

Mobile applications in COVID-19 detection and diagnosis: an efficient tool to control the future pandemic; a multidimensional systematic review of the state of the art

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Abstract

Background: In the modern world, mobile applications are essential to human advancement and pandemic control is no exception. The use of mobile applications and technology for the detection and diagnosis of COVID-19 disease has been the subject of numerous investigations.

Objective: Since no thorough analysis of the COVID-19 epidemic prevention has been done using mobile applications. Due to this gap, the current study thoroughly covers the many uses of mobile applications for COVID-19 detection and diagnosis.

Methods: A search of five major research databases (ScienceDirect, Scopus, PubMed, Web of Science, IEEE) found 535 studies, among which 42 related to the diagnosis and detection of patients suspected of having COVID-19.

Results: Mobile applications can be categorized into five areas based on the content of these studies: contact tracing, data gathering, data visualization, artificial intelligence-based methods, rule- and guideline-based methods, and data transformation. Patients with COVID-19 have been identified using mobile applications employing a variety of clinical, geographic, demographic, radiological, serological, and laboratory data. The majority of studies concentrated on using artificial intelligence (AI) methods to identify people who might have COVID-19. Additionally, compared to other data types, symptoms, cough sounds, and radiological images were used more frequently.

Conclusions: Mobile applications could soon play a significant role as a powerful tool for data collection, epidemic health data analysis, and early identification of suspected cases. These technologies can work in conjunction with the Internet of Things (IoT), cloud storage, 5G, and cloud computing.

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Original Manuscript

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Abstract

Background: In the modern world, mobile applications are essential for human advancement, and pandemic control is no exception. The use of mobile applications and technology for the detection and diagnosis of COVID-19 disease has been the subject of numerous investigations.

Objective: Since no thorough analysis of COVID-19 epidemic prevention has been done using mobile applications. Due to this gap, the current study provides comprehensive information regarding the different fields of mobile applications in diagnosing COVID-19 diseases in the pandemic era, intending to help software companies and clinical researchers.

Methods: In this systematic review, 535 studies were discovered after searching five major research databases (ScienceDirect, Scopus, PubMed, Web of Science, and IEEE). Of these studies, only 42 were chosen after applying inclusion and exclusion criteria using the PRISMA protocol concerned with diagnosing and detecting COVID-19.

Results: Mobile applications can be categorized into five areas based on the content of these studies: contact tracing, data gathering, data visualization, artificial intelligence-based diagnosis, rule- and guideline-based diagnosis, and data transformation. Patients with COVID-19 have been identified using mobile applications employing a variety of clinical, geographic, demographic, radiological, serological, and laboratory data. Most studies concentrated on using artificial intelligence (AI) methods to identify people who might have COVID-19. Additionally, symptoms, cough sounds, and radiological images were used more frequently compared to other data types. Deep learning techniques, such as CNN, performed comparatively better in the processing of healthcare data than other types of AI techniques, which improved the diagnosis of COVID-19.

Conclusions: Mobile applications could soon play a significant role as a powerful tool for data collection, epidemic health data analysis, and the early identification of suspected cases. These technologies can work with the Internet of Things (IoT), cloud storage, 5G, and cloud computing. Processing pipelines can be moved to mobile device processing cores using new deep learning methods, such as lightweight neural networks. In the event of future pandemics, mobile applications will play a critical role in rapid diagnosis using various image data and clinical symptoms. Consequently, the rapid diagnosis of these diseases can improve the management of the disease's effects and bring excellent results in treating patients.

KEYWORDS

COVID-19; Detection; Diagnosis; Internet of Things; Cloud computing; Mobile applications; Artificial intelligence

Introduction

Following the widespread and rapid outbreak of COVID-19, the disease crossed geographical borders and had a devastating impact on the health, economy, and well-being of the global population. According to the World Health Organization (WHO), high-severity COVID-19 was reported in 16–21% of patients, and almost 3% died. In the case of other variants, however, local statistics in many countries indicated a high mortality rate, with some studies estimating a mortality rate of 4% or higher. Due to the novelty of the disease, ways to deal with it were not known early on; still, researchers considered the screening and rapid diagnosis of patients and their separation from healthy people to be significant steps in fighting the disease[1,2].

Early and low-cost diagnosis of infections in any pandemic is essential for pandemic control. Therefore, if it is possible to diagnose and quarantine infected cases in the earliest phases of an outbreak, the outbreak can be managed in the epidemic phase and will not become a pandemic. In the COVID-19 pandemic, various diagnostic methods have been employed, with the polymerase chain reaction (PCR) test being the primary diagnostic tool. Nevertheless, PCR is a time-consuming and costly method; until being diagnosed by this

diagnostic test, patients may freely transmit COVID-19 and accelerate its conversion into a pandemic by increasing the transmission rate[3,4].

In the COVID-19 pandemic, a wide range of technologies came to aid in faster diagnosis and screening of infected people, many of which proved successful. Meanwhile, mobile phones, as highly abundant tools and an information gateway, helped people update their information and make more accurate decisions. Besides being a platform for installing essential and valuable applications to detect infected people, smartphones help track people and examine the keywords used by them for making a diagnosis [5–7].

Numerous technical and review studies have addressed smartphone applications for COVID-19 management. Many of these studies have dealt with various mobile applications used to estimate the prevalence, lessons, opportunities, and challenges of these devices and disease management. Still, none of them has adequately focused on detection and diagnosis. The current study is the first to systematically review all the studies that have used smartphone technology to detect and diagnose COVID-19. Previous reviews examined a limited number of studies. Herein, by covering the maximum number of databases, an effort was made to explore all published articles that utilized smartphones to diagnose COVID-19. In the area of mobile phone applications for the diagnosis of COVID-19 disease, a thorough and complete study has not been conducted. Alnazi examined applications related to COVID-19 released on Google Play. The 12 studies reviewed included mobile-based software for contact tracing, awareness building, appointment booking, and online consultation. They only reviewed free applications although, this study was conducted in 2021, it did not include many scientific or commercial applications [8].

Asadzadeh et al. determined the scope of mobile solutions in the COVID-19 pandemic and reviewed 16 mobile application studies on COVID-19-related data processing. The reviewed studies were classified into four categories: prevention, diagnosis, treatment, and protection. Despite noting a different range of mobile applications, this study did not mention the details and algorithms of these studies [9].

Aslani et al. studied mobile health applications in pandemics and epidemics. They examined 17 studies and explored common respiratory diseases and lung infections. Although this study was published during the COVID-19 pandemic, it did not mention mobile applications related to COVID-19[10].

Kondylakis (2020) examined 12 studies into mobile applications for COVID-19 data analysis in a more comprehensive investigation. These 12 studies covered the following domains: training, information sharing, risk assessment, self-management of symptoms, contact tracing, home monitoring, and decision-making. Still, this study did not include studies use machine learning (ML) methods to predict and diagnose COVID-19. It also did not deal with mobile applications for COVID-19 diagnosis and primarily focused on studies on COVID-19 education, care, and management using mobile applications[11].

Almalki et al. analyzed and discussed all the apps available on Google Play and the Apple Store and provided a brief explanation. Among its flaws, this study did not review scientific or academic studies and only examined mobile applications available in the market, many of which were developed without scientific or clinical supervision. Therefore, it is difficult to rely on these applications, as they lack scientific support, and cannot be introduced to or proposed by the communities[12].

Table 1 lists some studies that addressed mobile technology applications for COVID-19 data management, including the researcher's name, publication year, main topic, and number of studies covered.

Table 1: Related studies in mobile applications in detecting and diagnosing COVID-19.

Researcher, Reference Country	Main topic	Number of covered research	Year
T. Alanzi.[8], Saudi Arabia	Mobile App used during the COVID-19	12	2021
A. Asadzadeh et al. [9], Iran	Mobile health solutions	16	2021
Aslani et al, [10], Iran	mobile health applications in epidemic and pandemic outbreaks	17	2020
H. Kondylakis et al. [11],Greece	Mobile Application in COVID-19	12	2020
Almalki M et al. [12], Saudi Arabia	Implemented App in combating COVID-19	115	2020

This study aims to fill the gap left by previous review studies by conducting a comprehensive review of studies that dealt with smartphone applications in the diagnosis of COVID-19 disease, providing solutions based on technological models, and answering research questions so that researchers and health systems can envision the devices and their applications in preventing future pandemics.

Methods

The present systematic review aimed to identify relevant studies that used smartphone technology for COVID-19 diagnosis and detection. The systematic search strategy was developed based on previous studies and the authors' knowledge.

Search Criteria

This systematic study, which was conducted for the first time using this method, aimed to investigate research related to detecting and diagnosing COVID-19 using a variety of smartphone applications. The main objective was to address the following analytical questions (AQ):

- AQ1: What are the uses of smartphones for COVID-19 detection and diagnosis?
- AQ2: What data smartphones use to detect and diagnose COVID-19?
- AQ3: Which artificial intelligence (AI) methods and algorithms are utilized to process smartphone data?
- AQ4: How successful have smartphone applications been in COVID-19 detection and classification?
- AQ5: What suggestions can be made to improve the quality of mobile applications in disease diagnosis and pandemic control?

The researchers reviewed the electronic databases publishing articles on medicine and computer science. They concluded that PubMed, Web of Science (WoS), Scopus, IEEE, and ScienceDirect contain the most relevant articles. The search used keywords and logical expressions such as those in Table 2. The investigation was conducted from November 1, 2019, to late April 2022, and relevant published articles were extracted. The Embase database was eliminated from the examination due to the proximity of the publications.

Table 2: Keywords and search terms

Keyword	Logical combination of keyword
COVID-19	(("COVID-19") AND (Detection OR Diagnosis) AND (Smartphone OR Mobile Application OR Mobile App))
Detection	
Diagnosis	
Smartphone	
Mobile	

Data extraction

Relevant studies and details of their methodology and results were recorded in data extraction forms. The main elements of the methods and results were recorded in data extraction forms to identify AI algorithms and techniques. Two researchers performed data extraction (AMR and MG), and discrepancies between the researchers were resolved by discussion with an independent researcher (AH). The extracted data elements included the first author's name, country of origin, research population, data used, purpose, method, the role of the mobile application, and the evaluation method. The search in reputable databases was performed based on the search strategy, and 535 articles were extracted. After reviewing the articles' abstracts and full texts, applying the inclusion and exclusion criteria, and selecting articles relevant to the title of the present study, 42 full-text articles were finally selected. This process was performed based on the PRISMA flowchart, as shown in Figure 1.

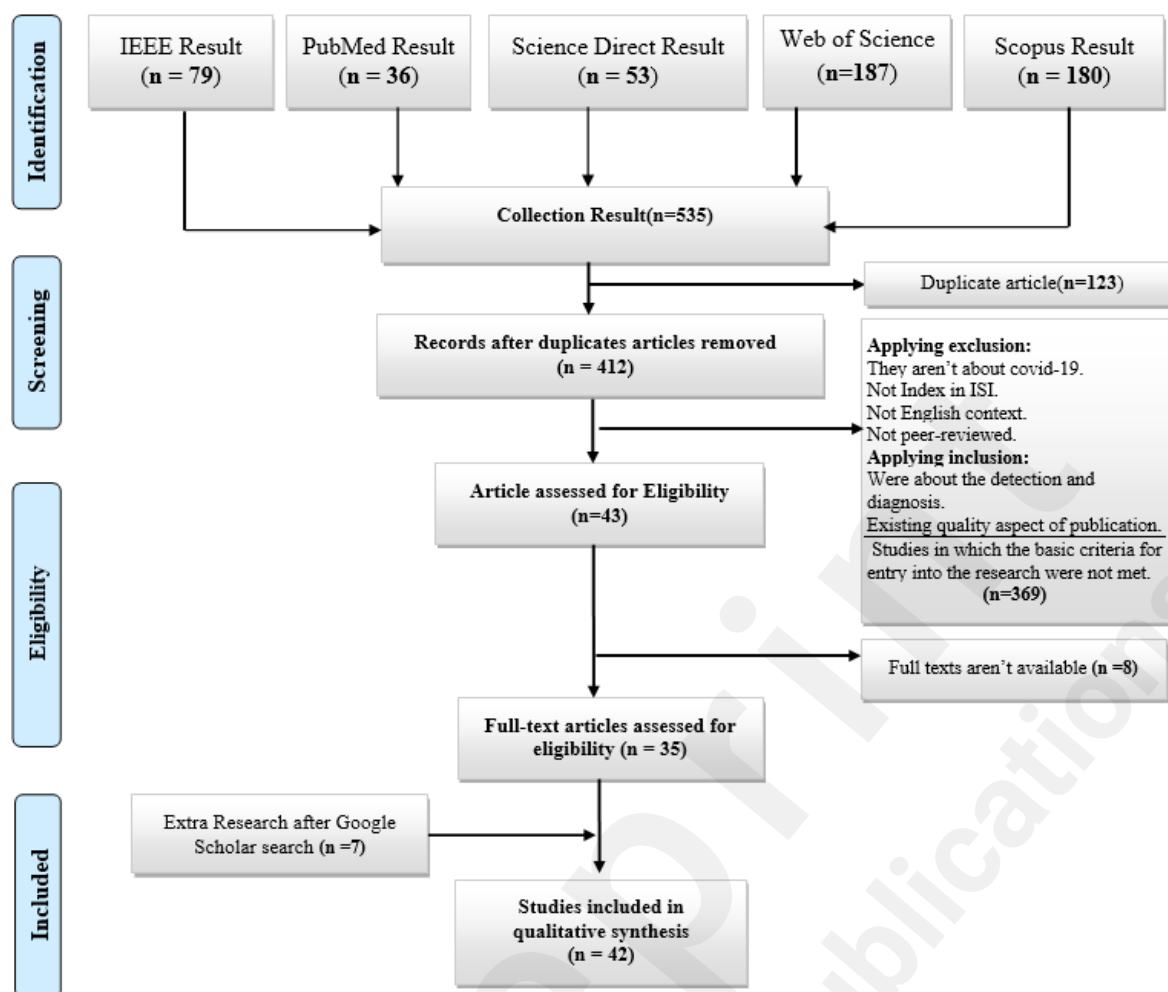


Fig. 1 The review process and how to exclude papers according to the PRISMA flow diagram.

Results

Due to the newly emergent status of COVID-19, the titles, abstracts, and keywords of all the papers published between 2020 and 2022 were reviewed, and 42 articles were ultimately selected as eligible. By comprehensively examining the mobile applications, the role of smartphones is described in six areas with different types of COVID-19 datasets, including “Smartphones play the role of a platform for data collection”, “visualizing the input data”, “installing AI-based processing software”, “determining contact tracing”, and “COVID-19 data processing based on role-based and guideline-based methods” to detect and diagnose COVID-19. A taxonomy was developed to better organize the content and concepts related to mobile applications for COVID-19 diagnosis and detection, as shown in Figure 2.

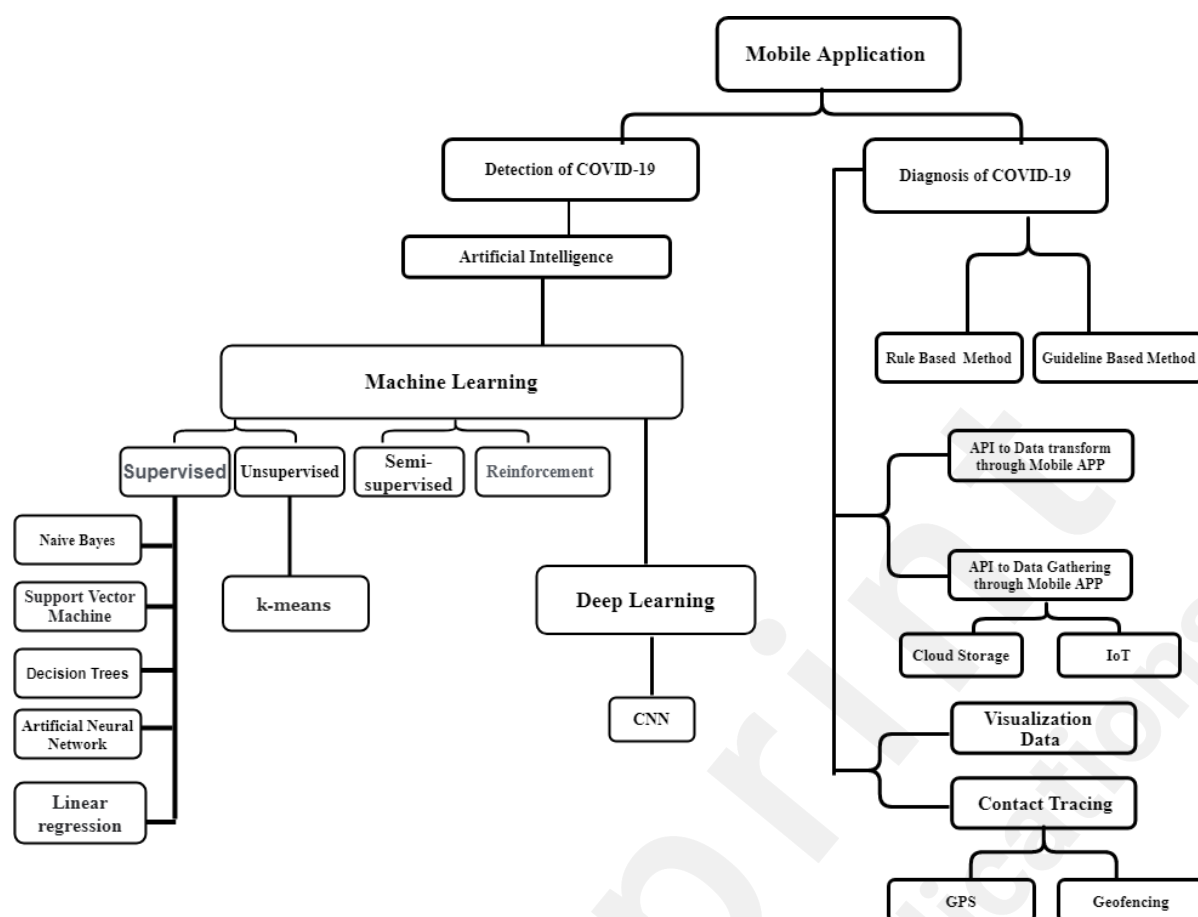


Fig. 2 The taxonomy of mobile applications in the COVID-19 pandemic

The taxonomy presented in this research classifies the studies conducted in line with the investigation into two branches: detection and diagnosis.

In the field of detection, the artificial intelligence method has been used more, which includes machine learning techniques that include traditional machine learning algorithms such as supervised, unsupervised, semi-supervised, and reinforcement learning; on the other hand, deep learning deals with images and sounds. On the other hand, rule-based and guideline-based techniques were mainly used to diagnose of COVID-19 in mobile applications.

Detection vs. diagnosis of COVID-19 in mobile applications

The terms *detection* and *diagnosis* are used interchangeably in many studies, but they differ in meaning and usage. These two terms are used differently in different settings. In clinical settings and diagnostic laboratories, the term "diagnosis" is used, while in computer vision and pattern recognition, observing the first definite signs in determining the status of a disease is called "*detection*". By examining the differences between these two terms in the dictionary and by inquiring from clinicians, a 2021 study found that *detection* identifies disease in a set of patient and non-patient cases. In *detection*, the disease is distinguished from other conditions, such that other cases may or may not have a disease-free status. However, the precise level and type of disease are completely specified during diagnosis. In the *diagnosis* concept, different cases might have a disease status or belong to other classes of abnormality or non-health, which can be determined [4,13,14].

Accordingly, *detection* is used for studies that distinguish cases of COVID-19 from healthy and normal cases. In contrast, *diagnosis* is used for studies that indicate COVID-19 from other infectious pulmonary diseases, e.g., different types of pneumonia. Detection makes sense in sets where other conditions (not infected with COVID-19) are specified, and COVID-19 can be distinguished with certainty from types of pneumonia or other coronaviruses[4,13,14]. By reviewing the extracted articles, it was found that 25 articles used deep learning to *detect* (identify) COVID-19, whereas 12 studies used it to *diagnose* COVID-19 from other diseases. Three studies did not precisely mention that *diagnosis* was the study's objective. In addition, in two studies, the goal

was to *diagnose* and *detect*. Figure 3 shows the amount of research performed to detect and diagnose COVID-19.

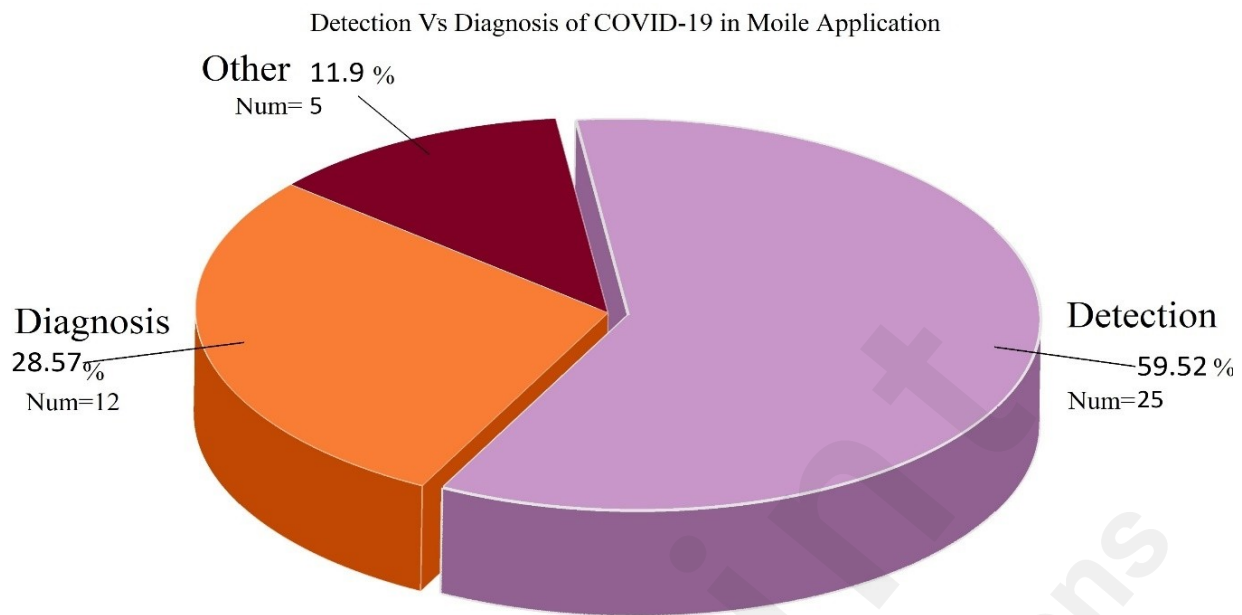


Fig. 3: Aim of studies in the analysis of COVID-19 data in mobile applications

An overview of the role of smartphone applications in the diagnosis of COVID-19

The applications were classified into the following categories by reviewing all the studies conducted on mobile technologies and applications in line with research objectives.

Mobile applications for gathering data from users

In some mobile applications, the sole purpose was to collect data for processing. These applications received data through a standard smartphone from mobile devices as input devices in perception layers and sent them to the edge and cloud layers, where processing took place. In this case, mobile applications send data from the output of biosensors to higher-level systems for processing.

Mobile applications as a platform to transform messages and data

Another application of mobile phones for COVID-19 diagnosis was processing keywords related to COVID-19 in social media using smartphones or analog messaging methods. In this method of COVID-19 diagnosis, the main terms representing the COVID-19 diagnosis were counted, and the COVID-19 diagnosis was made based on the number of uses of these words and their relationship with pronouns and sentence components.

Mobile applications in contact tracing analysis

One of the main applications of smartphones was contact tracing to diagnose and classify COVID-19. Thus, smartphones are utilized to diagnose cases of COVID-19 that have been in contact with infected people. Many studies employed mobile applications to trace people via trackers, geo-fencing, and GPS.

Mobile applications for data visualization

Mobile applications have been used to visualize the data received from biosensors or other data collection tools in many studies. After receiving the data, it was displayed to users via statistical charts. Smartphones carry out this task as the first step in data processing, which means gathering data and visualizing this data for COVID-19 diagnosis. In the next stage, these data can be transferred to higher levels of processing, such as cloud and fog.

Mobile application to analyze COVID-19 data based on guidelines and rules

A notable study on COVID-19 diagnosis using mobile phones involved ontologies, clinical guidelines, and rules. Due to COVID-19 diagnostic guidelines in healthcare centers, guideline- and role-based methods for COVID-19 diagnosis are expected to be very popular among clinicians and physicians. By incorporating these guidelines and rule bases into mobile applications, clinicians and stakeholders can see the process as more tangible and acceptable.

Mobile applications to analyze COVID-19 data based on AI algorithms

One of the most frequently used mobile applications for COVID-19 diagnosis is an AI-based application in which learning occurs. Various AI methods, such as machine learning (ML) and deep learning, have been employed in these applications. These studies utilize different clinical data, sounds, and radiology images. Data is collected in two ways: by mobile application designers and developers, and by clinical application users using mobile applications.

Since most mobile applications processed and predicted COVID-19 infection, they incorporated different AI algorithms that involved two methods: methods based on traditional ML algorithms and those based on deep learning algorithms.

Data used in mobile applications for COVID-19 detection and diagnosis

A wide range of data is utilized in mobile applications and according to specialty domains, different scientific disciplines made the initial diagnosis of COVID-19 differently. Mobile applications use a range of data for collection, classification, analysis, transfer, and visualization. These applications dealt with various data, including nasal swap samples, personal clinical data, signs and symptoms, voice and sounds, radiology images, words, and terms in media.

Several studies used a combination of data types. Some others employed subjective clinical data and symptoms. Moreover, some applications utilized a variety of radiology images and patients' voices (cough).

Table 3 lists all the mobile application studies to diagnose COVID-19. This table presents the studies with the first author's name, publication year, data, application method, mobile role, and evaluation outputs.

Table 3. Studies evaluating mobile applications used for COVID-19 diagnosis (or a goal similar to diagnosis).

Author(s)	Data	Goal	Method	Mobile role	Evaluation output(%)
Adra et al.	Symptoms, clinical and bibliography data	COVID-19 Risk prediction	Machine learning	Platform to applied model in calculating risk prediction	N/A
Arma, A et al	Sound	Diagnosis	Machine learning	Platform to analysis Speech and sound analysis	N/A
Arma, B.	Symptoms	Diagnosis	Rule-based reasoning	Gathering symptoms and receiving alert (SMS)	N/A
Ar, G. et al.	smartwatch, activity tracker data, symptoms, and testing results	differentiate COVID-19 positive	Single decision threshold	Data Collecting	Accuracy =83.34
Arman, S. K. et	Heart Rate, Blood Cell counts,	Diagnosis	Send patient data to the physician	Estimate the HR, receive data from the wireless sensors used for	N/A

	temperature		and receive measuring white blood cells (WBCs) output from a and red blood cells (RBCs) levels, physician and estimate air temperature		
an, A. et al.	Cough sounds	Diagnosis	Deep learning	Receive cough sounds and analyzing using a designed App	N/A
khhtar, H. et al	Cough, Temp	SpO ₂ , Diagnosis	Rule-based reasoning	Collecting data, sending, Show the assessment	N/A
hti, D. et al	Symptoms	Diagnosis	Machine learning	A platform for Applied application	Accuracy=99
lik Ertuğrul,	personal data and observed symptoms (Image, sound, ...)	Prediction	Ontology Rule	and Application Platform	N/A
ghded, H. S.	CT Scan, Cough voice, breathing sound, Fatigue	Diagnosis	Deep learning	Application Platform	N/A
ngarajan, A.	CT images	Diagnosis	Deep learning	Application Platform	

There are several mobile applications available to Detect COVID-19 or its variance, as shown in Table 4. An overview of the studies is shown in this table, which includes the name of the first author, the publication year, the data, the application method, the mobile role, and the evaluation results.

Table 4. Studies that used mobile technologies to detect the disease of COVID-19

Author(s)	Data	Goal	Method	Mobile role	Evaluation output (%)
cen, A. et al	Cough	Detection	Deep learning	Platform to applied COVID-19 detector via cough sound	Accuracy=79 F1 Score=80
o, K. et al	Wastewater sample	Detection	Biosensor analysis	Interface to send data	N/A
ak, B. et al	Speech voice	Detection	Machine learning	A platform for an application	Accuracy>82–86
M. A. et al	breath, cough, and voice sounds	Detection	Deep learning	A platform for an application	Accuracy= 94.5 and 92.08
ubidi, A. F. et al	Blood index	Detection	Machine learning	A platform for an application	Accuracy=89
met, S. et al	Thermal Images and Location	Detection	Thermometer and Send location	API to calculate and send data	N/A
quedich, M. et al.	Contact tracing	Detection and Management	and Guideline based	A platform for an application to prescribe the drug and send an alarm	N/A
ataş, E. et al	Cough Voice	Detection	Machine Learning	Platform for Applied Application	Accuracy=96.5

sthi, N.	Ultra sound images	Detection	Deep learning	Platform for an Applied	Accuracy=83
fik, M.et al	Cough sounds	Detection	Machine and Deep learning	A platform for an Applied	Accuracy=98
snanik, E.et al	symptoms	Detection	Rule-based reasoning	A platform for applied application	N/A
omarchuk, A. et al.	Breathing and Cough sound	Detection	Deep learning	A platform for Applied application	N/A
eyas, S. K. et al	X-ray Images	Detection	Deep learning	Platform for Applied application	Accuracy:98.4
nsin, J. et al	symptoms	Detection	Rule-based reasoning	Platform for an application	N/A
jeev, S.et al	Cough and clinical data (SpO2 level, body temperature, heart rate, symptoms)	Detection	Machine learning	A platform for Applied application	Accuracy: 85
omarchuk, A. et al.	Breathing and Cough sound	Detection	Deep learning	A platform for Applied application	N/A
hra, K. F. et al	X-ray Images	Detection	Deep learning	Platform to trace and analyze keyword	Accuracy=98.6
de, L. et a	Cough	Detection	Machine learning	Platform to analyze Cough sound	Accuracy=82
aciu, S. et al	Bluetooth data	Virus Detection	Contact management	Contacts tracing	N/A
, C. et al.	Nasal swap sample	Virus Detection	Aptasensors fluorescent	Visualization the data	N/A
ouni, P. et al.	Nasal Swab Sample	Detection	RNA analysis	Data visualization	Sensitivity in under 30 min
pock, H. et al	Audio and Sound	Detection	Machine learning	Platform to install an application	N/A
ng, C. K. et al.	symptoms	Detection	Medical protocol	Receiving data and analysis using a designed App	N/A
zi, H. et al.	Heart Rate, Feeling features, and Blood Pressure	Detection	Machine Learning	Collecting data from users	Accuracy= 83.34 ± 1.6
everría, P. et al.	Sound, Symptom	Early detection, management of close contacts	Guideline	Gathering signs and symptom	N/A
na, A. et al	CT- Scan	Detection	Deep Learning	Process unit and platform to applied model	Accuracy and F1 Score =99.58
n, S. et al.	Spike protein and nucleocapsid protein	Detection	Data transferring	Receiving, gathering, and transmitting data in edge layers	N/A
n, Z., et al	Temperature and heartbeat	Detection	Comparing received data with normal	Receive data from a sensor and send it to the database	N/A
ng, W. et al.	Keywords in social media	Detecting SARS-CoV-2 outbreak	the Analysis emerged keyword	Platform to install WeChat to trace and analyze keyword	N/A
U. S. et al.	Speech and voice	Detection	computational audit techniques	Data Collecting	N/A

F. et al. Horse nasal swab Detection Machine learning Deciding based Results achieved
samples and in ~30 minutes.
Visualization of the data

Having thoroughly scrutinized the particulars of the investigations delineated in Tables 3 and 4, the methodologies implemented therein, the scholarly community involved, and the significance of mobile applications in the detection of COVID-19, we are now equipped to provide answers to the number of the research questions.

To answer AQ1, although different applications have been employed, the main applications belong to six functional domains: contact tracing, data gathering, data visualization, artificial intelligence-based platform to analysis the data and signal, rule-and guideline-based methods framework to decision making, and data transformation. Contact tracing is a critical application and strength of this technology for the timely diagnosis of COVID-19 due to its high availability rate, serving as a module for accessing GPS satellites, determining people's positions, and accessing higher data transaction layers such as cloud and fog. Berquedich adopted a model for contact tracing and designed technology to reduce hospital visits and alert people who were in contact with patients to seek healthcare. Some domains, such as the processing of patients' voice and audio data for COVID-19 detection, have received more attention, whereas biosensor data visualization applications have been less frequently designed and presented. Figure 4 depicts the six functional dimensions of smartphones for COVID-19 diagnosis.

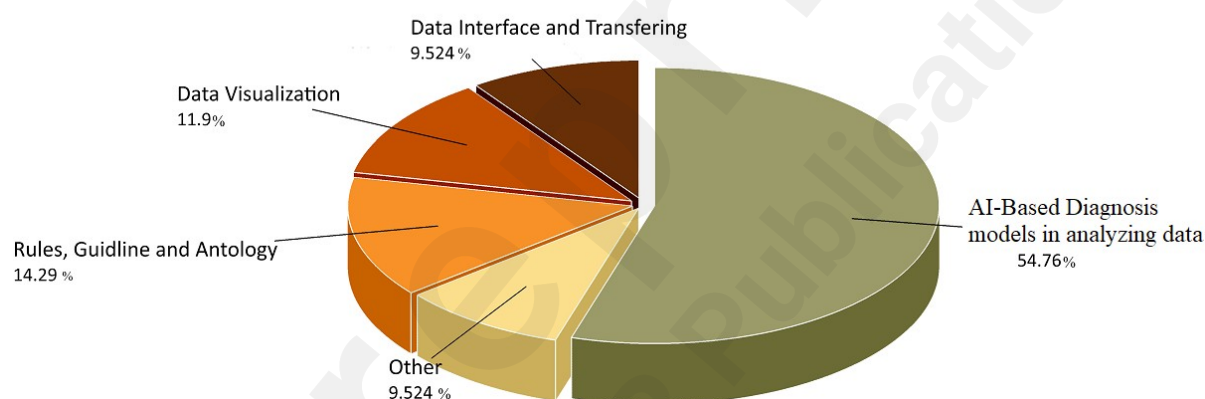


Fig. 4. Areas of application of mobile applications in the diagnosis of COVID-19

As can be seen in Fig. 4, AI-based methods have formed a large part (about 54.7% of the methodologies at the core of smartphones to diagnose the disease COVID-19. It is believed that the researchers' view was on mobile phones as on-site processing tools for faster detection of COVID-19. On the other hand, the applications that embedded guidelines and rule-based techniques in the processing core of their mobile applications to analyze the markers were powerful tools for processing all kinds of numerical data and presented them to the users as a piece of point-of-care equipment. These aspects of mobile applications have been of great importance among researchers due to the ease of faster analysis of input data and the data input gates of mobile phones for more immediate identification of patients. So more than 14% of mobile applications analyzed all kinds of biomarkers using guidelines and rules to access a model in the field of COVID-19 diagnosis by classifying the input data. A extensive rate of mobile applications also focused on visualizing (11.9%) and transferring (9.5%) data.

One of the strengths of mobile technology in identifying and diagnosing diseases, especially infectious diseases, is the visualization of data received from IoT technologies and biosensors. After analyzing the data with hardware chips and equipment or nucleic acid analysis, the signals are transferred to the mobile application for visualization through various means, such as IoT and Bluetooth. In these studies, the blood, serology, and saliva data analysis, after DNA and amino acid analysis, was sent by biosensors to mobile applications for visualization [24, 25, 44, 49].

In some other studies, one of the most influential features of smartphone technology that had a significant impact on COVID-19 diagnosis and detection was the reception and collection of data from people suspected of having COVID-19. This information can include saliva samples, clinical signs and symptoms, vital signs, demographic information, cough sounds, and medical history. The mentioned types of information are obtained

by mobile phones, the equipment connected to and embedded in them (e.g., chemical sensors), and the recording of vital and clinical signs is stored by mobile phones or moved to the cloud, allowing other computing devices to access this volume of information. Some studies dealt with using smartphones for collecting patient data; for computation, they provided the data in a centralized space to the specialist or decision support systems [18, 19, 22, 23, 29, 50].

We observed many features to answer AQ2. The design and development of mobile-based applications for COVID-19 detection and diagnosis were commensurate with the frequency of COVID-19 diagnosis data. In other words, for frequent data such as coughs, applications that used this type of data to diagnose COVID-19 were the most frequent. Figure 5 presents the usage of data types in mobile applications.

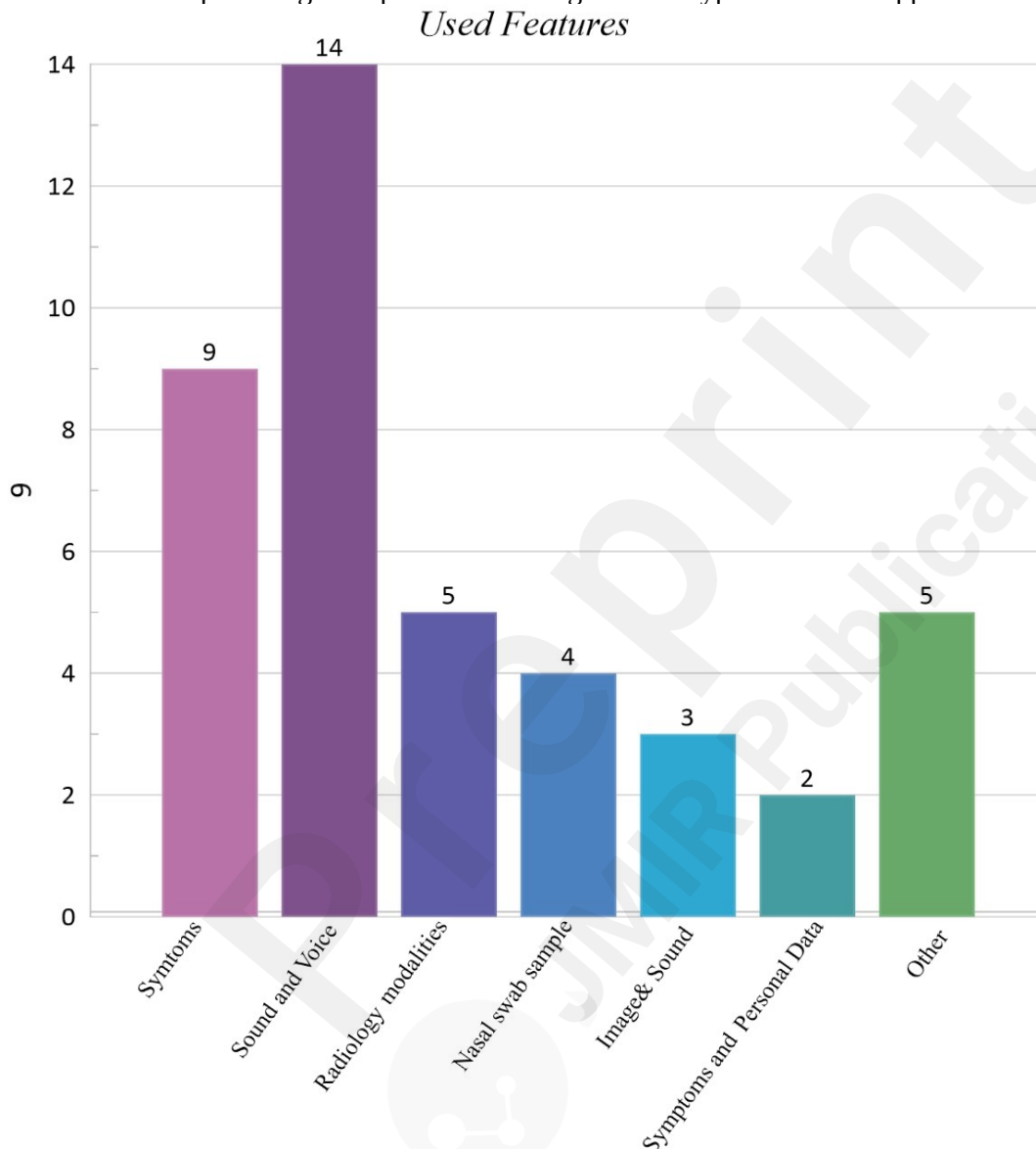


Fig. 5: Data used in the detection and diagnosis of COVID-19

Several laboratory biomarkers, diagnostic tests, biographical data, histories of diseases, and the voice, and cough sounds of patients were used as input features to applications based on methodology. According to Figure 5, it seems that the amount of research using these features has a linear relationship with the diagnostic methods of COVID-19, as most mobile applications use the features of signs and symptoms as well as the sounds of patients and their coughs. In many applications designed to increase the accuracy of disease diagnosis, a combination of these features was used. Since mobile devices can receive and save sounds, these applications have used this feature significantly.

For the analysis of nasal swab samples, applications that utilized biosensor technology incorporated multidisciplinary knowledge and utilized additional hardware. Following the sample analysis, the resulting data

were transferred to the mobile application via Wi-Fi or Bluetooth, which was then used to automatically diagnose COVID-19. As a notable study, one can mention aptamers as a robust molecular tool for COVID-19 diagnosis [12]. The findings revealed that mobile technologies in pandemic control and prevention had been a hot research topic and an exciting and trendy approach.

To answer AQ3, the notable use of smartphone applications in COVID-19 prevention assists clinicians with the timely diagnosis of COVID-19. AI methods such as ML and DL algorithms achieved remarkable results in the COVID-19 diagnosis. Many researchers [8, 10, 13, 24, 32] who used clinical data such as serology data, vital signs, and symptoms adopted ML algorithms. These features were received from users and applied to the ML model to diagnose COVID-19. Different ML algorithms have been employed for this purpose.

Since the main symptoms of COVID-19 diagnosis are cough sounds, the type of coughs, and respiratory sounds, many researchers have adopted ML methods and algorithms such as SVM and ML methods to identify patients' sound patterns [10, 17, 37,45]. Sound feature extraction was carried out based on mathematical algorithms. Using mobile applications to classify these features led to the automatic diagnosis of COVID-19.

Due to the complexity of detecting the pattern of cough sounds, several studies required more efficient and voluminous methods, so they used deep learning algorithms. After training with more significant data and obtaining a more efficient model on systems with more powerful processing units such as GPUs, these algorithms were applied to smartphone operating systems with the cough sounds of people suspected of COVID-19. The methods in this category differentiated infected from non-infected cases by receiving patients' sounds with higher accuracy and precision [9, 27]. Tawfik et al. utilized ML and deep learning methods simultaneously and achieved a 98% accuracy [39].

Radiographic images offered another facility for rapid diagnosis of COVID-19 and, thus, pandemic control. Deep learning methods and the CNN (convolutional neural network) algorithm were also used in studies using these images in mobile technologies. These models were optimally designed by training on radiology images using concepts such as transfer learning. At the point of care (PoC), they helped clinicians diagnose and detect new cases. These applications demonstrated optimal performance, and achieved an accuracy of >92%. By automatically extracting the features using manual feature selection, the bias in the results of diagnostic models is eliminated [15, 26, 42, 43].

Artificial intelligence algorithms have been employed in various techniques utilized within mobile phones, and developers have attempted to enhance their efficiency by adjusting the parameters of these algorithms. Some studies used no performance evaluation index to determine the success rate of these applications in answering the AQ4. As for applications that used AI methods, studies utilized the metrics in the confusion matrix. For different AI methods, different levels of accuracy were obtained. Table 4 presents these values for each ML and DL methods.

Table 4: AI performance based on two different methods

AI Methods	Accuracy (Min-Max) %
Machine learning algorithm	(83 - 99.5) %
Deep learning algorithm	(91-99.6) %

Studies that used all kinds of numerical variables as features, such as signs and symptoms, have employed the ML method. Still, in others that use features in sounds and images as recognition features, DL methods were selected due to their high efficiency.

By calculating the approximate average accuracy of the AI-based models in the detection and diagnosis of COVID-19, it can be concluded that the ML algorithms used in mining the COVID-19-related data achieved good results. Also, in analyzing the sound data, radiology, or a combination of them, DL methods achieved high accuracy; in many cases, this accuracy was reported above 95%. In Table 4, the diagnostic performance rate of studies that use two methods based on AI has been shown.

The findings demonstrate the acceptable results of AI methods. In studies using applications to visualize RNA and DNA analysis tests, they detected cases of COVID-19 in a shorter time due to their sensitivity.

Discussion

In this study, after reviewing all the research conducted on mobile applications for the diagnosis of Covid-19, several research questions that may have arisen for researchers and healthcare application development companies were answered.

The upcoming section will provide answers to the remaining questions by analyzing and evaluating the data entrance, technological method, and performance metrics of the methodologies outlined in the main Tables.

To address AQ5, it is recommended to utilize mobile applications for gathering data from PoCs obtained from individuals, monitoring devices, or clinical data generators. In modern techniques, edge layer devices are used in the healthcare devices layer. Therefore, it is strongly advised to incorporate higher-level technologies, such as fog and cloud, for computing processes or computational units in distributed data clusters. Figure 6 suggests and illustrates a model of this mobile application for diagnosis.

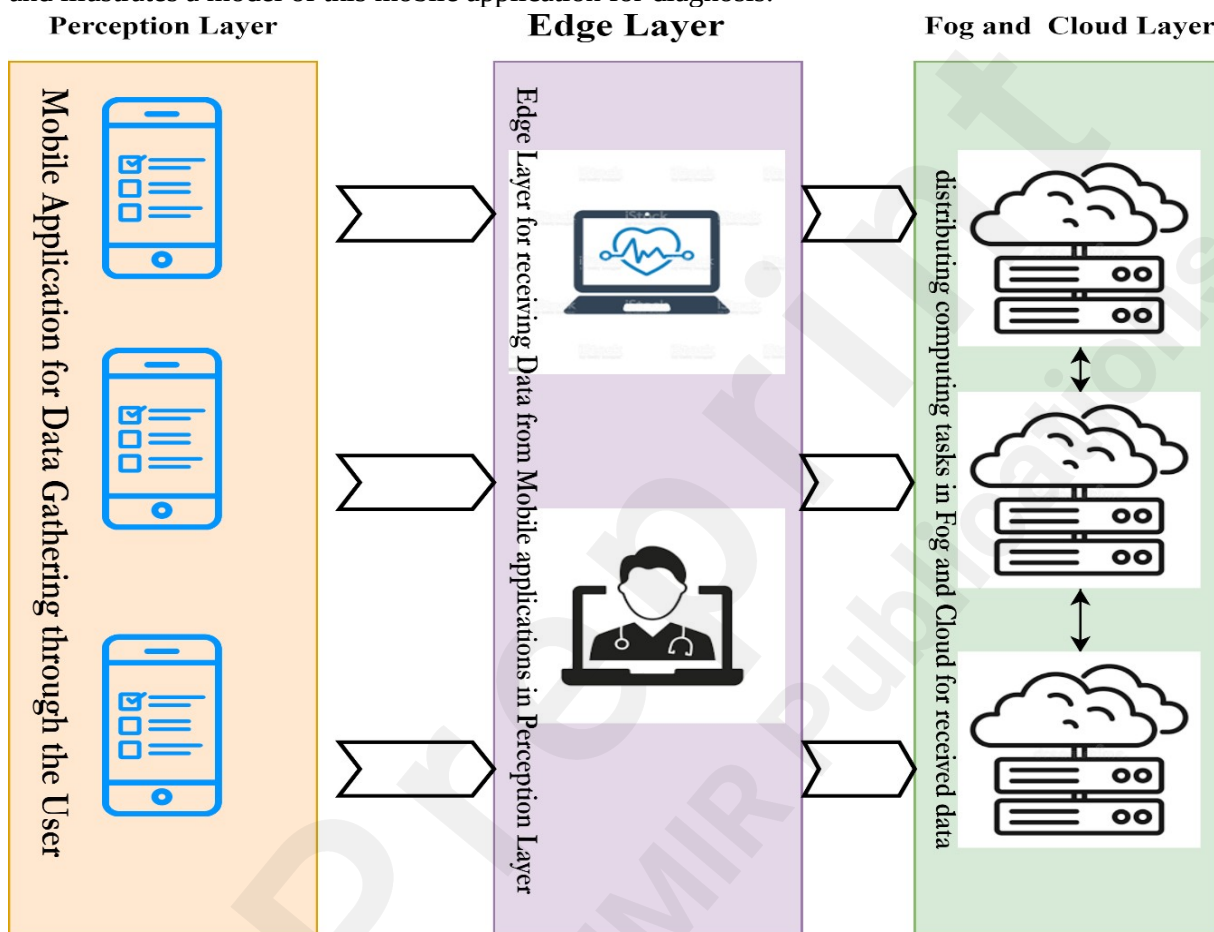


Fig. 6. Suggested model for mobile applications in gathering data from smartphones.

In the case of mobile phone applications that are used as data transmitters at the perception level, it is suggested to use 5G instead of 4G in centers and geographical areas that have access to this technology to transfer structured and unstructured data to a higher layer. By using this technology, and transferring health care data to the fog and cloud spaces, it distributes computing and data processing. The model of Figure 7 is proposed for mobile phone applications with the purpose of data collection from sensors, biosensors, and monitoring equipment.

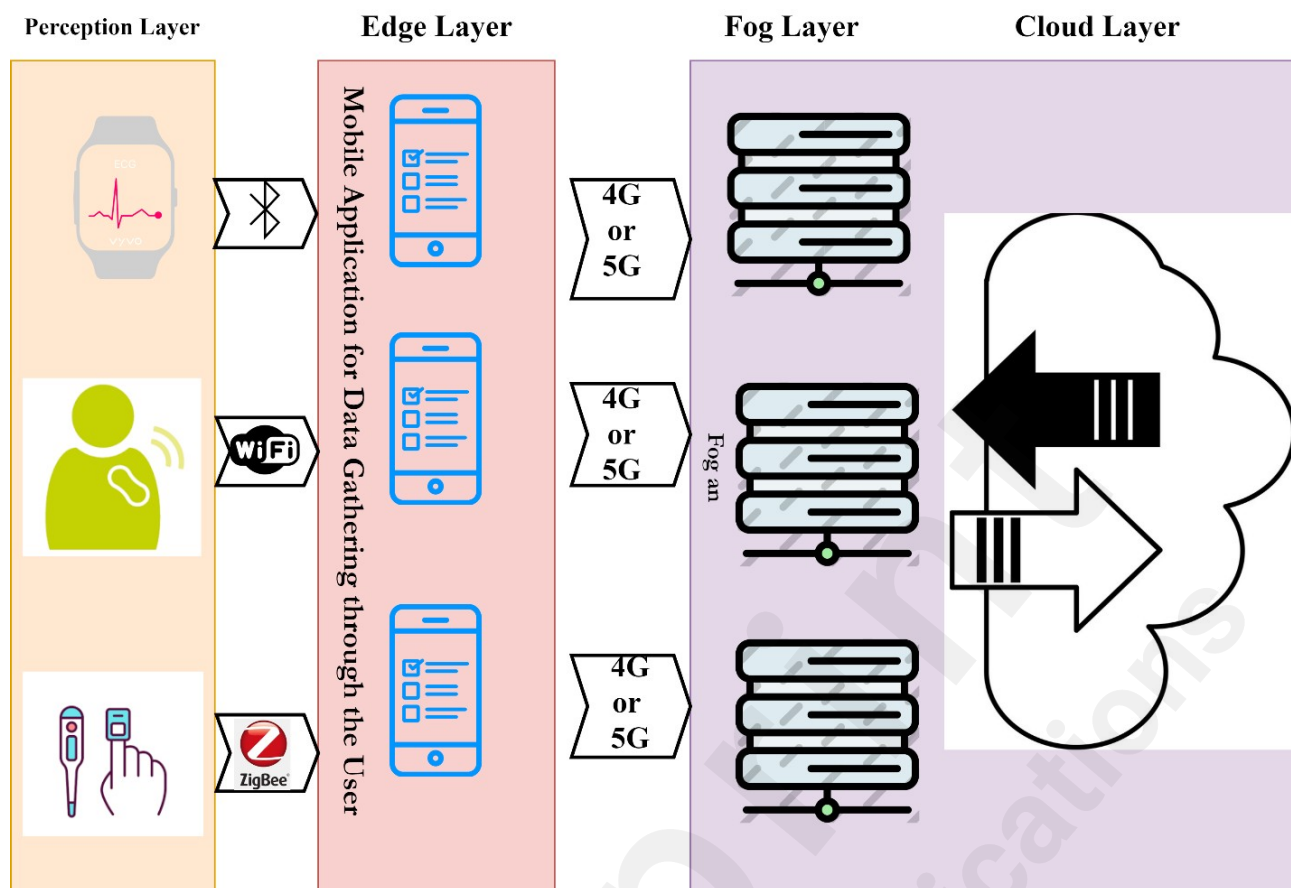


Fig. 7. Suggested model for mobile applications in transmitting data from Health Sensor, Biosensor, and Monitoring devices

We compared the studies in terms of the requirements of AI methods. In the use of AI algorithms, the volume of the dataset, overfitting prevention methods, and method lightness (for use in mobile phones) are the parameters of the quality of studies incorporating AI methodology in mobile phones. Since the included studies did not mention these cases, future studies should adopt methods to prevent overfitting when using ML methods. In ML methods, it is advised to use three methods: early stopping, dropout, and cross-validation. Besides the mentioned methods, data augmentation techniques should be used in deep learning methods so that the resulting model is free of any overfitting.

Studies utilizing deep learning algorithms in smartphones should take the following points more carefully into account:

- 1: Data pre-processing plays a vital role in model convergence and speed [51]. It is recommended that future studies employ data pre-processing techniques, especially for images.
- 2: Model parameters must be optimized to develop a robust and valid model. Future research should adopt the concept of transfer learning and pre-trained networks, and these networks should be customized to the investigation.
- 3: Mobile phones have a limited processing unit. As a result, it is suggested that the models be designed using cutting-edge techniques. It is preferred to use lightweight pre-trained CNN networks such as MobileNet, MobileNetV2, and Efficient to obtain lightweight models that efficiently run on smartphones.
- 4: In studies using mobile phones for data collection and visualization, we recommend using cloud storage and 5G technologies that significantly contribute to the comprehensiveness of the data and image visualization.

Conclusion

Mobile technology with various applications can help with COVID-19 diagnosis and detection and play a vital role in controlling the COVID-19 outbreak. Contact tracing can prevent additional contacts during an epidemic or pandemic outbreak of any disease. Thus, on the front lines of outbreak control, healthy people can be

separated from infected people and be alerted through their mobile phones. In the second step, mobile application technology, biosensors (for rapid diagnosis), and AI methods (for diagnosis in the early and acute stages of the disease) can reduce the high mortality rates and minimize the consumption of hospital resources. In the third step, mobile technology as a powerful tool can help clinicians form repositories of clinical data and signs and symptoms and collect data from individual smartphones to create such repositories and big data. This can shed more light on the disease, its symptoms, the prognosis, and the treatment outcomes. In this and future pandemics, smartphones and their applications can be an integral part of controlling the disease and improving patients' survival.

Authors' Contributions

MGZ, Search Methodology, Search strategy, Search in Databases. MG, CFC, Data visualization, data gathering, TT, AAA, HS, Data gathering, Data organization. HS and MGh Main table preparation, writing, review. MGZ, Writing - review & editing, Investigation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Conflicts of Interest

none declared.

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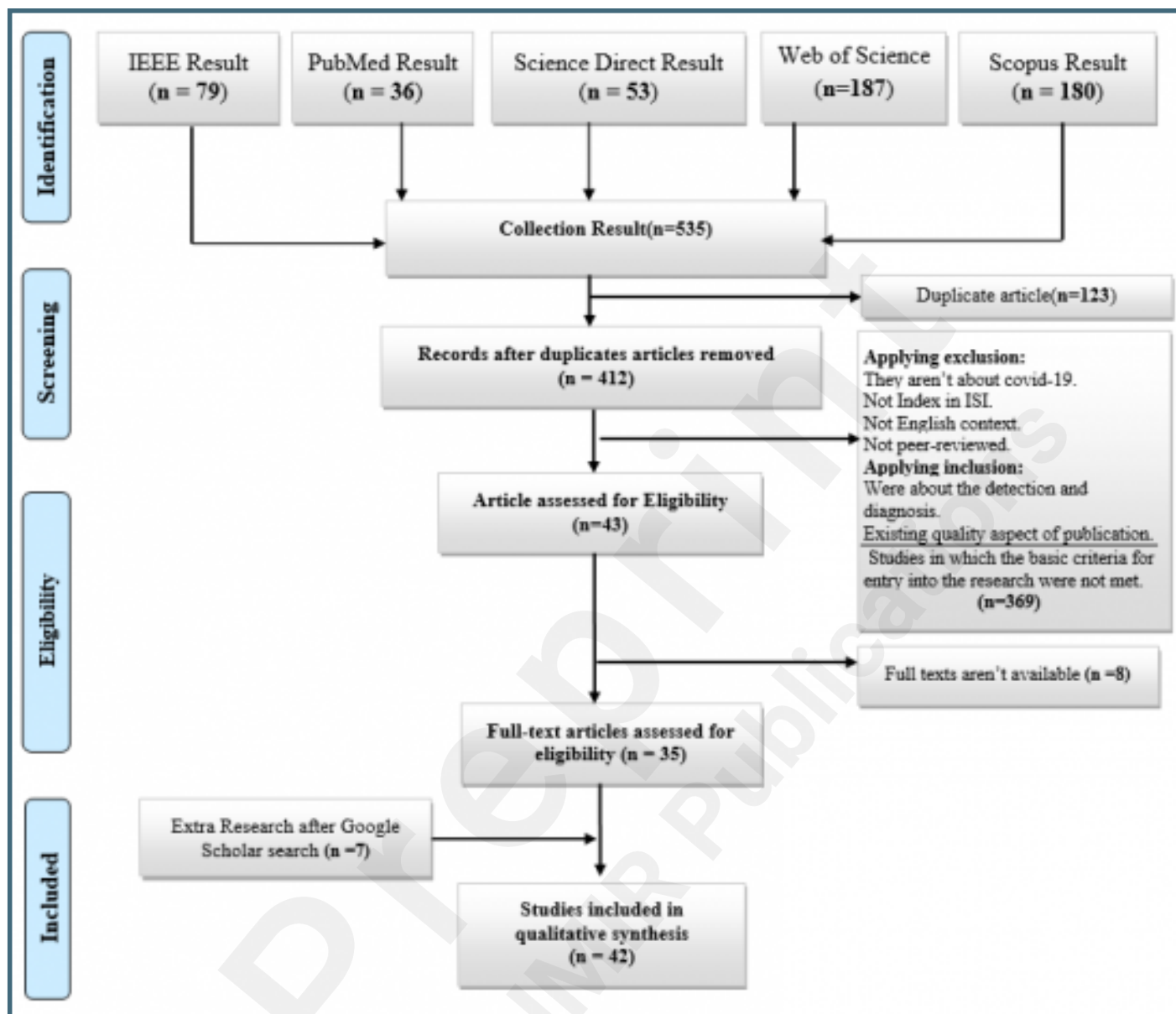
Abbreviations

AI: Artificial Intelligence
IoT: Internet of Things
WHO: World Health Organization
PCR: Polymerase Chain Reaction
ML: Machine Learning
AQ: Analytical Questions
WoS: Web of Science
CNN: Convolutional neural network
N/A: Not Mentioned(Not Available)
SpO2: Saturation of Peripheral Oxygen

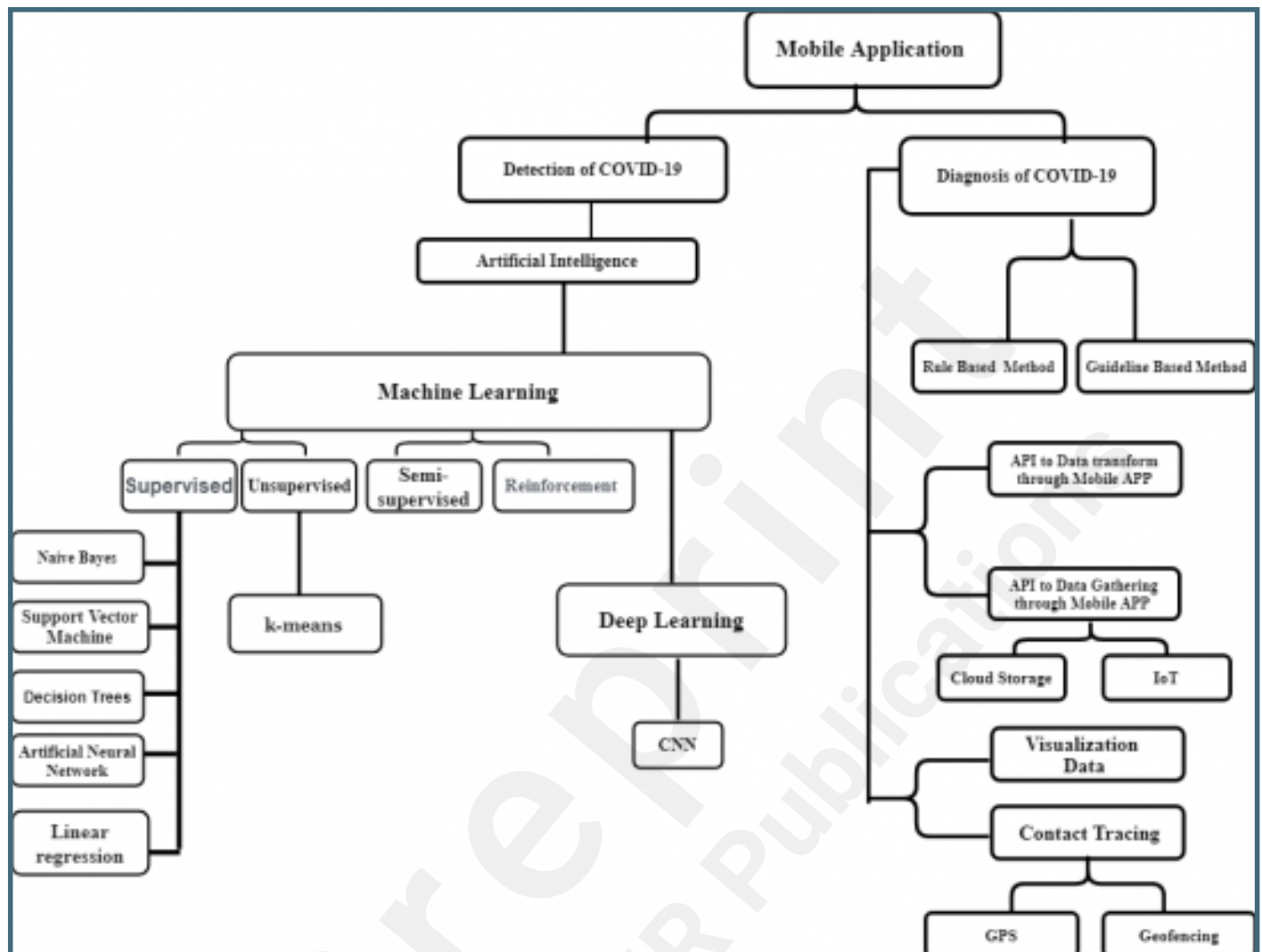
Supplementary Files

Figures

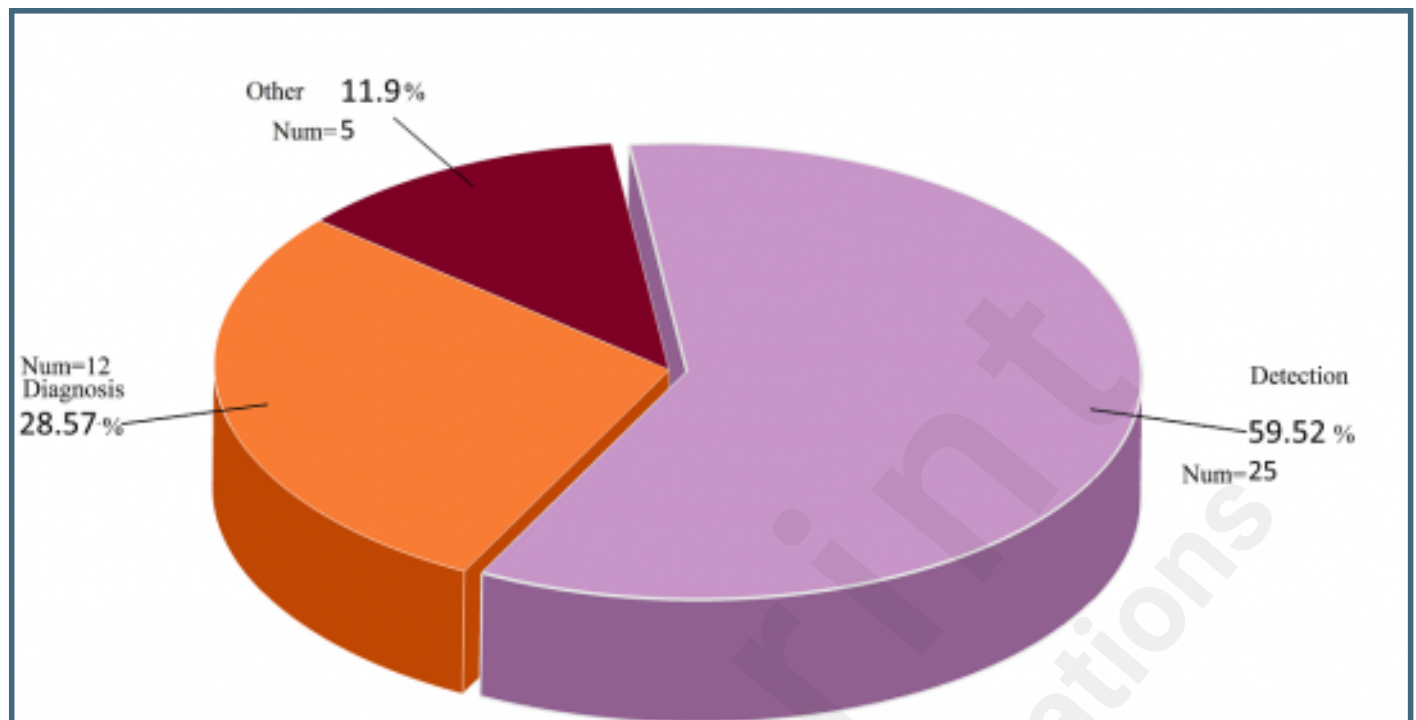
The review process and how to exclude papers according to the PRISMA flow diagram.



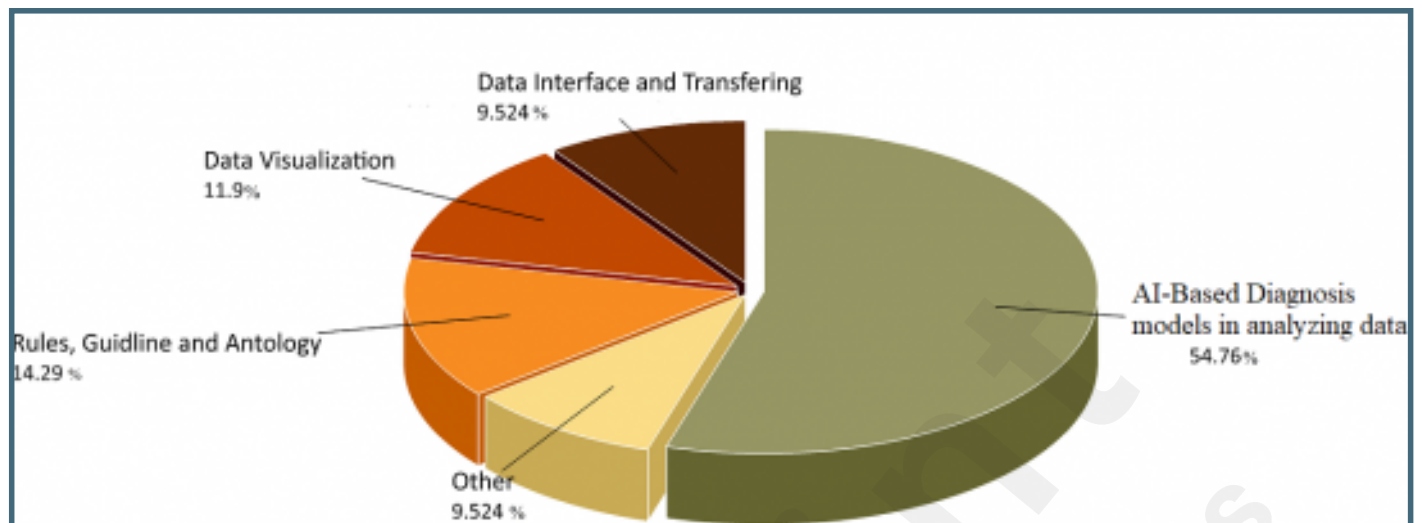
The taxonomy of mobile applications in the COVID-19 pandemic.



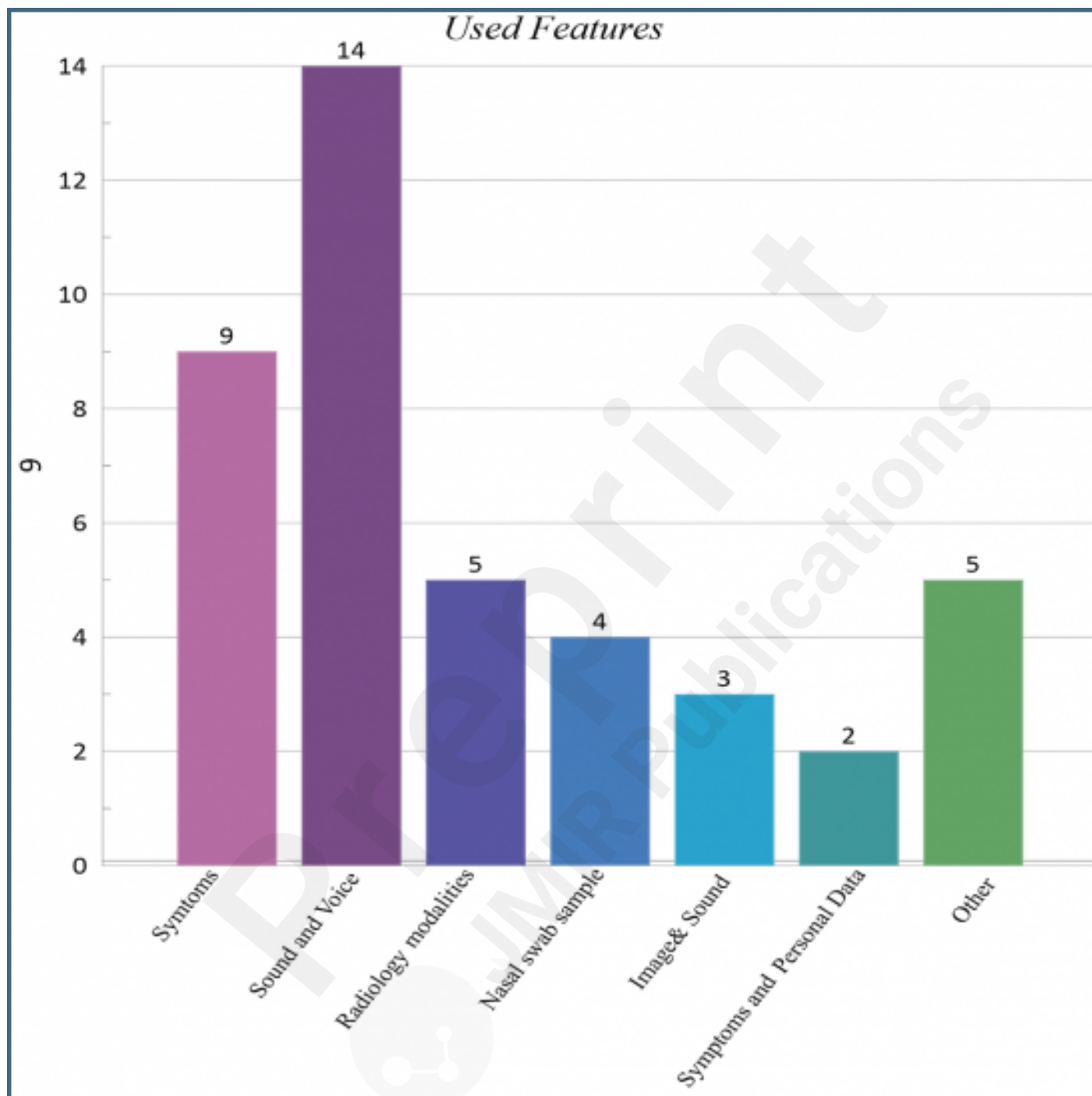
Aim of studies in the analysis of COVID-19 data in mobile applications.



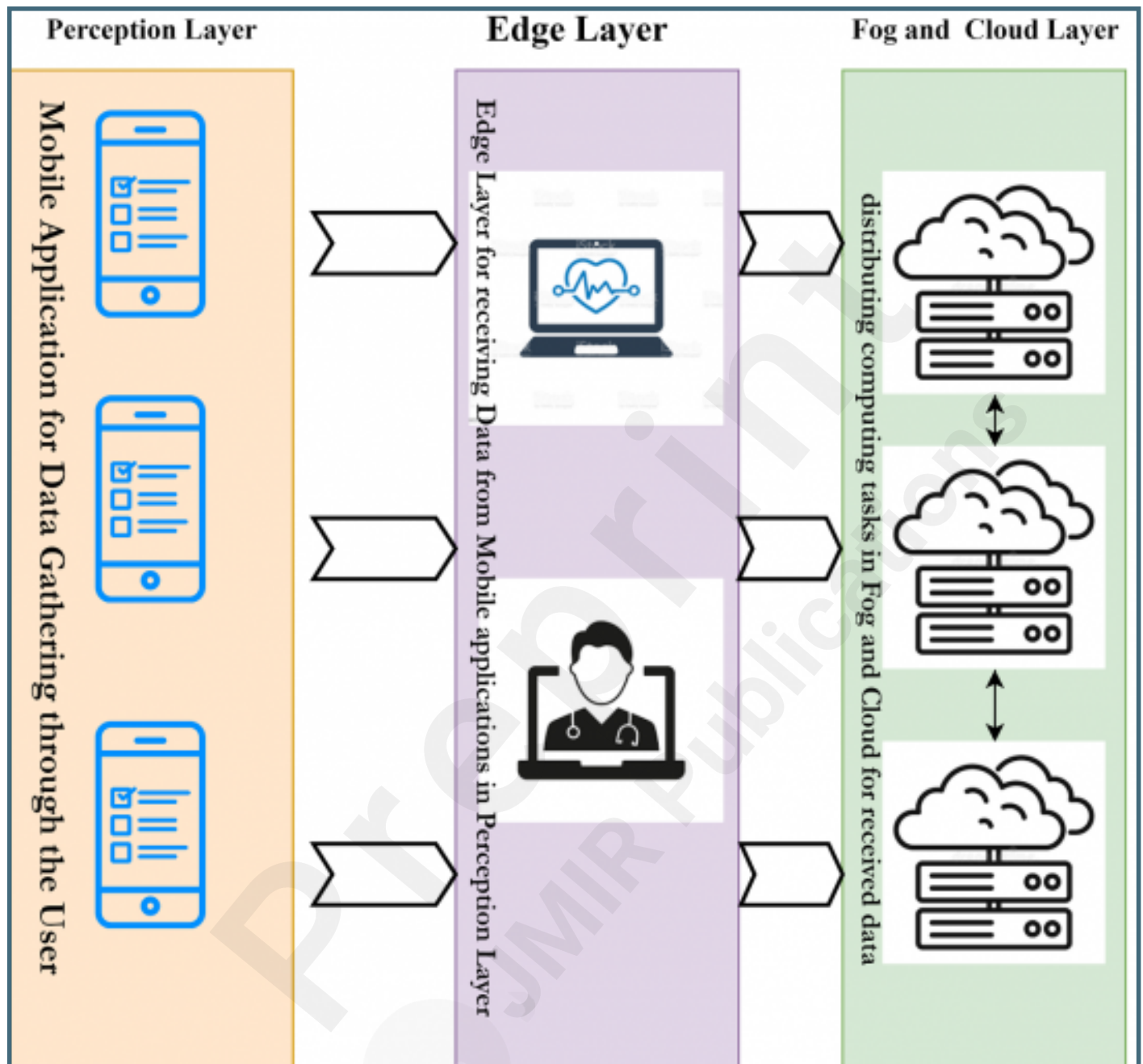
Areas of application of mobile applications in the diagnosis of COVID-19.



Data used in the detection and diagnosis of COVID-19.



Suggested model for mobile applications in gathering data from smartphones.



Suggested model for mobile applications in transmitting data from Health Sensor, Biosensor, and Monitoring devices.

