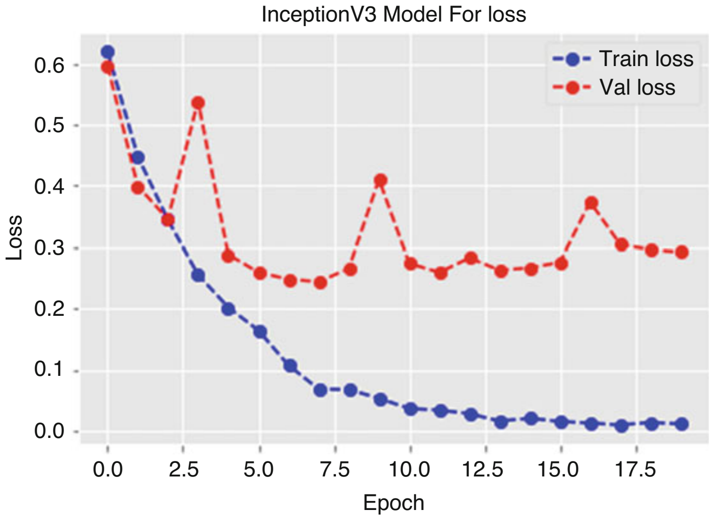


Fig. 10 InceptionV3 training and validation loss

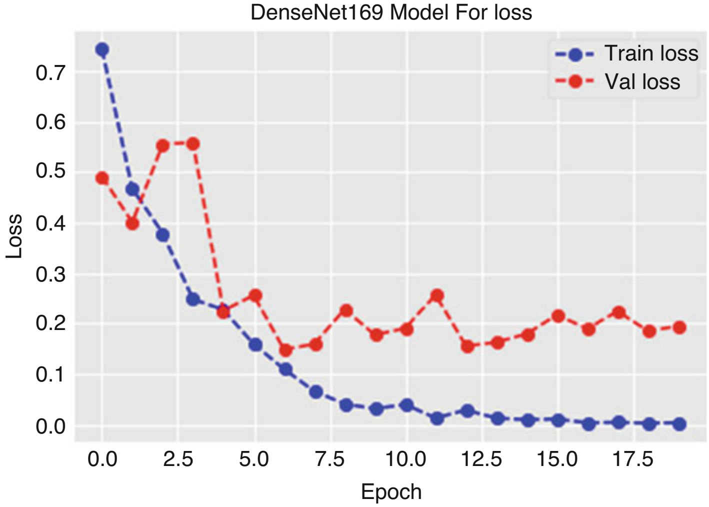


Fig. 11 DenseNet169 training and validation loss

Validation Accuracy The validation accuracy of the TL models for the COVID-19 are 0.9295, 0.9521, 0.9244, 0.9169 for the models InceptionV3, DenseNet169, ResNet50V2, and Xception respectively as shown in Table 7. Validation accuracy for each epoch is shown in Figs. 14, 15, 16, and 17.

AUC Curve The AUC curve value of the TL models for the COVID-19 cases detection are 0.9199, 0.9555, 0.9420, 0.9426 for the models InceptionV3,

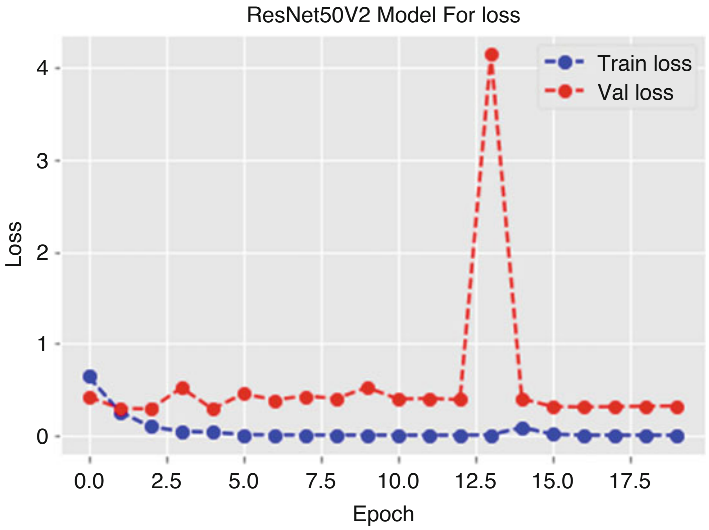


Fig. 12 ResNet50V2 training and validation loss

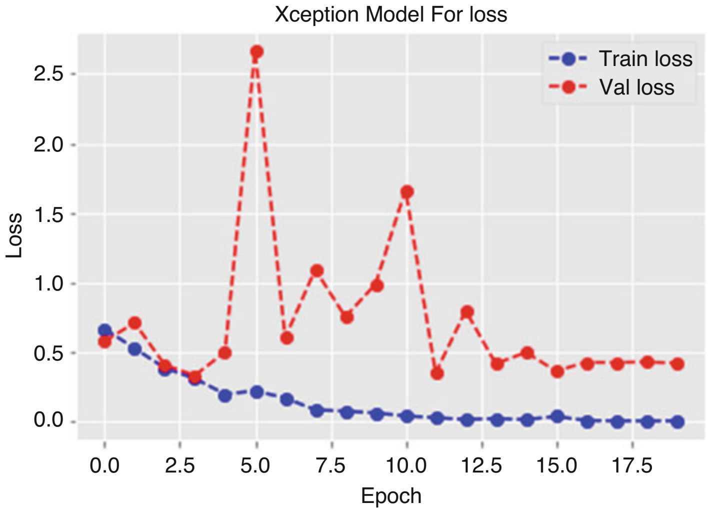


Fig. 13 Xception training and validation loss

DenseNet169, ResNet50V2, and Xception respectively. The ROC curves from the four classifiers that were selected are shown in Figs. 19, 20, 21, and 22, along with a comparison of the performance of the algorithms. Figure 18 displays the TL models AUCs and it can be seen that DenseNet169 outperformed the other models with an AUC of 96%.

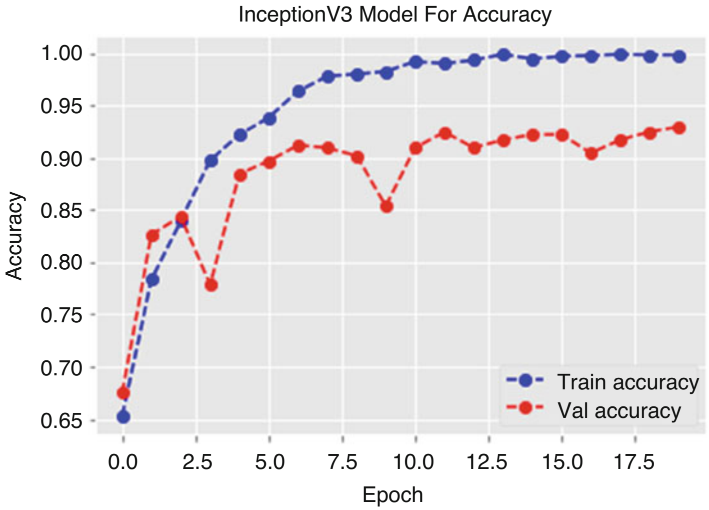


Fig. 14 InceptionV3 training and validation accuracy

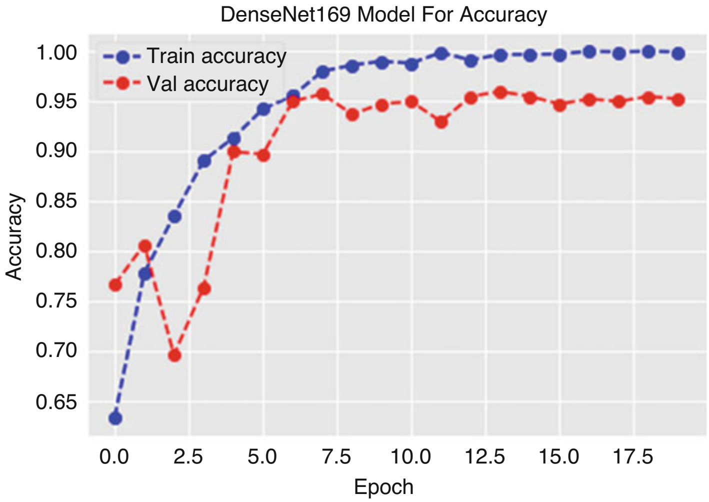


Fig. 15 DenseNet169 training and validation accuracy

The findings of Fig. 23 show that the models created using the InceptionV3, DenseNet169, ResNet50V2, and Xception models were effective in foretelling confirmed and potential COVID-19 cases. This proves that our suggested Internet of Things solution may combine these four effective frameworks. By merging the outcomes, this might be accomplished for the four trained models, based on a plurality vote. The DenseNet169 TL model outperformed all the other three models with 96% accuracy, 96% precision, 96% recall, and 96% f1-score.

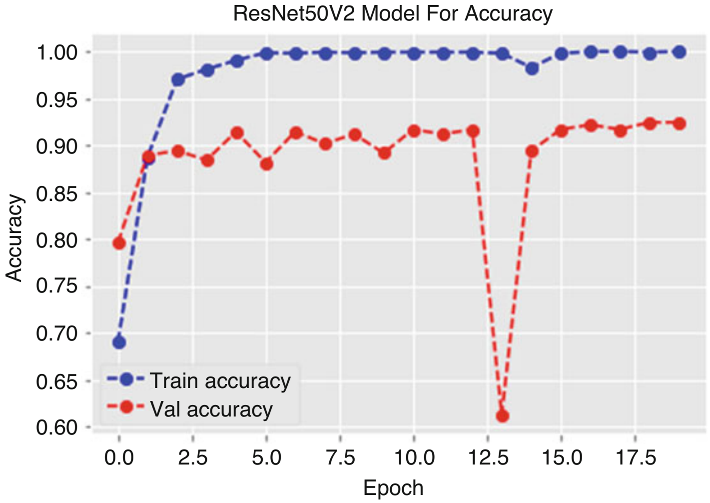


Fig. 16 ResNet50V2 training and validation accuracy

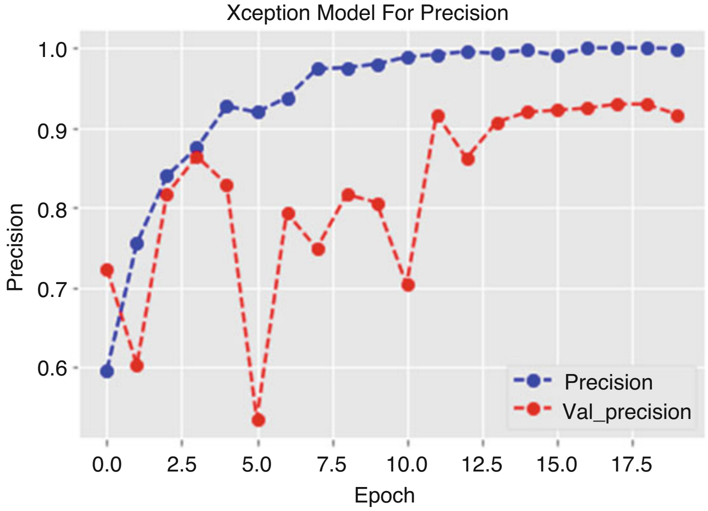


Fig. 17 Xception training and validation accuracy

3.2.3 Comparative Analysis

The research found in the literature evaluated numerous trained models in the literature indicates that COVID-19 classification training and assessment accuracy is encouraging. The majority of models that were employed and show great COVID-classification accuracy were either binary classifiers or they had been trained on CT-Scan images. Binary classifiers are more accurate than models trained on

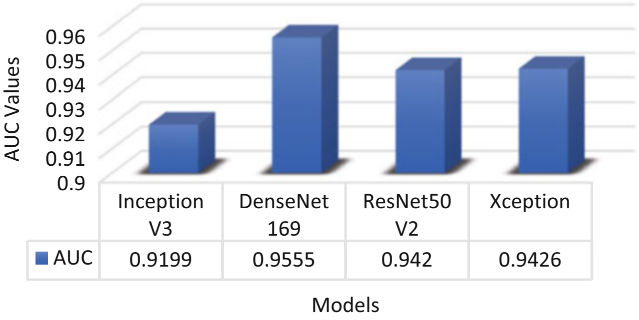


Fig. 18 TL model AUC

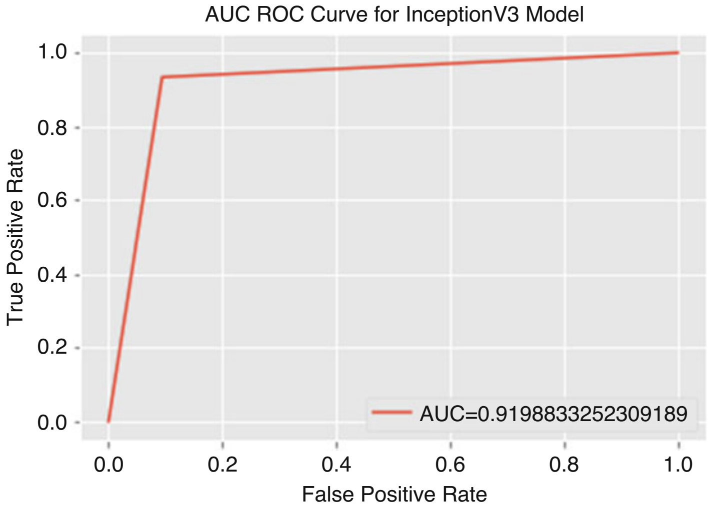


Fig. 19 InceptionV3 AUC ROC curve

multiple classes since they have fewer classes to predict. Another issue with earlier models was that they were more sophisticated and hence more computationally expensive to be 90% accurate.

Despite having more classes, a smaller COVID-19 dataset, and a simpler model than much other research in the literature, we have achieved greater results based on performance. Due to the scarcity of COVID-19 data and the likelihood that their research models utilized less data than ours, prior studies were also at a disadvantage. It is unfair to compare those study models with fewer data to ours because the number of COVID-19 datasets is growing daily and research in this area is improving daily. However, using the DenseNet169 TL model on the test COVID dataset, our results outperformed the state-of-the-art, as shown in Table 8, with an accuracy of 96% and an AUC ROC score of 95.5%.

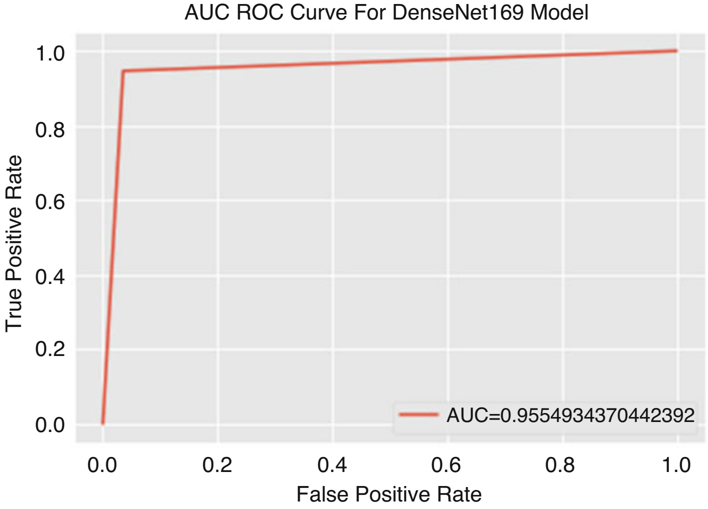


Fig. 20 DenseNet169 AUC ROC curve

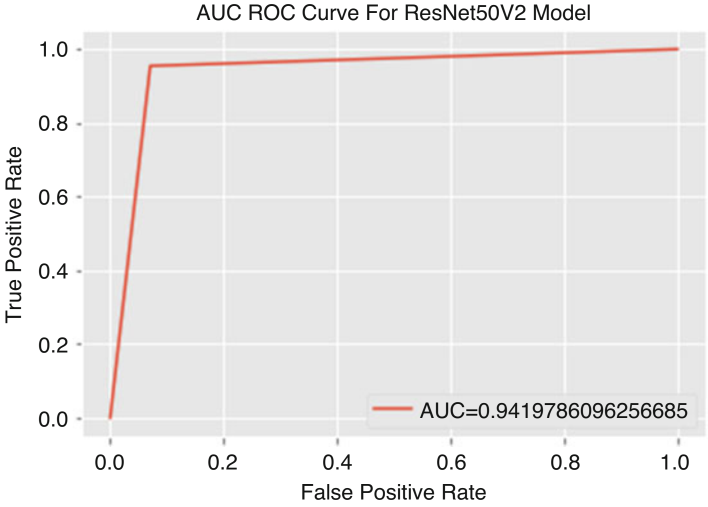


Fig. 21 ResNet50V2 AUC ROC curve

4 Discussion

As this study employed 1252 COVID-19 CT images and 1229 non-COVID-19 CT images, respectively, the problem of class imbalance had no impact on the binary classification in this investigation., where there is a significant imbalance in the class distributions. Classifiers frequently produce low predicted accuracy for the

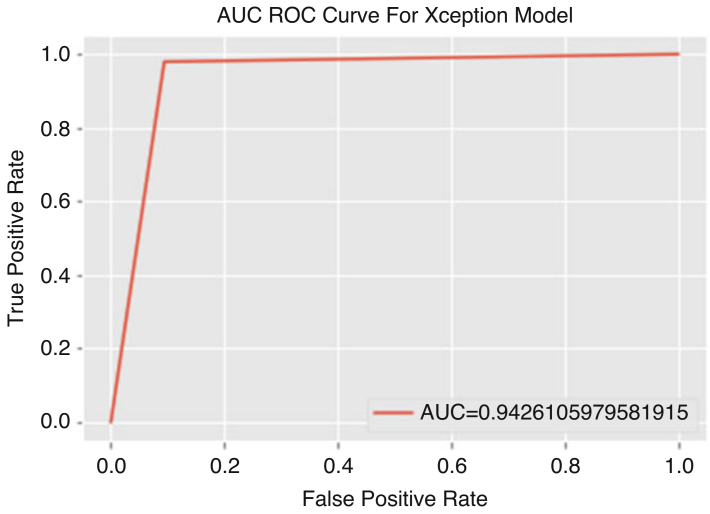
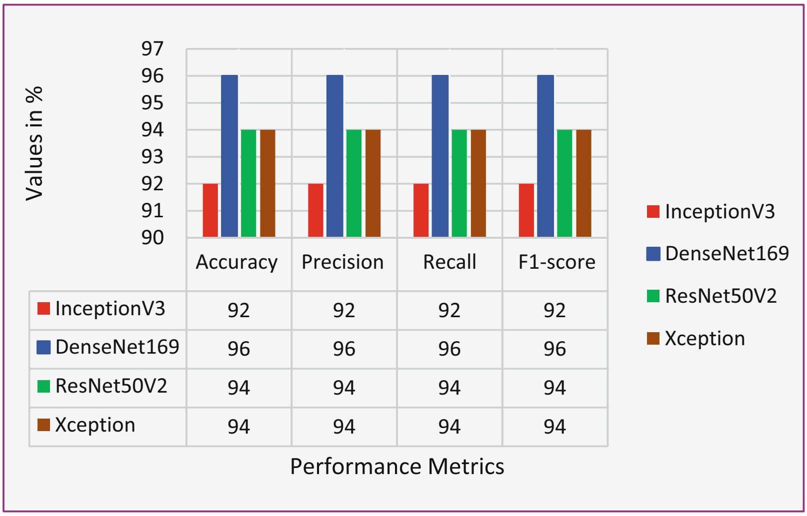


Fig. 22 Xception AUC ROC curve



	Accuracy	Precision	Recall	F1-score
🟥 InceptionV3	92	92	92	92
🟦 DenseNet169	96	96	96	96
🟩 ResNet50V2	94	94	94	94
🟫 Xception	94	94	94	94

Fig. 23 Performance results on the Testing dataset

minority class as a result of unbalanced data. The class labels in medical databases are frequently unbalanced because just a few patient samples were taken and the cost of acquiring annotated data. The deep domain adaptation is one of several methods that have been developed for correcting the class imbalance in medical imaging [54]—to remedy the dearth of large quantities of labeled data, the weighted loss strategy involves altering the loss function to provide a loss that is constant across

Table 8 Models performance evaluation

Authors	Method	Accuracy	F1-score	Precision	AUC
Duta, Roy & Anjun [51]	ResNet50V2 Xception InceptionV3	66%70%71%	——	——	——
Kumari, Ranjith, Gujjar, Narasimmam & Zeelani, [52]	Xception InceptionV3	83%80%	—	—	—
Anwar & Zakir	EfficientNet	90%	90%	–	90%
Albahli, Ayub, & Shiraz [53]	DenseNet	92%	–	–	85%
Proposed Model	**InceptionV3** **DenseNet169** **ResNet50V2** **Xception**	**92%96%94%94%**	**92%96%94%94%**	**92%96%95%95%**	**92%96%94%94%**

all classes, down sampling involves removing pictures from the majority class, and oversampling, This involves applying artificial data augmentation to incorporate more images from minority classes [55, 56]. Challenging issues with imbalanced data and research on potential answers may be found in [57].

5 Conclusions

To stop COVID-19 from spreading, a potent COVID-19 Diagnosis System Using Transfer Learning and IoT in a Smart Hospital Setting has been presented. The proposed architecture includes clinical details of reported COVID-19 cases and transfers learning-based models for monitoring COVID-19, along with information for clinicians concerning potential COVID-19 cases. Additionally, the system makes it possible to classify affected individuals in real time to observe the spreading of COVID-19. Four TL models were put to the test in an experiment using a real IoT CT scan COVID-19 dataset: (1) InceptionV3, (2) DenseNet169, (3) ResNet50V2, and (4) Xception. The result shows that all the TL models obtained more than 90% accuracy on the test, validation, and training datasets compared to 71% in the InceptionV3 model [58], 84% in the Inception V3 model, 83% and 63% in the Xception and Resnet 50 model respectively [52]. So, using deep learning algorithms, it is feasible to detect potential COVID-19 instances effectively and reliably via TL models. The usage of the suggested real-time IoT-based dataset and devices might hypothetically lessen the consequences of the spread of COVID-19 in addition to death rates through the early detection of COVID-19 incidents. Future research can take the security features of the suggested model into consideration.

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A Blockchain-Based Secure Framework for Homomorphic AI in IoHT for Tackling COVID-19 Pandemic

Hossain Kordestani, Roghayeh Mojarad, Abdelghani Chibani, Kamel Barkaoui, and Wagdy Zahran

1 Introduction

Internet of Things (IoT) networks are becoming integral parts of the modern-day. Healthcare has always been a major application domain such that a subset of IoT, known as the Internet of Healthcare Things (IoHT), is dedicated to this domain. With recent advances in Artificial Intelligence (AI), e-health has reached new heights in recent years [1]. In the wake of the COVID-19 pandemic, the entire healthcare sector worldwide has received a fright from a wide range of factors, including its capacity and deliverability, promptness in responding, and the availability of real-time information and analysis. Many works used AI and IoHT to combat the recent pandemic and assist the population. For instance, studies were conducted on the

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calculation of risk factors, diagnosis of COVID-19 [2–6], as well as monitoring and tracking the affected patients, both directly [7, 8] and indirectly [9, 10].

The outbreak of the pandemic broke many traditional boundaries, and it was a scene of international cooperation. The advancement of AI in IoHT services is hindered by many security concerns in such situations: (1) Data Confidentiality: Clinical information about patients is among the most sensitive data. In addition to the confidentiality for individuals, when a nation decides to transfer data to a foreign country for analysis, the level of confidentiality is stepped up. In such situations, anonymization is not sufficient. (2) Technology Edge: There is no doubt that AI providers want to maintain their competitive advantage, particularly during pandemics, when there is a high demand for AI services. (3) Integrity: It is imperative that the integrity of the system is maintained when the services are related to the health of the population. Such a change, if undetected, could have irreparable consequences. (4) Availability: Availability of health services can significantly influence the health of a population; therefore, it is a vital concern in such a system. An unanticipated burden on the healthcare system is inevitable in pandemic situations, making its availability even more challenging [11]. Hence, a secure platform for AI services in IoHT networks is essential in light of these concerns.

In IoHT applications, a massive amount of data at high speed is produced, which could surpass the potential of centralized servers. Moreover, the data stored in the servers are prone to modifications and deletions; in other words, their integrity is in danger.

Blockchain, a decentralized tamper-proof data structure, can be a solution to address the availability and integrity concerns. The decentralized architecture of blockchain avoids the single point of failure and intrinsically extends the availability of service. Moreover, because of the use of cryptographic algorithms in blockchain, the integrity of data is computationally guaranteed.

Although blockchain technology enhances the availability and integrity of IoHT applications, they are not entirely secure with respect to the privacy of nodes [12]. Hence, off-chain solutions for handling confidentiality concerns are required. A common practice is to use asymmetric encryption suites for such purposes [13]. The asymmetric encryption enables data consumers to access the data; i.e., the data consumers are trusted entities. However, in many cases, the data owner might require the computation of an untrusted entity, particularly the AI provider. The latter is necessary for the meaningful use of IoHT data; however, since data is precious for AI providers, one might choose not to trust them. Traditionally, this untrust is handled using non-disclosure agreements and privacy policies, but they are both proven weak in practice. Homomorphic encryption allows computation over the encrypted data without leveraging the plain data. Hence, it could be a solution to handle the privacy concern in the context of IoHT applications. To the best of our knowledge, only a few studies have considered homomorphic encryption for IoHT data in the blockchain; however, they do not consider AI in the system.

For instance, BeeKeeper 2.0 [14] proposes a decentralized outsourcing computation scheme based on Hyperledger Fabric blockchain.[1]

In this chapter, we propose a blockchain-based secure framework for homomorphic AI in IoHT networks in order to tackle pandemics securely. It enhances the availability of IoHT applications because of the distributed architecture of blockchain technology. The proposed framework provides data integrity thanks to the cryptographic algorithms used in blockchain technology. Moreover, it enables homomorphic AI on the data because of homomorphic encryption, which allows AI on the encrypted data without leveraging the plain data or any details from the AI provider. The main contributions of the proposed framework are the followings:

- Defining the security concerns for AI outsourcing in IoHT applications
- Proposing a secure framework for AI outsourcing using homomorphic encryption, which can be used to tackle pandemics such as COVID-19
- Avoiding any leverage of input data or AI model with the use of homomorphic operations
- Ensuring the integrity of data using hash algorithms in blockchain technology
- Maintaining the availability of service with the help of the distributed architecture of blockchain technology

The remainder of this chapter is structured as follows: in Sect. 2, the required principles of this framework, that is, blockchain technology and homomorphic encryption, are explained. The related works are reviewed in Sect. 3. The details of the proposed framework are presented in Sect. 4. The security evaluation of the proposed framework using formal approaches is provided in Sect. 5. A use case is described in Sect. 6 to evaluate the proposed framework. Lastly, the conclusion and future works are provided in Sect. 7.

2 Preliminaries

2.1 Blockchain

A blockchain is a type of decentralized ledger technology that allows the replication, sharing, and synchronization of data [15]. The term "blockchain" refers to the chain of blocks that are linked together using hash values to create a data structure. As a result of the hash values and digital signature connecting each block, any modification of one block cannot be computationally possible without modifying all the subsequent blocks as well [16]. Data integrity in a blockchain is ensured in this manner. An anonymous peer-to-peer cash system, such as Bitcoin [16], is a popular application of blockchain, which has spurred research on its use in other areas. Blockchain platforms such as Ethereum [17] offer the functionality of smart

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[1] https://www.hyperledger.org/use/fabric.

contracts, which are event-triggered programs that allow scripts to be run over the data. Permissionless blockchains, such as Ethereum, do not restrict access to contents, and any peer may access them. Therefore, if the data is confidential, off-chain encryption is necessary.

Additionally, blockchain is not intended to store extensive data, but rather to store smaller data, such as transactions [18]. It has been proposed that extensive data should be stored in an off-chain distributed system and the address of that data be stored on the blockchain [19]. IPFS (InterPlanetary File System) [20] is a distributed file system that can be used in this regard.

2.2 Homomorphic Encryption

A homomorphic encryption scheme is a group of cryptographic schemes that allow computations to be performed over encrypted data in order to address the confidentiality concerns involved in outsourcing computations. If the encryption of the result of an operation $\odot$ over two messages equals the encryption of the result of the operation $\odot$ over the encryption of messages, the encryption scheme is considered homomorphic over the operation $\odot$. In Eq. 1, this definition is formalized.

$$\forall m_1, m_2 : Enc(m_1) \odot Enc(m_2) = Enc(m_1 \odot m_2) \tag{1}$$

Generic homomorphic encryption procedures can be outlined as follows [12], where C is the superset of all cryptograms:

- $KeyGen(1^\lambda, \alpha)$: The $KeyGen$ function returns key triplets consisting of a private key, a public key, and an evaluation key (sk, pk, evk) based on a security parameter λ and an auxiliary input α.
- $Encrypt(pk, m)$: given the plain-text message m and the public key pk, $Encrypt$ function allows encrypting the message using the public key and yields to a crypogram $c \in C$.
- $Decrypt(sk, c)$: using the private key sk, the user might decrypt the ciphertext c to yield plain-text message m.
- $Evaluate(evk, C)$: given the set of all cryptograms C and the evaluation key, $Evaluate$ function yields a new cryptogram c^*.

3 Related Work

In the context of IoHT networks, blockchain is a suitable solution for data storage and distribution due to the aforementioned features. Researchers have worked on modifying blockchain to be used in the context of the IoT and IoHT [10, 13, 21–23].

IoHT networks can benefit from artificial intelligence with its scalable and accurate real-time data analysis. Based on a review of existing studies of big data analysis and computation load-balancing in IoT applications, these studies can be classified into four categories [24]:

1. Cloud analysis: Cloud servers are used for big data analysis. These systems are limited in terms of accuracy, speed, latency, and computing capacity due to the use of a centralized server.
2. Fog analysis: During the analysis of the IoT data, data collection and load balancing are performed in a distributed manner. However, the fog intelligence is managed by a central controller, resulting in issues such as resource management and scalability.
3. Edge analysis: Training is completed by the edge nodes, while processing is completed by the cloud server. Edge servers are responsible for extracting features and scaling data in order to facilitate data analysis by the cloud server.
4. Device analysis: Peer-to-peer networks are used to provide data analysis on the data collected by the nodes.

The conventional encryption systems are not capable of protecting intermediary services from the leakage of personal information [12]. The homomorphic encryption method is a privacy-preserving encryption technique. Cloud systems with homomorphic encryption use a homomorphic encryption algorithm to encrypt and store data, and then to retrieve the data, the query is encrypted and sent to the cloud as well. By executing a prediction algorithm, the cloud server is able to retrieve the query results without knowing the contents of the query or the data [12].

In [25], homomorphic encryption is proposed for the purpose of providing security and privacy in VANETs. It is proposed that location and distance information be encrypted using homomorphic encryption before being compared. In this case, no information about the location data is revealed by the result. A secure multiparty computation scheme is used in order to verify the location information. In this approach, the privacy of the vehicles can be protected from attacks.

Sun and Yan [26] is another work that addresses the privacy concerns associated with smart vehicles by using homomorphic encryption to secure location and identity privacy within vehicle-to-grid networks. A wireless network transmits the identities, consumption patterns, parking spots, and charging spots of electric vehicles to the power grid system. According to this proposed approach, the aforementioned link is protected through the use of homomorphic encryption. It is also proposed in [27] that a privacy-preserving route reporting scheme can be obtained in a smart vehicle environment using homomorphic encryption. Each vehicle encrypts its route information using homomorphic encryption and transmits the encrypted information to roadside units. Consequently, the vehicles are able to report their future routes without revealing any personal information.

The drone system is another example of IoT that can benefit from homomorphic encryption. A linearly homomorphic authenticate encryption scheme (LinHAE) has been proposed for securing ground control centers for drones in [28]. The LinHAE protocol provides a means of verifying both the authenticity and confidentiality of a message. With fast encryption, evaluation, and verification procedures for the real-time controller, it supports linear operations between the ciphertexts. Consequently, LinHAE ensures a high level of protection against attacks aimed at compromising message confidentiality and integrity.

An authentication protocol that preserves privacy based on homomorphic encryption is presented in [29]. In an IoT network, the proposed protocol enables users to generate any number of authenticated identities arbitrarily, thereby ensuring complete anonymity. Users of the proposed protocol are protected against being tracked by peers, service providers, authentication servers, or any other infrastructure. However, authentication servers that run collaboration protocols are capable of tracing and identifying the attacker in the event of disputes or malicious activities. As a lightweight protocol, it is well suited to IoT applications.

Among the very few studies that have considered homomorphic encryption and blockchain together, BeeKeeper 2.0 [14] is a compelling example. The verifiable information on BeeKeeper 2.0 is publicly stored in the blockchain so that auditors may verify the transactions. As blockchains are tamper-resistant, the integrity of stored information is assured. To prevent data leakage, the data is encrypted using homomorphic encryption to permit computations to be performed on it without compromising its integrity.

4 Proposed Approach

4.1 Security Requirements

The proposed framework addresses the privacy concerns associated with the use of third-party services within a distributed network. We focus on IoHT networks since they are integral to combating pandemics. Blockchains are considered a backend for secure distributed platforms for their well-established characteristics. Blockchain, artificial intelligence, and the Internet of Things are becoming increasingly intertwined [30]. The authors have stated that IoT-based applications are connected, flexible, and efficient; blockchain enhances security and transparency, and artificial intelligence provides data analytics. Thus, the focus of this chapter is on the integration of artificial intelligence into blockchain-based IoHT networks while maintaining privacy.

This framework addresses the following security concerns:

- Ownership: Data owners are the sole controllers of their data under our framework, which ensures that the data owners retain ownership.
- Transparency: Throughout our framework, all shared activities should be publicly tracable; this allows auditors to verify all procedures.

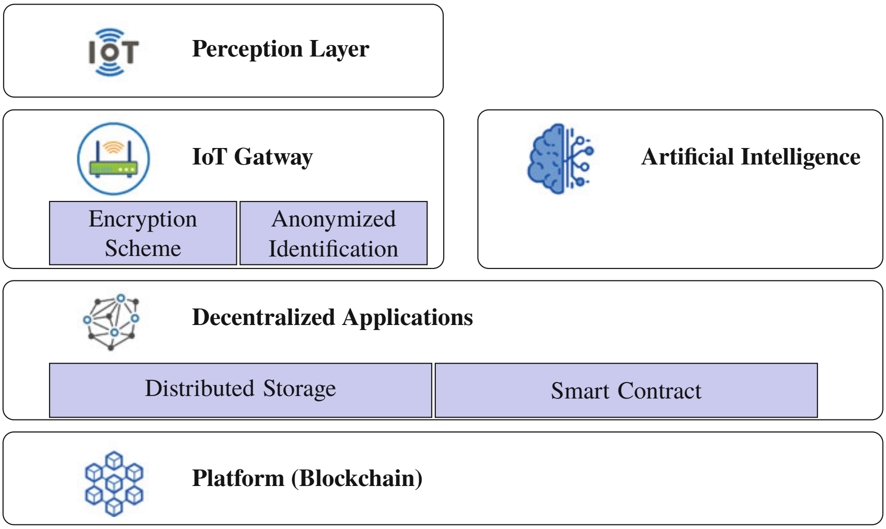

Fig. 1 General architecture of the proposed blockchain-based secure framework for homomorphic AI in IoHT networks

- Confidentiality: The owner of the data should have the ability to set only authorized users to access the data, and any unauthorized access should be prohibited.
- Integrity: It should be possible to detect any changes in the data in our framework, and any data in our framework should have guaranteed integrity.

4.2 Architecture

We propose a framework that utilizes blockchain and homomorphic encryption technologies to allow us to take advantage of both technologies. Using the former, integrity is ensured through a distributed immutable platform. Using the latter, computation is enabled without compromising the integrity of the data.

Figure 1 illustrates the general architecture of the proposed framework, and the following sections provide details of each component.

4.3 Platform Layer

Distributed ledgers can be viewed as immutable decentralized databases in the blockchain. Furthermore, smart contracts provide a robust mechanism for executing event-driven actions on the blockchain. Accordingly, the proposed framework is based on blockchain technology. In this proposed framework, the blockchain network functions as the backbone, as all the other components communicate using the blockchain network.

4.4 Decentralized Application Layer

Decentralized Applications (DApps) are stored and executed through decentralized networks, such as blockchains. DApps serve as a logical layer that orchestrates the framework. Smart contracts and data storage are the two main aspects of DApps. The logic workflow of the system is handled by the former, whereas distributed data storage is handled by the latter. The following sections discuss these two subcomponents.

4.4.1 Distributed Storage Component

Blockchains are not general-purpose databases; therefore, large data sets cannot be stored efficiently on them. Hence, in the proposed framework, we propose storing the data off-chain, i.e., outside the blockchain. The InterPlanetary File System (IPFS) [20] is one of the most widely used technologies for this purpose. IPFS is a distributed file system that allows users to access, store, and secure files across a network. In essence, it combines distributed hash tables, an incentivized block exchange, and self-certifying namespaces. Peers use this protocol to store files and serve them with the content address of the files they are storing. Through the use of a distributed hash table, the other peers can find and request the content. IPFS and blockchain provide an accessible and immutable method of storing distributed hash tables.

4.4.2 Smart Contract Component

Smart contracts are event-driven scripts that are executed on the blockchain. Due to the inherent features of blockchain, smart contracts can guarantee the execution of certain processes in the event of certain events. Smart contracts are used in our proposed framework to ensure that the various components of the system work as intended.

The data is encrypted using the encryption scheme as it is created, and anonymous identification information is placed in the distributed storage system. An event triggers the smart contract upon receiving a new piece of information and organizes the storage of that information. Blockchains hold the hash of the stored data along with the identification of the data owner. As part of the smart contract, AI is also triggered to be executed on the updated data; the resulting information is similarly stored, and the data owner is informed of the outcome. Smart contracts are used to manage all of these processes.

Using smart contracts, any data in the blockchain will be securely stored in a distributed storage. The hash for each piece of data will be stored within the blockchain. AI will have processed the data, and the analysis results will be stored within the blockchain.

4.5 IoT Gateway Component

Traditionally, IoT gateways collect and send data from IoT devices to external platforms. The proposed framework consists of IoT gateways that connect the IoT network of one peer to the blockchain. Since IoT gateways are required to perform some pre-processing on data, they are considered to possess more computation power compared to IoT devices.

4.5.1 Encryption Process

As we detailed in Sect. 2.2, homomorphic encryption is an answer for secure outsourcing of computation. The main objective of such a scheme is to enable computation on the data without revealing its content. The outsourced computation of the proposed framework is classification; hence, we propose to encrypt the IoT data using homomorphic encryption schemes.

Considering that raw IoT data contain no identifying information and are typically meaningless on their own, we assume that the confidentiality of raw IoT data is not of critical importance. It is, therefore, necessary to encrypt the data after they have been collected and labeled with the user's identification by the IoT gateway before they are stored in the distributed storage system.

4.5.2 Anonymized Identification Process

Anonymous trustless peer-to-peer transactions characterize the blockchain network. Therefore, we follow the same approach when it comes to storing data. Our proposed framework uses secure hash algorithms to identify data. Cryptographic hash functions are one-way functions whose reverse cannot be computed.

With the help of a hash algorithm, peers are able to calculate their identifications efficiently; however, other peers are unable to determine the peer from the identifications. Furthermore, it allows AI to determine which data belongs to the same peer.

4.6 Artificial Intelligence Component

Any smart IoHT application relies on AI data analysis due to the benefits it provides. It is usually not feasible to execute AI algorithms locally in IoT networks due to their high computational requirements. As with any other service, AI providers prefer to offer their services online rather than locally to avoid being subject to reverse engineering and losing some of their advantages. AI providers collect data to extend their work; therefore, they may collect any available data. Thus, users are concerned about the privacy of their personal data when using AI services.

We consider using homomorphic AI on the data in the proposed approach in order to offer users the benefit of AI services without compromising the confidentiality of their data. Ideally, our proposed AI framework should be able to work efficiently with encrypted messages.

The homomorphic machine learning requirement has been explored in various existing works. The following three classification models for encrypted data have been discussed in [31]: hyperplane decision-based classifier, naïve Bayes classifier, and decision trees.

A homomorphic encryption scheme has also been presented in [32] for a similar class of classification algorithms. Aside from traditional classification, [33] also discusses secure data processing for neural networks. As well as the confidentiality of the data, they noted that the configuration information was also confidential. In essence, a neural network is defined by the latter type of information.

4.7 Perception Layer

In our proposed framework, the perception layer is closest to the physical layer. It is composed of IoT devices that interact with the outside world. Various IoT devices, such as wearable sensors, mobile phones, and environmental sensors, are used to collect data.

4.8 Workflow

Figure 2 illustrates a typical workflow of the proposed framework which is presented using Business Process Model and Notation (BPMN). In the proposed framework, the following actors are involved:

- User
    - IoT device (Sect. 4.7)
    - IoT gateway (Sect. 4.5)

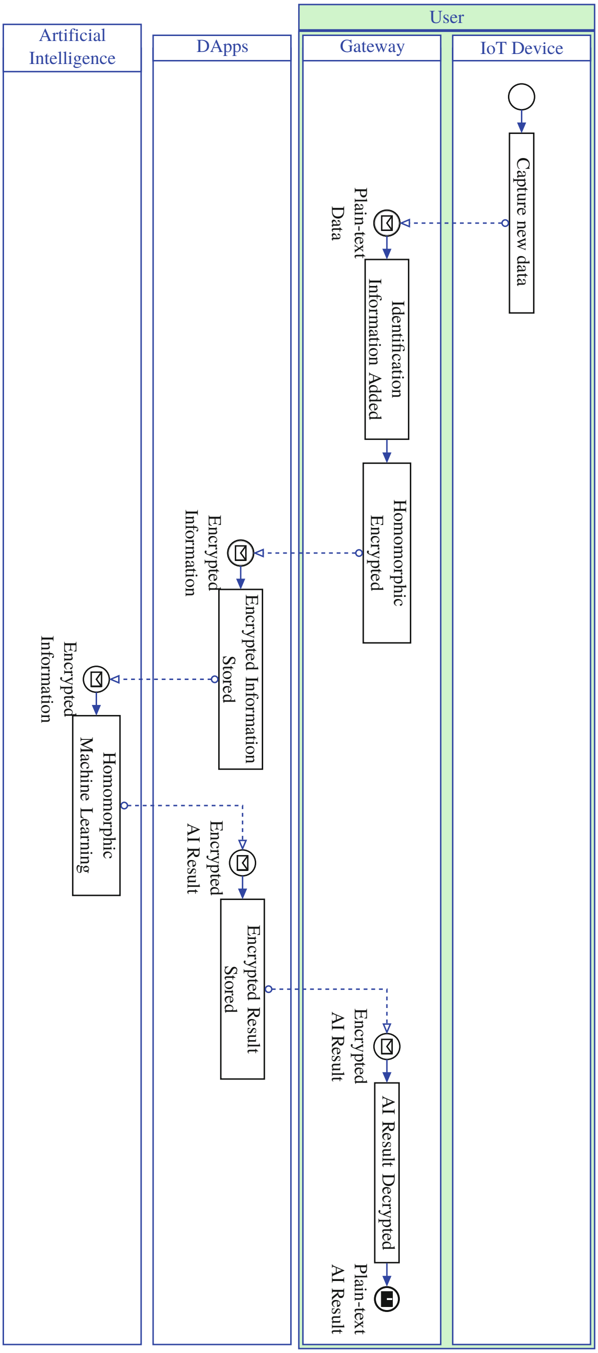

Fig. 2 General workflow of the proposed blockchain-based secure framework for homomorphic AI in IoT networks

- DApps
  - Distributed storage (Sect. 4.4.1)
  - Smart contracts (Sect. 4.4.2)
- AI (Sect. 4.6)

The relationship between distributed storage and smart contracts is not depicted to simplify the workflow. Data arriving at DApps, either from IoT gateways or AI, is verified for integrity using their hash values. Afterward, the contents are sent to the distributed storage system for storage. This produces a hash value of the contents as well as a unique address for retrieval.

As a first step, data is collected in IoT devices, e.g., measuring heart rate using an IoT pulsometer. Plain data is transferred to the gateway for formatting. Where the data is encrypted, and anonymized identification is generated and sent to DApps. Prior to sending the message to the distributed storage for the purpose of storing the cryptogram of the new data, smart contracts verify its integrity. The AI component can access the cryptogram using a publicly available address when it is stored. A homomorphic machine learning algorithm may be applied to the cryptogram by the AI component, and the data may be sent back to the DApps for storage. Similarly, DApps store encrypted AI results in distributed storage using the same approach. By using the user's key, the user is able to access the encrypted AI result and decrypt it in order to gain access to the AI results.

5 Security Evaluation

Our analysis of the proposed framework's security aspects is presented in this section. Table 1 summarizes the notations used in this section.

5.1 Formal Description

5.1.1 Proposed Framework

In the proposed framework, an IoT device generates data d. The latter is processed in the IoT gateway by adding the anonymized identification information h_{id} and encrypting the message with the homomorphic encryption scheme ($c_d \leftarrow E(d)$). The collection of these messages creates a message m to be stored in the blockchain.

When the message has been evaluated for integrity, it is transferred to distributed storage. It provides a unique address a_m that can be used for further access to the message. The blockchain stores the hash of the data, the anonymous identification information of the owner, and the address that can be accessed by the user through smart contracts.

Table 1 Notations used in formal modeling of the proposed secure framework for homomorphic AI

Notation	Description
d	Raw data
$E(m)$	Encryption on message m
c_m	Cryptogram on message m
$D(c)$	Decryption of message m
$AI(m)$	Classification of message m
r	Result of AI
$H(m)$	Secure hash digest on message m
h_m	Digest value of message m
a_m	Address of message m in the distributed storage
u	User of the system
$Own(u, m)$	Is u the owner of message m
$Acc(u, m)$	Has u read access to message m
$\mathcal{M}$	The set of all messages
$\mathcal{T}$	The set of all transcations
$\mathcal{U}$	The set of all user
π_{c_x}	The key related to the cryptogram c_x

As new information becomes available, smart contracts inform the AI component. Using distributed storage, AI accesses the data. AI verifies the hash value of the message before any other process is performed. Then, AI performs a machine learning algorithm on the encrypted data ($c_r \leftarrow AI(c_d)$). A similar process is followed for the processing and storing the new data after these data have been transferred back to the smart contracts.

Smart contracts notify the user via their IoT gateway that machine learning results are available. Through the IoT gateway, the encrypted result h_r is retrieved using the address a_r. The encrypted result is decrypted $r_d/getsD(c_r)$ after verifying the hash value.

Despite the fact that the decrypted result is the result of machine learning algorithms on the data d itself, $r_d = AI(d)$, the AI component does not have access to the data d directly. Figure 3 summarizes the logical flow of the proposed framework.

5.1.2 Requirements

There are three main broad security requirements that must be addressed in any framework: (1) Confidentiality: Data may only be accessed by authorized entities. (2) Integrity: only authorized entities are permitted to modify data. (3) Availability: authorized parties have access to the system at all times. It is necessary to agree on the authorized entity for all security concerns mentioned above. Data owners are the only individuals authorized to access their data and derivatives of their data under our proposed framework. Moreover, since the IoT data are essential to be preserved

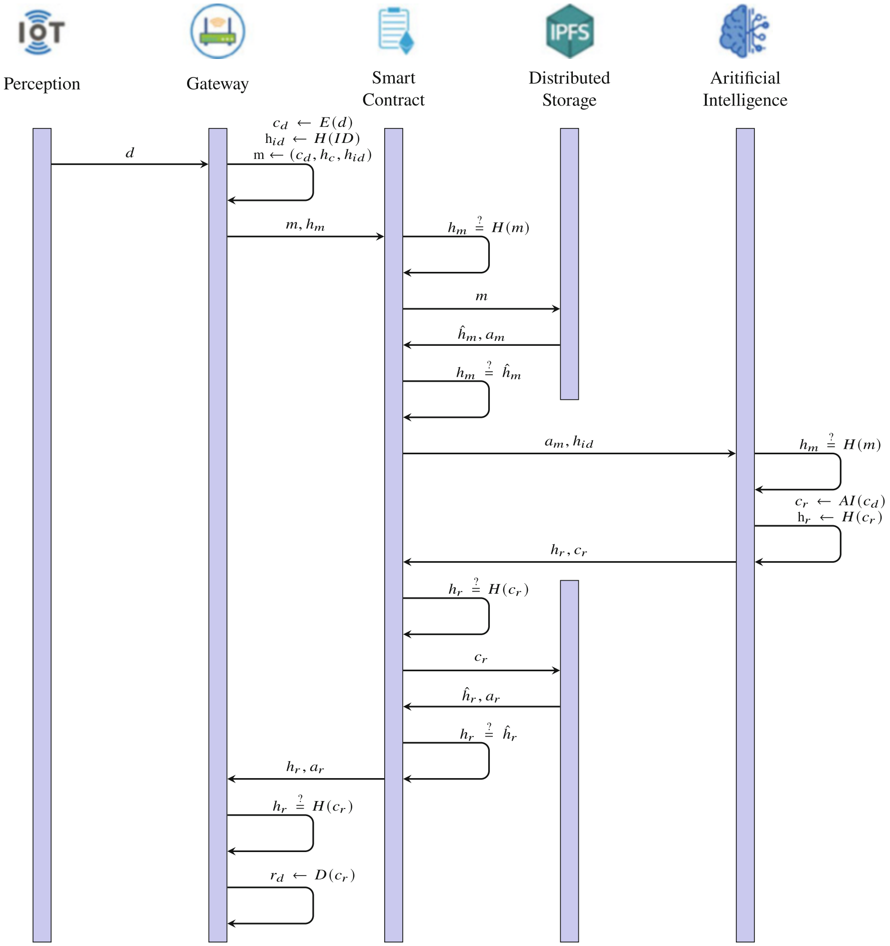

Fig. 3 Logical flow execution of the proposed framework

for historical purposes, no entity is permitted to modify the data once it has been incorporated into the framework.

Based on the above assumptions, the security requirements of R1:ownership, R2:transparency, R3:confidentiality, and R4:integrity discussed in Sect. 4.1 are formalized as follows:

$$\text{R1} : \forall m \in \mathcal{M}, \forall u \in \mathcal{U} : Own_t(u, m) \Rightarrow Own_{t+1}(u, m) \tag{2}$$

$$\text{R2} : \forall e \in \mathcal{T}, \forall u \in \mathcal{U} : Acc(u, e) \tag{3}$$

$$\text{R3} : \forall m \in \mathcal{M}, \forall u \in \mathcal{U} : Own(u, m) \iff Acc(u, m) \tag{4}$$

$$\text{R4} : \forall m \in \mathcal{M} : m_t \implies m_{t+1} \tag{5}$$

5.1.3 Assumptions

We have presumed that the IoT gateway is secure throughout the proposed framework. Our framework relies on the security of the cryptology algorithms that are used. Hence, we assume that the homomorphic encryption schemes and hash functions in this framework are secure. Furthermore, we assume that blockchain technology ensures data integrity and availability, as discussed in Sect. 2.1. This formal proof relies on the following assumptions:

- Because of the blockchain's intrinsic feature, any data in the blockchain will remain intact over time (Eq. 6).
- Any data in the blockchain are publicly available for all the users (Eq. 7).
- Blockchain logs all traces of the transactions in an immutable ledger (Eq. 8).
- The hash values of two different messages are never identical (Eq. 9).
- Only with having the encryption key, a user can get plain text data from a cryptogram (Eq. 10).
- Only the data owner has the encryption key (Eq. 11).

$$\text{BC1} : \forall x \in blockchain : x_t \Longrightarrow x_{t+1} \tag{6}$$

$$\text{BC2} : \forall x \in blockchain, \forall u \in \mathcal{U} : Acc(u, x) \tag{7}$$

$$\text{BC3} : \forall e \in \mathcal{T} : e \in blockchain \tag{8}$$

$$\text{DS} : \ H(m_1) = H(m_2) \iff m_1 = m_2 \tag{9}$$

$$\text{E1} : \ \Big(Acc(u, c_x) \Rightarrow Acc(u, x)\Big) \Leftrightarrow Acc(u, \pi_{c_x}) \tag{10}$$

$$\text{E2} : \ \forall u \in \mathcal{U} : Acc(u, \pi_{c_x}) \Longrightarrow Own(u, x) \tag{11}$$

5.2 Formal Verification

5.2.1 Integrity

The integrity of the proposed framework can be formalized as $\forall m \in \mathcal{M} : m_t \Longrightarrow m_{t+1}$. As mentioned in Sect. 5.1.1, each data arriving in the blockchain is hashed and verified with the provided hash value. If the two hashes match, the data is stored in the distributed storage, whereas its hash value and its address are stored on the blockchain (m_0). Due to the immutability of the data in the blockchain, we can conclude that $H(m)_t \Longrightarrow H(m)_{t+1}$. For a message in the distributed storage to be changed from m to $H(\hat{m})$, its hash value should be updated to another value in the next timestep $H(\hat{m})_{t+1}$ (Eq. 12). Based on the immutability of blockchains and the characteristics of hashing algorithms, the integrity of the message in the proposed framework is formalized as follows:

$$
\begin{aligned}
&\exists m, \hat{m} \in \mathcal{M} : H(m)_t \implies H(\hat{m})_{t+1} \\
&\text{Eq. 6} : \forall m \in \mathcal{M} : H(m)_t \implies H(m)_{t+1} \\
&\implies \quad H(\hat{m})_{t+1} = H(m)_{t+1} \\
&\text{Eq. 9} : \forall m_1, m_2 : H(m_1) = H(m_2) \iff m_1 = m_2 \\
&\implies \quad \hat{m} = m \\
&\implies \quad m_t \implies m_{t+1} \\
&\implies \quad \forall m \in \mathcal{M} : m_t \implies m_{t+1}
\end{aligned} \tag{12}
$$

5.2.2 Ownership

Each data record stored in the proposed framework is associated with an anonymous identification number h_{id}, which corresponds to the data owner. Similar to the proof above, this value is stored in the blockchain, allowing the following to be proven:

$$
\begin{aligned}
&Own(u, m) \iff h_{id} \\
&Eq.\,12 : h_{id_t} \iff h_{id_{t+1}} \\
&\implies \quad \forall m \in \mathcal{M}, \forall u \in \mathcal{U} : \hookleftarrow \\
&\qquad Own_t(u, m) \implies Own_{t+1}(u, m)
\end{aligned} \tag{13}
$$

5.2.3 Transparency

In this proof, we rely on the transparency and availability characteristics of blockchain, formalized in Eqs. 7 and 8, respectively. Due to the immutable nature of blockchain transactions, it is possible to demonstrate the transparency of the framework as follows:

$$
\begin{aligned}
&\text{Eq. 7} \quad : \quad \forall x \in blockchain, \forall u \in \mathcal{U} : Acc(u, x) \\
&\text{Eq. 8} \quad : \quad \forall e \in \mathcal{T} : e \in blockchain \\
&\implies \forall e \in \mathcal{T}, \forall u \in \mathcal{U} : Acc(u, e)
\end{aligned} \tag{14}
$$

5.2.4 Confidentiality

In the proposed framework, data is always presented in encrypted form, except before the IoT gateway, which we assumed to be secure. No one can access the cryptogram in accordance with the security of the encryption scheme, which illustrates the confidentiality of the proposed framework. Our indirect proof for confidentiality is that there is an unauthorized user $\hat{u}$ who has access to the message m (Eqs. 15 and 16). Since we assumed that the IoT gateway is secure, the user $\hat{u}$ has access to the message through the blockchain (Eq. 16). Nevertheless, based on the encryption scheme's security characteristics (Eq. 10), the assumptions are contradicted and the confidentiality has been demonstrated (Eq. 17).

$$\begin{aligned} & \exists \hat{u}, m : Acc(\hat{u}, m) \wedge Own(\hat{u}, m) = false && (15) \\ \Longrightarrow \quad & \exists \hat{u}, m : Acc(\hat{u}, c_m) && \\ \Longrightarrow \quad & Acc(\hat{u}, m) \wedge Own(\hat{u}, m) = false && (16) \\ \text{Eq. 10, 11}: \quad & \Big(Acc(\hat{u}, c_m) \Longrightarrow Acc(\hat{u}, m)\Big) \Longrightarrow Own(\hat{u}, m) && \\ \Longrightarrow \quad & \bot && (17) \\ \Longrightarrow \quad & \forall m \in \mathcal{M}, \forall u \in \mathcal{U} : \hookleftarrow && \\ & Own(u, m) \Longleftrightarrow Acc(u, m) && \end{aligned}$$

5.2.5 Availability

Due to the distributed system of blockchain, storage, and artificial intelligence, a single user cannot deprive others of computational resources in the proposed framework. Our proposed framework will generally be available as long as a sufficient number of distributed nodes is maintained.

The addition of homomorphic encryption will inevitably diminish the performance of the system; however, this depends on the particular homomorphic AI employed. For example, the overhead can be 0.72 seconds [33]; this is acceptable given the limited throughput of public blockchain, which is between 3–15 transactions per second [34].

6 Use Case: COVID-19 Monitoring

The identification of any ailment, whether overwhelming or not, as early as possible is crucial for the treatment of the condition in order to save as many lives as possible [35]. The use of rapid detection and screening measures will prevent the spread of pandemic contamination, including COVID-19, on the ground and accelerate the associated assurance process. The healthcare system is already overburdened in the event of a pandemic; therefore, it is vital to create a substitute system for diagnosing the disease. Given the advancement of AI and IoHT, this combination could result in promising results with minimal burden on the health sectors [8, 9, 35].

As with COVID-19, critical vital signs, such as body temperature and oxygen saturation, can be collected by IoHT. They help identify whether or not the infection is present and its identification the severity of the illness [5]. The AI providers prefer not to disclose their knowledge and details under such circumstances, where the knowledge of the disease is incomplete and constantly improving. However, both individuals and governments are skeptical of sharing sensitive medical information.

In the proposed secure framework for homomorphic AI, the IoHT data are homomorphically encrypted. These data can be analyzed using homomorphic AI on the encrypted data without decrypting them. The AI results are also encrypted, and only the holder of the key to the homomorphic encrypt scheme, i.e., the data owner, can decrypt it. Therefore, the proposed framework enables individuals/governments to use AI to analyze the medical data for diagnosis of COVID-19; without leveraging their privacy. Moreover, the analysis results, i.e., if the patient is contaminated and the stage of contamination, are kept private for only the individual who requested the analysis.

In addition, in the healthcare sector, especially during pandemics, the availability and integrity of service can impact lives. In the proposed framework, the use of blockchain would guarantee the availability and integrity of such services. Blockchains are based on digital signatures and distributed systems.

7 Conclusion

The global healthcare sector has faced new challenges as a result of pandemics such as COVID-19. There were many uses of AI and IoHT during the recent pandemic to assist the population. There are security concerns in international cooperation that prevent AI from being implemented in IoHT services. The primary concerns are believed to be the confidentiality of data, the technological edge of AI providers, the integrity, and the availability of services. Blockchain can address the concerns of availability and integrity. However, it lacks enough solutions for the confidentiality of data. A common practice is the use of asymmetric encryption, which presumes the trustfulness of the data recipient. However, in the case of AI outsourcing, the service provider might not always be trusted. To address security concerns, we propose a blockchain-based framework for homomorphic AI in IoT networks in this chapter. Our proposed framework emphasizes AI as the core computation of IoT networks. Based on the technology of blockchains and distributed storage, the proposed framework ensures integrity and availability in a decentralized network. As part of the proposed framework, homomorphic encryption is employed to enable privacy-preserving computation, mainly for AI applications. Furthermore, the proposed framework is formally demonstrated to meet the IoT-based computation's security requirements. To evaluate the proposed framework, we present a use case for diagnosing and monitoring COVID-19 during a pandemic. Furthermore, we discuss how the proposed framework can provide a secure platform for collaborating within untrusted entities during pandemics. However, other quality aspects, such as latency and computational overheads, must be studied in future works. Moreover, a realistic implementation of this framework for comprehensive experiments is planned in future studies.

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Blockchain-Based Solution for Patient Health Records Sharing by Adopting Private Decentralized Storage

Meryem Abouali, Kartikeya Sharma, and Tarek Saadawi

1 Introduction

The recent Covid-19 pandemic has pushed the healthcare system to adopt various IT technologies [1], posed a lack of interoperability, and obliged the providers and healthcare organizations to proceed toward embracing new technologies and standards in no time [2]. Furthermore, the fight against the Covid-19 outbreak proves that efficient health record sharing and access to data among different healthcare systems can improve the patient's health, facilitate effective health resource allocation, and mitigate medical errors [3]. The healthcare sectors disclosed that advancing interoperability is essential to most healthcare activities by fusing patients' healthcare data into one platform for providers to quickly identify the root of a patient's conditions and empower them to make more informed and faster decisions [4]. Furthermore, broadening data interoperability will reduce the time it takes to diagnose patients' conditions by presenting data to care providers in real-time and consistently. Hence, interoperability will boost efficiency across healthcare sectors, making data sharing efficient, and the providers will have enough time to treat more patients in less time. In addition, it will eventually help improve patients' health experience, with healthcare organizations gaining access to improved tools and better information as technology evolves. Furthermore, accessing advanced technology regarding patient health records sharing would create a better work balance and access to more complete patient data for the providers and reduce administrative load.

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As we walk away from the Covid-19 pandemic, we must ensure that accessing accurate information is essential to patients' health [5]. Thus, all stakeholders of the healthcare organizations must collaborate efficiently and improve the interoperability among them by implementing the right technologies to have secure patient health records sharing and a professional working system. Hence, healthcare sectors must invest in public health by encouraging reform toward more resilient health systems, better centered around what patients need and sustainable over time. Although the patient health records sharing process in many healthcare organizations has become automated, many healthcare systems still perform this process manually [6]. In addition, the lack of coordination among various healthcare organizations and inadequate technical infrastructure impacts the access to and examination of medical records. Therefore, many patient health data require more security and privacy protection.

One major problem the healthcare system faces today is unauthorized access to patients' health data containing some of the most sensitive patient information. Thus, it makes the healthcare system a prime target for cybercriminals. From a security standpoint, the healthcare system is inadequately prepared to deal with hackers seeking access to highly confidential data and demanding payment in return. This results in the reduction of patient trust, crippling the healthcare system and threatening humans [7]. The exploitation of the vulnerabilities in the healthcare system can result in the healthcare sector undergoing much pressure to deliver good services and can be extremely damaging to the day-to-day operations of the health data system by blocking access to files [8]. While healthcare practices oversee sensitive patient health records, security must be considered their top priority by adding multiple layers of security and protection [9]. Currently, healthcare practices depend extremely on technology to deliver the appropriate care. However, they must implement the right technology and protocols to prevent cyber threats and safeguard these practices.

This chapter's remainder is structured in the following manner: Section 2 describes background knowledge. Section 3 presents the motivation. Section 4 presents the related work. Section 5 describes the system implementation. Section 6 discusses the security and privacy aspects of the developed system. Finally, Sect. 7 presents the conclusion and possible future work.

2 Background Knowledge

This section contains a brief technical background that explains the most prominent technologies forming the developed system.

2.1 Ethereum Blockboard

Besides being distributed, Blockchain is secure by design and resilient to node failure, misbehaviors, or malicious acts. These characteristics made it appealing for many applications, such as medical records and identity management [10]. It is a technology that uses distributed ledger. Blockchain is an information storage and transmission technology that is transparent, secure, and operates without a central control body. Also, a blockchain is a data structure where the records are stored in a linked sequence of blocks, making it harder to modify or change the blocks without changing the hash value. When a transaction is made, it will be recorded and added to a block. Blockchain data cannot be changed or altered, making it relevant for ensuring security in healthcare [11].

The Blockchain refers to a trustless, decentralized transaction database, also known as a ledger, maintained by a group of nodes called miners; each node runs a consensus protocol. The Ethereum blockchain used in this system is public, a non-restrictive, permissionless distributed ledger system. There are no restrictions over nodes joining the network and performing operations like accessing records, verifying transactions, or doing proof-of-work and mining. The data on the public transaction chain is still safe because the transaction has been verified by the node and is immutable [12]. Therefore, everybody is allowed to participate. Furthermore, users can generate a set of keys and an address that enables them to interact with other entities in the blockchain network. Therefore, everybody has the right to create transactions and append information to the ledge. It needs an incentive system to ensure the correct functioning and existence of the network. The incentives are in the form of rewards and fees. Ethereum has a built-in currency, called ether (Fig. 1).

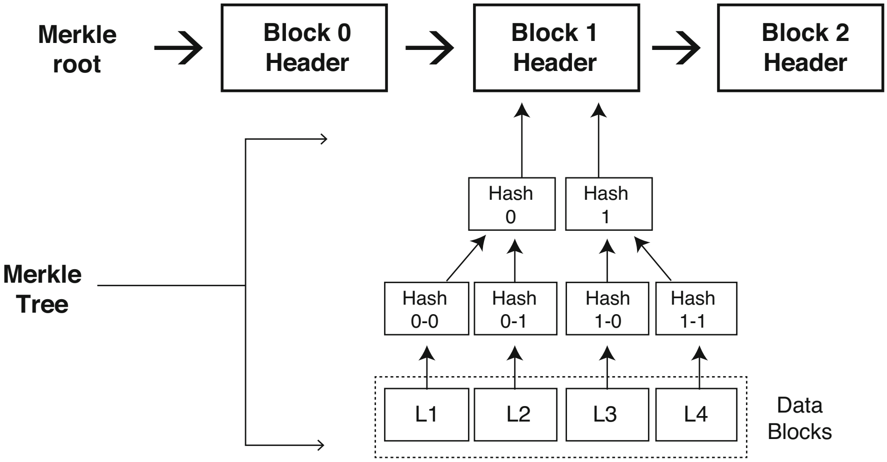


Fig. 1 Linking of blocks using the hash value of the previous block [13]

2.2 *Private Interplanetary File System (PIPFS)*

It is a protocol and peer-to-peer distributed network to connect all devices with the same file system. A private Interplanetary File System (PIPFS) uses content addressing to identify files in a global file system uniquely. In other words, the Private Interplanetary File System provides a high throughput content-addressed distributed file system forming a generalized Merkle Directed acyclic graph (DAG). PIPFS uses the hash of files to uniquely identify them, so if somebody uploads two files with the same hash value. IPFS pin them to the server, creating only one entry in the content-addressed storage block. IPFS has no single point of failure. IPFS has no access control, and hash values can directly access files over IPFS. This makes it easier to integrate with different blockchains as an off-chain storage solution where blockchain act as an access control system [14]. The essential components in IPFS have distributed hash tables, Block Exchanges, and Merkle DAG. Retrieving a file can be carried out through the peers in the network using a cryptographic hash or unique fingerprint of the file using the content addressing property of IPFS. In private IPFS, each node indicates the nodes that can connect with them and do not communicate and respond to outside nodes in the network. This results in complete protection from public monitoring [15]. Furthermore, it is distributed, and the data may be accessed from any nodes participating in the network, which ensures availability. The scalability of the private IPFS can be realized if the network's topology can be specified and built as desired [16]. Concerning this work, private IPFS is used to solve the issue of blockchain-limited storage size and store infinite health records off-chain.

2.3 *NuCypher*

NuCypher is a software aiming to provide a security and privacy layer for decentralized applications built on public blockchains, such as Ethereum. NuCypher enables developers to store, share, and manage private data and aims to add an interoperable security layer to various blockchains where developers can grant permission to sensitive information on several Dapps. NuCypher KMS provides encryption and cryptographic access controls without reliance on a central service provider. It leverages state-of-the-art proxy re-encryption technology to allow the re-keying of encrypted data. This allows a decentralized network of nodes to provide key management operations without accessing private keys or plaintext data. Moreover, with the Ethereum system, interoperability is streamlined, security is assured, and storage can be leveraged. It allows users to share encrypted data without sharing private keys or decrypting data in transit. The platform offers two main services: a private key management system and a dynamic access control service. NuCypher is an extra encryption layer known as a proxy- re-encryption allowing developers to share data among themselves securely and without breaches.

Furthermore, NuCypher serves as added security and privacy layer for decentralized applications [17]. The protocol, a decentralized key management system (KMS), aims to give developers the ability to store, share, and manage private data on public blockchains. Developers receive this encryption service via a network of NuCypher nodes in exchange for a fee paid in ETH [17]. In addition, NuCypher is intended to modernize data security infrastructure while emphasizing compliance with internal security policies and regulatory requirements. The banking and healthcare sectors that deal with a huge volume of details leverage the advantages of the NuCypher privacy encryption system.

2.4 Ethereum Smart Contracts

Smart contracts are digital programs based on the blockchain consensus architecture, which are self-executing chain codes when the terms of the agreement are met without the involvement of an intermediary by encoding the rules of certain network transactions. Furthermore, the smart contract makes the transactions traceable, transparent, and irreversible. Currently, it is written in the Go language, installed and initiated by authorized participants on channel peers. Moreover, the decentralized structure of the smart contract makes it self-enforcing and tamper-proof [18]. It is a computation triggered by a transaction. Once the contract is deployed, it cannot be changed. All blockchains have built-in contracts that implement their transaction logic. The information tampers proof, and encrypted transaction logs are exchanged among participants. It helps to make the transactions occur securely and function in an organized manner. In addition, the smart contract integration with Blockchain allows for flexible and logical design for real-time word problems such as storing and exchanging electronic health records [19].

2.5 Proxy Re-encryption (PRE)

A proxy re-encryption is a cryptographic approach that permits a semi-trusted proxy server to re-encrypt the ciphertext encrypted by one user's public key into another ciphertext without disclosing the secret message to the proxy. In other words, the Ursulas in the proxy re-encryption is standing ready to envoy decryption rights from one secret key to another by eliminating the reliance on central service. It only permits the data to be perceptible to the owner [20]. In our system, the patient conveys a message to the provider through a semi-trusted proxy server without sharing the patient's private key with either the proxy or the provider and without revealing the secret message to the proxy shown in Fig. 2. It will enable a proxy to transform a ciphertext encrypted under one key into an encryption of the same message under another key. The proxy re-encryption aims to perform its transaction without releasing much information about the users. We used a timing-enabled

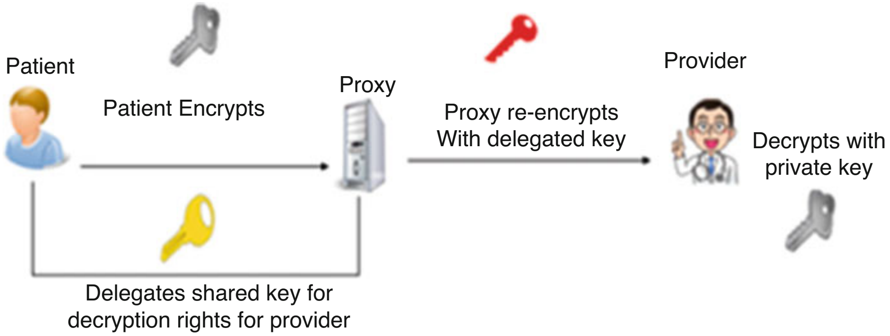


Fig. 2 The interaction in the PRE environment between patient and provider

proxy re-encryption system where the patient sets an expiration time during which the provider can retrieve the records. Otherwise, if the provider is not able to get hold of the records before the time is up, the patient has to create another access policy for the provider [21].

3 Motivation

This chapter emphasizes the security part of patient health record sharing. With the expansion of big health data, a common solution is outsourcing large volumes of data to third parties like cloud storage which poses the threat of either data breach or leakage of sensitive information to unauthorized entities. Hence, the privacy and security of health data sharing is a major barrier when outsourcing private data to a third party. So, to ensure that only legitimate and authorized users have access to health records, we developed a system that will ensure the privacy and security of the sharing. Furthermore, our solution overcomes all the issues and limitations traditional frameworks suffer. Furthermore, to ensure our preparedness to react to future crises [22], the elevated examination level must enhance transparency and clearly define who is authorized to access the data and who does not.

Our developed system conquers most of the limitations. Furthermore, it improves access to health data by designing a comprehensive system where all the components are distributed to facilitate smooth data-sharing between patients and providers and the patient care journey [23]. We need a neutral and universal infrastructure linking this healthcare system to avoid data fragmentation and enable the providers to understand individual patients better while having an entire perspective on the situation [24]. Thus, we need to be more effective with the data we collect and share by creating a system that connects patients with their providers and allows for sharing their data securely and preserving their privacy. This chapter describes a system that would ease the stress between the patient and the provider. It calls for the use of modernized technologies and the adaptability of the open platform to improve the care delivery of patient health data beyond the Covid-19 pandemic [25].

Our developed system can serve as a prototype system that can be customized to fit other industrial fields and solve their security challenges. Providers must take advantage of our developed system to overcome the health data sharing gap and data fragmentation to avoid a future healthcare crisis [26]. Although no healthcare organization can go on irresistible from cyber-attacks, various steps must be taken to decrease the chance of being a victim of a patient data breach. Thus, it is important to use secure and compliant systems to mitigate the risk of cyber-attacks on healthcare systems. Therefore, IT professionals need to put the required preventive measures in place and balance protecting patient safety, promoting the development of innovative technology, and being ready to react to such attacks.

Our developed system will ensure that the patient PHRs collected from various healthcare entities and stored on the patient's private IPFS will be shared securely with any authorized provider promptly [27]. Furthermore, the scheme uses smart contract technology to implement access delegation of patient health record sharing. Thus, patient-centric access control allows patients to set the policy about who has the right access. In this chapter, we take into consideration the preservation of patient privacy when developing this healthcare system. At the same time, granting the patient full control over his health records sharing with an authorized provider.

4 Related Work

The pandemic accelerated technological advancement and its adaptation in the healthcare industry. If not for the pandemic, it probably would have taken the healthcare industry another decade to reach where it is today. Moreover, the lack of data sharing between providers and providers- patients becomes problematic. To help increase access to care and improve the overall healthcare industry for both healthcare systems and patients, a well-developed system that can overcome all the challenges can be implemented to enhance data sharing. Furthermore, many approaches were developed to ensure security and HIPAA compliance regarding patient data and information sharing across medical providers. However, the healthcare system still faces major challenges concerning the security and privacy of the data. Therefore, securing data sharing within the healthcare sector becomes necessary. In this sector, we will examine some approaches related to patient data sharing.

The authors in [28] propose an approach that implements the access management protocol and take advantage of the cloud service for electronic health records. The scheme presents a secure architecture that permits the patient and the provider to access data. Furthermore, the framework is scalable, where that data is stored in the cloud, reassures end-to-end privacy, and facilitates data sharing between patients and providers. Furthermore, the scheme enforces the access control process by using an authentication mechanism and check of user permissions. However, no privacy is guaranteed, as no authorized user can access the data.

The authors in [29] present a framework based on the Hyperledger Fabric blockchain to allow authentication and authorization mechanisms. The framework makes use of the smart contract logic to store the to enforce access control to PHR. HIPAA-compliant cloud storage ensures the stored data's integrity, confidentiality, and availability. The framework is scalable with the key management system that allows the patient to upload one encrypted record and share it with many providers. The patient would only have to upload the data once and share the records with more than one provider. However, no evaluation of the performance metrics has been made to test the framework's performance.

The authors in [30] present a blockchain-based architecture for patients' electronic health systems that enhances interoperability, security, and privacy and allows real-time data access. The providers assist by validating health data in the mining process. In addition, this architecture uses the smart contract to deny access and perform a proxy re-encryption service to share the encrypted health data among providers. However, the architecture needs to be tested in terms of scalability, and the patient needs control over his health data.

The authors in [31] propose a framework based on the Hyperledger blockchain to handle a patient's health data. The framework implements an access control management mechanism, cloud storage, and user interface. The encrypted data is stored on the cloud, while the generated hash is stored on the Blockchain. However, this framework still needs to overcome the issue of interoperability.

The authors in [32] present a Hyperledger fabric blockchain based on electronic health records-sharing system between patients and providers. All users must be registered in the system of the network are registered in the system. The performance of the system is examined.

However, the system uses a centralized approach. Our system is unique from the previous approaches because it guarantees data security by implementing multiple authentication factors. Although the above and existing approaches have implemented the same technologies to share patient health records, our novel system provides additional steps and the latest technologies to ensure no unauthorized provider can access the patient health records.

5 Developed Model and Its Implementation

This section introduces our novel system using accountable schemes for securing data-sharing mechanisms and discusses all the system's essential components. The stakeholders of the system are described as follows:

- The patient—is the data owner
- Healthcare entities—the data encryptors. They decrypt patient data and upload it to private IPFS.

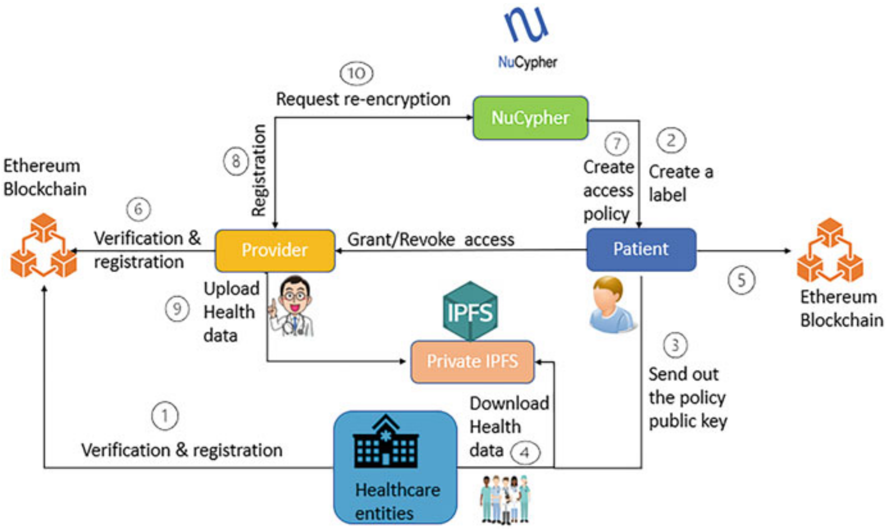


Fig. 3 The developed framework architecture

- Provider—the data receiver. He retrieves data after he gets authorization from the patient to access data
- Ursula is a node in the NuCypher network that receive information about a user policy governing access to his encrypted data and is rewarded for re-encrypting.

During the Covid-19 pandemic, patients' data was fragmented among several healthcare systems leaving patients under total stress when they desire access to their health data and sharing it with their healthcare providers. Therefore, we must design and develop a novel healthcare system that can preserve the privacy and security of sensitive data where patients can collect their health records on their private IPFS and get a hold of all the prior health records. Once healthcare entities have received the public policy key from the patient, they can encrypt the patient data and upload the encrypted data and the encrypted symmetric key to the patient's private IPFS. Thus, the reference to the location of the encrypted data is generated and pushed to the Blockchain. Then the patient can share his health record with as many providers as he needs without consulting with the healthcare entities (Fig. 3).

Our system lets patients fully engage in their health decision-making by controlling their data. Thus, it permits patients to participate and actively participate in their health, have a direct connection with their health providers, and contributes to improving their health and well-being. Thus, the patient's private IPFS can serve as his own data storage where he can share his health history with any provider from anywhere in the globe. Now, the provider can access the patient data after he gains permission from the patient to retrieve the encrypted data. Next, the provider can decrypt the data after requesting the re-encryption from the NuCypher Ursula. Then, the provider uses his private key to decrypt the symmetric key. This

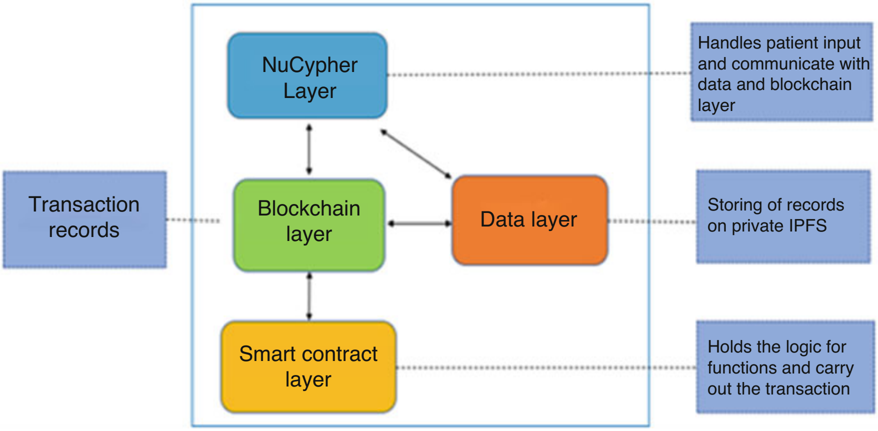


Fig. 4 System design

process allows authorized providers to access data in real-time and make efficient patient health decisions. Finally, our system coordinates care among providers and improves patients' experience of receiving excellent care. The system's purpose is to provide the patient with the tools to control his data fully.

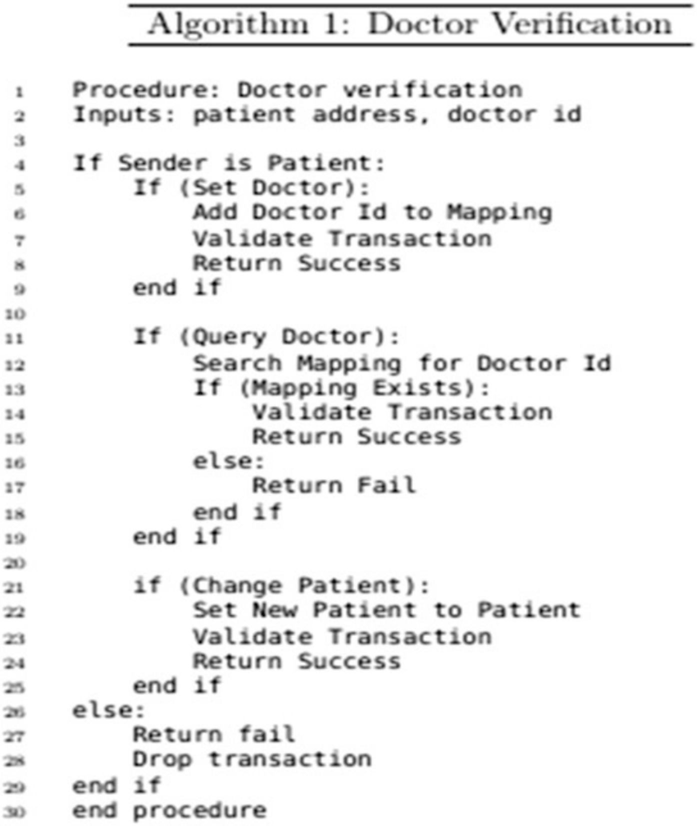
The system can be divided into four essential layers: the NuCypher layer, the Blockchain layer, the Smart contract layer, and the data layer. In the coming section, we will discuss each layer's role and components and how they communicate with each other according to Fig. 4.

Our developed framework consists of four layers:

5.1 Smart Contract Layer

The smart contract handles the provider and the healthcare entities' verification and authentication. The purpose of verifying and authenticating the provider and the healthcare entities is to ensure that no unauthorized entity has to access the sensitive data. Furthermore, the smart contract is initiated by the patient, and it is part of the smart contract layer. The main functionality is to ensure that any submitted information from the provider contains the correct information. Thus, the smart contract reviews and matches the provider information against the ones submitted by the patient.

The purpose of managing the provider's access is to ensure that the provider is assessing only the required data. If the provider fails to provide the required information, access is denied. Patients can approve or deny the provider access to their health records. After getting approved, the provider can get the reference location of a patient's data and retrieve data from the patient private IPFS in the



Algorithm 1: Doctor Verification

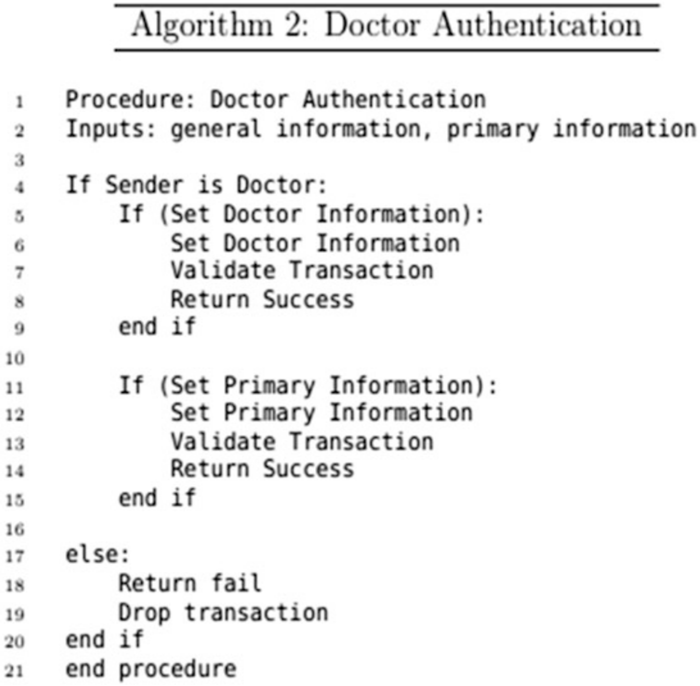
```
Procedure: Doctor verification
Inputs: patient address, doctor id

If Sender is Patient:
    If (Set Doctor):
        Add Doctor Id to Mapping
        Validate Transaction
        Return Success
    end if

    If (Query Doctor):
        Search Mapping for Doctor Id
        If (Mapping Exists):
            Validate Transaction
            Return Success
        else:
            Return Fail
        end if
    end if

    if (Change Patient):
        Set New Patient to Patient
        Validate Transaction
        Return Success
    end if
else:
    Return fail
    Drop transaction
end if
end procedure
```

Fig. 5 Smart contract deployed by the patient for verification

data layer. In our work, we used three smart contracts, one initiated by the patient to do provider verification and the other deployed by the provider and the healthcare entities for the authentication process, respectively. Figure 5 shows Algorithm 1, which describes the snippet of the smart contract that handles the provider. In contrast, Figs. 6 and 7 show Algorithms 2 and 3, which handle the healthcare entities and the provider authentication process.

5.2 Blockchain Layer

The blockchain layer performs the verification and authentication of the entities. Authenticating the provider ensures that all transactions are sent from an authorized entity and recorded in the Blockchain. Furthermore, the healthcare entities perform a hash calculation on the patient health records, and the reference to the data location



Algorithm 2: Doctor Authentication

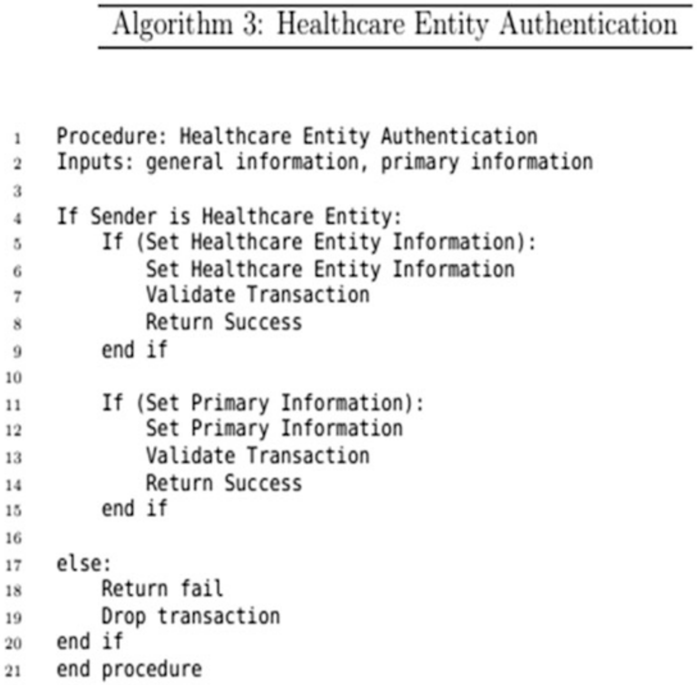
```
Procedure: Doctor Authentication
Inputs: general information, primary information

If Sender is Doctor:
    If (Set Doctor Information):
        Set Doctor Information
        Validate Transaction
        Return Success
    end if

    If (Set Primary Information):
        Set Primary Information
        Validate Transaction
        Return Success
    end if

else:
    Return fail
    Drop transaction
end if
end procedure
```

Fig. 6 Smart contract deployed by the provider for authentication

is pushed to the Blockchain to guarantee its integrity and legitimacy. The authorized provider's attributes are checked against the access policy; if it matches, he will obtain the corresponding location. The generated hash value from the encrypted health data that is stored in the patient private IPFS is stored in the Ethereum blockchain.

5.3 Data Layer

We create a Private Interplanetary File System (PIPFS) as off-chain storage to store the massive health data. The network contains four virtual machines (four nodes) using a vagrant and virtual box. They are connected through the same swim. We start each node with 'ipfs daemon' and view peer nodes with 'ipfs swam peers'. Furthermore, the hash function generates the encrypted data's hash when uploaded to the patient private IPFS and sent to the Blockchain. In contrast, the massive amount of data accompanying patient health records are stored on private IPFS. Therefore, the provider can utilize the generated hash value to retrieve the patient data. The purpose of this layer is to ensure authenticity and confidentiality.



Algorithm 3: Healthcare Entity Authentication

```
Procedure: Healthcare Entity Authentication
Inputs: general information, primary information

If Sender is Healthcare Entity:
    If (Set Healthcare Entity Information):
        Set Healthcare Entity Information
        Validate Transaction
        Return Success
    end if

    If (Set Primary Information):
        Set Primary Information
        Validate Transaction
        Return Success
    end if

else:
    Return fail
    Drop transaction
end if
end procedure
```

Fig. 7 Smart contract deployed by the healthcare entities for authentication

5.4 NuCypher Layer

To ensure the security of patient health records sharing, we implemented multiple levels of security, and NuCypher is one of them. We built it on top of the Blockchain. Its purpose is to serve as dynamic access control and secrets management to add extra security to the healthcare system [33]. In addition, NuCypher implements a threshold split key re-encryption scheme to decentralize its network. Umbral is the NuCypher threshold PRE and encryption scheme. Umbral allows data owners to give decryption rights to others and will enable users to keep data private and share information securely. Furthermore, Ursula, a chain of operating nodes, re-encrypt data for the recipients. With PRE, proxies can re-key data from one key to another without revealing any sensitive information. Moreover, NuCypher serves as a communication medium between the data layer and blockchain layer to facilitate the process of encryption and decrypting the patient data and then uploading it to his private IPFS.

The flow diagram below in Fig. 8 describes the sequence flow of the steps from the provider sending a request to the patient to having access to his data until the provider can retrieve the data from the private. IPFS, where the verification and authentication of the transaction is an essential step to ensure no leakage of

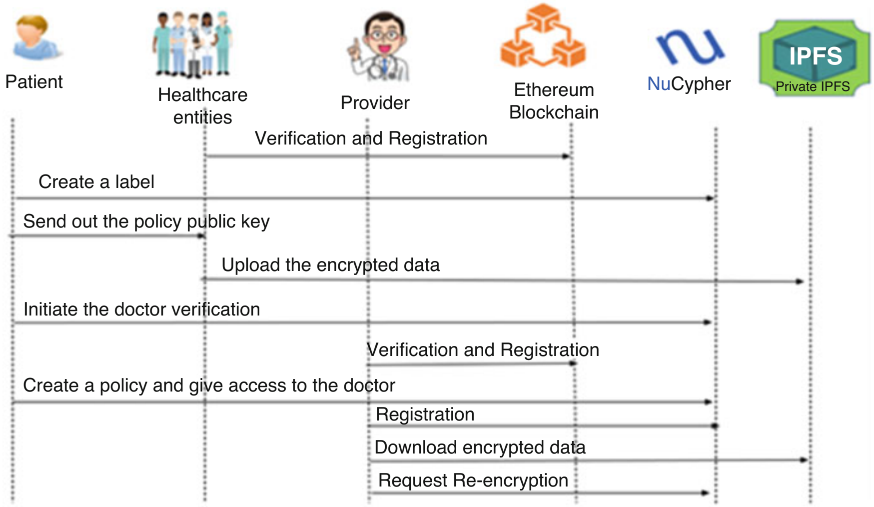


Fig. 8 Flow diagram of the developed system

vital information is happening. Hence, health data can be encrypted once under the patient key and seamlessly grant and revoke access to that data to care providers anytime.

The system's flow diagram in Fig. 8 shows the detailed steps as follows:

- The healthcare entities get verified and establish an account in the Ethereum blockchain. Then, the patient develops a label for the health record and gives away the public policy key to the healthcare entities.
- The healthcare entities generate a symmetric key to encrypt the health record. Then, the public policy key is used to encrypt the symmetric key. Finally, the encrypted health data and the encrypted symmetric key are uploaded to the patient private IPFS to lessen the burden on the network and increase the efficiency of accessing the files. This process is repeated every time the patient has a medical visit.
- The provider requests the available patient health history. Once the patient approves the provider request, the patient initiates the verification smart contract to verify the provider. After the provider gets authenticated, he can open up an account on the Blockchain and register with NuCypher.
- The patient creates an access policy for the provider by generating a re-encryption key, splitting it into n key fragments, and sending it to n Ursulas.
- The provider fetches the file that has the encrypted patient health records and the encrypted symmetric key. Then the provider requests re-encryption of the symmetric key so the provider's public key can encrypt it. Once the re-encryption process is done, the entire health records bundle is sent to the provider.

- The provider decrypts the encrypted symmetric key using his private key. Then the provider decrypts the health records using the symmetric key. Therefore, the provider gets the original patient health records. This process shows how secure the encryption and decryption of shared health records are. Furthermore, the privacy and confidentiality of the users and the health records are preserved.

6 Discussion

In this section, we examine and analyze the functional capability and evaluate the performance of our system; some test cases are explored to assess the system's effectiveness and possible challenges and limitations.

6.1 Analysis of the Security and Privacy Aspects

Our system allows patients to share their health records with their providers without sacrificing the security and privacy of data. The system is built using decentralized components. In addition, the provider authentication scheme and the use of the proxy re-encryption ensure that intruders cannot access the patient's vital data. The system takes advantage of NuCypher features to guarantee the confidentiality of the active entities and does not expose their private keys. Moreover, the patient data is kept in a distributed and decentralized private IPFS, which eliminates the reliance on trusting a centralized third party to store the data and ensures security against getting compromised by cyber-attacks like a DDOS attack.

The system benefits from using the Ethereum blockchain to trace transactions and permit the generated hash value to be stored in the chain and the encrypted data in the private IPFS. Besides, the Ethereum smart contract allows the verification and authentication of the entities. Our system guarantees one approved account for each entity which eliminates the case of Sybil attacks or impersonation attacks.

Our system is guarded against insider or outsider attackers. We implemented multiple levels of security to ensure the security of the shared health records. The decentralized nature of our framework prevents the system from being unavailable even if some nodes get compromised [34]. Therefore, it prevents the system from downtime attacks. Furthermore, we evaluated the smart contracts against vulnerabilities and fixed them to prevent attacks aimed at stealing or tampering with the assets.

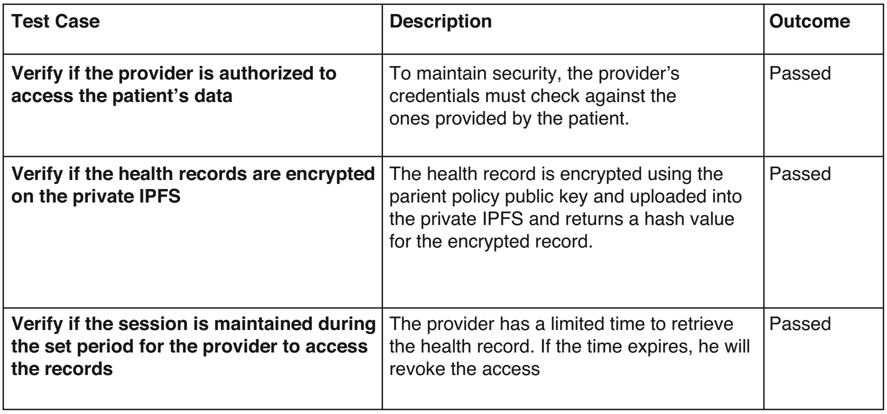
The system protects the privacy of the active entities and their identities. No sensitive information of the entities is exposed during health records sharing from the patient to the provider or stored in the database.

6.2 Data Security

Data security is preserved through the integration of decentralized components in the system. At the same time, smart contracts handle the transaction access control by verifying the provider information against the provided information by the patient. Then, the encrypted data is added to off-chain shared storage medium patient private IPFS. The integrity is guaranteed. The security in the developed system has been tested against a few test cases, as illustrated in Fig. 9. The evaluation was successful as the provider was authenticated, and his credentials were checked against the patient-provided ones. Then verify whether the health records are encrypted on the private IPFS and return the corresponding hash value of the encrypted records. Furthermore, the system is assessed, the session is maintained, and the provider can retrieve the records before the session is expired.

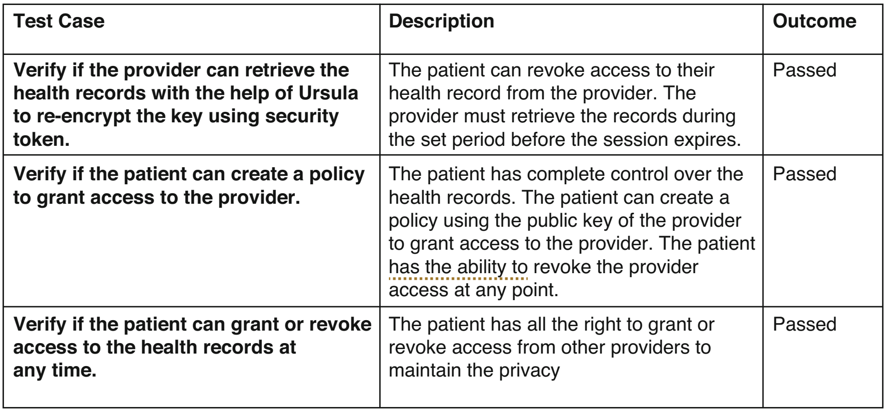
6.3 Data Privacy

The data privacy of the patient health records are protected by ensuring that patients have complete control over who accesses their health records and that no sensitive health information is disclosed during this process of sharing. Thus, only the authorized provider whose information satisfies the access policy that the patient creates can retrieve that data. During the process of data sharing, the identity of the patient and the provider is disclosed. Our system employs multi-factor authentication mechanisms to preserve the privacy of the shared data. The data privacy in the system is decided based on granting authorization to the provider to access the health record. The access control for the health records is examined against some test cases, as shown in Fig. 10.



Test Case	Description	Outcome
Verify if the provider is authorized to access the patient's data	To maintain security, the provider's credentials must check against the ones provided by the patient.	Passed
Verify if the health records are encrypted on the private IPFS	The health record is encrypted using the parient policy public key and uploaded into the private IPFS and returns a hash value for the encrypted record.	Passed
Verify if the session is maintained during the set period for the provider to access the records	The provider has a limited time to retrieve the health record. If the time expires, he will revoke the access	Passed

Fig. 9 Security evaluation



Test Case	Description	Outcome
Verify if the provider can retrieve the health records with the help of Ursula to re-encrypt the key using security token.	The patient can revoke access to their health record from the provider. The provider must retrieve the records during the set period before the session expires.	Passed
Verify if the patient can create a policy to grant access to the provider.	The patient has complete control over the health records. The patient can create a policy using the public key of the provider to grant access to the provider. The patient has the ability to revoke the provider access at any point.	Passed
Verify if the patient can grant or revoke access to the health records at any time.	The patient has all the right to grant or revoke access from other providers to maintain the privacy	Passed

Fig. 10 Enhance data privacy and access control

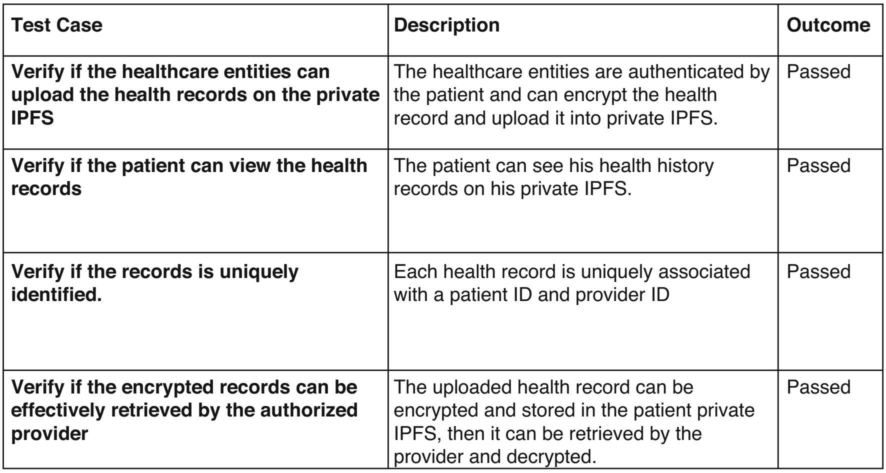
6.4 Data Integrity

The system preserves the data integrity where the patient health records are encrypted and stored in a decentralized private IPFS storage. The generated corresponding reference to the location of the encrypted data is sent to the Blockchain for validation and storage. In contrast, the successfully encrypted patient health data is pushed to the off-chain storage [35]. Therefore, it will be impossible for intruders to change or modify the ledger because any changes will result in the modification of the hash value. The efficient storage of health records has been assessed against a few cases, as shown in Fig. 11, to confirm if the healthcare entities successfully uploaded the patient health records on the private IPFS.

The result indicates that authorized healthcare entities can grant access from the patient to upload the encrypted records into IPFS. Furthermore, the PRE algorithm and Umbral protocol encrypt health records. In addition, the authorized provider is assessed if he has access to the health records granted by the patient. Furthermore, it evaluates if the patient can view his health history on his private IPFS. Besides, the system assesses whether a record can be particularly identified or not. Additionally, the system has been examined to see if an authorized provider can retrieve the encrypted record and effectively decrypt it. The outcome is successful.

6.5 Fine-Grained Access

Control of patient health records sharing is realized using NuCypher software. For example, the patient can create one label for each health record and share it among multiple providers by creating various access policies for the same label.



Test Case	Description	Outcome
Verify if the healthcare entities can upload the health records on the private IPFS	The healthcare entities are authenticated by the patient and can encrypt the health record and upload it into private IPFS.	Passed
Verify if the patient can view the health records	The patient can see his health history records on his private IPFS.	Passed
Verify if the records is uniquely identified.	Each health record is uniquely associated with a patient ID and provider ID	Passed
Verify if the encrypted records can be effectively retrieved by the authorized provider	The uploaded health record can be encrypted and stored in the patient private IPFS, then it can be retrieved by the provider and decrypted.	Passed

Fig. 11 Efficient storage and data integrity

Meanwhile, the denial of access can be made by the patient at any point in the sharing process.

6.6 Avoid a Single Point of Failure

The system removes the need for a centralized third-party database to manage and store the data. All the included components in our system are distributed technologies in their nature. Therefore, even if some nodes are exploited or get down, the system will be up and running, and the system's availability will not be affected [36].

6.7 Patient-Centric

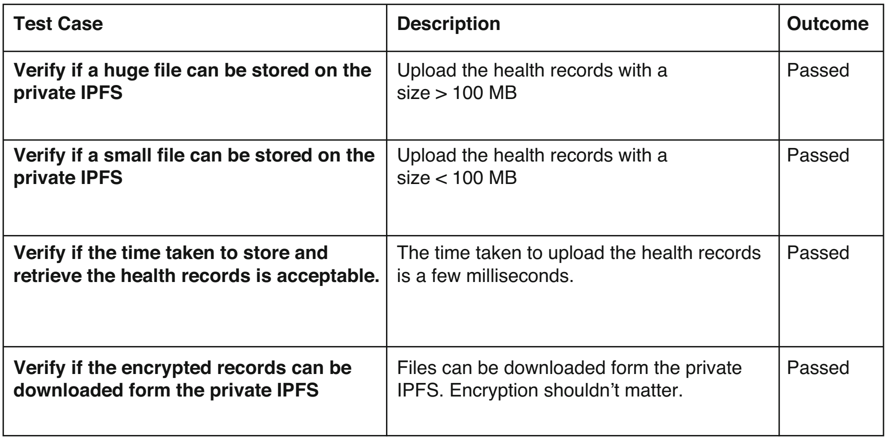
In this system, the patient initiates the smart contract in the Ethereum blockchain to handle the verification and authentication of the provider. In the meantime, the patient has to create a label for the data and generate an access policy to permit the provider to access the data. Moreover, a proxy re-encryption scheme is used to re-encrypt the patient's private key with the provider's public key, then send the public policy key to the healthcare entities. Healthcare entities use the public policy key to encrypt patient health records. Hence, the patient can revoke unauthorized access to the health records at any point in the process. The procedures mentioned above allowed the patient to be in charge and control the sharing of health records.

6.8 Scalability

The system in this chapter stores the encrypted patient health records in off-chain storage called a private IPFS while sending the corresponding hash value to the Blockchain. Hence, the issue of limited blockchain size is solved, increasing the capability of processing and storing large health records at low latency. Therefore, our system combats the scalability challenges that exist in other systems. Furthermore, the system contributes to data scalability by storing the hash value of the health records on the chain and the encrypted data off the chain in the decentralized private IPFS. The scalability of the data has been inspected against a few test cases, as depicted in Fig. 12. A record of 100 MB was uploaded successfully to the private IPFS. Also, the average time multiple providers took to retrieve the record was 50 seconds. As a result, our system can support larger health records at low latency.

6.9 System Comparison

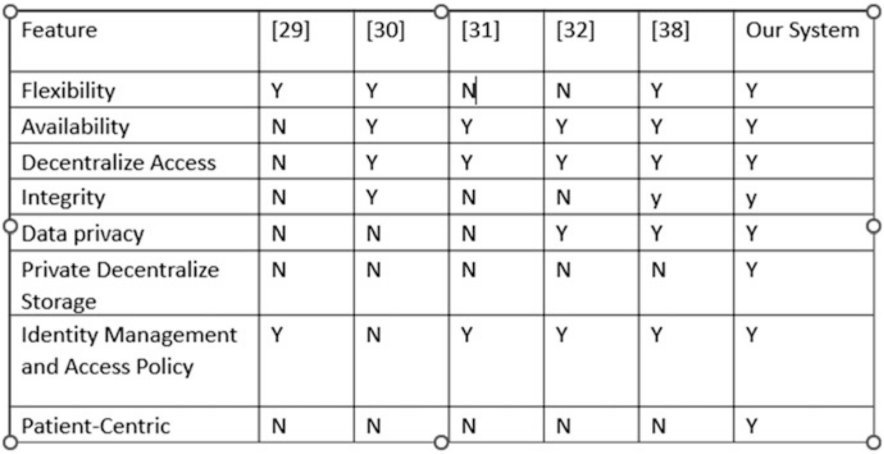
This system is different from our previously developed system because it gives complete control to the patient over his health records and the ability to choose whom to share them with [34, 35]. The difference is in terms of the approach and the choice of the storage type regarding the patient's data. In this chapter, our system uses private IPFS to store the data, which allows the patient to control and manage his health records fully. Furthermore, after each health visit, the patient can request the healthcare entities to encrypt this data and upload it to his private IPFS. Then, anytime the patient wants to share his data with a new provider, he can create an



Test Case	Description	Outcome
Verify if a huge file can be stored on the private IPFS	Upload the health records with a size > 100 MB	Passed
Verify if a small file can be stored on the private IPFS	Upload the health records with a size < 100 MB	Passed
Verify if the time taken to store and retrieve the health records is acceptable.	The time taken to upload the health records is a few milliseconds.	Passed
Verify if the encrypted records can be downloaded form the private IPFS	Files can be downloaded form the private IPFS. Encryption shouldn't matter.	Passed

Fig. 12 Evaluation of data scalability

Table 1 Comparison between our system attributes with other works



Feature	[29]	[30]	[31]	[32]	[38]	Our System
Flexibility	Y	Y	N	N	Y	Y
Availability	N	Y	Y	Y	Y	Y
Decentralize Access	N	Y	Y	Y	Y	Y
Integrity	N	Y	N	N	y	y
Data privacy	N	N	N	Y	Y	Y
Private Decentralize Storage	N	N	N	N	N	Y
Identity Management and Access Policy	Y	N	Y	Y	Y	Y
Patient-Centric	N	N	N	N	N	Y

access policy in NuCypher and grant access to the designated provider upon request (Table 1).

Regardless of the effectiveness and the resiliency of our developed system, some limitations affect it and pose some constraints on its performance, such as high transaction and network latency due to the Implementation of the Ethereum blockchain that uses proof of work. In addition, a proof-of-work system requires fast computers that use large amounts of energy resources. As the network grows, the transaction times can slow since it takes so much energy and power. Hence, it requires massive computational power and electricity and generates electronic waste. Moving to proof of stake and changing miners with validators can reduce transaction costs and supply, improve congestion, reduce computing power, and make the system much faster and more user-friendly [37].

6.10 Perform the Vulnerability and Security Analysis on Smart Contract Code

We administered the vulnerability and security scanning on the smart contract code to check for common bugs and vulnerabilities. It is essential to guarantee that the applied smart contract is bug and vulnerabilities-free, and secure against attacks [38]. We examine the vulnerabilities of Ethereum smart contracts to protect the code and the information on the network, as they may be vulnerable to attacks. This results from poor and negligent programming practices in the solidity language. Any exploration of the Ethereum platform results in detrimental monetary loss. Thus, testing smart contracts for vulnerabilities has become important to gaining confidence in a contract's functionality. The code of the smart contracts was verified

```
Patient.sol
Contract locking ether found:
   Contract Patient (patient.sol#9-60) has payable functions:
    - Patient.setDoctor(uint256,bool) (patient.sol#35-38)
   But does not have a function to withdraw the ether
Patient.changePatient(address).newPatient (patient.sol#48) lacks a zero-check on :
          - patient = newPatient (patient.sol#50)
Pragma version>=0.7.0<0.9.0 (patient.sol#3) is too complex
solc-0.8.15 is not recommended for deployment
healthcareEntity.sol

healthcareEntityAuthentication.setPrimaryInfo(uint256,address,string).healthcareEntityAddress
(healthcareEntity.sol#20) lacks a zero-check on :
          - _address = healthcareEntityAddress (healthcareEntity.sol#24)

Pragma version>=0.7.0<0.9.0 (healthcareEntity.sol#3) is too complex
solc-0.8.15 is not recommended for deployment
getInfo() should be declared external:
   - healthcareEntityAuthentication.getInfo() (healthcareEntity.sol#42-54)


doctorAuthentication.sol
doctorAuthentication.setPrimaryInfo(uint256,address,string).doctorAddress
(doctorAuthentication.sol#17) lacks a zero-check on :
          - _address = doctorAddress (doctorAuthentication.sol#21)

Pragma version>=0.7.0<0.9.0 (doctorAuthentication.sol#3) is too complex
solc-0.8.15 is not recommended for deployment

getInfo() should be declared external:
   - doctorAuthentication.getInfo() (doctorAuthentication.sol#39-51)
```

Fig. 13 Smart contracts scan report

for popular security vulnerabilities using two scanning tools. To achieve this, we used a smart contract analyzing tool called “Smart Scan” [39] to detect DoS due to unexpected revert vulnerability in Ethereum smart contract. Also, we detect DoS and the “Slither” [40] tool, which is software that runs a suite of vulnerability detectors on the contract code. It also provides implicit guidelines to smart contract developers about insecure coding patterns and insecure coding patterns, and any unexpected ether flows (Fig. 13).

All the vulnerabilities that were discovered in our smart contracts report were fixed. We repeated the procedure, and now our smart contracts have proved secure and bug-free of known vulnerabilities. Figure 14 depicts the scan report after resolving all the vulnerabilities and shows that the smart contracts are free from any vulnerabilities that can threaten our system and attack our network.

Scan Report After resolving vulnerabilities:

doctorAuthentication.sol

```
gazi@Gazi:/mnt/d/Downloads/CCNY/Blockchain Research/smart-contracts-main$ slither
doctorAuthentication.sol

doctorAuthentication.sol analyzed (1 contracts with 80 detectors), 0 result(s) found
```

```
gazi@Gazi:/mnt/d/Downloads/CCNY/Blockchain Research/smart-contracts-main$ slither doctorAuthentication.sol
doctorAuthentication.sol analyzed (1 contracts with 80 detectors), 0 result(s) found
```

healthcareEntityAuthentication.sol

```
gazi@Gazi:/mnt/d/Downloads/CCNY/Blockchain Research/smart-contracts-main$ slither
healthcareEntityAuthentication.sol

healthcareEntityAuthentication.sol analyzed (1 contracts with 80 detectors), 0 result(s) found
```

```
gazi@Gazi:/mnt/d/Downloads/CCNY/Blockchain Research/smart-contracts-main$ slither healthcareEntityAuthentication.sol
healthcareEntityAuthentication.sol analyzed (1 contracts with 80 detectors), 0 result(s) found
```

patient.sol

```
gazi@Gazi:/mnt/d/Downloads/CCNY/Blockchain Research/smart-contracts-main$ slither patient.sol

patient.sol analyzed (1 contracts with 80 detectors), 0 result(s) found
```

```
gazi@Gazi:/mnt/d/Downloads/CCNY/Blockchain Research/smart-contracts-main$ slither patient.sol
patient.sol analyzed (1 contracts with 80 detectors), 0 result(s) found
```

Fig. 14 Scan report after fixing all smart contracts vulnerabilities

7 Conclusion

Recently, patient health records in the healthcare sector have experienced considerable problems with privacy breaches and unauthorized access to data. Hence, this chapter sets out to solve challenges faced in the healthcare industry regarding the security of patient health record sharing by using novel technologies such as Ethereum blockchain, private IPFS, and NuCypher. We took advantage of the use of Blockchain, which has successfully replaced trusted parties in many systems, such as healthcare, to maintain the privacy and security of health records when shared with an authorized provider. Furthermore, our developed system can remove the need for centralized medium or cloud-based storage. Therefore, our novel system will be used as a foundation for various business opportunities and as an open source. The novel technologies create a secure and vigorous solution to share patient data and create a secure interaction between the patient and the provider. Furthermore, the system can store the hash value generated from the encrypted data on the Blockchain while the patient's confidential data off-chain on his private IPFS. Moreover, the evaluation of security and privacy aspects of our developed system reveals promising results and a reliable system that can be scaled and support big data such as patient health records. Furthermore, it is important to delegate the access control of the health records to the patient to have the ability to choose with whom to share the data.

Our system is fully decentralized, secure, and resilient, eliminating reliance on a trusted third party. Furthermore, we have implemented and assessed the functionalities of our solution. Also, we ensured the system's smart contracts were vulnerable and bugs free, demonstrating the resilience and security of the created smart contracts against well-known attacks. Thus, the system's uniqueness enables it to fit any model requiring massive data sharing. In the future, we plan to enhance the system's overall performance by reducing its latency and increasing the throughput, switching to the Ethereum blockchain that uses proof of stake instead, and getting rid of the miners. Furthermore, we will assess the Blockchain's scalability and efficiency in the real world by increasing the number of patients and providers and the size of the health records stored in private IPFS. Also, assesses some performance metrics and their overall effectiveness. In addition, various upgrades could improve the system's overall performance

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Part V
Case Studies and Frameworks

On Natural Language Processing to Attack COVID-19 Pandemic: Experiences of Vietnam

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1 The Outbreak of COVID-19 Disease

If the world has witnessed the emergence of the Severe Acute Respiratory Syndrome (SARS) epidemic in China in 2002–2003 and the Middle East Respiratory Syndrome (MERS) on the Arabian Peninsula in 2012, then in the period of 2019-now, the world has been put in disorder by a virus strain called nCov. While the two former diseases are caused by Corona Viruses (CoV), which are a large family of viruses that cause illnesses ranging from the common cold to more severe diseases,[1] the last one (nCov) bears the imprint of a new strain that has not been previously identified in humans. The new virus was then subsequently named the "COVID-19 virus". Characterized by the virus that caused the SARS epidemic, COVID-19 infection has symptoms such as the common cold and respiratory symptoms such as dry cough, fever, and breathing difficulties. In more severe cases, it can cause pneumonia, severe acute respiratory syndrome, and death.

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[1] www.who.int.

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1.1 The Global Spread of COVID-19

The first case of COVID-19 was reported on 1 December 2019 in Wuhan City which is the largest city in Hubei Province and the most populous city in Central China. On 31 December 2019, the World Health Organization (WHO) was formally notified about a cluster of cases of pneumonia in Wuhan City. By 20 January, WHO was aware of confirmed cases that were outside of China, see Footnote 1.

On 30 January 2020, Dr. Tedros Adhanom Ghebreyesus, the WHO Director-General, declared the nCov outbreak a public health emergency of international concern which is WHO's highest level of alarm. On 11 March 2020, the rapid increase in COVID-19 cases all over the world led WHO to issue a statement calling "COVID-19" as a "Global Pandemic" [8]. COVID-19 has infected every continent by December 2020, after causing dozens of cases reported in Antarctica, the last continent the virus has reached on earth.

The corona virus disease has been recognized as a worst crisis by experts since World War II with severe consequences related to a high mortality rate in individuals with heart disease, diabetes, and cancer, as well as the elderly. However, the medical world has also witnessed these effects in people who have never had an underlying medical condition.

For most people, COVID-19 seems to take 2–9 days to cause symptoms, which unfortunately makes the novel coronavirus more dangerous. Since it is a virus that has never been seen in humans, no one is immune to it. In the period when an infected person is asymptomatic or mildly ill, they could transmit the virus to dozens of other people as easily as influenza.

Due to the COVID-19 pandemic, the world economy was heavily affected by the drop in demand, the disruption in the supply chain of goods. This dynamic can be seen in heavily affected industries such as tourism and manufacturing, where many production factories have had to close due to lack of raw materials as well as workers being infected with the virus.

1.2 COVID-19 Pandemic in Vietnam

In Vietnam, the COVID-19 pandemic is part of the ongoing worldwide pandemic of coronavirus disease 2019 (COVID-19). In 15 months since the epidemic began in January 2020, the country had only registered fewer than 3000 cases and 35 deaths. However, the situation changed when the Delta variant arrived. From April to October 2021, Vietnam experienced its largest outbreak to date, with nearly 800 thousands infections, especially in the largest city, Ho Chi Minh city, and some satellite provinces, Binh Duong, Long An, Dong Nai. Around one third of the population were under some strict social distancing orders from the late of July till October. As of July 2022, the COVID-19 is gradually returning. Some countries around the world still have a large number of infections and they have to blockade and social distance. This situation has crippled Vietnam's preventive health care system and place an extreme stress on it.

The disease's containment has been rendered very difficult by the introduction of new corona virus strains as well as the easy going transmission. Even for the medical systems of such developed countries as the United States or the Euro zone, the hospitals have been paralyzed in the face of a massive tsunami of patients who have continued to grow and have not been alleviated for a long time. So, what's the solution so far?

2 Approaches Against COVID-19

Soon after the onset of COVID-19, the World Health Organization (WHO) suggested that artificial intelligence (AI) could be a valuable non-medical intervention in solving the major problem. With allied technologies like Big Data, IoT, and Data Science, AI can assist the against-pandemic combat in a variety of ways, including detecting outbreaks, facilitating diagnosis, identifying patients with fevers, and hastening DNA sequencing, among others [21]. COVID-19 has prompted AI researchers to explore solutions to assist doctors, medication developers, and society in preventing and reversing the illness in recent years.

This will aid authorities and health systems in identifying infected patients and others with whom they have come into contact, as well as isolating the source of infection and providing necessary healthcare. When scientists are confronted with a problem, the first priority is to gather as much information as possible on the problem. The whole picture leads to appropriate options. To prevent the spreading, we need to figure out at-risk persons take necessary isolation measures as soon as possible.

At times when COVID-19 spread strongly in Vietnam, disease prevention is based on isolating and promptly treating patients and those who have been in contact with them for a certain period (potentially infectious period). This approach has proven effective when helping Vietnam become one of the countries with the lowest number of infections in the world (before the fourth wave of the Delta variant). In detail, the following steps have been implemented:

- Information collection: The healthcare facility collects epidemiological information from patients, including patient information and their timeline (Fig. 1).
- Information extraction: From the timeline, the tracing team needs to extract information that supports the treatment of the patient (date of onset symptom, hospitalized and positive dates) and the time that they can infect others (usually from the onset symptom date to the isolation date). The tracing team extracts information about people who contact the patient and the location history during that time.
- From the extracted information, the medical team test the contacting persons of the patients and inform people who might in danger of contacting.

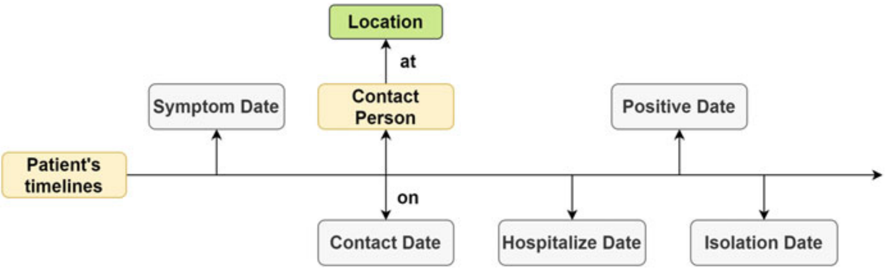

Fig. 1 Illustration of a COVID-19 patient's timeline, including: date of symptom onset (symptom date), date of contact with others (contact date), contact person, location, hospitalize date, positive date, and isolation date

In the above steps, information extraction plays an extremely important role. It must ensure that necessary and important information is extracted quickly and accurately so that the medical team can effectively implement epidemic prevention measures. However, the work is done manually with a time of about 3 min/a case report. Meanwhile, the data after the outbreak of the pandemic is enormous. They are written in the form of reports by different people and do not follow a certain structure. Therefore, extracting information manually in a short time is also extremely difficult while the human resources of medical facilities are limited.

Fortunately, rapid and automatic information extraction can be supported by AI, or more specifically, natural language processing (NLP) systems.

2.1 Natural Language Processing

Natural Language Processing (NLP) refers to the branch of AI, concerned with the interactions between computers and human language, in particular machines are trained to process and analyze large amounts of unstructured text data, like social media posts, news, online customer reviews, etc. This technology was created with the expectation that a computer could "understand" the contents of documents and make use of them to accurately extract information and insights contained within the documents to execute other tasks.

In the matter of classification, as shown in Fig. 2, NLP tools use text embedding to transform text into numerical vector, then machine learning or deep learning algorithms are fed training data and expected outputs (tags) to train models to produce a valid output given a specific input. Machines then learn to build their own "knowledge" before making predictions for unseen data (new texts).

Typical applications in NLP include Machine Translation, Text Summarization, Named-Entity Recognition, Parts-of-Speech (POS) Tagging, Information Retrieval, Information Grouping, Sentiment Analysis, Answering Queries, and Automated Speech Recognition (ASR).

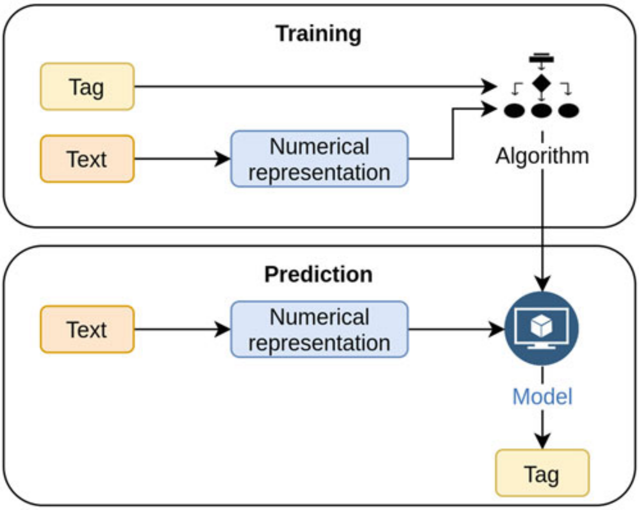

Fig. 2 Classification model in the field of NLP

In the health care industry, natural language processing has numerous potential applications. NLP can increase the consistency, synchronization, and accuracy of health records by converting unstructured text to a standardized format. It can automatically extract suspicious signs from notes in the medical records. “There’s this explosion of data—not just genomic data, but all sorts of data—in the healthcare space, and the industry needs to find the best ways to extract what’s relevant and bring it together to help clinicians make the best decisions for their patients.”, said Vanessa Michelini, Distinguished Engineer and Master Inventor leading the genomics division of IBM Watson Health. NLP has nearly limitless potential to bridge the gap between the immeasurable amount of data generated every second and the limited cognitive capacity of the human mind.

In response to the explosion in the number of patient records during the COVID-19 pandemic, Named Entity Recognition (NER), a sub-field of NLP, has been studied and applied in contact tracing of infectious clusters in the community.

2.2 *Named Entity Recognition*

Named Entity Recognition (NER) is a process with which key entities can be recognized and categorized in a sentence or a chunk of text by an information extraction technique. NER systems help to solve information extraction problems (as mentioned at the beginning of the section) quickly and efficiently. In detail, NER’s input is unstructured text (sentence or paragraph) and NER’s output is relevant nouns predefined like people names, locations, dates, organizations, monetary values, and more. Using an algorithm, NER makes it easy to sort unstructured data and detect key information, which is important when faced with big data. Some common formats of inputs can be listed as news, science, official, informal, or domain topics like sports, business, finance, healthcare, etc.

In addition to the three major groups including “people”, “locations” and “organizations” which are commonly researched, there are many other entities such as sub-parts of “locations” including street, city, district, country, or time, date, money, and brand. In the medical field, the entities to look for are usually the patient’s identifiable characteristics (name, age, gender, address), disease-related characteristics (date of symptom onset, date of hospital admission, date of positive test result, etc), genes, proteins, drugs, etc.

2.2.1 Approaches

Rules-Based Approaches The initial NER research comprised of hand-crafted rules-based methods that were too closely aligned to a very fixed structured textual set [18]. The common methods of this approach are Dictionary-Based, Rules-Based, and Regular expressions.

Among the mentioned methods, the most preferred one is Rule-based. In this context, it should be noted that this approach has many limitations mainly due to its rigid corresponding to a certain data format.

- The number of categories is unlimited compared to the constraint size of the dictionary.
- Names might be abbreviated.
- Verified entities sometimes depend on the surrounding context.

It is clearly stated that being too reliant on a certain structure does not perform well, leading to a new approach: generalization.

Statistical Learning Approaches The need for standardization led to Supervised machine learning. Supervised learning techniques trained on a large annotated showed high innovation potential since their core learning algorithms are language-independent i.e. supports multilinguality and current approaches already produced state-of-the-art results for NER and demonstrated near-human-like performance. The prominent methods include statistical techniques like Hidden Markov Models (HMM), Decision Trees, Maximum Entropy Models (ME), Support Vector Machines (SVM), and Conditional Random Fields (CRF). CRF in particular is one of the most preferred algorithms since it uses many leading and lagging non-local sequences to train the probability of the output tags.

Deep Learning Deep learning is a machine learning method using multi-layer neural networks and is considered. One advantage of deep neural networks compared to classical statistical techniques is feature engineering since features are learned automatically that eliminates the human element required in many applications. Deep learning models with respect to engineered features have recently shown impressive outcomes over a wide range of domains. In Sect. 4, we will cover the deep learning approach in more detail.

2.2.2 Evaluation Metrics

Many metrics are designed to assess the quality of NER systems. Precision, Recall, and F1 score are three typical measures in general, where

- Precision is the percentage of correct predicted entities of the total entities predicted by the model.
- Recall is the percentage of entities correctly predicted by the model of the total entities in the corpus.
- F1 score is the harmonic average of Precision and Recall

$$\frac{1}{F1} = \frac{1}{2}\left(\frac{1}{Precision} + \frac{1}{Recall}\right).$$

However, NER can fail in many cases, especially when the phrase to be recognized is quite long, the prediction may be only partially correct and not counted as a successful recognition. In academic conferences such as CoNLL, a modified version of the F1 score [19] has been introduced as follows:

- F1 score is the harmonic mean of Precision and Recall.
- Precision for an entity name is the number of predicted entities that exactly match the spread with the gold standard evaluation data. I.e. when [LOCATION Ha] [LOCATION Noi] is predicted but [LOCATION Ha Noi] was the correct answer, precision for this entity is zero. Precision is then averaged over all predicted entity names.

2.3 COVID-19 Prevention Studies in NLP

Many available data sets about Covid-19 have been collected and contributed to the global research community for applying recent advances in NLP with the hope of providing insights to support the global fight against the pandemic. Among NLP global datasets on COVID-19, COVID-19 Open Research Dataset (CORD-19) is one of the most prominent. CORD-19 is known to be the result of a collaboration of the US Government and multiple other organisations and LitCovid, maintained by the NIH, which indexes papers published on PubMed related to the pandemic [2]. They help facilitate many types of research works including NER. Many studies investigated these data [9] to construct a pipeline upon the Named Entity Recognition tools for Chemicals, Diseases, Genes and Species in CORD-19. [3] proposed BioBERT model—a pre-trained language model which is trained on the CRAFT corpus (a collection of nearly 100 full-text medical articles manually annotated for eleven different medical entity types) to aid in downstream NLP tasks such as named entity normalisation (NEN), text summarisation, and named entity recognition (NER).

Compared to other languages, Vietnamese data resources for NER task are quite limited when there are only two public data sets from the VLSP 2016 [15] and VLSP 2018 [16] NER shared task. In terms of COVID-19, PhoNER_COVID19 [20] is currently the only Vietnamese NER dataset about COVID-19 published to the community by VinAI Research. PhoNER_COVID19 is collected from crawl articles tagged with "COVID-19" or "COVID" keywords from famous Vietnamese online newspapers and includes 10 entities related to COVID-19 patients' information.

In addition, there is also a lot of research inside and outside the field of NLP that is contributing a lot to the prevention of COVID-19.

3 Dataset for NER System Building

In the previous section, the NER system was mentioned as a way to solve information extraction problems, especially in epidemic prevention in Vietnam. Data is an integral part of building a NER system. In this section, it will be shown the process of creating a dataset for our NER system which is used to support epidemic prevention in Vietnam.

3.1 Data Collection

During the time of supporting the prevention of the COVID-19 epidemic, we have been shared data by Centers for Disease Control and Prevention (CDC), Vietnam, for our research. Shared data includes case reports that were encrypted personal information. These reports are sent from many different medical facilities, so they do not have the same template. That is also why the system cannot apply rule-based or template-based methods to these raw data. In total, 700 case reports were collected.

Realizing that the data is still small, more data were collected from reputable sources and Vietnamese online news sites such as: Data Service Portal,[2] Portal of The Ministry of Health about COVID-19 Passion,[3] VietNamNet[4] and VnExpress.[5]

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[2] https://congdulieu.vn.

[3] https://covid19.gov.vn.

[4] https://vietnamnet.vn.

[5] https://vnexpress.net.

Table 1 Entity types description

Entity types	Description
NAME	Name of patient
GENDER	Gender of patient
AGE	Age of patient
ADDRESS	Address of patient
HOS_DATE	Date that patient was admitted to hospital
SYM_DATE	Date that symptoms appear in patient
ISO_DATE	Date that patient is isolated
POS_DATE	Date that patient positive for COVID-19
CON_DATE	Date that patient contact with anyone
CON_PERSON	Person who contact with patient
LOCATION	Location where the patient passed

3.2 Entity Types

As mentioned in the previous sections, it is necessary to extract important information to carry out effective tracing measures. The information is aggregated and proposed in the form of entity types—labels that the system needs to recognize and return. Specifically, we define eleven entity types including:

- Patient information: full name (NAME), gender (GENDER), age (AGE) and address (ADDRESS).
- Information related to the patient's treatment: Date of hospitalization (HOS_DATE) and date of positive (POS_DATE).
- Information to assist in tracing: the time that patient can infect others—starting from the date of symptom onset (SYM_DATE) to the date of isolation (ISO_DATE), the date that the patient has contact with others (CON_DATE), people the patient has been in contact with (CON_PERSON), and the locations the patient has visited (LOCATION).

The description of entity types is in the Table 1.

3.3 Data Overview

Among the dataset mentioned in above sections, we found that VLSP 2018 has the right format for our data. Specifically, XML tags were used to annotate entities, and because of the nature of our entity types, our data also has nested entities. It is found that there are at most four entity levels in our data. They are leveled according to the number of entities they nest: one entity is level-2, two are level-3 and three are level-4. For instance:

<ENAMEX TYPE="LOCATION">Friend's home (contact with
<ENAMEX TYPE="CON_PERSON">friend</ENAMEX>)

at Dong Da, Ha Noi</ENAMEX>

LOCATION is level-2 entity type and CON_PERSON is level-1 entity type.

3.4 Annotation

We divide the annotation process into 3 phases:

- Case reports were cleaned by checking for typos, typographical errors, duplicates, etc. Entities were then manually annotated with XML tags as in VLSP 2016 and VLSP 2018. Cross-checking method was used to correct wrong annotations and detect text errors. After a 2-week first phase, 5154 sentences and 6481 entities were collected.
- Data are crawled from portals. Part of these data has formats that closely resemble the data in the first phase. The data was cleaned, manually annotated, and cross-checked as the first phase in 2 weeks. There were 7952 sentences and 7069 entities after the second phase.
- In the final phase, data are collected from reputable Vietnamese online news sites. This phase took longer to clean the data than the previous two, with the annotation and cross-checking took a total of 3 weeks. After the final review, the dataset contains 10,271 sentences and 11,128 entities.

Detailed statistics of the data in Table 2 with three parts: train, valid and test were split.

Table 2 Statistics dataset

Entity type	Train	Valid	Test	All
NAME	455	133	146	734
AGE	472	138	144	754
GENDER	437	139	135	711
ADDRESS	454	137	137	728
SYM_DATE	358	49	62	469
HOS_DATE	709	139	147	995
POS_DATE	682	117	140	939
ISO_DATE	698	140	139	977
CON_PERSON	3773	957	637	5367
CON_DATE	1448	336	262	2046
LOCATION	2044	1067	987	4098
Level 1 entities	10,354	2937	2579	15,870
Level 2 entities	848	352	301	1501
Level 3 entities	282	51	42	375
Level 4 entities	46	12	14	72
Entities	11,530	3352	2936	17,818
Sentences	6162	2054	2055	10,271

4 Deep Learning Approach

Since the late 2000s, deep neural networks have developed rapidly and strongly. They have created a new era in artificial intelligence—the era of deep learning. With the development of both computer hardware and augmented computing techniques, neural networks have significantly increased hidden layers and diversity of architectures. Variants of recurrent neural network (RNN), convolutional neural network (CNN), and generative adversarial network (GAN), as well as powerful techniques that increase the model's performance such as residual connection, [7], attention mechanism [1], etc have continuously achieved the state-of-the-art in many different fields of machine learning in particular and artificial intelligence in general. As for NLP, the introduction of attention mechanism in 2014 has made a strong step forward, contributing to helping NLP achieve new achievements on most tasks. However, the limitation of long-term dependencies and non-parallel architecture of RNN is still a big challenge. After many efforts, Transformer [22] appeared in 2017 to solve the above challenges. Transformer and the pretrained models using its architecture have continuously achieved new state-of-the-art across every NLP task. In this section, some models will be reviewed and we will discuss about the reason for choices of our system experiment.

4.1 Transformer and BERT-Style Models

4.1.1 Attention Mechanism

Let's assume a sequence-to-sequence model was build for a machine translation task that consists of two RNN models: Encoder and Decoder. As shown in Fig. 3, the Encoder takes a source language sequence and encodes its information into a context vector. The decoder uses that context vector to decode the tokens[6] in turn in the target language sequence. However, [1] has proven that using just one vector to decode all tokens in the target language is not really good. Instead, Attention [1] was proposed as a mechanism that the model is learned to focus on a specific number of tokens (or focus on some tokens more than others) for a more accurate prediction. Figure 4 shows us the model using the attention mechanism. Attention represents the relationship between the predicted token in the decoder and the tokens in the encoder. Information about that relationship is then passed into the context vector. Ref. [1] and many other studies have demonstrated the effectiveness of attention in representing relations between tokens and have significantly improved performance for variants of RNN.

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[6] A token is an instance of a sequence of text. A token can be either a word, a character, or a subword. In Fig. 1 example, a token is a word.

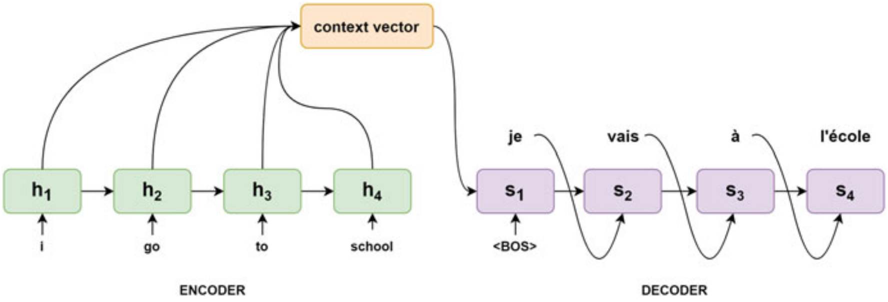

Fig. 3 English to French machine translation model using RNN architecture

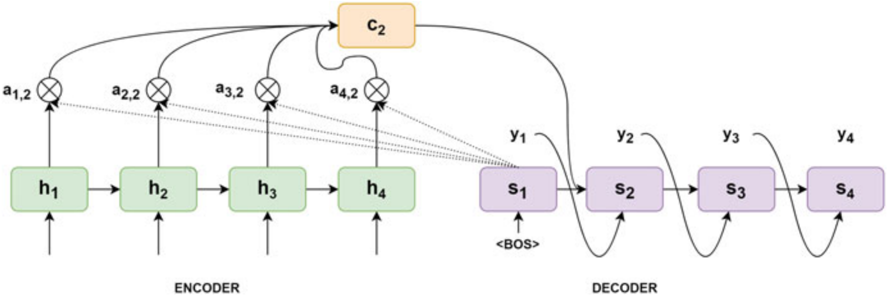

Fig. 4 The model uses the attention mechanism. Where $a_{i,j}$ are the attention scores, h_i are the hidden states of the encoder, s_j is the hidden state of the decoder, c_j are the context vectors and y_j are the predicted tokens

4.1.2 Transformer

The transformer [22] architecture consists of two parts. The encoder layers and the decoder layers are connected through cross-attention. Through the calculation at each layer, the output will keep the length and dimension of the input, so the model can stack layers with an arbitrary number of N. Figure 5 illustrates Transformer architecture including sub-layers such as:

- **Self-attention**: As observed in the subsection above, the attention mechanism better represents input sequence based on the relationship between tokens in sequence and token used for prediction. Realizing that, self-attention is proposed with the idea: create sequence representation by applying the attention mechanism between the tokens in the sequence to show the relationship between them. This idea has proven its effectiveness as the main component that helps Transformer outperform the models that came before it.
- **Multi-head attention**: responsible for summarizing different representations from self-attentions (each head is a self-attention) by concatenate and project them:

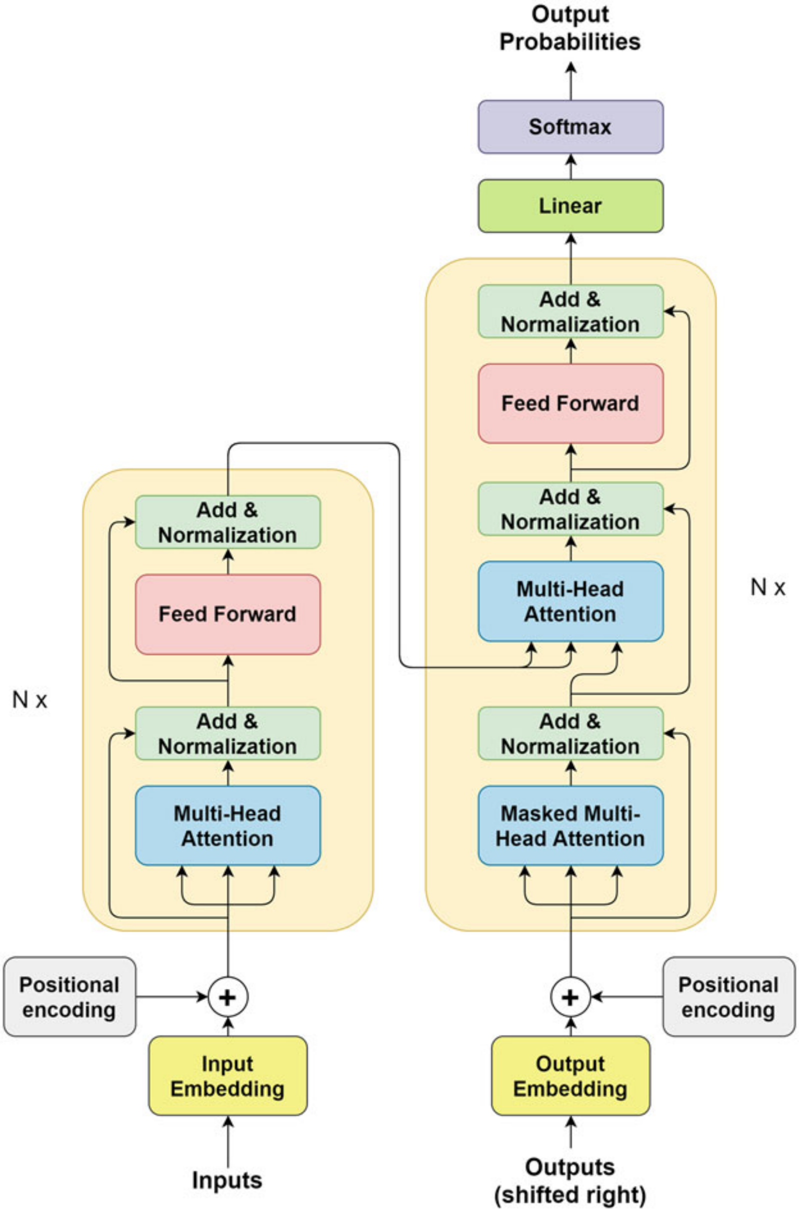

Fig. 5 The Transformer architecture [22]

$$Multihead = Concat(head_1, ..., head_2)W^O$$

where the projection is the matrix parameter $W^O \in R^{hd_h \times d_{model}}$ (h is the number of heads, d_h is the number of dimensions of each head and d_{model} is the number of dimensions of the input and output of the model).

- **Positional encoding**: Self-attention, multi-head attention, or other sub-layers in Transformer don't need sequential computation like RNN. However, an alternative mechanism is needed for the RNN's ability to represent the token position which is crucial in representing the input sequence. Therefore, positional encoding is proposed as a layer that encodes the positions of tokens into their representation vector.
- **Input embedding**: embed the input sequences into vectors that have dimensions equal to the dimensions of the model (d_{model}).
- In the layers, there are also components that help the model work effectively such as: feed forward, add and normalization, and residual connections. In addition, in the decoder layers, there is an additional Masked multi-head attention sub-layer: responsible for masking the tokens behind the token being decoded, in order to simulate the decoding process in model training.

Thanks to training on huge amounts of data and based on Transformer's powerful and efficient architecture, pretrained models like BERT [5], RoBERTa [10], XLM-R [4], PhoBERT [13], and more have achieved the state-of-the-art on NLP tasks. They have contributed to ushering in a new era of NLP and making NLP thrive in recent years. In the following sections, we will introduce pretrained models that are powerful and suitable for our system.

4.2 BERT

The masked multi-head attention was referred as a sub-layer masking the tokens behind the predicted token. To better explain this sub-layer, consider the following example:

"I have lived in Chicago since 2019."

Suppose we want to train the model to predict the tokens behind the "in", the tokens behind it should be masked before training, otherwise the model will see the tokens that need to be predicted and will not learn anything. The sequence will be masked as

"I have lived in <mask> <mask> <mask> <mask>"

However, when humans want to understand a sentence or predict a hidden word, they don't just look at the words in front of it. Instead, we look from two directions—the front (left to right) and back (right to left) of the masked word to predict it. BERT is proposed based on that idea.

BERT stands for Bidirectional Encoder Representations from Transformers. As the name implies, BERT uses multi-layer bidirectional Transformer encoder. Since

Transformer layer encoders do not have masked multi-head attention sub-layer, it is added to BERT as an architectural innovation of Transformer. BERT is trained on two tasks where masked multi-head attention plays an important role in processing the training data. Those two tasks are:

- **Masked language modeling**: randomly mask some tokens and use the remaining tokens (from two directions) in the sequence to predict them. Example: Predicting the masked token in the sequence:
  "I have lived in Chicago <mask> 2019."
- **Next sentence prediction**: The input sample consists of two sentences. In which, 50% of the samples are two consecutive sentences and 50% of the samples are two random sentences. The model has to predict whether the second sentence is a continuation of the first sentence or not.

The above two tasks are self-supervised learning where the data provides training signals itself. They allow BERT to be trained on huge amounts of data without human annotation.

In terms of architecture, BERT has two versions: $\text{BERT}_{\text{base}}$ and $\text{BERT}_{\text{large}}$. $\text{BERT}_{\text{base}}$ consists of 12 layers, hidden size of 768 and 12 self-attention heads. $\text{BERT}_{\text{large}}$ consists of 24 layers, hidden size of 1024 and 16 self-attention heads.

With significant improvements in architecture and training data, BERT can create high-quality contextualized embedding of the input sequence. They help BERT achieve the state-of-the-art in a variety of downstream tasks in NLP including NER. Therefore, the multi-lingual version of BERT (mBERT—BERT trained on multilingual datasets) has been chosen to experiment in our system.

4.3 Other Models

RoBERTa a variant of BERT using the Transformer architecture. RoBERTa improved and changed several training strategies to outperform BERT on many downstream tasks in NLP. The improvements of RoBERTa compared to BERT such as:

- Training on longer sentences, with bigger batch size and larger dataset in longer time
- Remove next sentence prediction task
- Dynamic masking (different from BERT which only randomly covers once, RoBERTa covers 10 different ways during training).

XLM-R inheriting improvements from RoBERTa, XLM-R is a multilingual model trained on more than two terabytes of cleaned Common-Crawl [4] data in 100 languages (including Vietnamese). The XLM-R comes in two versions: $\text{XLM-R}_{\text{base}}$ with 12 layers, 8 self-attention heads, and $\text{XLM-R}_{\text{large}}$ with 24 layers, 16 self-attention heads. XLM-R outperformed mBERT on cross-lingual benchmarks and

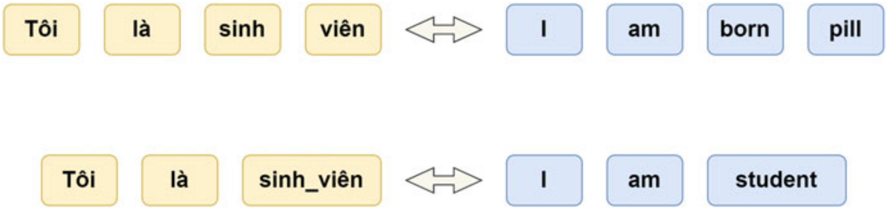

Fig. 6 A Vietnamese to English translated sentence is separated into syllable tokens (above) and word tokens (below). Word consists of syllables that joined together by a "_" sign after segmentation

achieved the state-of-the-art on many NLP tasks. Many studies have shown that XLM-R works very well on Vietnamese such as [6, 17, 20], etc. XLM-R is also one of the models used for our experiment.

PhoBERT is the latest state-of-the-art language model for Vietnamese. PhoBERT outperformed other models on many Vietnamese NLP tasks. PhoBERT also inherits improvements from RoBERTa, but there are several important points that make it work well with Vietnamese NLP tasks:

- PhoBERT is trained on word-level corpus: In Vietnamese, a word consisting of one or more syllables and syllable-level segmented sentence can have a different meaning than word-level segmented sentence. As the example in Fig. 6 shows, the word-level sentence gives a more correct meaning than the syllable-level sentence. Realizing this, PhoBERT is trained on both syllable-level data and word-level data (while previous models were only trained with syllable data) which contains performed word and sentence segmentation by RDRSegmenter [14] from VnCoreNLP [23].
- The Vietnamese dataset is much larger than other models: While other models only trained on 1GB of Vietnamese Wikipedia, PhoBERT trained on 20GB of data including 1GB of Vietnamese Wikipedia and 19GB of cleaned Vietnamese news corpus.

PhoBERT was also selected for the experiment on our system with two versions: PhoBERT$_{\text{base}}$ (12 layers with 12 self-attention heads) and PhoBERT$_{\text{large}}$ (24 layers with 16 self-attention heads).

5 System Building

Based on the created data and the mentioned models, the experiments were conducted and the NER system was developed.

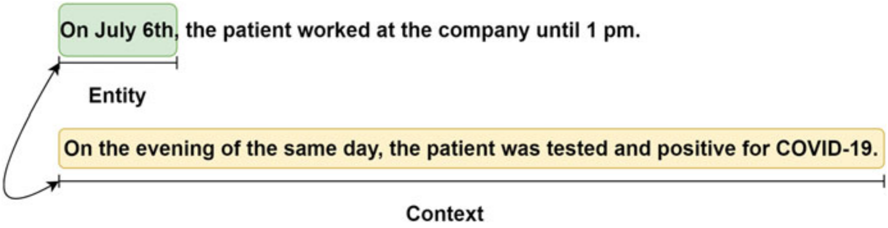

Fig. 7 Entity and its context are not in the same sentence

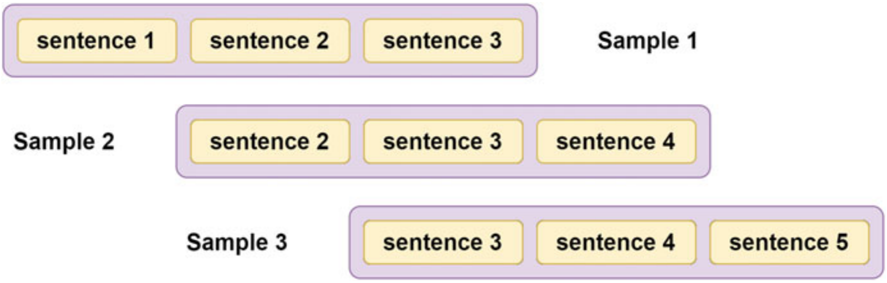

Fig. 8 Illustration of cross-sentence context

5.1 *Data Processing*

It is found that, in the dataset, there are many cases where the entity and the context to recognize it are not in the same sentence (Fig. 7 illustrates an example of this). In some cases, they are quite far apart. Therefore, a cross-sentence context should be implemented and it is wide enough to contain both the entity and the context. Based on [12], the training samples containing consecutive sentences were set up. A sample consists of a main sentence, then context supporting sentences are added one by one until the maximum sequence length is reached (256 of PhoBERT and 384 of other models in our setting). Figure 8 illustrates this idea.

5.2 *Training and Evaluation*

The AdamW [11] is used to fine-tune models with weight decay of 0.01, learning rate of 5e-5, and batch size of 32. Since its arrival in 2019, AdamW has been widely used to train as well as fine-tune BERT-style models. The level-1, level-2, and joint models were trained separately in 30 epochs on an NVIDIA Tesla P100 GPU via Google Colaboratory.

The performance of level-1 entities with level-1 and joint models (Table 3), level-2 entities with level-2 and joint models were evaluated as in Table 4.

Table 3 Performances of recognizing level-1 entities on valid set and test set

	Valid						Test					
	Level-1 model			Joint model			Level-1 model			Joint model		
Model	Prec.	Rec.	F1	Prec.	Rec.	F1	Prec.	Rec.	F1	Prec.	Rec.	F1
mBERT	76.21	78.75	77.46	74.81	76.43	75.34	76.48	78.78	77.59	74.79	76.58	75.96
XLM-R_{base}	74.11	76.00	75.05	71.95	73.45	72.67	75.23	77.43	76.19	72.13	73.98	73.12
XLM-R_{large}	77.86	79.72	78.69	76.43	78.52	77.59	78.78	80.39	79.52	76.87	78.16	77.68
$PhoBERT_{base}$	80.49	82.81	81.46	78.12	80.32	79.59	81.23	83.12	82.14	78.79	80.76	79.69
$PhoBERT_{large}$	**82.69**	**84.42**	**83.57**	**81.23**	**83.82**	**82.58**	**83.13**	**85.63**	**84.41**	**81.89**	**83.75**	**82.59**

The bold values implies that they are the best measurement scores

Table 4 Performances of recognizing level-2 entities on valid set and test set

	Valid						Test					
	Level-2 model			Joint model			Level-2 model			Joint model		
Model	Prec.	Rec.	F1	Prec.	Rec.	F1	Prec.	Recall	F1	Prec.	Rec.	F1
mBERT	68.24	70.03	69.13	63.59	66.01	64.98	68.59	70.58	69.64	63.99	65.97	64.89
XLM-R$_{base}$	67.97	70.12	69.19	62.12	64.01	63.28	68.45	70.78	69.51	63.13	65.46	64.59
XLM-R$_{large}$	69.07	72.28	70.89	64.45	66.75	65.48	70.13	72.01	71.58	65.37	67.77	66.53
PhoBERT$_{base}$	71.81	73.98	72.96	66.69	71.02	68.77	72.14	74.56	73.58	67.64	69.35	68.43
PhoBERT$_{large}$	**73.74**	**75.88**	**74.76**	**68.51**	**71.41**	**70.25**	**74.19**	**76.62**	**75.99**	**69.21**	**72.03**	**70.78**

The bold values implies that they are the best measurement scores

5.3 Experimental Result

Looking at Tables 3 and 4, it is observed that PhoBERT$_{\text{large}}$ outperforms other models with precision of 82.69, recall of 84.42, f1-score of 83.57 on level-1 entities and precision of 73.74, recall of 75.88, f1-score of 74.76 on level-2 entities. Besides, mBERT and XLM-R achieve quite good results. We aggregate the performance of PhoBERT$_{\text{large}}$ across entities including level-1 and level-2. Table 5 shows that the model achieved very good results with entities such as: NAME, AGE, GENDER, ADDRESS with very small error. Meanwhile, the model also performed quite well with LOCATION, CONTACT_DATE and CONTACT_PERSON with about 86% and above average with DATE entities.

5.4 Error Analyst

In this section, an error analysis is conducted to further clarify the results stated above. Through statistics, it is observed that: There are a total of 543/3352 errors on valid set and 411/2536 errors on test set. Such data were divided into three groups of errors to conduct the analysis.

The first group includes errors about missing spans of long entities, accounting for 143/543 errors on valid set and 79/411 on test set. Most of them are long LOCATIONs or long CONTACT_PERSONs. Besides, there are also some errors of long NAMEs, long ADDRESSs or long DATEs.

The second group which accounts for most of the errors with 301/543 on valid set and 297/411 on test set, is the mistakes of the dates. The cause comes from:

- A context can contain many dates.
- Sentences with the same keyword and pattern refer to an entity, but only one sentence contains the correct entity. For example: On 19/2, the patient was admitted to hospital A for appendicectomy. On 29/ 2 patient was admitted to hospital A for a re-examination of the incision. On 3/3, the patient was hospitalized at hospital A because of COVID-19 infection. The same “the patient was hospitalized at hospital A” but only“3/3” is HOSPITALIZE_DATE.

The third group includes errors that confuse entities (except DATE entities) with each other (99/543 on valid set and 35/411 on dev set), mostly: confusing LOCATIONs with CONTACT_PERSONs, CONTACT_PERSONs with NAMEs. This is because the model confuses the proper names of the entities with each other.

Table 5 Performance of recognizing entities with $\text{PhoBERT}_{\text{large}}$ on valid and test set

Dataset		NAM.	AGE	GEN.	ADD.	SYM.	POS.	HOS.	ISO.	LOC.	C.D.	C.P.
Valid	Prec.	98.47	97.53	98.43	99.78	83.46	71.25	76.64	74.56	77.93	86.13	85.75
	Rec.	99.51	99.43	99.89	98.53	87.23	74.34	78.47	78.29	82.31	87.61	86.13
	F1	98.99	98.43	99.39	99.32	85.18	72.69	77.59	76.55	80.03	86.92	85.77
Test	Prec.	95.23	98.58	99.98	98.71	74.16	74.75	75.65	78.66	79.25	85.23	84.95
	Rec.	96.23	99.42	99.53	99.78	75.56	77.81	79.28	81.26	83.53	87.33	88.29
	F1	95.73	98.81	99.69	99.23	74.98	76.32	77.39	79.75	81.46	86.45	86.59

5.5 In Reality

With our best model, a system was developed for testing by the COVID-19 prevention and information analysis team. The results show that the system can extract information at a speed of 0.78s/case report, saving a lot of time and effort compared to manual work (about 3 min). An extra post-processing step for the model output with rule-based was also implemented to increase accuracy. However, there are still about 15% of the reports that need to be corrected by humans. Besides, there are also many new and complex report templates that need to be handled. Therefore, the system is still need to be improved to be able to overcome those challenges to be used widely in the future.

6 Conclusion

In this chapter, an AI-based approach using NLP for COVID-19 prevention was proposed. The system was implemented and tried in practice in Vietnam. The detail process was presented. In addition, a new nested NER dataset for Vietnamese on the topic of COVID-19 was set. This dataset can contribute to the development of NLP for Vietnamese and multilingual as well as contribute to the prevention of COVID-19.

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VacciNet: Towards a Reinforcement Learning Based Smart Framework for Predicting the Distribution Chain Optimization of Vaccines for a Pandemic

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1 Introduction

Infectious diseases and pandemic outbreaks have impacted the world history by shaping societies, changing war outcomes, influencing socio-economic policies and political standpoints, and overall paving the way for innovation in medicine and technology [1]. A growing consensus among researchers is that, one of the most effective way of controlling pandemic outbreaks is a well-timed and efficiently managed vaccination strategy. In the phase-1 of *Covid-19* vaccination, the doses were made available to the most vulnerable population, based on age and occupation. For every country in the world, once the vulnerable population is vaccinated during phase-1, vaccination drives switch to phase-2 of distribution where the mass population gets vaccinated at once. With this phase of vaccination, several issues are associated, for example, vaccine wastage and shortage in different locations, excess cost of supply and storage due to inefficient balance between supply and demands, etc. The United States (USA) Department of Health and Human Services adopted the Operation Warp Speed (OWS) strategy for Covid-19 vaccine distribution in January 2021 [2], which does not consider several important optimization factors.

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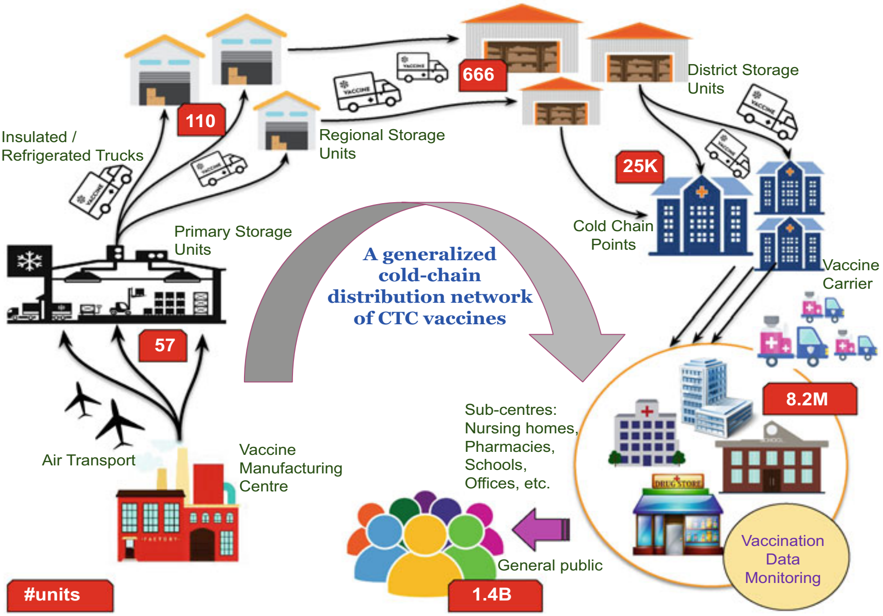

Fig. 1 A generalized diagram of vaccine distribution cold-chain network. Here, the unit counts are from data of India (an example case) [4]

According to the recent updates in the World Health Organization (WHO) Covid-19 dashboard, globally there have been 5 billion vaccinations administered. Currently 2 billion people, which is only 29.9% of the world's total population, are fully vaccinated. The mutations of the *SARS-CoV-2* virus has made development of mutation-resistant vaccines and administration of seasonal vaccinations inevitable in the near future [3]. Till date mass vaccinations for Covid-19 booster doses are getting carried out, while emergence of new strains and viral outbreaks remain a high possibility. Figure 1 shows a typical cold chain vaccine distribution network for a country. For delivering 1 billion Covid-19 vaccines USA spent nearly **2 billion US dollars**, about **22%** of which is associated with Controlled Temperature Chain (CTC) transportation [5]. Frozen essential goods need high maintenance to avoid damage as well. Even in front-line health centres, there is a cost for refrigerated storage of the supplied vaccines. If we continue to conduct uncoordinated vaccine distribution, global GDP loss in the coming time can amount to **US$ 9.2 trillion** [6]. At the present, no automated approach to commercially solve this issue has come up that can help mitigate economic crisis due to mismanaged CTC supply-chain. From our observation of the world-economics during the past 2 years, it is evident that an automated solution to optimized vaccine or other CTC good supply network can essentially reduce wastage of human and monetary resources by big pharmacies, governments and other companies. Hence, in this chapter we attempt to propose a solution with deep learning based approach. We limit our experiments and solutions to vaccine supply chain in this chapter, but our framework can be implemented on any CTC essential item supply chain in a country given the demand of that item in the state, the population of the state, with minor changes in the data pre-processing methods. This is possible because our framework is built simply on three major data inputs: (1) demand of an essential CTC commodity (in our case it is vaccine), (2) section of population already supplied with the concerned commodity, (3) section of the population yet to receive the commodity, (4) costs associated with the supply of the commodity to various location in a certain state of a country. With these factors in mind we have constructed our *Vaccinet* framework, such that it can be easily adapted to predicting optimal distribution of any CTC essential commodity other than vaccine. We have trained and tested our framework using state-wise vaccination data from the USA, however our framework can be easily adopted to be trained on similar data from any other country.

With the aforementioned motivations, our main highlights and contributions in this chapter are threefold.

1. We implement a Recurrent Neural Network (RNN) [7] based vaccine demand prediction model. We use supervised learning mechanism to train a light-weight deep SRU (Simple Recurrent Unit) [8] model to predict the state-wise daily vaccination requirements based on the collected vaccination drive data of different states in the US,
2. We perform feature engineering on the collected vaccination data to help train our SRU predictor model with an added attention block to increase the model convergence speed while training.
3. We implement a Reinforcement Learning (RL) based Deep Q-network [9] to optimize the state-wise vaccine allocation as per the state-wise demands and propose a training algorithm for the same.

The rest of the chapter is arranged as follows—in Sect. 2 we discuss the existing research in this area and explain how our work and contribution is different from the earlier works. We introduce our working methodology and proposed framework in Sect. 3 and finally provide the evaluation results of our framework in Sect. 4. Finally, we discuss the comparison of our work with the earlier works, the limitations as well as the future prospects of our work in Sect. 5.

2 Related Work

Vaccine distribution network primarily depends on vaccine coverage, release time, and deployment methods [10]. Some Food and Drug Administration (FDA) approved vaccines need expensive CTC handling for thermostability and hence need accurately optimized procurement, distribution, and storage management strategies to help curb global pandemic and economic crisis [11–13]. Babus et al. [14] examined occupation based infection risks and age based fatality risks of general population to model an optimal vaccine allocation strategy. Matrajit et al. [15] evaluated selective objective functions to estimate vaccination coverage and effectiveness.

A concatenation of Reinforcement Learning (RL) and Contextual Bandits sub-models in feed-forward has been proposed in [16] for phase-1 Covid-19 vaccination distribution. The authors in [16] have used death-rate, recovery-rate, hospital facilities, etc. of a state as input attributes to predict which part of the population is at a higher risk of pandemic fatalities and therefore needs priority vaccination. Although several optimization policies have been adopted for prioritizing vaccine allocation at an early stage of a pandemic (phase-1), there exists a research gap in developing economically optimal vaccine distribution strategies during mass vaccination (phase-2). This chapter attempts to bridge the said gap and to the best of our knowledge *VacciNet* framework is the first attempt at this.

The major problems associated with mass vaccination drives are dense, highly mismanaged cold chain distribution networks that can incur unnecessarily large expenditures by governments and health institutions over a very small span of time [5, 6]. In a country that is suffering or that has suffered from the economic damages due to a pandemic, an efficient vaccine or essential item supply chain can help save resources. Since frozen products like vaccines can have huge supply chain costs, effective methods of distribution strategies are extremely critical. We address this problem with our novel deep-learning based methodology detailed in the section below.

3 Our System: Overview and Design

In this section of the chapter we explain the workflow of our method, detail the data-flow in proposed framework, elaborate the architecture design and mathematical working of the same, and finally provide the implemented learning algorithm.

3.1 Proposed Framework

We provide a detailed discussion of the methodology adopted, Deep Learning (DL) models implemented, and their architecture components in this section.

3.1.1 Design Components and Operation

Figure 2 shows the basic block diagram of our proposed framework. We include two stages in our method—(1) Supervised Learning of a RNN-based *predictor* model and (2) Reinforcement Learning. We collect and pre-process the vaccination data of each state in US[1] to create the time-series input feature space for training RNN-

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[1] https://ourworldindata.org/us-states-vaccinations.

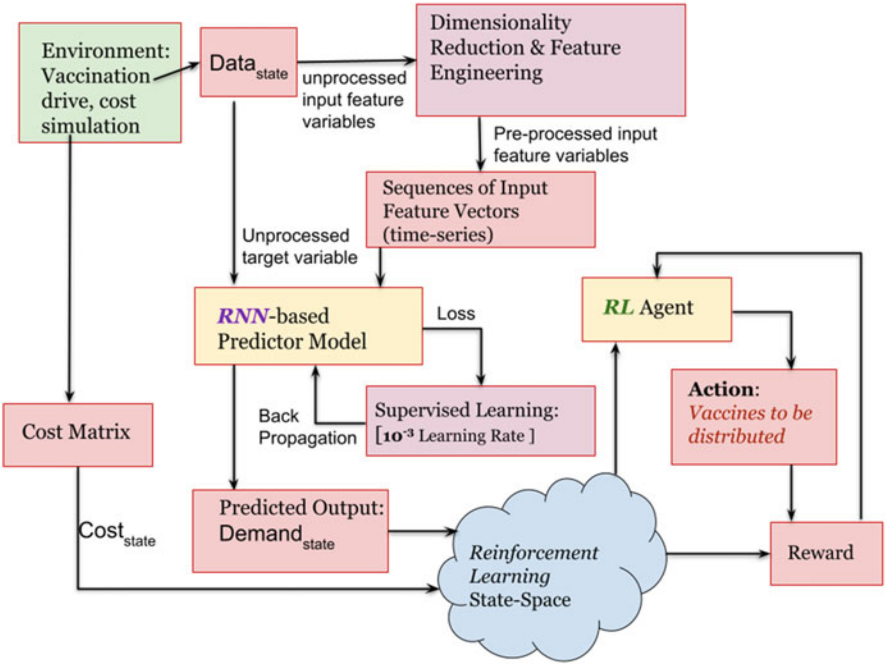

Fig. 2 Overview of VacciNet

based SRU model. We further detail the data preparation in Sect. 4.1. This SRU model trained and tested on real vaccination data, is capable of predicting the daily vaccination demands of each state in the US. We call this model the *predictor* model. The aim of the *predictor* is to find the daily vaccination requirement of a state based on the state's population and total people vaccinated till a stipulated date. The next step of our framework includes training a deep Q-network (*RL-agent*) with Reinforcement learning such that it can generate the most optimal vaccine allocation per state with minimum cost of vaccine supply-chain. In a reinforcement learning system, the *environment* is the entity with which an *RL-agent* interacts to gain a set of valid observations, also called the *state-space* of the RL algorithm. The interactions of the *RL-agent* makes it take certain actions in the *environment* as permissible in the defined *action-space* of RL algorithm. These actions get better with each iteration of training the *RL-agent*, such that the agent learns reach the best probable state in the over-all *state-space*. We have listed the over-all process in Algorithm 1. However, the last line of the algorithm can be explained with the reinforcement learning algorithm, which is explained in Sect. 3.2 and Algorithm 2.

In our system we defined the *environment* as—(1) the vaccine demands in each state of a country, and (2) the vaccine supply-chain costs associated to meet the demands. The vaccine demands ($Demand^{state}$) are the output from the trained *predictor*. We simulated the *cost matrix* data considering several real-world parameters that impacts the cost of temperature controlled supply-chains. This data simulation is further explained in Sect. 4.1.2 in the later part of the chapter. Algorithm 1 helps elaborate the workflow of the framework while the complete mathematical foundations of our proposed method is discussed in Sect. 3.2.

3.1.2 Choice of the *Predictor* Model and the *RL-Agent*

As explained previously, we attempt to create two models—a *predictor* model to infer the daily vaccination demands of a state, and a *RL-Agent* which can optimize the vaccine distribution chain. The vaccination data is in the form of a time-series, where one data-point is dependent on the previous set of data points. We use a deep Simple Recurrent Unit (SRU) [8] as the *predictor* model which is a recently introduced variant of RNN that has advantages over Quasi RNNs (QRNNs) [17] and Kernel Neural Networks [18] for their "light recurrence" connections with relatively less parameters [8]. The "highway connections" in SRUs give them an edge over the popular Long Short Term Memories (LSTMs) [19] and Gated Recurrent Units (GRUs) [20] with improved training and inference time. Hence, we select SRU units to construct our RNN-based predictor model that allowed us to reach effective results with minimal effort in training it. We utilize an attention mechanism [21] in SRU *predictor* training that allows us to converge the model **2.9 times faster** than standard SRU model. We took the time measurement while training the models on Ubuntu 18.04 workstation with Intel Xeon 32 Core processor, 16GB DRAM and 2 NVIDIA GTX 1080 8GB GPUs and compared the time required for model convergences. Although a multitude of techniques have been adopted in the earlier works for supply chain optimization methodologies [22], we propose to use deep Q-networks (DQNs) [9] to optimize the distribution chain using Q-learning. Q-learning has picked up popularity in most recent areas of research due to the sustainability, reliability and high accuracy of the learning method. Q-learning models are easy to implement, train and deploy alongside give high performance compared with other techniques.

3.1.3 Model Architecture Details

Figure 3 shows the detailed data-flow diagram of our proposed framework. As illustrated in Fig. 3, our deep *predictor* model consists of two SRU [8] layers (*SRU Layer 1* and *SRU layer 2*) with 10 units each, and a single unit dense layer. The inputs to the SRU units are pre-processed feature attributes, *total_population* (state population), *people_partially_vaccinated* and *people_fully_vaccinated*. We also include an *attention* block [21] in getting the final output y which is the predicted daily state-wise vaccine demand (previously explained $Demand_{state}$). The *attention* block generates *context vector* from the hidden layer output *feature vector*. This helps the model behaviour (inter-mediate feature representation) to focus on important parts of the *input*, before it reaches the *fully connected layer*.

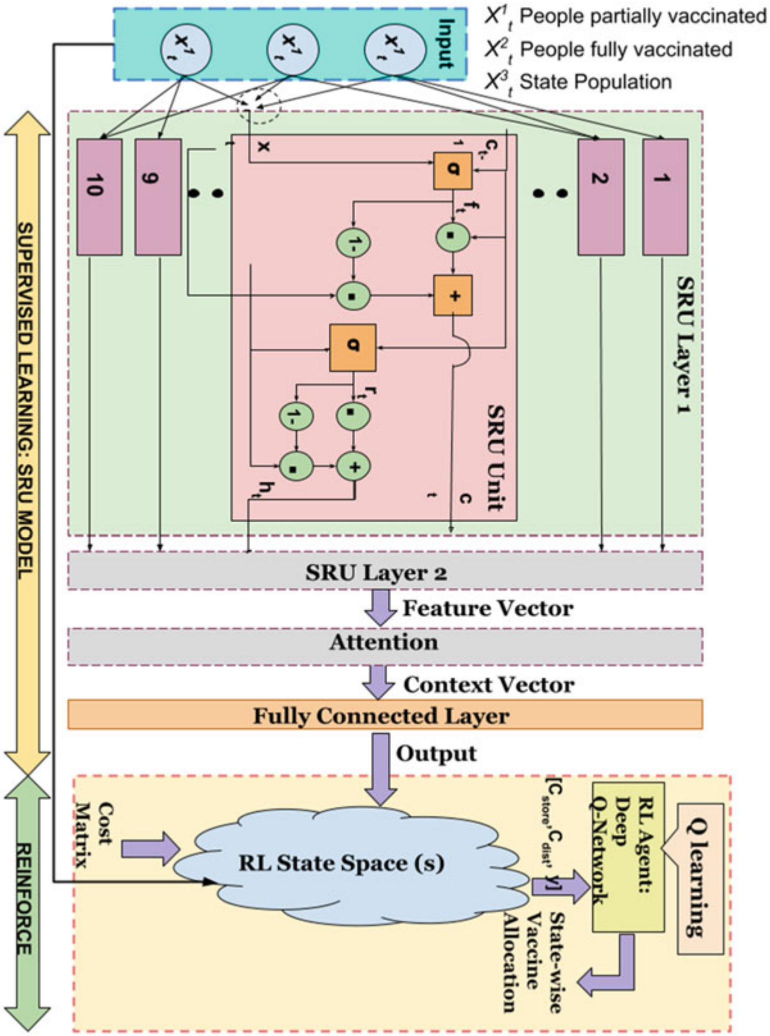

Fig. 3 The detailed data-flow diagram of *Vaccinet*. The input vector represents the $Data_{state}$ variable that consists of 3 components—people partially vaccinated (X^1_t), people fully vaccinated (X^2_t) and state population (X^3_t). The output vector represents the $Demand_{state}$ variable. Cost matrix is the $Cost_{state}$

For the DQN *RL-agent* we train a deep network of 4 dense layers in RL based Q-learning algorithm. The details of the working of a single SRU-unit (as shown in Fig. 3) and the mathematical foundations of our RL algorithm are detailed in Sect. 3.2. The details of data pre-processing and preparation for the SRU *predictor* and the DQN *RL-agent* are discussed in Sect. 4.1.

Algorithm 1: Vaccine distribution chain optimization

```
Data: state-wise vaccination data, state-wise cost matrix data
Result: state-wise vaccine allocation
$Cost_{state} \leftarrow$ {state-wise cost matrix};
$Data_{state} \leftarrow$ {state-wise vaccination data};
$Allocation_{state} \leftarrow \{\phi\}$;
$Demand_{state} \leftarrow \{\phi\}$;
for $index_{state}, input\_features\ in\ Data_{state}$ do
    $Demand_{state}[index_{state}] \leftarrow SRUPredictor(input\_features)$;
end
$statespace \leftarrow \{Demand_{state}, Cost_{state}\}$;
$Allocation_{state} \leftarrow RLagent(statespace)$;
```

3.2 Mathematical Formulations and Training Algorithm

The vaccination data collected from vaccination drives in the US consists of data on number of people partially vaccinated, fully vaccinated, and the state-wise doses administered in a day. The state-wise vaccination done (*daily_vaccinations*) is our target variable, and hence remains an unprocessed continuous numerical data. Whereas, we pre-process the other two variables along with state population data to generate final input feature space of SRU *predictor* (details in Sect. 4.1). The input data (as shown in Fig. 3) represents a sequence of features, x, over a set of contiguous dates per state. We represent the input as $x = \{x_0, x_1, x_2, ..., x_T\}$, where x_t is a set of feature for the timestep/date t. T represents the upper bound to the sequence. We can then formulate a single layer of SRU with the computations shown in Eqs. (1), (2), (3) and (4), where, W, W_f and W_r are layer parameter matrices, v_f, v_r, b_f and b_r are learn-able parameter vectors. Here, Eqs. (1) and (2) represents the *light-recurrence* property of SRU layer, while (3) and (4) represents the *highway connectivity* property.

The output of the SRU layer is given by h_t in Eq. (4) while f_t, which involves sigma-activation σ, represents a light recurrence computation in Eq. (1), which is highly parallelizable due to the point-wise multiplication ($\odot$) of v_f and c_{t-1}. In Eq. (3), r_t represents a highway connection and c_t in Eq. (2) represents the state of the SRU cell. Coupled with an *attention* mechanism, the model is trained using a *mean-squared error* loss against the target feature vector *daily_vaccinations*, y, of an area using supervised learning method.

$$f_t = \sigma(W_f x_t + v_f \odot c_{t-1} + b_f) \tag{1}$$

$$c_t = f_t \odot c_{t-1} + (1 - f_t) \odot W x_t \tag{2}$$

$$r_t = \sigma(W_r x_t + v_r \odot c_{t-1} + b_r) \tag{3}$$

$$h_t = r_t \odot c_t + (1 - r_t) \odot x_t \tag{4}$$

For the next step of our proposed framework, the RL phase, we take the output ($Demand_{state}$) of *predictor* as one constituent of *state-space*, whereas for the cost-matrix in the *state-space* we utilize Eq. (10) in Sect. 4.1.2. This data is generated for daily vaccinations in each state of the country.

$$s_{state} = \langle Cost_{state}, Demand_{state} \rangle \tag{5}$$

$$Q^*(s, a) = E[r + \gamma \max_{a'} Q^*(s', a')] \tag{6}$$

Given a state space s_{state}, the agent follows a policy π with which it produces an action a. From this action, it receives a reward given by $Q_\pi(s, a)$. The model tries to maximize its reward by optimizing its *action space* thereafter represented by $Q^*(s, a)$, which is defined in Eq. (6). The variables r and γ are the immediate reward and the discount factor respectively, whereas s' and a' represents the subsequent permissible state and action spaces of the *RL-agent* model. When the Q-function is represented by a neural network, it can cause instabilities and often diverge from target solution. This happens due to the instabilities in correlation coefficients between Q-value and target values and minor alterations in the Q-values causing drastic changes in policy. Hence, Mnih et al. [9] introduced experience replay and iterative updating in Q-learning. In this concept, the *RL-agent* has a collection of experiences called memory. We define experience e_t at time-step t as (s_t, a_t, r_t, s_{t+1}) and memory D_t at time step t as $e_1, e_2, ..., e_t$. Here, s, a, and r refers to the state-space, action, and reward at time-step t respectively. Each *state-space* is formulated by Eq. (5). We use a neural network with weight vector θ as Q-network in our Q-learning algorithm. At each iteration k of our iterative weight update method, we train the Q-network to reduce the root mean square log error in the Bellman [23] Eq. (6). We use root mean square log error (RMSLE) [24] as loss function to update weights in Q-network as given in Eq. (7). RMSLE is more robust to outliers in the data. Since the demand in a state or costs of vaccine allocation can be largely different on some days, the real data of this sort is expected to have multiple outliers. Hence, we carefully choose the loss function.

$$L_k(\theta_k) = E_{s,a,r}\left[\sqrt{\frac{1}{K} * \sum_{k=1}^{K}(log(E_{s'}[y|s, a]) - log(Q(s, a, \theta_k)))^2}\,\right] \tag{7}$$

In Eq. (7), θ_k, and Q are the weight vector, and Q-value at kth iteration respectively. The aim of the Deep Q-Learning is to find an optimal policy π such that the total reward is maximized, this can be represented by the expected discount return (G_t) function in Eq. (8). Our reward function is multi-objective in nature, and the RL algorithm tries to reach a trade-off between the cost for vaccine distribution in a state $Cost_{state}$ and the vaccine allocation in that state $Demand_{state}$ as per the demand. Hence in the reward we apply a piece-wise linear [25] negative function [26] over cost data and positive function for vaccine allocation, that is, we start giving negative or positive rewards for cost exceeding predefined threshold and vaccine allocation lower than demand for the state respectively. Hence, we train the deep Q-network to maximize the total reward given by Eq. (8).

$$G_t = \sum_{k=0}^{\infty} \gamma^k r_{t+k+1} \tag{8}$$

As shown in Algorithm 2, vectors $Cost_{state}$ and $Demand_{state}$ constitute the *state-space* s of RL. The DQN *RL-agent* is repeatedly trained with data of each state, which we consider to total at S states. The function ϕ represents the pre-processing performed in the state vector at a particular time-step t. We train our *RL-agent* with mini-batches of size 16. For the data of each state in the US, we initiate the training with random actions by the *RL-agent* using ϵ-greedy policy [27, 28]. For every increasing time-step t, we assign the action a_t from the maximum expected return at that time-step following policy π that maps the state vector sequence s_t with the permissible actions a using $argmax$ function. Following which we update the state of the RL in the next time-step s_{t+1}. For experience e_t in memory set D, we update the parameters of the target action-value function $\hat{Q}(s, a)$. We use stochastic gradient descent (SGD) [29] optimization algorithm to update the network parameters of *RL-agent* Q with the loss calculated as per Eq. (7). In the Sect. 4.2 of the chapter, we show the results of varying γ and learning-rate in the RL-algorithm.

4 Experiments and Evaluation

In this section, we elaborate the data processing techniques implemented to carefully select the suitable input features for our SRU *predictor* and we also discuss the preliminary results of training the SRU with and without the attention mechanism.

4.1 Data Preparation and Analysis

In this section of the chapter we describe the collection and pre-processing of the data from various vaccination drives in different states of the USA, and the simulation of cost matrix data considering various parameters in a cold chain distribution channel. This pre-processed data constitutes the total *state-space* of the *environment* of our RL Algorithm 2.

Algorithm 2: RL Algorithm

```
Data: $Cost_{state}$ sequence, $Demand_{state}$ sequence
Result: trained target action value function $\hat{Q}$ to give better rewards $r$
Initialize action-value function $Q$ and target action-value function $\hat{Q}$ with random weights $\theta$ ;
for $state \leftarrow 1$ to $S$ do
    Initialize $D_{state}$ to capacity N;
    $s \leftarrow \langle Cost_{state}, Demand_{state} \rangle$;
    for $episode \leftarrow 1$ to $M$ do
        $s_1 \leftarrow \langle Cost_{state,1}, Demand_{state,1} \rangle$ ;
        $\phi_1 \leftarrow \phi(s_1)$;
        for $t \leftarrow 1$ to $T$ do
            if $t = 1$ then
                Randomly select $a_t$ with a probability of $\epsilon$ ;
            end
            else
                $a_t \leftarrow argmax_a Q_t(s_t, a; \theta_1)$;
            end
            $s_{t+1} \leftarrow \langle s_t, a_t, \langle Cost_{state,t}, Demand_{state,t} \rangle \rangle$;
            $\phi_{t+1} \leftarrow \phi(s_{t+1})$;
            $D \leftarrow \langle \phi_t, a_t, r_t, \phi_{t+1} \rangle$;
            Random sample mini-batch $\langle \phi_k, a_k, r_k, \phi_{k+1} \rangle$ with $N$ transitions from $D_{state}$;
            for $e_t = \langle s_t, a_t, r_t, s_{t+1} \rangle$ do
                $\hat{Q}(s, a) = E[r + \gamma \max_{a'} \hat{Q}(s', a')]$;
            end
            SGD (stochastic gradient descent) on $L_k(\theta_k)$ with respect to $\theta_k$ with pre-defined learning rate; Weights of $\hat{Q} \leftarrow$ weights of $Q$ ;
        end
    end
end
```

4.1.1 Vaccination Drive Data Preparation for RNN Based SRU Model

The data[2] consists of state-wise Covid-19 vaccine administration details of USA, with date stamps from 1st January to 9th August, 2021. Figure 5 shows the daily number of doses of vaccines (*total_vaccinations*) administered per state. We observe the data distribution across 240 dates such that the vaccinations peak when the demand is highest in each state, and as the number of people vaccinated falls, the number of vaccinations administered falls. We find the population for each state from the official census of USA.[3] There are 240 sets of data points for each state. We analyse the correlation plots for all the given attributes collected from the public dataset in Fig. 4. From this plot we observe that the feature attributes *total_vaccinations*, *total_distributed*, *people_vaccinated* , and

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[2] https://ourworldindata.org/us-states-vaccinations.

[3] https://www.census.gov.

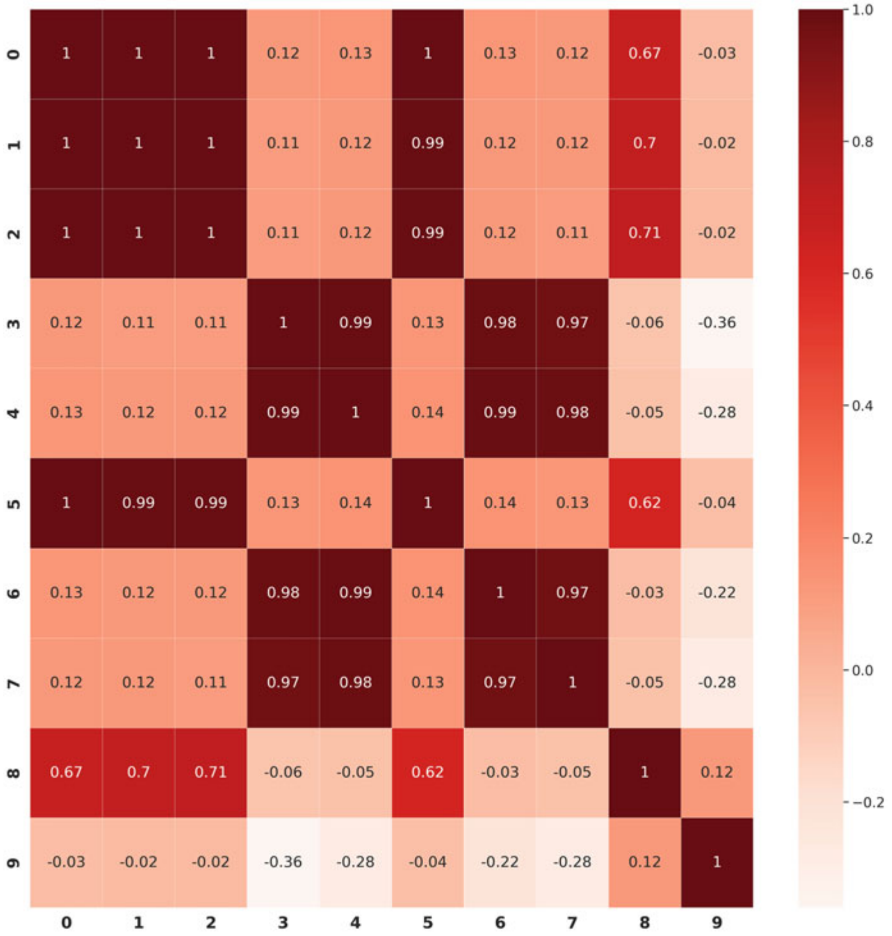


Fig. 4 The mapping of the values in the x and y axes are as follows: 0—total_vaccinations, 1—total_distributed, 2—people_vaccinated, 3—people_fully_vaccinated_per_hundred, 4—total_vaccinations_per_hundred, 5—people_fully_vaccinated, 6—people_vaccinated_per_hundred, 7—distributed_per_hundred, 8—daily_vaccinations and 9—daily_vaccinations_per_million

people_fully_vaccinated (attribute numbers 0, 1, 2 and 5 in Fig. 4) have the highest positive correlation with the target attribute *daily_vaccinations* (attribute number 8 in Fig. 4). However, these feature attributes have high mutual positive correlation as well. Hence to prepare a better input feature space for our SRU *predictor* model we derive a new feature from the available feature attributes (Fig. 5).

From the raw data attributes, *total_vaccinations* and *people_fully_vaccinated*, we calculate a new feature, *people_partially_vaccinated*. The *total_vaccinations* and *people_fully_vaccinated* are total number of Covid-19 vaccinations administered and total number of fully vaccinated people (first and second dose) respectively, in a particular state till a specific date. The formula to derive it is given by Eq. (9).

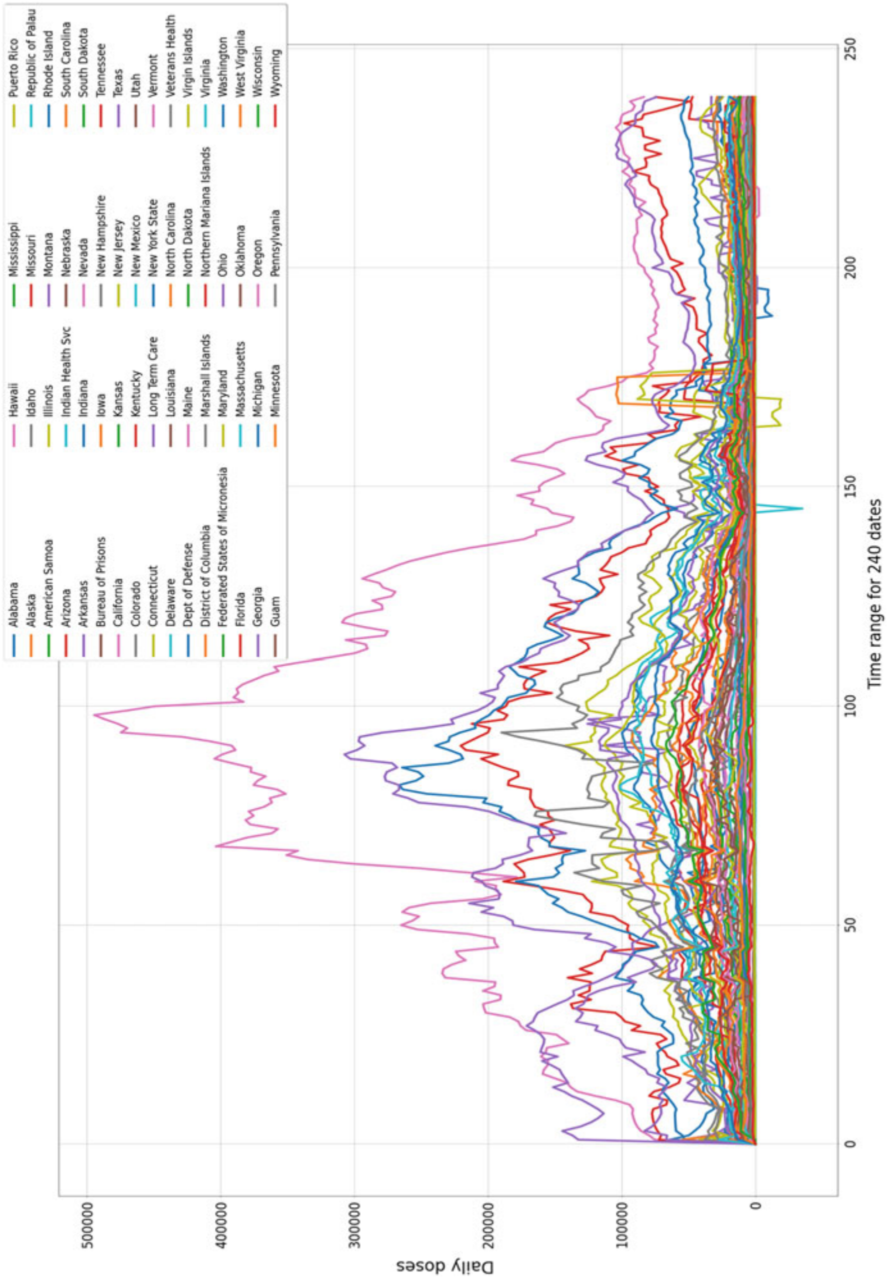


Fig. 5 State-wise daily vaccinations vs time. The daily vaccinations gradually rise and fall indicating the gradual increase and decrease of demand as more people are vaccinated overtime

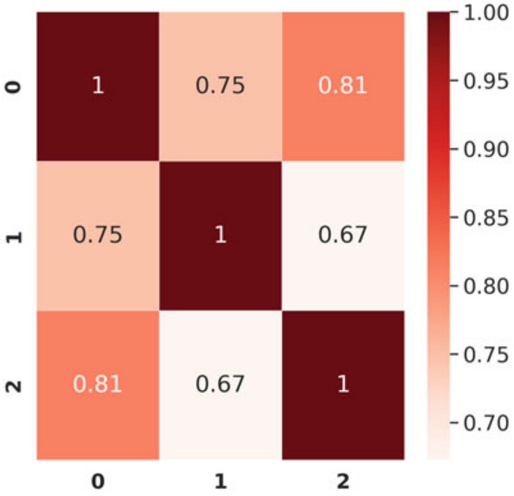


Fig. 6 Pearson's correlation matrix plot for the set of inputs to the SRU model. The x and y axes values map as follows: 0—total_population, 1—people_partially_vaccinated and 2—people_fully_vaccinated

$$N_S = total\_vaccinations - 2 \times N_D \tag{9}$$

In Eq. (9), N_S and N_D represent the number of people vaccinated with a single dose and both the doses respectively. These two parameters along with the state population data (X^1, X^2, X^3 respectively) constitute the input to the *predictor* model. In Fig. 6, we show the values of *Pearson's* correlation coefficients for the final input features to our SRU model. By ensuring a low correlation between the input variables, we create a stable dataset for the *predictor* model's training.

Hence, the input to the SRU model is given by the sequence of a set of 3 features, *total_population*, *people_partially_vaccinated*, and *people_fully_vaccinated*, from the first date to a selected vaccination date. The data is split into *80%, 10%* and *10%* for *train-set*, *validation-set*, and *test-set* respectively. The ground truth for training and evaluating the SRU model is given by the *daily_vaccinations* target attribute values from the dataset (Fig. 7).

4.1.2 Cost Matrix Data Preparation for State Space of Q-Learning

According to Thomas et al. [30], there are a number of major cost components in a health system temperature controlled supply chain network. These include the costs related to—(1) procurement, (2) storage, (3) transportation, and (4) management. This is a function-wise categorization of cost data. In tier-wise categorization of cost data, particularly in case of our analysis, we divide it into the costs related to—(1) Government Medical Store Depots (GMSDs), (2) state-wise and (3) regional costs. Generally in a vaccine distribution chain, vaccines from a centralized distribution location is supplied across various states in a country. These are referred to as GSMDs. For example, in India, there are 7 GMSDs from which the vaccines are

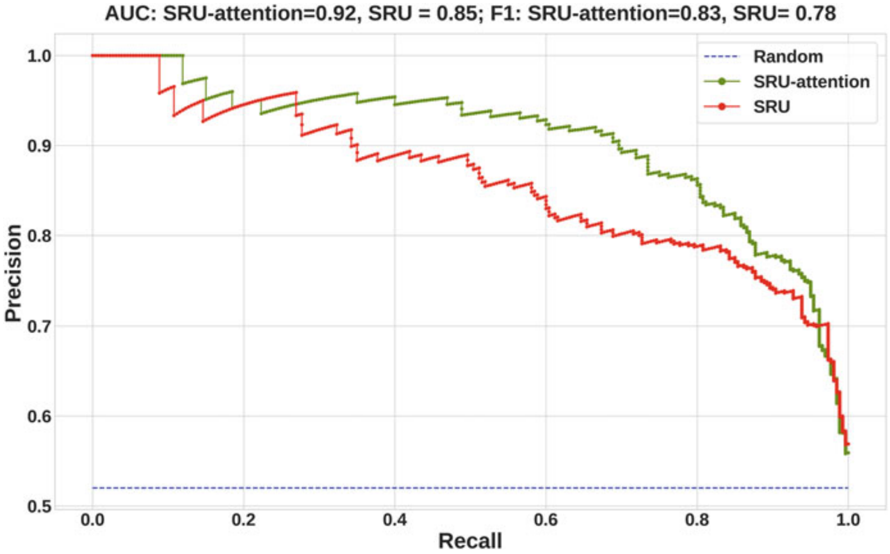


Fig. 7 Precision-Recall (PR) curve of VacciNet's *predictor* SRU, with and without attention

distributed all over the country. Since we only have state-wise vaccination data available for the USA, we apply the functional categorization of supply-chain cost components for state-wise tier category. To aid this explanation we provide a chart in Fig. 8. Hence, for our cost data generation, we need the following major cost-components:

1. labor cost in procurement,
2. labor, space (inventory), equipment and fuel costs in storage,
3. labor, vehicles and fuel costs in transportation, and
4. labor and operational costs in management.

For each of the above parameters we simulate the relevant cost values for each state in the USA to create the cost-matrix $Cost_{state}$ in the *state-space* of our DQN *RL-agent*. This calculation of cost associated with vaccine supply in each state of the USA is done using Eq. (10). Here, we have assumed that the distribution to different states takes place from a common source location, which is generally the case in real world scenario.

$$Cost_{state} = \sum_{i=proc,stor,trans,mang} \times (\Pi_{j=labor,fuel,space,equip,vehicle}(W_{i,j} * Cost_{i,j}) / \sum_{i} W) \tag{10}$$

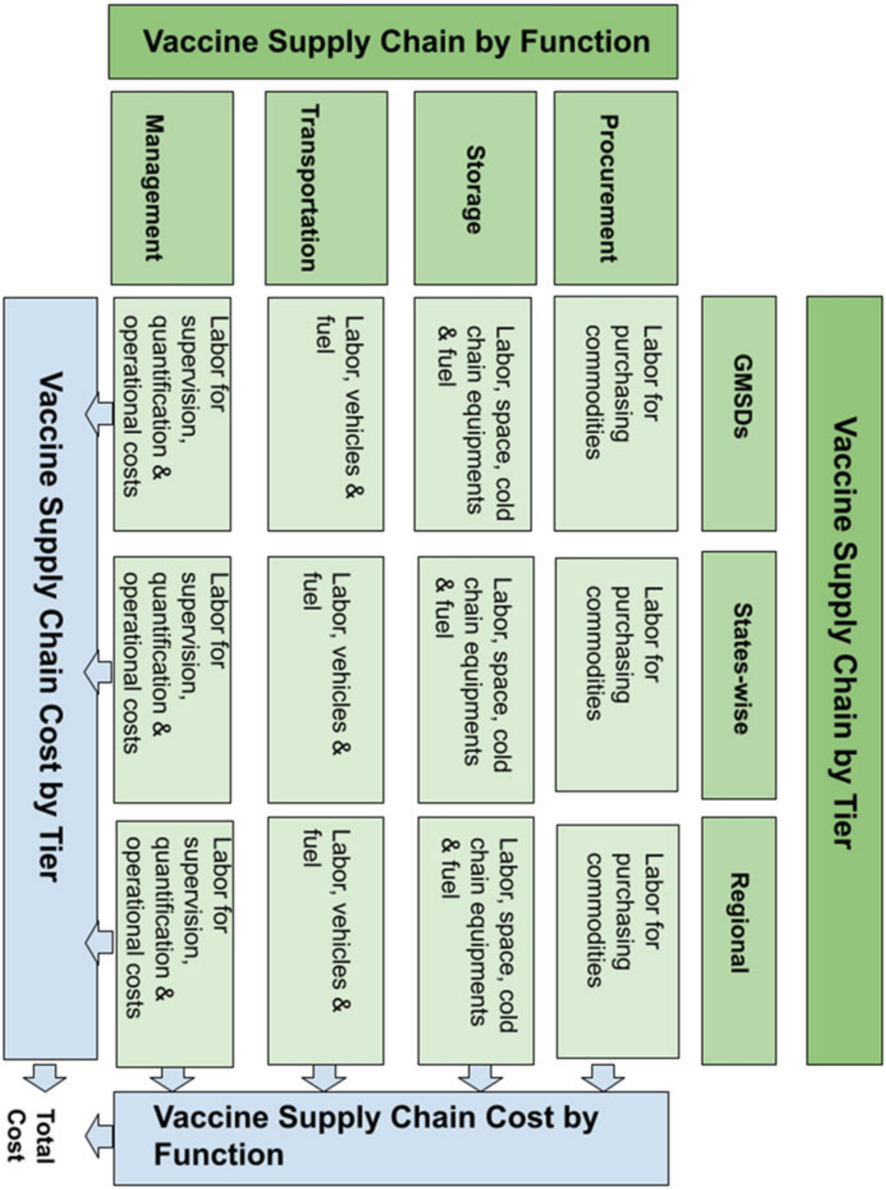


Fig. 8 Supply chain cost categorization for cold chain distribution of vaccines

In Eq. (10), $proc$, $stor$, $trans$, $mang$ refers to the costs associated with procurement, storage, transportation and management respectively. We simulate the cost matrix $Cost_{i,j}$ by generating the values for each state. This simulated data takes into account the distances of the states from the centre of distribution, the general financial condition of the state, the unemployment ratio, and the budget allocation of the state towards Covid-19 pandemic. Although this data is simulated to replicate a real world scenario, the supply-chain prices highly vary in the real case. However, with the availability of the cost of distribution data, our framework can be re-trained on it to provide good results. To ensure further variations in the final cost per state, we introduce a weight element for each cost element. Here, $W_{i,j}$ represents the total weight matrix with few of the weight elements assigned zero value purposefully. For example, when there is no cost associated with space or inventory in procurement, the relevant weight element will be zero in value. The other values of weight elements are randomly simulated ranging from > 0 to 1. This helps us calculate a weighted average of the cost values which is normalized to get a normal distribution of numbers. This is an additional pre-processing step for better training of the DQN *RL-agent*. This normalized weighted average cost values along with the vaccine demand predictions from the SRU model form the environment state space of the RL framework.

4.2 Model Evaluation

In this section of the chapter, we provide the details of the evaluation of our two learning methods—supervised learning of RNN-based SRU *predictor* model and reinforcement learning of DQN *RL-agent*.

4.2.1 SRU *Predictor* Evaluation

The SRU *predictor* does not require more than 10 dimensionally expanded features to learn better representations. Hence, for simplicity of the architecture we limit the number of SRU units to 10 per layer. The attention mechanism aids in constructing fixed size context vectors from the encoded representations. The context vector improves the decoding step performed by the single dense/linear layer. Without the attention mechanism, the model takes a much longer time to converge to lower values as evident from Fig. 9.

Without the attention mechanism, the input of the sequences is required to be fixed to 240×3 (240 sequences of 3 features each) so that the input to the dense layer would always be of size $240 \times 10 = 2400$ (10 feature outputs per SRU layer). The sequences are required to be padded as well resulting in excess of zeros that contributes to the poor learning, which is solved using attention. It also enables variable length inputs. As shown in Fig. 7, Precision-Recall (PR) curve of SRU *predictor* model with attention mechanism has better Area Under Curve (AUC) and F1-score (F1) than that without attention on test dataset. With *attention* block, the AUC increase from 0.85 to 0.92 and F1-score increase from 0.78 to 0.83. For

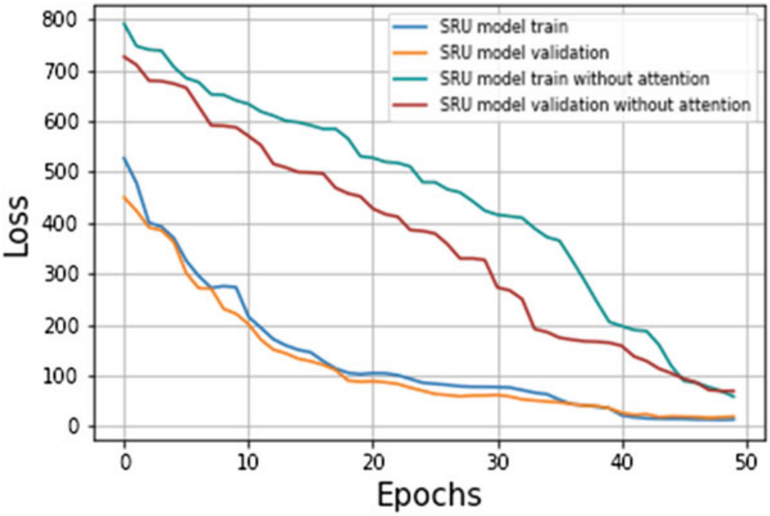
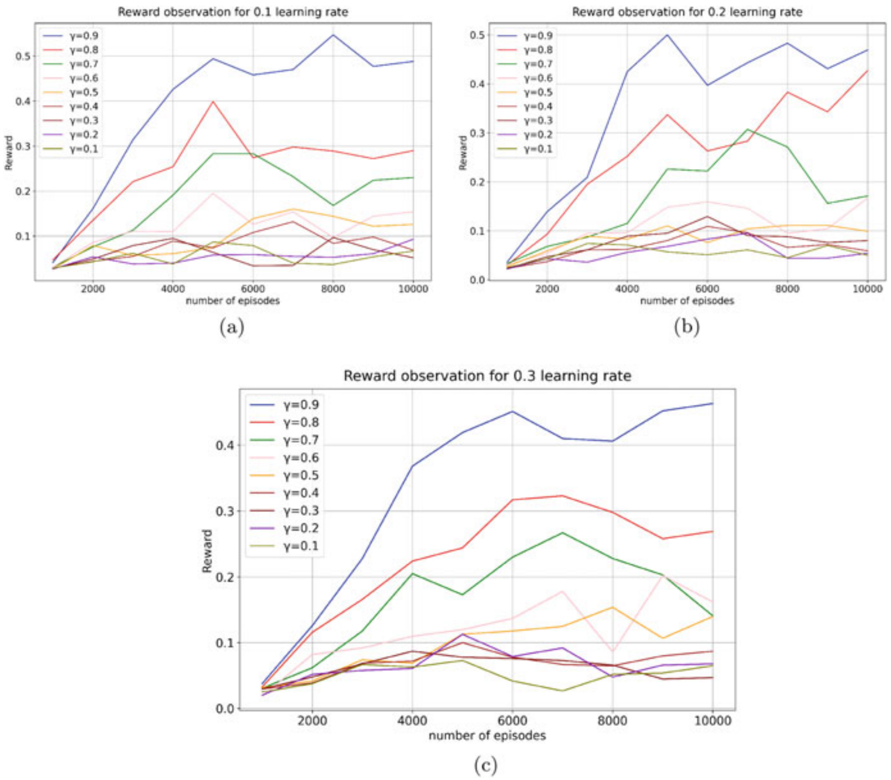


Fig. 9 The SRU without the attention network starts at a higher loss. The SRU with the attention mechanism converges 2.9× faster than SRU without attention network

time-series data, with a continuous target variable it is a challenging task to reach good accuracy. We determine the accuracy in terms of F1-score with a pre-defined threshold to determine how close the predicted values are to the ground truth. We defined the allowable deviation of predicted output in the range of 10%–20% with respect to the target variable.

4.3 DQN RL-Agent *Evaluation*

We train our RL framework based on Algorithm 2 for each of different states in USA. In our experiments we initialize the exploration probability to 1 and reach minimum exploration probability value of 0.001 with an exponential decay rate of 0.0001. We train our deep Q-network on 10,000 episodes with 1000 iterations in each. We use different initial learning rates as shown in Fig. 10, and in each case observe the reward for different discount factors ranging between 0.1 and 0.9. From the figure we observe that in all the cases, discount factor 0.9 is giving the highest rewards. We observe the min-max scaled average reward per state transition is 0.678 with initial learning rate 0.1 and γ value 0.9. This is the best performing model we inferred from our problem formulation.



(a) (b)

(c)

Fig. 10 The reward observations with respect to progressing episodes of deep Q-Learning with varying γ values (discount) for different learning rates. (**a**) For learning rate $= 0.1$. (**b**) For learning rate $= 0.2$. (**c**) For learning rate $= 0.3$

5 Discussion and Conclusion

There exists a number of earlier works based on deep learning methods for optimization of supply chain management tasks, especially in the cold chain networks which require refrigeration and hence contribute immensely in the total supply cost. Some of the earlier works in this area include implementation of block chain technology [31–33]. Nikolopoulos et al. [34] implemented time series models, regression models, LSTMs (Long-Short Term Memory) [19] to forecast supply demands. LSTMs are popularly used in several earlier works for supply chain management solutions [34–37]. Although LSTMs are the state of the art deep learning models in time-series data analysis, they are difficult to train (large training time) and deploy. Reinforcement learning (RL) techniques are being used in supply chain network optimization works for a long period of time as well [38–40]. Among several RL techniques, Q-learning has however over the years proven to be more efficient in terms of training complexity and deploy-able model performance metrics. Traditional Q-Learning with Q-Tables have been replaced by Deep Q-Learning with deep neural networks (Multilayer Perceptrons or MLPs) [41] called deep Q-Networks (DQNs) [9]. Deep Q-learning has risen to be more accurate in predictions given sufficient data. DQNs are a more energy and memory efficient implementations of RL. Deep Q-Networks have been used for demand-supply synchronization [42]. Although there exists some studies on supply chain optimization techniques, the scenarios change in pandemic situation. There is a gap in research related to analysing the cost of essential item supply according to the demand during socio-economic crisis. It is critical to reach the right trade-off between cost of supply and demand of supply. Due to the recent pandemic in the year of 2020, we took into notice an otherwise overlooked flaw in the world-wide healthcare infrastructure. During the sudden upsurge of massive demands for vaccines and medicines across various nations, the world still relied on age-old techniques to strategize vaccine allocations. After the priority vaccination procedure was completed, the mass vaccination drives brought in new challenges where human errors in the supervision of the vaccine distribution networks caused major financial damages to countries. Every nation allotted huge budget towards vaccination drives, yet there was supply shortages in some vaccination centres while others faced large storage costs, or reshipment costs. Furthermore, there was uncertainty and indecision related to partial and full vaccinations. To the best of our knowledge, our work is the first of a kind that addresses all these issues. We propose a framework that is capable of reaching the right trade-off between cost and demand. In the future scope of our work, the VacciNet framework can be scaled to optimize a denser vaccine distribution chain provided more granular data of exact locations of medical centers, pharmacies, vaccination centres, etc. Our RL based learning technique gets better with the amount of data it trains on. There is a lack of publicly available data on vaccination, vaccine supply and supply cost. Provided data from many more countries, and more granular data on supplies to cities and local pharmacies, our framework can be further trained for robustness.

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AI-Based Logistics Solutions to Tackle Covid-19 Pandemic and Ensure a Sustainable Financial Growth

Hanane Allioui, Azzeddine Allioui, and Youssef Mourdi

1 Introduction

Human beings are gifted with a set of skills serving to perceive, understand, organize, analyze, and learn their environment. These abilities are the intelligence allowing the investigating and solving of problems, which is the purpose of research to advance different fields. This has given rise to Artificial Intelligence (AI), which aims to reproduce human intelligence to automate tasks, thus easing and supporting decision-making. This makes it possible to increase the performance of financial systems, particularly during pandemic issues such as Covid-19 [1].

The logistical processes are often simple for an individual, such as stock assessment, product location, or activity planning. In practice, these tasks require a strong knowledge of the logistics activities, as well as management techniques considering time and pandemic inquiries [2]. However, in challenging environments, traditionally performing these tasks is time-consuming and resource intensive. In addition, staff fatigue can affect performance by increasing the risk of mismanagement or poor decision-making to tackle Covid-19. This calls for AI-based solutions to support experts, help with emergency logistics tasks, and advance the functionalities of financial systems [3].

The primary pioneers of AI date back to the 1950s. However, real-world uses could not be done until the evolution of powerful methods with the capabilities to maneuver large amounts of data [1]. Over the past few decades, AI-based tools

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have agitated decision-making systems in the field of logistics. Therefore, the quality of logistics services has been gradually increasing due to the adoption of advanced approaches. Meeting the needs or supporting the decision-making process is attracting increased interest, so electing the appropriate intelligent method for a logistics system has become a must. AI techniques are recognized for their robustness, efficiency, and scalability [4]. They allow the processing of large masses of data. The logistics sector is one of the fundamental areas of application of AI, especially for extracting more information to ensure a clever prediction. With the development of AI approaches, several concepts, increasingly powerful and innovative, have appeared to provide computer systems with the ability to make predictions and propose solutions for complex problems affecting the logistics flow. For this reason, the orientation of the research works of AI in logistics is divided into two big main classes:

- Weak AI: in contrast to its nomenclature, this class tends to perform a task in a more robust way than traditional techniques. These techniques offer systems with a strong ability of human reasoning to remedy complexities. In this sense, distributed artificial intelligence (DAI), which is often represented by multi-agent systems (MAS), can implement intelligent distributed solutions.
- Strong AI: These approaches offer the ability to learn, adjust and evolve to better solve a given problem. This family is beneficial for analyzing bulk data from logistical environments, understanding workflow, and developing to overcome new situations never discerned.

In addition, traditional models of management, data processing, and decision-making in logistics operations are plagued by performance, timing, and cost issues. The adoption of AI techniques has undeniably contributed to the growth of the Logistics sector. Hence, it is quite essential to characterize the different techniques of AI, according to their contributions to logistics, precisely the delivery process.

This study followed the five-step process as shown in Fig. 1. In the logistic framework, the definition of intelligent behavior, as well as the means of knowledge reproduction, remains an emerging and thorough need. However, the choice to use one technique or another depends on the nature of the data, needs, as well as applications. The current research provides:

- A better understanding of the methods through which AI-based technologies impact the logistics sector.
- Empirically analyze the anterior works related to AI technologies for better financial insights.
- Close research gaps regarding the direct, and indirect effects of AI capabilities on logistics.

This chapter is structured as follows. An explanation of the interests of smart solutions is provided in Sect. 2. Then, the third section highlights the optimization challenges in the logistics sector. Then the main importance of automation and AI is explained in the fourth section. Later, the last section concludes the chapter.

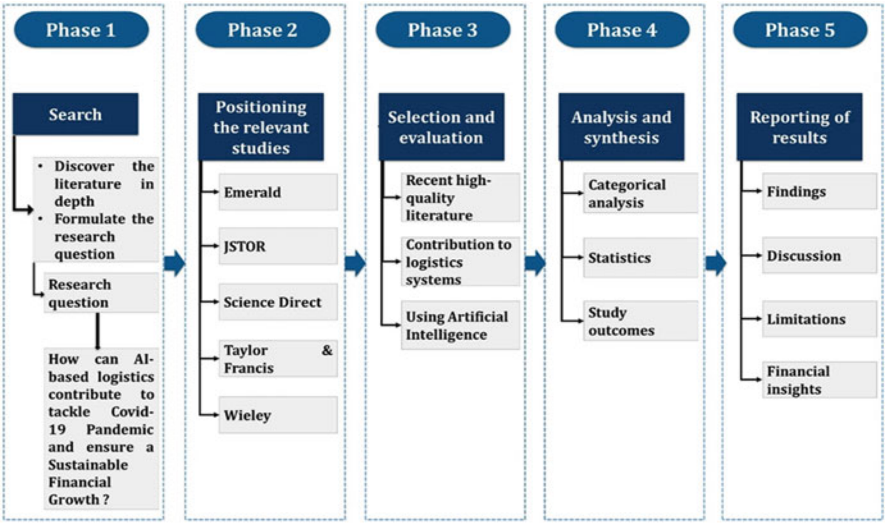

Fig. 1 Research process

2 Era and Interests of Smart Solutions in Logistics Systems

The increasing scientific, theoretical, and practical progress, as well as the fields of study of the new structures, shows a very promising capability for solving many complex puzzles such as resource planning, fast data processing of logistics activities, generalization, optimization . . . etc. Neural networks are implemented to meet these needs and supply good logistic performance.

2.1 AI Applications in Logistics

In recent years, Machine Learning (ML) algorithms have earned relevance in a variety of research fields such as business management, engineering, economics, marketing, medicine, and industry [5]. However, with every technological change, some industries react faster and more aggressively than others. The ML model revolution is following the same path, and in the logistics industry, several applications have emerged. Logistics, being a highly data-dependent industry, has solicited the implementation of many ML applications. Figure 2 shows the top 9 application areas of ML algorithms in the logistics sector.

Correct and truthful demand prediction in supply chain management has several benefits (for example reduced carrying charges, and optimum inventory stages). By employing machine learning patterns, firms are capable to take advantage of the benefits of analytical demand prediction.

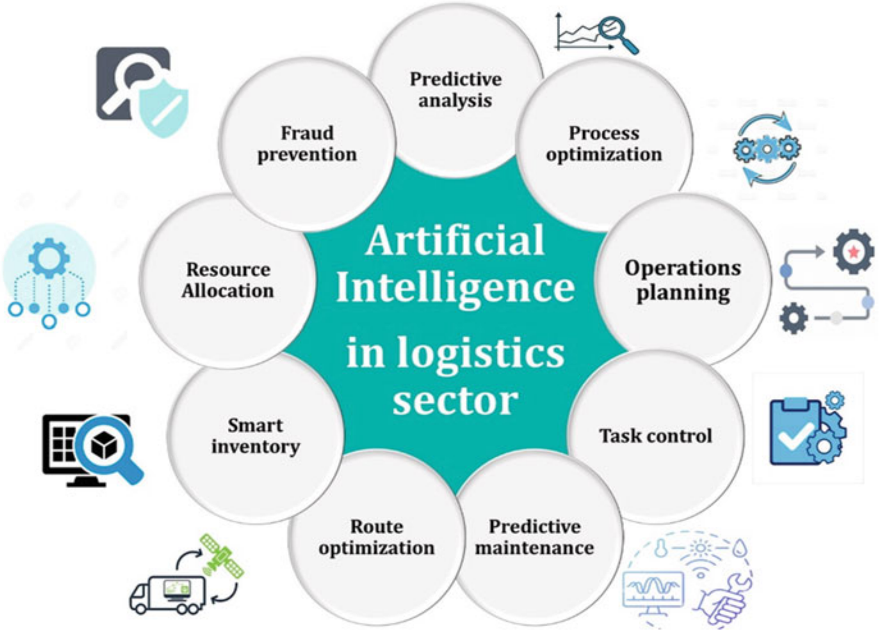

Fig. 2 Applications of AI models in the logistics sector

2.2 *Roles of Learning Techniques*

Unlike standard classification problems, where the network output is the only important thing, planning problems, or those of optimization, require not only discrimination to filter the input data, but also a mechanism to analyze the features learned in the distinct stages. Different methods use various mechanisms in the logistic framework. In this sense, some standard networks have contributed significantly to the improvement of logistics activities, as they are frequently used as the basis of decision-making systems, among others: Support Vector Machines (SVMs), decision tree forests, and clustering. These techniques were often used before the deep learning(DL) revolution for solving problems arising in logistics environments [6–10]. However, solutions based on deep learning have been better qualified than previous techniques. This has supported its position and become a standard for decision-making puzzles. By the way, a general architecture, of a logistic system, can be based on a network facilitating the extraction and classification of features to obtain a powerful solution. Deep learning remains a data-driven discipline. As the training data and input samples increase, the results are better. As a result, deep learning with its generative models is an active research area.

The extensive use of ML or Deep Learning (DL) solutions is currently setting the stage for structural modifications in the manner managers will consolidate the stream of goods through the logistics environment [11]. Transparency at every stage will massively increase through rapid data evaluation and reliable forecasting. This will continuously support initiative-taking logistics within the warehouse, moving, and finally in the retailer store, and could drastically reduce expenses and optimize shipment schedules. Connecting numerous applications in an incorporated infrastructure, as a replacement for algorithms running separately in a specific phase of the supply chain, is becoming the norm in most businesses.

Innovative approaches correlating the last mile concept may enable sellers to offer better services to customers and strengthen new shopping standards. To meet these growing expectations, firms should boost the autonomy of the used algorithms, and tightly combine deep learning approaches along with advanced data collection processes. The automation level could be improved with the adoption of cognitive systems. Yet, the understanding of human skills remains a crucial potential, in operational logistics, to provide better smart decision-making approaches.

Over the upcoming years, intelligent automation solutions are much needed in all industries, for instance for data processing, document management, default prediction, and predictive analytics. It is thus important to emphasize the massive potential of DL algorithms to enhance the efficiency of the existing processes, reduce cost, and warrant the continuous expansion of logistics business processes. For that, experts expect important growth in trade and production through AI and DL-based methods by 2030. The areas of manufacturing and shipping perform a significant role due to the efficiencies gained through automation. Concerning the adoption of advanced approaches in primarily manufacturing sectors, this policy makes almost no sense for business managers, particularly those facing constant adjustments in production and delivery activities.

Automotive industry is striving to increase its supplier organization with ML and DL tools and has had immense success. Most of these tools are focused on professional support for systems integration and implementation of innovative solutions. However, adapting learning to existing functional CRM and ERP can provide added value to the overall logistics infrastructure. Primarily, because DL expertise can drop the problems, which are part of conventional business software resolutions.

Traditional systems are developed using interactive databases and may take weeks to deliver accurate information, that can be anticipated immediately with the use of learning algorithms. The effective integration, into the advanced infrastructure, requires the cooperation of interdisciplinary teams (data engineers, data scientists, software engineers, industrials, managers, and technical experts). These teams should adopt four types of measures to develop the reliability of processes: Firstly, it is important to guarantee adequate quality and quantity of training data. Secondly, it is mandatory to prevent ambiguous “black frame algorithms” not including appropriate knowledge of the process systematics. Thirdly, all stakeholders should be involved to provide transparency and trust throughout the development stages. Lastly, a main key factor should not be misjudged, which is the sufficient commitment between budget contributors and decision-makers, to enable further investments in technologies beyond short-term productivity.

Car manufacturing firms intensively process numerous use cases along with the supply chain respecting the cost shapes. This is specifically true around manufacturing and development processes. Intelligent algorithms for predictive maintenance and advanced production fault detection remain vital to improve the production cycle and identify avoidable defects. By the way, predictive maintenance is based on the monitoring of equipment, and the processing of their data. By analyzing this data, it is possible to expect and schedule an intervention at the most proper time. Wang discussed the influence of AI on predictive maintenance by highlighting the importance of DL technologies. This work listed several innovative techniques (for instance: deep belief networks, deep feedforward networks, convolutional neural networks, and long-term memory), which are the key elements to successful industries of the future [12].

At present, transportation and warehousing services form one of the most expensive fields that must be managed. Therefore, there is a powerful demand to improve the expense form of the used systems, especially concerning e-commerce. Overall efficiency improvement can be achieved by employing endways predictive analytics and further warehouse automation to process real-time information.

The adoption of ML in logistics can strengthen problem detection to avoid the interruption of the business [13]. Employing a robust forecasting system allows the supply chain company to manage the resources adequately and respond intelligently to possible issues and threats. Gursch et al. [14] reviewed research projects around applying machine learning solutions for process checking and control, planning, and predictive maintenance. In addition, the authors emphasize that ML provides solutions warranting the automation and optimization of the process, as well as addressing complex problems using advanced programs.

ML can refine the complications of planning tasks. ML techniques can be applied to train highly developed algorithms or manage the available data to optimize inefficiency and waste in several fields [15]. In addition, using ML in logistics creates an adaptive ecosystem to successfully manage the possible disruptions that may occur. Gomes et al. develop a decision assistance system for manufacturing planning and control using ML, this system helps in creating basic work practices and ensures efficient production [16].

Adopting ML in supply chain activities contributes to overcoming overstock issues to provide better warehouse management [17, 18]. The analysis and predictive capabilities of ML can also investigate a huge amount of datasets rapidly while avoiding possible human mistakes, which may occur in a typical situation. Lolli et al. developed an ML approach to tackle the problem of multi-criteria inventory classification while decreasing simulation efforts [19, 20]. In addition to process important datasets, ML can provide powerful solutions along with other technologies such as IoT and sensor devices [21]. Bonino and Vergori presented an ML architecture able to connect internal to external value chains within innovative factories using advanced technologies. Thus, the authors emphasized how innovative intelligent systems will transform daily production and well-organized logistics activities by implementing multi-agent systems and ML technologies [22]. Machine learning algorithms can both improve production conditions and reduce the probability of fraud by automating real-time work processes to identify patterns abnormalities or deviations.

2.3 AI Techniques in Favor of Logistics Systems

AI approaches form an advanced concept for decision-making. They are often confronted with an imminent question between reliability and timing. For this purpose, different variants have been used to solve anomalies detected in a logistic environment, or to improve the classical logistic approach toward more intelligent and efficient procedures.

Deep neural networks are essentially feedforwarded neural networks, which contain several connected neurons. The word DL indicates that multiple layers are connected. Each layer of neurons is in a perception situation waiting to obtain information from the prior layer, then after the processing, it transfers the outcomes to the next level [23]. CNN or convolutional network stays one of the key DL algorithms. Its particularity of convolutional layers gives it priority to be applied to image processing tasks, but its use can be extended to other contexts [24].

For classification problems, K-means remains the most used clustering algorithm. K-means, which belong to the unsupervised family, group and classify several objects based on their special attributes or parameters. The letter K refers to the positive integer number of object groups. The Value of K should be specified before the start of the algorithm [25]. Since K-Nearest Neighbor is the common and efficient supervised learning method, it is applied to associate new data spots with remaining similar classes by exploring the existing dataset. The algorithm should be trained according to certain criteria to cluster the new data and check their similarity with the K-neighbors [26].

Another common supervised algorithm is support-vector machine SVM, which is characterized by its minimal computational complexity. Utilized to handle classification and regression issues, SVM can process easily in both binary and multi-class environments [27].

Also, in the framework of supervised learning, decision trees, and random forests allow the definition of a model by fulfilling certain rules according to the characteristics of the dataset. Then, the SVM model is employed to forecast the value of the latest target variable [28].

Since supervised learning procedures aim to process labeled data, they are used in the logistics sector for fraud detection [29, 30], the proposal of itineraries [31, 32], adaptive filtering [33], and security and location issues [34]. This group of algorithms includes two separate types: classification and regression.

The classification includes the process of recognizing, understanding, and sorting several objects into predetermined categories or sub-populations. Classification algorithms utilize input training data to predict the probability that the following data will match the predetermined categories. While classification aims to organize the data, regression aims to investigate the relationship between separate features or variables and a determined variable or result. This predictive method allows the prediction of continuous outcomes. Decision Tree, Naive Bayes, Random Forest, and SVM are the widely used algorithms for classification tasks [35].

Using the Kernels mechanism, SVM can find the distinctions between two distinct objects or classes, to model nonlinear decision boundaries. Compared to SVMs, random forests are much more used thanks to their easy implementation and the capacity to handle high-scale datasets. Naive Bayes (NB) is often used to develop solutions able to tackle real-world troubles like spam detection and text classification [36]. Even though NB and SVM can be trained faster than random forests or decision trees, they achieve better accuracy in less prediction time.

The unsupervised learning family aims to provide algorithms able to manage unlabeled data while using input data heuristically. The unsupervised approaches are widely employed to forecast anomalies, cell clustering, intrusion detection, and load balancing. To group data considering the fundamental similarities or dissimilarities, unsupervised clustering requires a decent classification algorithm such as K-means or hierarchical clustering.

Reinforcement learning (RL) learns through distinct phases and develops the relationship between reward-action among the agents and the studied environment [37]. This action-reward context is very practical to solve different problems. Even if RL does not involve an enormous training dataset, the agent should know the function of the state- transition. RL provides promising approaches easy to model but necessitates a considerable time to reach a stable state.

3 Challenges of Optimization in the Logistics Sector

The design of a suitable algorithm requires the identification of the most proper solution strategy for a particular optimization challenge. The goal of this section is the study the concept as well as the main optimization models while integrating both inventory decisions and transportation, to explore further opportunities to improve the logistics delivery networks.

Logistics process optimization can lead to several positive results for logistics companies, from superior efficiency to improved worker satisfaction. Yet the achievement of logistics optimization depends on defeating certain trials. Proactively tackling these challenges can warrant a considerable change in the outcomes of the logistics optimization program. Some mistakes must be avoided to develop a successful optimization process:

- Not acquiring buy-in after executives: In logistics, the buy-in is vital to ensure the success of any activity. Neglecting the gains can affect the new logistical projects, which can lead to many obstacles. For that, an optimization strategy should engage executives to support the proposed changes that may result from this strategy. To gain that support, from leaders, it is important to highlight the value of the optimization program and the way it will promote the logistics processes.

- Not concentrating on the workers: It is crucial to remember that logistics processes are often performed by people, so the human side must be considered while constructing the process optimization strategy. When modeling and developing logistics processes, therefore, it is required to recognize the importance of the human element. As a result, the optimization should consider all the critical roles such as department managers, digital professionals, HR, training, etc.
- Ignoring the role of technologies: All over the world, technological advances are driving important changes in the field of logistics activities due to the global trend of digital transformation. Optimization strategies should therefore employ the latest available technology.
- Over-dependence on an improvement methodology: To improve logistics processes, it is important to use adequate methodologies to ensure continuous optimization of logistics activities. Some methods focus almost on reducing development variation and deficiencies in both production and delivery stages. But this tight focus also ignores other aspects that can provide innovative logistics processes.
- Not adopting a structured optimization approach: Logistics process optimization is crucial for business management. Optimization efforts are required therefore to include process management, design, reengineering, and mapping. As mentioned, it is essential not to depend too strongly on an upgrading methodology that may be limited in these scopes.
- Fixing the logistics processes without interest in the outcomes: A result-driven method promises the performance of the delivery respecting the strategic metrics. The trap is to prevent the use of some metrics that are disconnected from the logistics' key performance indicators.

The choice of optimization method remains crucial to solve the different problems and overcome the logistics difficulties. Some optimization methods offer superior results in continuous problems, yet they are not suitable for combinatory problems, and the other way around. Alternatively, mixed-variable problems pose a different kind of difficulty, as they mix both continuous as well as discrete optimization variables.

3.1 Combinatory Optimization

Combinatory indicates the possibility of finding a combination or a rearrangement of a limited set of features. Combinatory problems are thus distinguished by a fixed set of practical resolutions. However, these optimization problems are not always easy to solve, because the volume of the set of results can be exceptionally significant.

The process of combinatorial optimization consists of locating one or additional optimal solutions for a well-described space. Such troubles arise in practically all areas of logistics management (e.g., database management, facility location, finance, inventory control, marketing, production, scheduling, etc.). Indeed, the flexibility of the combinatory models results from the reality that numerous logistics activities and resources are inseparable. Moreover, several problems have merely a limited number of options and can therefore be appropriately modeled as combinatory problems.

These combinatory problems on graphs may seem, promising regarding the mathematical concepts, and their use in decision-making issues, in manufacturing, management, finance, or engineering, is extremely vast. In general, the methods used to address combinatory problems can be divided into two classes: exact and heuristic.

i. ***The exact methods***

   These methods guarantee the discovery of the best solution for a specific problem (but not in a fair time). Although the exact methods are frequently mixed with other procedures, three different approaches can be used to solve the combinatory problems exactly:

   - Enumerative techniques, in which many possibilities can be eliminated by dominance or probability arguments [38].
   - Relaxation and decomposition techniques involve embedding a set of complex restrictions into the continuous, mixed-variable function [39, 40].
   - A cutting plane approach is based on polyhedral combinatorics. In principle, if the original data of the problem are rational records, then Weyl's theorem indicates the existence of a limited system of linear inequalities [41].

ii. ***Heuristic methods***

   Heuristic methods do not usually guarantee the discovery of the best result, but generally deliver a near-optimal solution in a satisfactory time. The widely known heuristic methods, are called metaheuristics, which are often utilized to tackle combinatory problems, consist of ant colony optimization (ACO) [42, 43], evolutionary algorithms (EAs) [44], simulated annealing (SA) [45], tabu search (TS) [46, 47], etc.

3.2 Continuous Optimization

The major distinction between combinatory and continuous problems is that the exploration space is not fixed. Continuous optimization remains the core of mathematical science used to tackle real-world problems extending from biomolecule design to investment management. Continuous methods aim to find the minimum or maximum rate of an optimization function regarding real constraints. The application areas of continuous optimization are extremely broad. Numerous real-world issues and processes can be presented as continuous problems. Typical examples are the design of best forms (for example wings, turbines, etc.) or the selection of continuous parameter values for various industrial processes (e.g., temperature, pressure, etc.).

- Analytical approaches to solving a continuous problem require the minimization of the mathematical objective function.
- Gradient descent-based methods to process the numerical minimization of the objective function (i.e.: The steepest descent [48], Conjugate Gradient Method [49], Newton's Method [50, 51], etc.)
- Direct methods require any additional data about the objective function, except for the possibility to evaluate it at selected points. A multitude of algorithms has been proposed, including the simplex [52], Powell's Method [53], etc.
- The metaheuristics are used thanks to their capacity to find the global greatest, and not only a local optimum, such as Evolution Strategy [54, 55], Differential Evolution [56, 57], Iterated Density Estimation Evolutionary Algorithms (IDEA) [58–60], Particle Swarm Optimization (PSO) [61], etc.

3.3 Mixed Variable Optimization

Mixed-variable problems are a mixture of both continuous and combinatory problems. These methods are much more complicated due to the amplified difficulties of mixed variable problems. For this reason, most of the methods are used to reduce some problem constraints and then attempt to solve the converted problem.

The most common methodology is to unravel the constraints so that they could be replaced by continuous variables. This way, the optimization can be resolved as a continuous problem. Mixed variable problems are most used in industrial systems [62–65] to tackle the challenges of designing helical springs, pressure vessels, welded beams, or thermal insulation systems [66–69]. The mixed methods are divided into two classes:

- Hybrid and relaxation methods: the methods are enhanced with a fixing mechanism to convert the continuous values into the allowed real standards. The most used hybrid techniques are Genetic algorithms (GA), differential evolution (DE) [70], and particle swarm optimization (PSO) [71].
- Native mixed algorithms: these methods can deal natively with mixed variable problems either using adaptive genetic search [72, 73], pattern search methods [74], or mixed bayesian optimization algorithm [75].

3.4 Challenges in Choosing the Right Method

The quality of the optimal solution varies according to several factors, such as the nature of the studied problem, the scope, the size, the search time, and the used implementation approach. However, metaheuristics are much used in combinatory problems. The primary constraint is the resolution time, which is usually short and insufficient to handle a combinatory problem. Furthermore, in most real situations, a relatively acceptable solution can be appropriate. It is not necessary to come up with a proven optimal resolution. Within the logistics environments, the choice of optimization approach remains difficult regarding the evolutive system constraints and requirements. Often, scientists, or industrialists, adopt only one known or common approach for satisfactory results. Yet, other methods are not examined and do not supply convincing arguments. However, it is often unclear whether they found the optimal solution or not.

4 Results and Discussions

After collecting the appropriate relevant papers, the phase of data analysis and synthesis starts. Whereas the purpose of the analysis is to describe the overall connections and to identify the associations between different studies. The results of this study are shown in the following subsections.

4.1 The Covid-19 Pandemic Accelerates Logistics Automation

Logistics automation takes a step forward with Covid-19. The coronavirus pandemic caused a drop-in industrial activity and, just as it was beginning to recover, companies were faced with new complications: social distancing, mobility restrictions, high demand for essential products, and new challenges in terms of e-commerce logistics, etc. In this context, companies have been forced to find solutions to improve the efficiency of their services, reduce lead times, and adjust their resource uses while ensuring financial prosperity.

4.2 Preventive Measures Against Coronavirus in the Workplace

Even before the pandemic, job automation was one of the solutions chosen by companies to gain competitiveness and financial progress. The integration of intelligent technologies in logistics environments enables firms to have a strong position regarding market changes so that they can warrant delivery on time [71, 72]. The growth of the sanitary crisis obliges companies to revise their activities to respect the sanitary recommendations and to apply preventive measures to avoid the contagion and the propagation of the virus. To do so, new methods of organization and collective and individual protection have been put in place. These measures can be regulated and changed according to the evolution of the situation, which is why it is quite recommended to often consult a team of experts with financial and technological skills for good operability of the companies in the market.

The priority for each company is to apply barrier measures by facilitating hand cleaning (including hydroalcoholic gel, water, etc.), encouraging the wearing of face masks, and ensuring that physical distances between workers are respected. The organization of the circulation of people and the distribution of spaces in the workplace has therefore been changed as much as possible, to guarantee a sufficient safety distance. There is no doubt that information and training are essential. On the one hand, workers should be aware of the consequences of reporting, once possible, if they have signs of the disease or if they had any contact with people with symptoms [73].

On the other hand, it is advisable to put up posters and signs reminding them of hygiene and prevention measures (e.g., coughing or sneezing into one's elbow or a handkerchief, avoiding touching one's eyes, nose, and mouth). In addition, it is imperative to regularly ventilate rooms and interior areas and to strengthen cleaning and sterilization, with emphasis on often touched surfaces (such as door handles, handrails or communal equipment, and elevator buttons). Individual responsibility for cleaning groups and shared work equipment should also be encouraged.

4.3 AI-Based Solutions During the Covid-19 Crisis

According to McKinsey [74], the economic crisis resulting from the coronavirus pandemic could stimulate the use of artificial intelligence for several reasons. First, due to increasingly tight margins, companies see automation or artificial intelligence as a solution to cutting costs. Although it stands for a superior primary investment matched to conventional storage practices, an automated warehouse offsets this expense with reduced operating and personnel costs. Thus, in a context where the presence of personnel in companies is reduced to a minimum, the robotic warehouse could guarantee endless service.

The containment and restriction procedures within stores have led to a huge expansion of e-commerce activities. Retail, grocery, and pharmacy firms have seen an exponential increase in online purchases. Consequently, numerous companies have opted to adopt AI solutions into their business to be able to process more orders while dropping the risk of errors. Automation and AI techniques not merely reduce the operator's presence to a minimum, but additionally increase protection, guarantee competitiveness in the market, and ensure the financial progress of companies [75].

i. ***Delivery and shipping***

   One of the highly successful solutions was the use of automatic truck packing and unpacking systems, which handles the rapid reception and dispatch of goods. These are conveyor systems fabricated of rollers and/or chains employing which the pallets are loaded and robotically unloaded from the trucks.

ii. ***Flow of goods***

The flow of goods requires a lot of movement in the warehouse. As companies look to keep the number of people per shift to a minimum, the installation of pallet conveyors or bin conveyors is recommended. These replace traditional material-controlling equipment and operators. As a result, manual handling of loads is reduced and safety in the plant is increased.

iii. ***Preparation of orders***

Order picking involves the continuous presence of workers within the warehouse to find the products they need. To minimize this movement and the number of workers crossing the same passage, sales can be picked using the "product-to-man" technique. Operators are assigned to a picking station and wait to receive the products.

iv. ***Management***

The Covid-19 crisis has emphasized the importance requirements to focus on the traceability of products and check all the logistics operations. A warehouse employing management software, for example, Mecalux's Easy WMS, supplies real-time visibility into the status of the supply chain. This software tracks goods until they are shipped to customers. The WMS also simplifies the application of sanitary measures in operations. For example, order preparation and shipping are expected to avoid direct interactions (between operators and carriers).

4.4 The Importance of AI-Based Solutions in the Pandemic Context

Many companies have taken advantage of the benefits of AI to address market changes. They all recognize that AI is a developmental opportunity through which they can overcome the challenges they face, including those resulting from the coronavirus pandemic.

Although the fragility of the world's markets from the perspective of globalization has been found, a small number of analysts claimed that it presents an immediate risk to the post-pandemic economic recovery process of Covid-19. Indeed, too rapid a recovery could cause supply chains to stop slowly in the face of a possible rebound in household consumption, as the first days of decontamination in Wuhan, China, showed impressive queues in front of many stores. The issue is not simply a matter of manufacturing units being able to return to their pre-pandemic production levels. They must also be able to receive sufficient volumes of materials, components, and subassemblies from their suppliers and subcontractors to produce finished products.

Nothing is more convenient to visualize a standard global value chain, and the logistics resources it mobilizes than to use the symbolic case of AI. Regardless of the existing peripherals, wireless technologies, and smart devices, designed and produced by suppliers and subcontractors: AI solutions are seen as a stylized representation of the supply chain. Local failures in procurement, manufacturing, or delivery, even of parts considered "secondary", can paralyze the entire supply chain, and thus prevent the availability of the finished product to the end customer.

AI solutions are not a unique or out-of-the-ordinary case of the value chain. In contrast, numerous industries, such as the automotive industry or household appliances, follow the same organizational scheme. Yet, the Covid-19 disease has brutally underlined two forms of weaknesses, that threaten the ability of logistics systems to prove resilience in the face of an external shock of an intensity unknown in recent history:

The recovery of logistics systems, on a global level, is expected to be slow, given the sanitary constraints imposed to avoid a new wave of contamination, making international supplies unreliable, both frequency and reliability. In addition, it is possible that various subcontractors and suppliers, particularly the small ones, who deal with financial issues, will not withstand the coronavirus crisis, despite the dedicated support of governments and international institutions. (Fed, Bank of Canada, European Central Bank . . .)

With the Covid-19 disease, a major global health crisis, we have discovered how dependent we have always become on technological performance, and at all levels of a supply chain. It is in this highly constrained context that the economic recovery of the post- Covid-19 era is bound to take place by opting for increasingly intelligent technologies. If logistics performance fails, even locally, Western economies could find themselves in a situation of recurrent stock-outs, preventing consumers from purchasing the products and services they have been waiting for.

Governments have chosen to continue with decontamination gradually, authorizing the reopening of stores and the resumption of certain entertainment activities in a piecemeal fashion. For governments, the gradual approach is associated with public health concerns. Of course, no political leader is publicly justifying the gradual exit from containment by the desire to limit the logistical difficulties that would inevitably arise from a too-rapid economic recovery. This would certainly be an indistinct speech for populations whose independence to consume will be restricted for a long time.

The world is therefore faced with an unprecedented contest: to deliberately revive its economies to prevent the increase of logistics disruptions, and to use a well-known Anglo-Saxon terminology. The logistics troubles are enormous because decisions must be realized by company managers. We are not talking about degrowth here, but rather about strategies for smoothing demand.

From this point of view, can we talk of a revolutionary break named "post- Covid-19 world"? The answer is probably negative and positive at the same time. The answer is negative because we can assume that the Covid-19 crisis is one of the different upcoming resilience scenarios. But the answer is also positive because the design of global value may be greatly examined, given the logistics dysfunctions.

Coronavirus disease has appeared in 2019, as a new virus never seen before, the entire human population is hypothetically vulnerable to Covid-19 infection. Rocking and disrupting the world, Covid-19 affected the normal living way, which people adopted before in cities and society. For example, because of the pandemic consequences and the demands for distance and hygiene, people are increasingly favoring the use of private cars, contrary to all the debates that have previously supported urban mobility. To this end, many studies have shown that better transportation decision-making requires consideration of sustainability as well as the quality of life in cities, which are subject to high automation and increasing mobility loads.

A review of the underlying literature reveals few studies on the interference among human mobility and viral epidemics. Some of these works have assessed the impact of the earlier outbreak on travel behavior and economic consequences e.g.: SARS and H1N1 [76, 77]. These studies have shown a rather remarkable decrease in mobility during pandemic periods. However, they are limited to the short term, studying just the pandemic period without exploring the post-pandemic world. This encumbrance that has traumatized the mobility of human beings has disrupted the world economy, so governments have been forced to find quick and efficient solutions. This has amplified the need for the adoption of technologies that can remedy the problem of mobility of people, in a sanitary setting, to conduct different daily tasks [78].

In the last 2 years, many researchers have discussed the vital importance of using IoT and intelligent technologies to deal with Covid-19 or even with probable future pandemics. Kadi studied the adoption of digital technologies and highlighted the influence of Covid-19 on the approval of various concepts e.g., e-Commerce, e-Health, e-work, and e-Education [79]. Ndiaye and al have presented a detailed review of IoT contributions to healthcare during Covid-19. Bai and al presented an agreement of various Chinese specialists on IoT-aided analysis of COVID-19. Singh and al have enlisted the different effects of IoT performance on healthcare considering efficiency, time, and cost [76]. Ting and al have explored various uses of IoT, and AI to mitigate the effect of Covid-19 [80].

4.5 Financial Insights

The ever-changing nature and complexity of technological change require increased vigilance on the part of financial institutions. Industrialists, scientists, and managers are creative, collaborative, and at the forefront of technology. Financial management tools must be constantly reviewed and updated to keep pace with changing processes, practices, and technologies. Financial teams face a growing challenge in effectively managing rapid changes in logistics systems, technology arrangements, and management strategies. Existing platforms generate many anomalies because their scope is often too broad, and they do not make sufficiently detailed use of available information. Traditional logistics systems degrade rapidly, their maintenance is becoming increasingly delicate, and they can be easily bypassed using new technologies.

A new generation of AI-based solutions enables financial experts to use internal and external data and apply advanced analytics to improve logistics operations. Decisions can now be made in real time, improving the performance of logistics processes, reducing waste, and optimizing associated costs. Artificial intelligence and its techniques are part of the methods that allow financial businesses to accelerate their digital transformation while ensuring impressive performance. The deployment of AI, particularly in the logistics sector, is a favorable ground for its development. Some of its uses are often innovative and could even inspire other sectors.

With raw material shortages, border closures, containment, and production limitations, the pandemic environment was simply unimaginable for many companies. However, companies quickly became aware of these challenges, and many reorganized their entire supply chains. I believe that this dynamic is based on five criteria: creating transparency, improving links with suppliers, optimizing the supply chain, diversifying suppliers to gain agility, and continuously monitoring potential risks.

At any given time, a company needs to know which suppliers it is working with on a given project and be able to see them at once. This is especially true for Tier 2 and Tier 3 suppliers, whose importance is far too often overlooked. It is precisely in times of crisis that the situation quickly becomes problematic: the disappearance of several partners in the same region can quickly lead to supply problems and eventually plunge even large companies into economic difficulties. The Covid-19 crisis is a clear example of this: in China, entire high-tech and AI regions had to suspend their activities, resulting in production stoppages and considerably longer delivery times for customers.

Companies can receive help from collaborating more closely with their suppliers to plan orders, make forecasts, and track inventories. The more structured and organized the dialogue, the more effectively suppliers can expect customer demands and better manage their product and subcontractor inventories – and thus inform their agents of potential delivery problems earlier.

It should be acknowledged that the right use of available data improves transparency at every stage of the supply chain, as all parties involved can use this data to optimize their work processes. Companies can assess their suppliers, better estimate risks and, if necessary, select new partners more quickly. And this is at every stage of the product life cycle. A beneficial approach in times of crisis.

Crises such as the coronavirus epidemic and the 2011 tsunami in Japan highlight the dangers of over-reliance on a single supplier or multiple partners in a single region. Companies need to diversify the suppliers of certain goods and services, just as an investor diversifies his portfolio to ensure stable income. Companies would be well recommended to maintain a close eye on the major risks to their business and their impact on the entire supply chain and thus the final product or service. If points (1) and (2) are in place, they will be able to switch to alternative suppliers in time and remain competitive. If a risk management system is already in place, it must constantly be updated and supplemented with information from external sources, such as weather data, analyses from reinsurers, or risk management solutions for supply chains, such as Risk Methods.

The Coronavirus crisis has plunged all companies into an unprecedented period. Our usual ways of working have been disrupted in the space of a few weeks and the changes we are currently experiencing will likely become the norm in the coming years. It is, therefore, necessary to adapt and evolve its operational frameworks to remain competitive. The logistics challenges are in this sense an excellent indicator of the useful transformations that we should adopt.

Financial entities must follow an increasing number of requirements: management directives, market regulations, and current technological trends. AI can help them, by transposing these standards into computer language, potentially reducing the costs of interpretation and implementation, especially in terms of reporting transactions and repositories. AI could thus contribute to improving the speed, quality, and relevance of the choice of reported data and their transmission to the relevant authority, which could have an impact on the risk measurement of the institutions concerned.

AI could also be used to improve logistical processes. Some institutions would use AI to reduce the cost of their asset mobilization requirements for derivatives transactions, while others would optimize their stress tests by better modeling their financial market activities with a large amount of relevant data, detect “biases”, and build better performing and more transparent models. AI is mainly based on data analysis, the selection of the data considered, as well as their “segmentation and perception” i.e., their exploitation, from which the user could draw a maximum benefit while automating the tasks. Financial executives, therefore, recommend that the intervention of third-party experts ensure the quality of the data analyzed before it is used by an algorithm that, fed with false or irrelevant data, would produce a questionable analysis whose use could be harmful to the financial market.

Although recent technologies have brought several risks (i.e.: inappropriate use of personal data, risk of market concentration among a limited number of providers, or bugging issues), the logistics revolution requires increased use of intelligent solutions to boost systems control as well as overcome the inequality in commercial and financial relationships. It is therefore recommended to put in place a common base of basic mutualized tools using an adapted governance system that prevents market risks and their operating rules. In addition, entire regulatory strategies would need to be adapted to the specificities of AI and finance to ensure sustainable prosperity. When using intelligent solutions, AI can provide guidance, and require at least some adjustments to logistical rules (e.g., directives on services, payment methods and electronic money, anti-money laundering and anti-terrorist financing regulations, modeling of capital requirements, the definition of risk factors and governance rules).

Some researchers and industrialists also expect financial supervisors to be particularly demanding on the quality of AI algorithm governance processes, both in the implementation, testing, and control phases, to ensure the traceability of decision-making processes. In this sense, the logistics experts indicate that they are considering, among their lines of action, the creation of cooperation mechanisms between supervisors at the logistics.

AI, and finance levels for better support of standardization initiatives and more generally methodological works tending to improve logistics modalities, whether at the national or international level. To conduct this mission of pronounced use of technologies, some authorities rely on AI, whether to recognize needs, predict results, study markets, etc. AI, already particularly developed in the logistics sector, must therefore benefit from an adapted framework taking into account the need to control specific financial risks. Its implementation on a more global level could lead to major changes, notably in the way powers are exercised and daily control activities are conducted within logistics establishments. Even with promising solutions from research studies, several questions arise before AI methods are adopted into the daily practice of logistics environments, the most important of which are listed below:

- First, it is essential to consider the powerful dependence on the quantity of data, especially training data. Given the differences in activities, services, and management protocols in logistic parks around the world, how to guarantee the usefulness of the developed methods? Therefore, it is necessary to implement evaluation methods for performance tests.
- Secondly, for the commercial development of a system, there might be ethical and legal issues, concerning the usage of the data from the training, as the execution depends on the quality of the training data.

Today's logistics experts are faced with an increasing number of tests. It is therefore quite laborious to complete a task on time and to produce accurate reports. However, new AI procedures should aid experts in making more accurate decisions and could also reduce the time to complete a task. The work presented in this chapter originates from the study of the problem that arises when considering planning, scheduling, and optimization decisions. These strategic problems are best known in current logistics systems. Therefore, optimization policies must be introduced implicitly.

Even if it is too early to talk about the emergence of a new model of industrial organization, which will have to stand the test of time, it may not be illogical to think of value-creation strategies based not on excessive globalization, but on a superposition of relatively autonomous economic zones. Network structures, based on massive outsourcing of activities, would not be called into question, but they would be deployed from now on in the framework of smaller territories. Thus, it is perhaps a logistically multipolar world that could emerge, a coronavirus succeeding where millions of environmental activists have failed.

4.6 Limitations and Future Implications

Like any other research work, this study has limitations. Conducting a literature study to identify the gaps and evaluate the current lessons in the logistics field can lead to a broader perspective. Since this study aimed to cover a wide-reaching area with several subfields, it was not possible to cover all the details related to literary works. Consequently, a more dedicated and high-technique evaluation is extremely recommended.

The results of this study confirm that many studies emphasize designing and developing models, frameworks, methods, solutions, etc., with few papers testing their real usability or application. This divergence could be addressed using further real-world functional data to test the proposed approaches. Moreover, using AI for logistics case study designs, problems analysis, and empirical comparisons, has the potential to improve the existing literature. In general, AI extends the ability to boost and improve logistics network management with a high level of productivity that cannot be reached only with traditional methods. Hence, This chapter encourages research on interactive decision-making to stimulate a deeper understanding, and thus develop the capabilities of AI tools to ensure financial growth.

This chapter has both financial and theoretical impacts that can be employed to research as well as practice processes in the logistics sector. This chapter explains the existing gaps and the importance of artificial intelligence for better future opportunities that can enrich the body of logistics systems. Not only can this cover the way for future scientists but also it can act as a structured guide that inhibits repetition and bias in leading AI-logistics studies to overcome a specific problem.

5 Conclusion

In the logistics sector, the choice of a management methodology remains difficult. Often, academics, or industrials, employ one approach and acquire suitable results, however, the examination of other approaches is required. This chapter, we have presented an analytical state of art covering the importance of AI approaches dedicated to the logistic sectors for financial growth. The challenge of implementing smart environments in the logistics sector lies in defining the collaborative modes of AI techniques to make the most of their complementarities, extract useful and relevant information, and provide more and more efficient solutions. It is therefore essential to present a robust framework encouraging the use of efficient approaches for better control of logistic environments.

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A Comparative Modeling and Comprehensive Binding Site Analysis of the South African Beta COVID-19 Variant's Spike Protein Structure

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Abbreviations

3D	Three Dimensional
BLAST	basic local alignment search tool
CASTp	Computed Atlas of Surface Topography of proteins
COVID-19	Coronavirus disease of 2019
GMQE	Global Mean Quality Estimate
PDB	Protein Data Bank
SARS-Cov-2	severe acute respiratory syndrome coronavirus 2
SP	Spike Protein

1 Background

The Coronavirus disease of 2019 (COVID-19) was determined to be a novel virus caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and may trigger a respiratory tract infection and is the cause for a viral outbreak which spread rapidly across the world since late 2019 [1, 2]. It is spread similarly to other coronaviruses, which are mainly through person-to-person contact. Its symptoms range from mild to deadly. It is unknown how long this pandemic will last, as it relies on various factors, including research to learn more about the virus and its structure, the search for a treatment, the success of vaccines released, and the efforts of the public to slow down the spread of the virus.

In late 2020 and early 2021, seven types of vaccines for people 16 years and older were released worldwide. These vaccines were developed at high speed, with

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human trials starting in March 2020. The COVID-19 vaccines protect against new virus variants because they provide a broad immune response [1]. Any mutations of the virus thus do not make the vaccine completely ineffective. It is possible to modify the composition of vaccines to protect against variants that appear to make the vaccine useless. To implement these modifications, the protein structures of the emerging variants should be analyzed quickly to ensure the continued effectiveness of the vaccines. The assessment of the structure of the virus is of high importance and is the primary step in fighting against the pandemic [2, 3]. Data on new variants of the COVID-19 virus is thus continuously collected and analyzed [4]. Since this virus is spreading rapidly and has been continuously mutating since early January 2020 [4], wet-lab experiments alone will not be feasible as they generally take some time. In instances like these, computational methods are of immense benefit. A faster, accurate computational method such as homology modeling may be employed to speed up the process of three-dimensional (3D) protein structure prediction.

The use of computational protein structural prediction aims to depict the 3D structures of proteins which have resolutions comparable to experimental results [5]. The computational method used in this chapter is homology modelling. It is the most accurate computational tool in creating reliable structural models. Homology modelling relies on observing that a protein's structural conformation is more highly conserved and valuable than its amino acid sequence in determining protein functions. Accurate models for 3D protein structure prediction are helpful for various applications. These include identifying the protein binding sites, predicting the effects of the mutations of proteins, and virtual screening [5].

For this chapter, the application of focus is protein binding site identification. A binding site on a protein can be defined as the part that binds to incoming molecules of comparatively smaller size [6]. Identifying binding sites on proteins is fundamentally crucial for structure-based drug design [5, 7]. Therefore, utilizing computational methods for 3D structure prediction and binding site identification assists in providing information about the Covid-19 virus. This could be used to discover a compound that may be used to create a more effective vaccine with reduced adverse side effects or even the ability to produce an anti-viral treatment.

The protein of interest for this chapter is the South African Beta Variant Spike protein, which can be located in the Protein Data Bank (PDB) with ID 7LYO. The spike protein (SP) of SARS-Cov-2 (COVID-19) plays an essential role in the receptor recognition and cell membrane fusion processes [8]. To simplify, it is responsible for the infection of the host. The SP is thus essential in viral infections, meaning that it is a possible target of analysis for the development of vaccines. Mutations of the virus, especially within the SP, enhance its transmission [9]. This variant was chosen as it was seen to be a variant of concern, as determined by the World Health Organization. Thus, it was one of the COVID-19 variants which require deeper analysis.

The first contribution of this chapter is to the existing literature through the demonstration of the identification of the protein binding sites and surface cavities of the binding pockets of the South African Beta COVID-19 virus using computational tools within the field of bioinformatics to assist with novel structure-based drug discovery and design. The following contribution would be presenting the 3D structure of the South African Beta variant's spike protein using a computational tool (homology modeling). It demonstrates the effectiveness of homology modeling as a computational tool for the prediction of a protein's 3D structure. It is complex and time-consuming to obtain experimental structures from standard lab techniques for every protein of interest.

2 Related Work

There are several journal articles stating the importance of the binding site identification of viruses, and even more so the importance of analyzing the structure of the COVID-19 virus during the pandemic.

During the pandemic, there was a lack of an effective treatment of the COVID-19 virus, resulting in a need for a greater understanding of the virus's epidemiology, transmission, evolution, pathogenesis, and diagnosis [2].

Identifying protein binding sites is vital for drug design, structure identification, and comparing the functional areas on a protein [10]. When the 3D structure of a target protein is known, one may then identify potential drug-binding sites in the protein using computational methods [11]. These binding sites can also be compared with known ligand-binding sites to establish their properties and binding ligands. Thus, the isolation of the Covid-19 virus protein's binding site has the potential to be the breaking point in novel drug discovery to improve upon the current vaccines available and potentially find novel anti-viral treatments [2].

Studies agree that computational structural modeling methods are valuable to understand proteins and their functionality and enable structure-based novel drug discovery and design against proteins which have unknown structures [12]. The prediction of protein 3D structures is a critical step in functional annotation and novel drug design [5, 13]. Understanding the structural differences of proteins in health and disease assists in designing potent drugs which may be used to overcome the diseases [13].

It has thus been determined in literature that a computational method such as homology modelling is a great candidate for predicting protein 3D structures. Utilizing homology modeling to analyze and understand the complex structures of the COVID-19 virus is essential [14].

Similar studies include [2] that predicted the protein structure of the COVID-19 main protein structure and aimed to identify its binding sites. It highlighted the importance of analyzing and understanding the complex structure of the COVID-19 virus. This article is highly similar to this study as they employ the same processes for 3D structure prediction of the Covid-19 virus. However, while [2] focused on the main protease structure (Mpro3), this chapter focuses on one of the recent variants of concern in South Africa, increasing its relevancy. Similarly, [3] predicted the theoretical (3D) structure of the COVID-19 protein and explored whether it may serve as use for protease inhibitor drugs [15] conducted a study that focused on predicting a library of phytochemicals obtained from several plant families which have been known to have a high binding affinity to the SARS-CoV-2 helicase enzyme. The findings of this article demonstrate the need for further in silico investigation of the structure of the COVID19 virus and its variants to provide insights into the use of plant-driven lead compounds to effectively fight against COVID-19.

This demonstrates how useful binding site identification and analysis is in discovering drug compounds that may be effective against the virus, whether they are plant-based or not.

3 Methods and Materials

The tools used for this chapter include the PDB, which was used for the downloading of the target protein, and the Swiss-Model template library for the template searching using basic local alignment search tool (BLAST) and HHBlits. The ProMod3 program on the Swiss-Model workspace was utilized for predicting and modeling the 3D structure of the target protein. Swiss-Model, PROCHECK, Ramachandran plot, Verify3D, and ERRAT have been utilized for validating the predicted 3D structure's reliability. The DeepSite algorithm has been used for the prediction and identification of the various binding sites of the protein while the Computed Atlas of Surface Topography of proteins (CASTp) had been utilized to depict further information on the binding pocket's structure, such as its volume and surface area.

Swiss-Model has been utilized to create and implement the homology model by following the standard modelling procedure. The automated modelling mode was utilized as it only requires the target protein as input, and the user may then select the template protein based on the Swiss-Model template library search results.

Swiss-Model provided model quality assessment and validation through various means such as the QMEANDisCo global and Global Mean Quality Estimate (GMQE) scoring functions which provide overall model quality measurements. The 'Comparison with non-redundant PDB' plot in Swiss-Model compares the predicted model to experimentally determined structures of similar size by utilizing Z scores. The 'Local Quality' plot provided us with the expected similarity of each model residue to the native structure. ERRAT relies on the notion that different atom types are non-randomly distributed to each other in proteins [16]. It was utilized to provide a statistically sound tool for identifying incorrectly built areas in the predicted structure.

Verify3D was employed for determining the compatibility of the protein structure and the underlying amino acid sequence.

Once the predicted protein was validated, the binding site identification was accomplished utilizing DeepSite and CASTp. DeepSite is built on top of a machine learning algorithm which makes use of state-of-the-art deep convolutional neural networks for determining binding pockets with high accuracy [17]. CASTp is a free online resource used for the location, delineation, and measurement of concave surface regions on protein 3D structures [18].

4 Results and Discussion

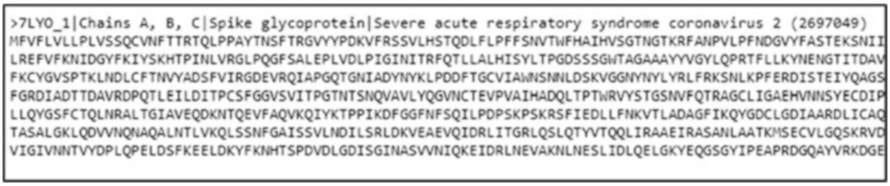
The structure of the target sequence was modelled by utilizing the template sequence of chain A.

A snippet of the target protein sequence can be seen in Fig. 1. The template selected was found by the HHBlits search and is the experimentally determined X-ray structure of the spike glycoprotein with entry ID 7b62.1A. The predicted 3D structure is shown in Fig. 2. The prediction of the protein structure is grounded on the amalgamation of the target template alignment with a sequence identify of 98.71, 0.24 coverage with monomer oligo-state, atomic resolution 1.82 and sequence similarity of 0.62. This template was chosen due to its high resolution and sequence identity, as compared to the other templates found in the search. The final GMQE score was determined to be 0.18 which is relatively low. However, this is expected as the GMQE score relies on model coverage. Thus, lower model coverage results in a lower GMQE score. The QMEANDisCo Global score was calculated to be 0.75, which is relatively good.

The Ramachandran plot as provided by PROCHECK in Fig. 3 and Table 1 displays the phi and psi distribution values for the non-proline and non-glycine residues. The triangular signs in the plot point to glycine whereas the square signs represent other residues. It indicates that 89% of the residues were found in the "most favored regions", while 9.9% were found in the "additionally allowed regions" and 1.1% in the "generously allowed regions". No residues had been found in the "disallowed regions". As can be seen in fig. 3, the red areas indicate the favored regions while the yellow indicates the allowed regions.

The use of PROCHECK determined that the residues all resided within the expected limits of the Ramachandran plot. Thus, the structure of the predicted protein is of good quality.

Verify3D determines the extent to which the 3D structure is compatible with its underlying amino acid sequence. It relies on the fact that 3D profiles which are



```
>7LYO_1|Chains A, B, C|Spike glycoprotein|Severe acute respiratory syndrome coronavirus 2 (2697049)
MFVFLVLLPLVSSQCVNFTTRTQLPPAYTNSFTRGVYYPDKVFRSSVLHSTQDLFLPFFSNVTWFHAIHVSGTNGTKRFANPVLPFNDGVYFASTEKSNII
LREFVFKNIDGYFKIYSKHTPINLVRGLPQGFSALEPLVDLPIGINITRFQTLLALHISYLTPGDSSSGWTAGAAAYYVGYLQPRTFLLKYNENGTITDAV
FKCYGVSPTKLNDLCFTNVYADSFVIRGDEVRQIAPGQTGNIADYNYKLPDDFTGCVIAWNSNNLDSKVGGNYNYLYRLFRKSNLKPFERDISTEIYQAGS
FGRDIADTTDAVRDPQTLEILDITPCSFGGVSVITPGTNTSNQVAVLYQGVNCTEVPVAIHADQLTPTWRVYSTGSNVFQTRAGCLIGAEHVNNSYECDIP
LLQYGSFCTQLNRALTGIAVEQDKNTQEVFAQVKQIYKTPPIKDFGGFNFSQILPDPSKPSKRSFIEDLLFNKVTLADAGFIKQYGDCLGDIAARDLICAQ
TASALGKLQDVVNQNAQALNTLVKQLSSNFGAISSVLNDILSRLDKVEAEVQIDRLITGRLQSLQTYVTQQLIRAAEIRASANLAATKMSECVLGQSKRVD
VIGIVNNTVYDPLQPELDSFKEELDKYFKNHTSPDVDLGDISGINASVVNIQKEIDRLNEVAKNLNESLIDLQELGKYEQGSGYIPEAPRDGQAYVRKDGE
```

Fig. 1 Snippet of target protein sequence

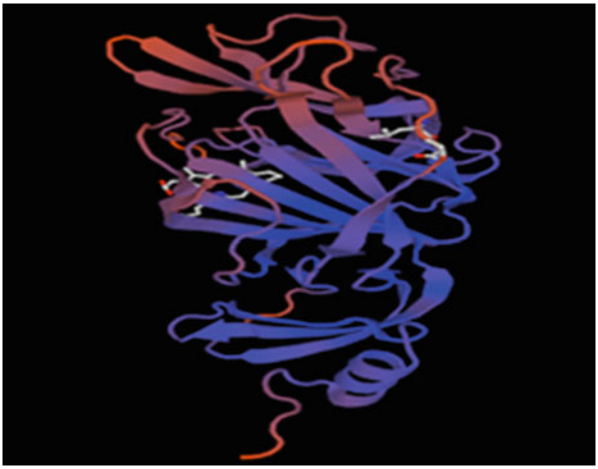


Fig. 2 Predicted protein 3D structure

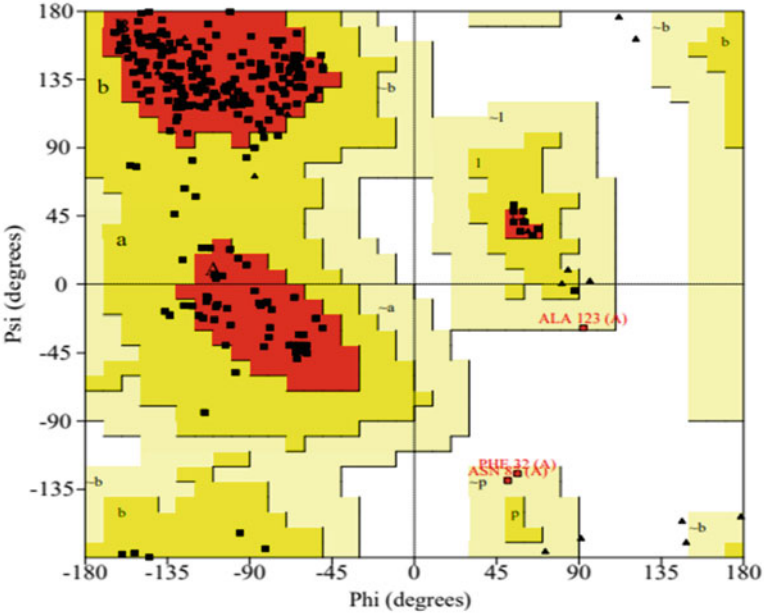
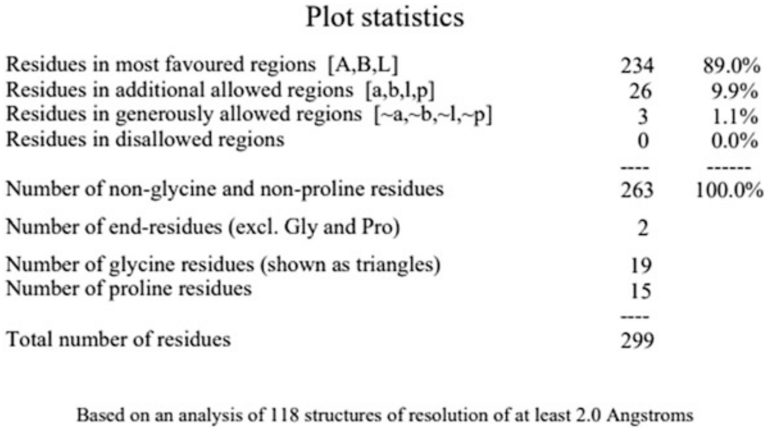


Fig. 3 Ramachandran plot as provided by PROCHECK

computed from correct protein structures have a high matching score with their sequences [19]. Its environment characterizes the residue positions in the 3D model.

A score of 0.2 for >80% of residues is seen as acceptable for the predicted structure to pass the VERIFY3D test. As can be seen, by the VERIFY3D score in Fig. 4, the predicted protein structure scored 0.2 for 98.66% of its residues. Thus,

Table 1 Ramachandran plot statistics as provided by PROCHECK



Plot statistics

Residues in most favoured regions [A,B,L]	234	89.0%
Residues in additional allowed regions [a,b,l,p]	26	9.9%
Residues in generously allowed regions [~a,~b,~l,~p]	3	1.1%
Residues in disallowed regions	0	0.0%
	----	------
Number of non-glycine and non-proline residues	263	100.0%
Number of end-residues (excl. Gly and Pro)	2	
Number of glycine residues (shown as triangles)	19	
Number of proline residues	15	

Total number of residues	299	

Based on an analysis of 118 structures of resolution of at least 2.0 Angstroms

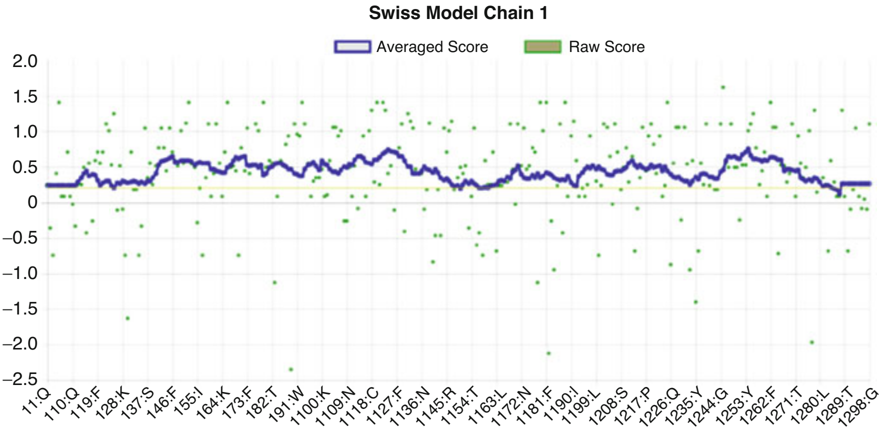


Fig. 4 Verify3D plot

the predicted 3D model is of high compatibility to its amino acid sequence and thus of good quality.

The Local Quality plot shown in Fig. 5 displays the expected similarity of each of the residues of the model, depicted by the x-axis, to the native structure (y-axis).

Residues that have a score less than 0.6 are seen to be of low quality. Figure 5 indicates that most residues have a score greater than 0.6, signifying that majority of the residues are similar to the native structure.

The “Comparison with Non-redundant Set of PDB structures” plot in Swiss-Model compared the predicted model to experimentally determined structures with a similar size. It utilized Z scores for this. To state it simply, it indicates how many standard deviations from the mean the predicted model score is. A Z-score of 0.0

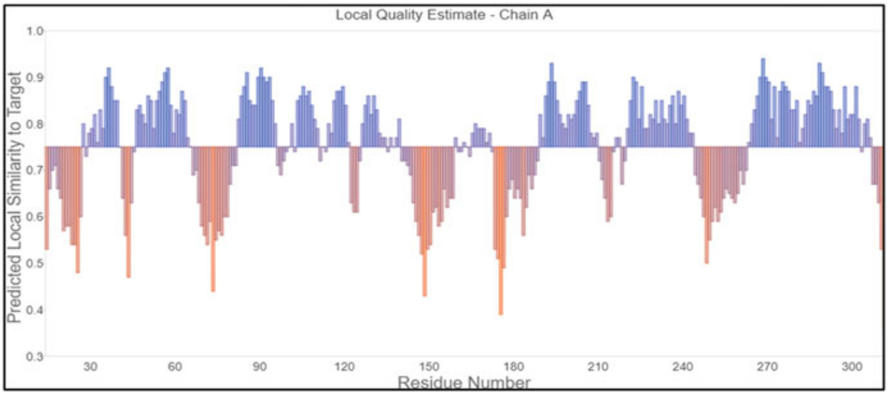


Fig. 5 Local quality estimate plot

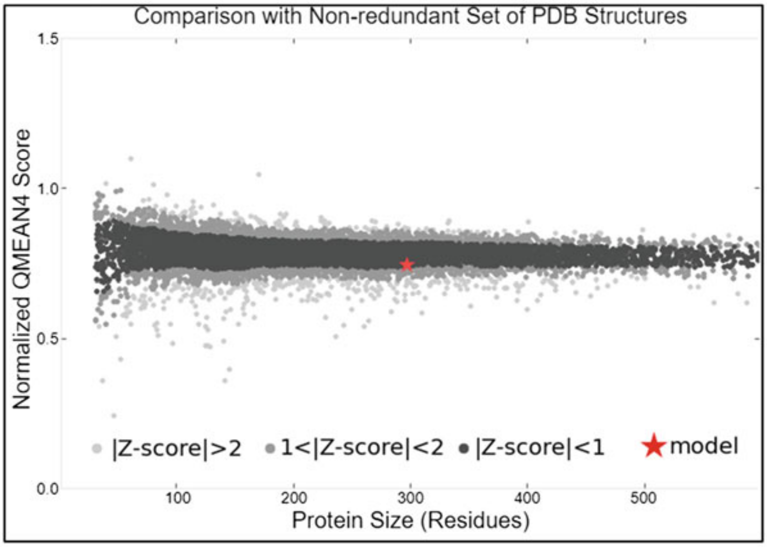
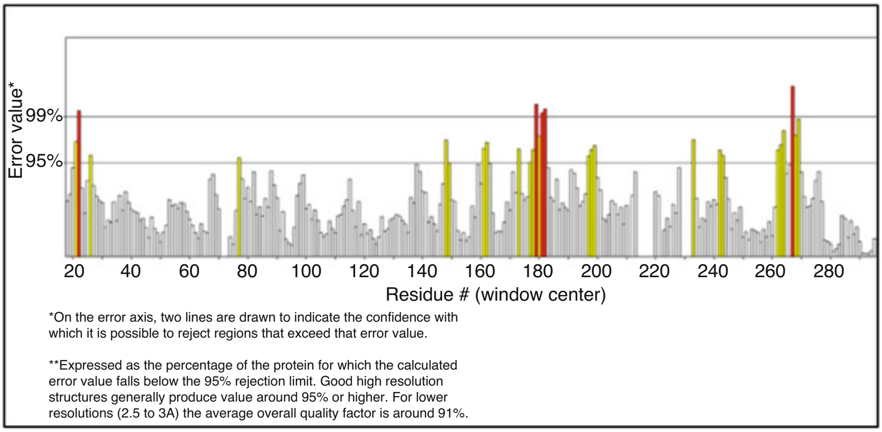


Fig. 6 Comparison with non-redundant set of PDB Structures

indicates a native-like structure, while a QMEAN Z-score below −4.0 depicts a low-quality model [20]. This plot is displayed in Fig. 6.

The X-axis in the plot depicts the protein length, while the Y-axis shows the QMEAN Z score. Each of the dots in the plot depicts an experimentally determined protein structure.

The predicted model being analyzed is depicted as the red star. The plot shows that the predicted model 3D structure has a Z score of between 0 and 1, meaning that it is within 1 standard deviation of the mean and has a QMEAN Z score of between



*On the error axis, two lines are drawn to indicate the confidence with which it is possible to reject regions that exceed that error value.

**Expressed as the percentage of the protein for which the calculated error value falls below the 95% rejection limit. Good high resolution structures generally produce value around 95% or higher. For lower resolutions (2.5 to 3A) the average overall quality factor is around 91%.

Fig. 7 Overall quality factor plot provided by ERRAT

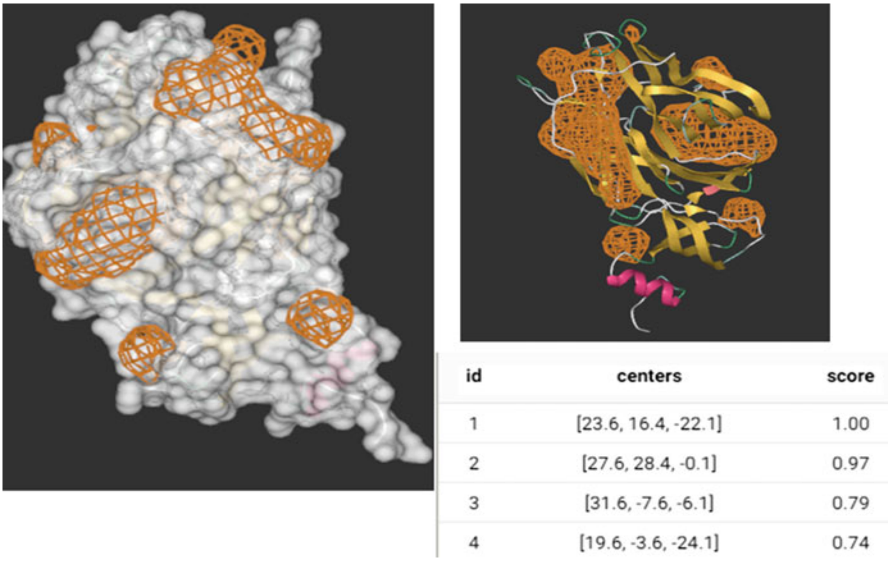
0.5 and 1. Thus, the predicted 3D structure performs exceptionally well compared to high-quality experimentally determined structures.

ERRAT provides the overall quality factor of the predicted protein structure based on the percentage of regions in the predicted structure that are incorrect [16]. A quality factor scores of >50% is good. In Fig. 7, it is seen that the overall quality factor is 90.146%, making it an excellent structure. ERRAT provides the plot in Fig. 7 to demonstrate the correct and incorrect regions in the protein structure. The plot depicts an error axis on which two lines are drawn. These lines provide the confidence (99% and 95%) with which it deems it possible to reject the regions on the protein which may have exceeded the error value. The overall quality factor refers to the percentage of the protein for which the value of the error lies below the 95% rejection limit. Proteins of higher resolutions would have produced 95% or higher quality factor scores. However, the predicted protein structure was of lower resolution and thus scored below 91%. Despite this, it is still a high score depicting that very few regions on the predicted protein are incorrect. In other words, the error rate for the predicted protein is meager.

The predicted binding pockets involved in the active site formation for the predicted protein, along with their centroids and scores are displayed in Fig. 8. The highest percentage is governed by the regions that are coiled and are seen as representing the higher conservation and stability levels of the predicted structure.

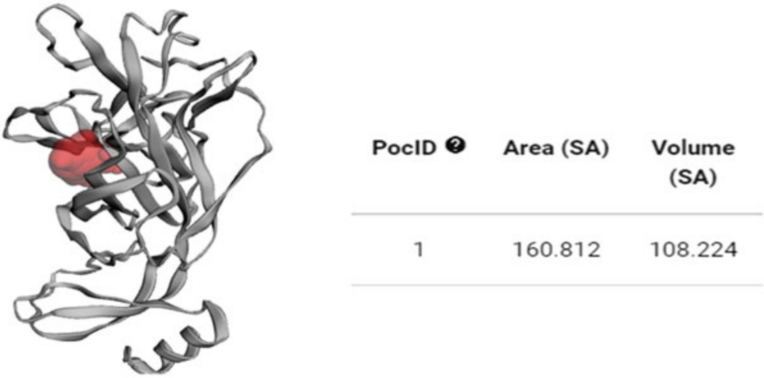
The binding pockets reside within the scores and centroids, which are 1.00 [23.6, 16.4, −2.1], 0.97 [27.6, 28.4, −0.1], 0.79 [31.6, −7.6, −6.1], 0.74 [19.6, −3.6, −24.1].

Deepsite provides a volumetric map of the binding pockets, demonstrating their position on the predicted protein. These binding pockets are depicted by the orange mesh surfaces on the protein. One can zoom in and analyze the structure of these binding pockets from all angles to understand their structure better.



id	centers	score
1	[23.6, 16.4, -22.1]	1.00
2	[27.6, 28.4, -0.1]	0.97
3	[31.6, -7.6, -6.1]	0.79
4	[19.6, -3.6, -24.1]	0.74

Fig. 8 DeepSite binding pocket prediction results



PocID ❓	Area (SA)	Volume (SA)
1	160.812	108.224

Fig. 9 CASTp binding pocket prediction

Furthermore, CASTp was utilized in addition to Deepsite for binding pocket prediction. It provides more information on the binding pocket's surface and structure, such as its volume and surface area. The results from CASTp can be seen in Fig. 9. By default, CASTp displays the results for one binding pocket at a time. As shown in Fig. 9, the binding pocket on the predicted structure is shown in red. Next is a table with the binding pocket ID, surface area, and volume. Thus, extra structural information on the binding pockets is provided by CASTp. In conjunction with the results from DeepSite, this information may prove helpful in novel structure-based drug design and discovery for the pandemic. However, further experimental analysis of the protein will be required to enable novel drug design and discovery.

5 Conclusion

The purpose of this chapter was to utilize homology modelling for the 3D structure prediction of the South African Beta COVID-19 variant and to identify its binding sites. This was motivated by the need for more analysis on variants of concern to better understand their structures and behaviors, and the hope that the findings presented may be useful in drug design and development. The homology model performed in Swiss-model produced a protein structure of good quality, with a QMEANDisCo global score of 0.75 and ERRAT overall quality factor of 90.146. The predicted protein passed the VERIFY3D test with 98.66% of residues depicting an average 3D-1D score $\geq$0.2. The Ramachandran plot, "Local Quality Estimate", and "Comparison with Non-redundant Set of PDB Structures" also pointed to a predicted protein structure of high quality suitable for binding site identification. DeepSite and CASTp were utilized for the binding site identification and performed very well in doing so. Deepsite predicted four binding sites (pockets) with scores of between 0.75 and 1, and CASTp predicted the binding sites (pockets) while also providing extra information such as their Surface Area and Volume. Thus, the procedures performed were successful and the results may prove useful for scientists in novel drug design and discovery, as well as furthering experiments. The findings indicate that this protein could be considered to be a possible drug target, and that further analysis of it is needed in determining its use in a targeted drug design against the COVID-19 virus.

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Availability of Data and Materials The datasets used and analyzed during the current chapter are available in the Protein Data Bank repository, The target protein used can be found at https://www.rcsb.org/structure/7lyo and the template protein can be found at https://www.rcsb.org/structure/7b62 [20].

Competing Interests The authors declare that they have no competing interests.

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Index

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