The Role of Internet of Things to Control the Outbreak of COVID-19 Pandemic

Aniello Castiglione, *Member, IEEE*, Muhammad Umer, Saima Sadiq, Mohammad S. Obaidat, *Life Fellow, IEEE*, and Pandi Vijayakumar, *Senior Member, IEEE*

***Abstract*—Currently, COVID-19 pandemic is the major cause of disease burden globally. So, there is a need for an urgent solution to fight against this pandemic. Internet of Things (IoT) has the ability of data transmission without human interaction. This technology enables devices to connect in the hospitals and other planned locations to combat this situation. This article provides a road map by highlighting the IoT applications that can help to control it. This study also proposes a real-time identification and monitoring of COVID-19 patients. The proposed framework consists of four components using the cloud architecture: 1) data collection of disease symptoms (using IoT-based devices); 2) health center or quarantine center (data collected using IoT devices); 3) data warehouse (analysis using machine learning models); and 4) health professionals (provide treatment). To predict the severity level of COVID-19 patients on the basis of IoT-based real-time data, we experimented with five machine learning models. The results reveal that random forest outperformed among all other models. IoT applications will help management, health professionals, and patients to investigate the symptoms of contagious disease and manage COVID-19 +ve patients worldwide.**

***Index Terms*—COVID-19, Internet of Things (IoT), IoT applications, sensors.**

I. Introduction

NOVEL coronavirus is given the name “severe acute respiratory syndrome coronavirus 2” (SARS-Cov-2) is the type of ribonucleic acid (RNA) virus. The World Health Organization (WHO) declared its outbreak as a pandemic and medical emergency in March 2020. This contagious disease affects the respiratory tract of humans and transfers from human to human and animals to humans. Sore throat, dry cough, fever, and diarrhea are major symptoms of the disease [1]. The COVID-19 pandemic is on the top of the global burden of disease and needs a cost-effective solution to overcome it. The Internet-of-Things (IoT) system is capable of data transmission over the network. It is an intelligent system, which can take the things in the world to connect each other through the Internet for information exchange and communication with the help of sensors following protocols [2]. The IoT can link service providers to the persons in need in emergency conditions. The IoT is a network that provides innovative applications and services through communication links [3]. The IoT devices capture information from the environment and can be sent to other devices or to the Internet [4]. Within the same network IoT devices are well suited. Moreover, the IoT emerges with the characteristics required to help the world in fighting against COVID-19. A wide range of IoT applications would be worthwhile to assure that guidelines provided by health professionals are being followed [5]. During the global pandemic situation caused by COVID-19, IoT helps by providing timely response through its sensors in the delivery of crucial information [6]. The role of IoT was not required to such extent as it is needed now to stop the outbreak of COVID-19. Due to the high speed of COVID-19 outbreak, an efficient and robust IoT-based setup is required to combat it.

This article proposes a COVID-19 monitoring system that starts with the collection of real-time data of infected persons using IoT-based sensors. This overall system is based on the IoT infrastructure, and severe cases will get early treatment and extra care for fast recovery. The recovery cases can be further monitored. Relevant data collection on a cloud platform can further provide assistance to better explore the nature of the disease. The proposed framework consists of four components: 1) data collection of disease symptoms; 2) health centers/quarantine centers; 3) data warehouse; and 4) health professionals. The main objectives of this complete IoT-based architecture are as follows.

1) To provide swift response to the infected patients after categorizing them according to the severity level of their disease and to reduce mortality rate.
2) To quickly identify severity level of COVID-19 patients, five machine learning models: 1) AdaBoost; 2) voting classifier (VC) [LR+SGD that are, respectively, logistic regression (LR) and stochastic gradient descent (SGD)];

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Aniello Castiglione is with the Department of Science and Technology, University of Naples Parthenope, Centro Direzionale di Napoli, 80143 Naples, Italy (e-mail: castiglione@ieee.org).

Muhammad Umer is with the Department of Computer Science, Khwaja Fareed University of Engineering and Information Technology, Rahim Yar Khan 64200, Pakistan, and also with the Department of Computer Science and Information Technology, The Islamia University of Bahawalpur, Bahawalpur 63100, Pakistan (e-mail: umersabir1996@gmail.com).

Saima Sadiq is with the Department of Computer Science, Khwaja Fareed University of Engineering and Information Technology, Rahim Yar Khan 64200, Pakistan (e-mail: s.kamrran@gmail.com).

Mohammad S. Obaidat is with the College of Computing and Informatics, The University of Sharjah, Sharjah 27272, United Arab Emirates, also with the King Abdullah II School of Information Technology, The University of Jordan, Amman 11942, Jordan, and also with the School of Computer and Communication Engineering, University of Science and Technology Beijing, Beijing 100083, China (e-mail: msobaidat@ gmail.com).

Pandi Vijayakumar is with the Department of Computer Science and Engineering, University College of Engineering Tindivanam, Tindivanam 604001, India (e-mail: vijibond2000@gmail.com).

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3) gradient boosting; 4) extra tree classifier (ET); and 5) random forest (RF), are applied.
3) The results show that RF achieved the highest result with 0.754 accuracy value on real-time symptoms-based data set.

The remainder of this article is organized as follows. Section II presents background information, Section III discusses the applications of IoT during COVID-19 phases, Section IV reviews challenges, Section V presents the proposed IoT base framework, Section VI discusses material and methods used in ML experiments, and Section VII details the results and discussion. Section VIII focuses on the significance of using IoT, and finally, Section IX concludes the article.

II. Background

The term IoT got in the public eyes in 2003 via auto ID center and the term was devised by the executive director of center, Kevin Ashton. Various companies invested at regular intervals in this domain after investigating its different aspects related to its future role and progress [7].

The IoT has the capacity to connect, share, organize, act, and react according to the situation and environment as it is an open network [8]. Vast research areas of IoT are growing rapidly in an interdisciplinary manner. Extensive research works have been performed to explore this field from technology to its applications in health, industry, business, and management. Currently, the main focus of research in IoT is to enable things to hear, see and smell, and communicate to share information. So, machines can be able to monitor and make decisions [9].

Wang *et al.* [10] highlighted the problem of reachability to the COVID-19 patients and claimed that it is the most important problem in the pandemic outbreak situation after vaccine development. Shuvra *et al.*, 2019 claimed IoT as the most powerful tool for data analytics, cloud computing power, and artificial intelligence. The ability of IoT devices to record and transmit data over the cloud can provide assistance in monitoring, diagnosis, controlling, and trends measuring.

Singh *et al.* [11] suggested that IoT-based facilities should be provided in the present situation as the COVID-19 pandemic. As the number of patients is increasing rapidly, reachability to the patients to provide extra care to get faster recovery can be easily possible with the use of IoT tools. IoT tools are well suited and proven to observe analytics using sensory products.

Rahman *et al.* [12] established an IoT-based real-time health monitoring system with the use of wearable IoT sensor devices, AI tools, and health testing on cloud. This system is applied using supervised and unsupervised machine learning models on public and health data and on social media real time. The monitoring system between the doctor and patient was enabled because of the latest AI, ML, speech recognition, cloud computing, automation, and block chain. IoT provides facilities, such as secure chat and telehealth, to the health monitoring system [13]. These facilities are available in mobile apps due to edge computing, lightweight application program interface (API), and easy user interface.

Fig. 1. Phases of COVID-19 pandemic.

III. Applications of IoT-Based Devices During COVID-19 Phases

The world is fighting against global pandemic conditions caused by the novel coronavirus since late 2019. Many efforts to control the disease spread and finding treatment for it have failed. Patients are dealing with symptomatic type and asymptomatic type COVID infection conditions, so there is a demand of global monitoring for patients and observing overall conditions.

IoT is a technological and innovative platform to deal with the pandemic situation of COVID-19 and cope with the challenges during its all phases. This technology is extremely helpful in capturing real-time information of infected patients [14]. Fig. 1 shows the significant phases related to the COVID-19 pandemic. IoT applications involve a large number of sensors that are interconnected with the network. It improves the safety of patients by providing an alert system and tracking COVID-19 patients. The application of IoT for the COVID-19 pandemic during different phases is discussed as follows.

A. Phase 1: Disease Infection and Detection

In the first step, IoT is utilized to capture health-related data from different locations of COVID patients and manage data virtually. As there is a high need of early diagnosis due to high chances of disease spread, especially in the case of asymptomatic COVID-19 patients. The spread of the coronavirus can be controlled by early diagnosis [15] and patients can quarantine. The IoT can speed up the process, and many devices can capture the body temperatures and take samples for lab tests. Early diagnosis will ultimately help health professionals to save lives and to make better plans for treatment [16]. It can be done by understanding the symptoms, such as cough, body ache, loss of smell and taste, sore throat, vomiting, diarrhea, and fever. Fever is most common among all symptoms during the COVID-19 infection; it may exceed 100 °F [17]. Sensors of IoT devices can capture data of patients, and diagnose and

Fig. 2. VICOODA thermometer.

Fig. 3. Smart glasses.

Fig. 4. Smart drones.

control COVID-19 [12]. Thus, IoT devices are used to capture information during this phase.

1) Smart Thermometer: To record the body temperature, various IoT-based smart thermometers are available. These IoT devices are available in different forms, such as radiometric, patch, and touch [18]. They are widely being used in early detection of diseases. Classic thermometers can also record temperature, but smart thermometers provide next level by pairing with mobile apps and tracking records and instantly showing results. These features make them more suitable in this pandemic situation. The Kinsa thermometer not only tells temperature but also provides extra guidance by connecting with the app that keeps log and tracks medication and location. Now, these data are used by a company to trace COVID-19 suspicious areas in the USA [19]. Many other smart thermometers include iHealth Forehead Thermometer, VICOODA Thermometer, isense, and ifever. These devices are wearable and can stick to the body. The use of these devices can improve and speed up the diagnosis process. Fig. 2 presents the Vicooda thermometer.

2) Smart Glasses: To reduce the human interaction, IoT-based smart glasses are among the best devices to record temperatures. These glasses use thermal and optical cameras, and are used to monitor crowds [20]. Glasses capture body temperatures in the crowd and also use face detection to make tracking easier. These recorded data are then managed on smartphones and sent to health officers [20]. A China-based company is producing smart glasses using infrared sensors and can monitor 200 people at a time [21]. Another example of smart glasses is Vuzix smart glasses that contain thermal cameras to record temperature and can update health officials with real-time data [22]. Fig. 3 represents China-based smart glasses.

3) Smart Drones: IoT-based drones are also capable of monitoring COVID-19 infected patients and infected locations. It also reduces human interaction with each other and helps in reaching to the hard area locations in very less time [23]. An example of a smart drone is shown in Fig. 4. Thermal drones are able to capture the temperature of a crowd. People having high fever can be recognized by this technology. It can record live streaming and record temperature in less time than if recorded by thermal guns. Another application is developed by a Canadian-based company to monitor remote temperatures using sensors and detect infected people by monitoring their coughing, sneezing, and heart rate [24].

4) Autonomous Swab Test Robots: IoT-based robots are being used in the early diagnosis phase as they are providing assistance to the health officials to reduce their stress level and risk of infection [25]. During the first phase to detect disease infection, autonomous robots can take swab samples of COVID-19 patients and also save the lives of lab technicians by avoiding interaction with the infected patients. Fig. 5 shows the process of collecting swab samples from a patient's throat. Another robot intelligent care robot detects symptoms of COVID-19 patients within 10 s by scanning temperature and other symptoms from 1-m distance [26]. During the implementation of self-monitoring via IoT technology, security and privacy issues are major concerns.

B. Phase 2: Quarantine and Social Distancing

After the diagnosis of contagious disease, there is a need for quarantine and maintaining social distance to avoid its spread. However, monitoring of patients either in hospitals or homes is still required. Quarantine is not recommended not only to the confirmed cases but also to the suspected cases. Certain areas of the city or country can be sealed for a certain period of time to control the disease, which is also called as lockdown [27]. The main purpose of all these activities is to stop the disease transmission from symptomatic or asymptomatic patients. IoT

Fig. 5. Autonomous swab test robot.

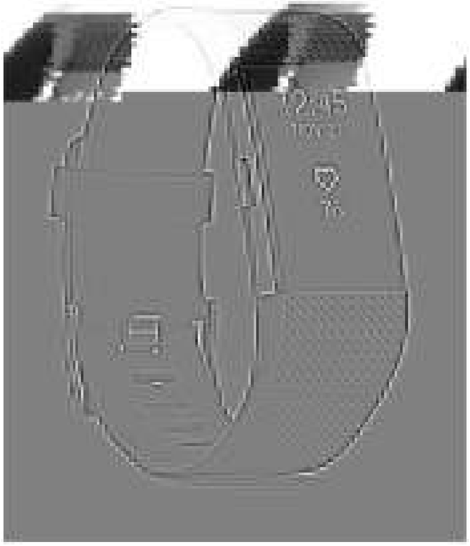

Fig. 6. IOT *Q*-bands.

devices are widely being used in this phase to monitor patients to ease the required tasks [28].

1) IOT Q-Bands: IoT *Q*-band is the cost-effective option to track COVID-19 cases by connecting with smartphones applications via Bluetooth. A patient wearing this band will be monitored by controlling authorities for staying at the same place during their quarantine. This band shares location information after every 2 min. If a patient removes this band from his arm or tries to leave the location, an alert will be sent to the authorities. Then, further investigation can be performed after it. U.S. implemented an e-bracelet for ankles during the quarantine time of patients [29]. Hong Kong used an e-wristband attached with a smartphone to monitor patients during their quarantine at airports [30]. IoT-based *Q*-band is shown in Fig. 6.

2) IoT Buttons: Controlling the spread of the infection during such thrilling pandemic conditions is one of the big problems. An alert system for the patient's family and administration about suspicious areas to implement emergency situations is an important part. These types of buttons are placed in Canada as an alert system for sanitizing or safety purposes [31]. These buttons can be placed anywhere according to the need and operated by battery power and attached to a network connection [32].

Fig. 7. Smart helmet.

3) Easy Band: This IoT device is used by sensing and collecting data. It works within a certain radius and shows an alert using LED lights. The working of bands varies with respect to persons. If someone with red LED light gets closer to the other, then the band starts beeping. The suspected cases can be traced using it, and social distancing can be maintained. It is a very cheap solution than smartphones for the safety of people. A pact wrist band is its example [33].

4) Smart Helmet: An IoT-based wearable helmet is another useful device to reduce human interaction and maintain social distancing [34]. Whenever a thermal camera or helmet detects a high temperature, it captures an image of the person and sends it to the connected device with alarm. Location history can be traced to check the places the infected person visited. This device has been implemented in UAE, Italy, and China to monitor the situation during quarantine [35]. Its example is KC N901 and shows 96% accuracy [35]. An example of smart helmet can be seen in Fig. 7.

5) Proximity Trace: To maintain workers' social distancing in industrial areas, proximity trace is being used practically [36]. It is also a wearable device, and whenever a worker gets closer to another worker, it warns with a loud sound. This device will help workers to keep more focus on their work instead of worrying about the interaction with one another. This trace device can easily stick on the worker's hat or body.

6) Broadcasting Drone: This drone is used to broadcast information in the area with very low or no Internet access. Many countries use this service for making announcements during their quarantine period to practice social distancing and guidelines [37]. "Go home" announcement is one of the examples in Spain [38].

7) Social Robots: During quarantine of longer periods, patients mostly got mental health disturbance because of isolation. Social robots are designed to stay with patients during this time [39]. They communicate with the patients to reduce stress and fatigue in the quarantine period. Paro is an example of such robots that help COVID-19 isolated patients to relieve their stress [40]. Paro Robot is shown in Fig. 8.

Fig. 8. Paro robot.

Fig. 9. IoT-based ambulance.

C. Management and Treatment

IoT also aims to connect people to the health professionals for communication and treatment using IoT devices.

1) Telemedicine: It is getting more attention in areas where the availability of physicians is not possible due to many factors. It became possible because of IoT that heart rate, diabetes, fever, and other symptoms can be monitored remotely without any physical contact. In telehealth setup, sensors capture data of the patient and send it to the cloud, and the doctor can monitor all details of the patient using mobile devices or computers. Telehealth plays a very important role during the COVID-19 pandemic situation. IoT-based healthcare devices are provided to the patients to be monitored by professionals by Health Arc [41]. The leading telehealth services are Sehatyab [42], continuous care [43], and net connect [44]. COVID-19 Gov Pk mobile app is the digital platform accessed by health professionals. All these services reduce the hospitalized monitoring of patients and improve the quality of life by providing them timely treatment at their homes.

2) IoT-Based Ambulances: During the COVID-19 outbreak, deaths of patients were increased due to the blockage of respiratory tract and those patients required intensive care on an emergency basis. The medical staffs remained under high pressure dealing with COVID-19 patients. IoT-based ambulances helped professionals to keep in contact with the ambulance staff to deal with serious patients [45]. Clearly, to take full advantage of this kind of ambulances, it is preferable to have high-speed vehicular networks to support the quick interactions among the involved actors [46], [47]. The information of patients is remotely accessed by medical experts with the help of IoT as shown in Fig. 9.

3) Social Media: As millions of people use social media, it makes it a suitable platform to connect with people regarding their health. Patients connect to their physician and can attend their live session to deal with this pandemic condition. These virtual meetings also stopped hospital visits for treatment [48]. Health professionals can prescribe medicine without physical contact. The IoT service can be utilized to capture patient symptoms and location.

Fig. 10. Automatic sanitizing door by Sandoirtech.

D. Eradication

Many economical problems have been created due to the lockdown. The government is taking necessary action in this recovery phase to eradicate the virus completely. Business and institutions are gradually reopening, and IoT is also playing a significant role in dealing with this situation to remove the virus completely.

1) Spraying Disinfectant: Cleanliness and keeping areas sanitized and disinfected are very important to remove the virus completely. IoT-based devices are used to spray the area before opening it for the public. China made drones that can spray and sanitize an area of a hundred meter in an hour. Spain has also used it for sanitizing purposes [24].

2) Automatic Sanitizing Spray: A smart epidemic tunnel is proposed by [49] to protect people using automatic sanitizing spray systems. This system automatically detects humans, and also detects motion and automatically sprays disinfectant when any individual passes through it. A Pakistani electronic company, Sandoirtech, also provided a cost-effective solution and designed an automatic sanitizing door at a very low price as shown in Fig. 10.

Fig. 11. Preventive measures to be safe during COVID-19 pandemic.

E. Preventive Measures

Many preventive measures are provided to people by their government to take care of preventive measures as shown in Fig. 11.

1) Wash hands with soap and use sanitizers after any contact.
2) Social distancing should be maintained.
3) Old age people and pregnant women should stay at home.
4) Avoid unnecessary touching to mouth, ear, nose, or eyes.
5) Door handles and surfaces should be sanitized daily.

1) Smart City: In recent times, due to the intense outbreak of the novel coronavirus, permanent IoT-based monitoring devices are installed at the important places of the city, such as airport infrastructures, bus terminals, market places, subways, and healthcare places. The smart city concept is being used in many cities, where at entry time and departure time, data are captured and analyzed. Li *et al.* [50] discussed many such sensors that are installed at different places and to provide real-time information. Many wearable IoT devices are also attached with the sensors of authorities for monitoring all activities to get rid of this disease. An example of smart city is presented in Fig. 12.

IV. Challenges to IoT

A. Scalability

The scalability of IoT devices is the biggest challenge as the number of IoT-based devices started to grow exponentially with the advent of technology. The applications of IoT devices are not only limited to household items but also used in stopping the spread of COVID-19. Bluetooth low energy (BLE) wearable is used for assessing the implementation of social distancing and for contact tracing of COVID-19 patients. All the data of this IoT-based application are managed on cloud storage. Therefore, large storage devices and computational systems are required to manage this data and obtain useful results. Besides, the energy requirements are also increased due to scalability.

B. Limited Bandwidth and Erroneous Data

As we are observing, the use of IoT-based devices is increasing with the spread of the COVID-19 pandemic. The COVID-19 spread control IoT-based wearables consist of many sensors and each sensor is transferring its values using the proper APIs. During recent years, the bandwidth is supplied by cellular networks for the data transfer of IoT sensors to cloud storage using APIs. However, with the rapid increase in the consumption of IoT-based wearables, the bandwidth of cellular networks is not enough to transfer the real-time data. Sometimes due to the lack of bandwidth and latency, erroneous data are transferred to cloud storage, which greatly affects the working performance of IoT wearables for COVID-19 protection.

C. Miscommunication and Privacy Issue of Data

As we discussed above about the scalability and bandwidth issue for IoT wearables, these issues give rise to other issues of miscommunication of data and privacy issues. The aftereffects of these issues are discussed in the following key points.

1) The IoT devices are attached to the body of people and live data are transferred (including personal information) of those people. Due to the lack of stability in IoT, no accurate cryptographic algorithms are available to safely transfer the data from IoT devices to cloud storage. The data can be intercepted from the communication path or forged, which results in the inaccuracy of devices [51], [52].
2) The data stored in the memory of the IoT device should not be accessible to everyone.

D. Interoperability Issues

After discussing the issues of scalability, bandwidth, and privacy, another big concern is interoperability during Internet-of-Medical Things (IoMT) functioning. In order to merge the IoMT provided facilities and services, we need to create a dynamically connected scheme for the accurate transfer of real-time data. In order to get more usage of IoMT technology, training sessions of medical personnel need to be arranged. More targets to be set for poor and remote locations during the COVID-19 period [53].

V. Proposed IoT Framework

IoT is an effective and easy to use solution of real-time problems faced on a daily basis. This section discusses the IoT-based framework, which could be utilized to identify and monitor the COVID-19 cases in real time. This architecture could help in treatment and in better understanding of different phases of the coronavirus disease. Our proposed framework is presented in Fig. 13. The framework consists of four components connected via cloud infrastructure: 1) data collection of disease symptoms; 2) health center/quarantine centers; 3) data warehouse; and 4) health professionals.

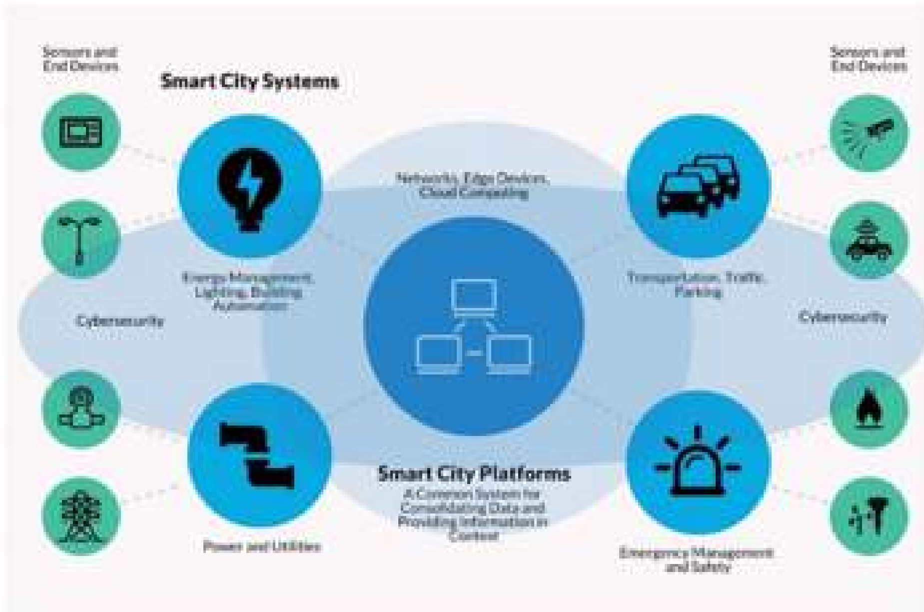

Fig. 12. Smart city.

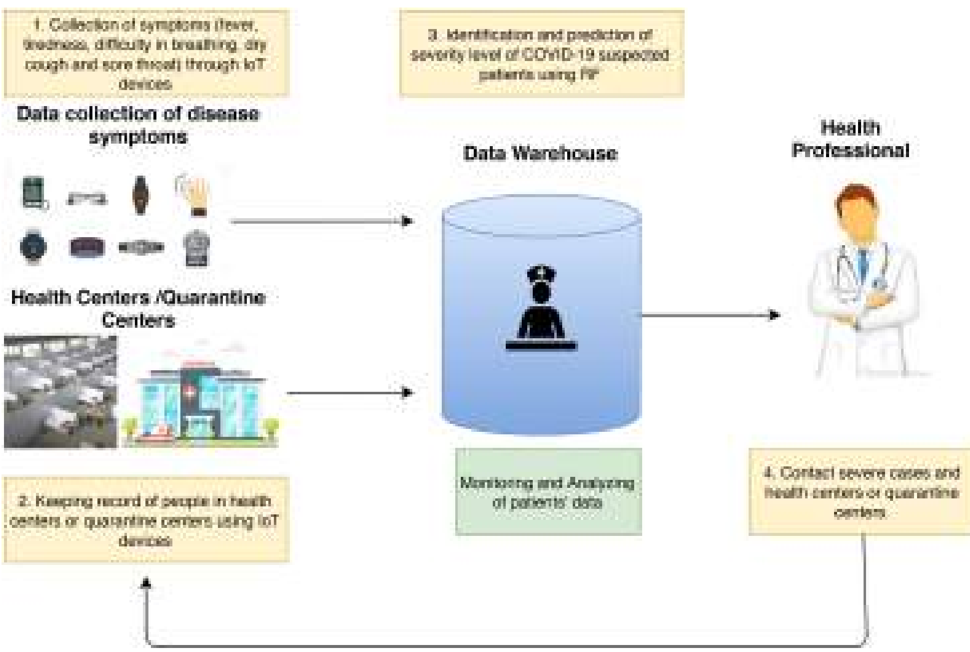

Fig. 13. Flowchart of the proposed IoT-based framework.

A. Data Collection of Disease Symptoms

Main objective of this component is to collect COVID-19 disease symptoms through IoT-based sensors in real time. The disease symptoms include cough, fever, shortness of breath, chest pain, fatigue, and sore throat. Several biosensors are available in the market to detect these symptoms, such as audio sensors with aerodynamic for cough detection, wearable temperature sensors to detect fever, shortness of breath can be detected through oxygen-based sensors, heart rate sensors can detect chest pain and fatigue, and sore throat can be detected with images. Other related information contact and travel history can be recorded by mobile apps.

B. Health Center/Quarantine Centers

The main aim of this component is to track information of isolated or quarantined patients in health centers or quarantine centers. Both technical and nontechnical data need to be recorded. Technical data include records of symptoms on the basis of time series and response of patient during treatment. Nontechnical data include age, gender, illness history, and travel history during the last weeks. Both types of record are important to deal with during treatment of the disease.

C. Data Warehouse

Data collected by sensors and uploaded to data centers are analyzed by machine learning algorithms. Machine learning

TABLE I
DATA SET SPECIFICATIONS

Attributes	Description
Country	List of countries person visited.
Age	Classification of the age group for each person, based on WHO Age Group Standard.
Symptoms	According to WHO, 5 are major symptoms of COVID-19, Fever, Tiredness, Difficulty in breathing, Dry cough, and sore throat.
Experience any other symptoms	Pains, Nasal Congestion, Runny Nose, Diarrhea and Other.
Severity	The level of severity, None, Mild, Moderate, Severe.
Contact	Has the person contacted some other COVID-19 Patient.

models can provide useful information on real-time data processing. These models could help in early detection of COVID-19 patients and can help in treatment. These useful results can then be utilized by researchers for detailed analysis to understand the nature of the disease.

D. Health Professionals

Health professionals will deal with the COVID-19 cases on the basis of machine learning model results for the identification of patients. These suspected patients will get swift responses and will further be screened for confirmation. These patients can be isolated and will get treatment and care on time.

All components of the framework are interconnected through the Internet. Real-time data of patient's symptoms recorded by sensors are uploaded from the users. Health-based record is maintained on the Internet and the results of models are shared with healthcare professionals and also communicate physician's recommendations. Furthermore, this framework can be used to provide after care and precautionary measures to connected users to avoid the virus.

VI. MATERIAL AND METHODS USED TO PREDICT THE SEVERITY LEVEL OF COVID-19

This section presents the data set and machine learning models used in the data warehouse component of the framework. We conduct experiments for quick identification of COVID-19 infection using machine learning models.

A. Data Set

The COVID-19 symptoms checker data set (https://www.kaggle.com/iamhungundji/covid19-symptoms-checker) is based on predefined standard symptoms suggested by the WHO to identify whether any person is having a coronavirus disease or not. The data set contains 27 attributes, which are further grouped into five major attributes. The attributes are country, age, symptoms, Severity, and contact. The details of each attribute are shown in Table I. This research work makes use of all 26 features to predict the severity (none, mild, moderate, and severe) of a person having the coronavirus as shown in Fig. 14. The data set consists of 316 800 records and each target label severity contains 79 200 records.

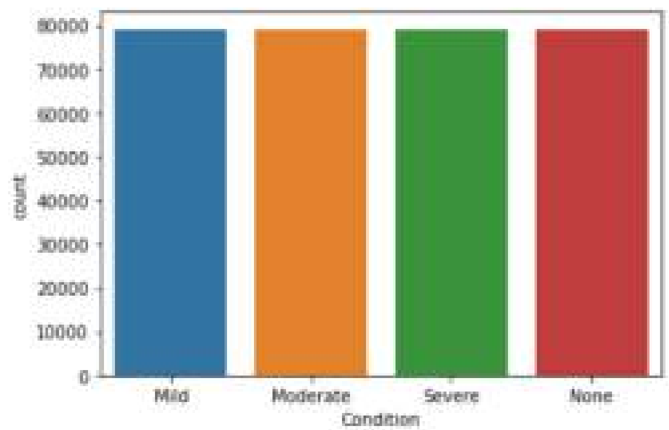

Fig. 14. Visual representation of COVID-19 symptoms checker data set.

B. Data Preprocessing

The data set contains many attributes that contain distinctive values, such as severity attribute contains records of none, mild, moderate, and severe values. Fever, tiredness, difficulty in breathing, dry cough, and sore throat attributes contain binary values in the form of "Yes" and "No." As we know, the learning classifiers need data to be in vector numeric form. Therefore, we apply a label encoding scheme on each attribute to convert textual static values into distinctive numerical values.

C. Predictive Models

Our work used data set to predict severity level of COVID-19 patients. The main function of the ML model is to estimate the current situation of an infected person. We employed the following machine learning models: Adaboost, gradient boosting, extra tree, RF, and VC (LR+SGD), and compared their performance. We implemented these models in Python using *Scikit-learn* [54]. RF uses decision trees and generates large numbers of trees to reduce variance. RF is being used in regression as well as in classification problems. RF uses a bagging method to generate results, and the final prediction is made on the majority voting of tree results. To avoid overfitting and variance, it uses bootstrap data set and random subset of features [55].

The adaptive boosting model, known as the AdaBoost model, is a very efficient boosting algorithm, which gives excellent performance in classification tasks. It performs in an accurate way by transforming weak learners to strong learners on the basis of misclassified instances in previous iterations [56]. It is about voting weights and performing better and achieving high accuracy by combining weak learners. AdaBoost can be used to find important features by feature importance score. Gradient boosting, known as GBM, is an ensemble technique based on boosting. It is also being used for regression and classification. It produces final predictions by combining weak learners such as decision trees [57]. During the boosting method, a weak learner is converted to strong learner after each iteration and fitted on modified version. It uses gradient in loss function to improve its performance. The

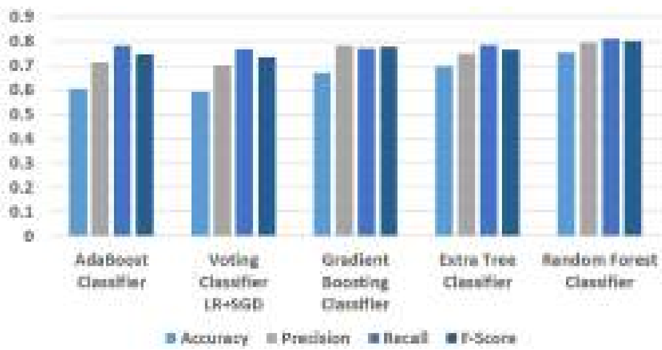

Fig. 15. Performance comparison of machine learning models.

loss function helps to find the efficiency of coefficient of models fitting over underlying data. Their working depends on the way of optimization.

ET is an ensemble model that aggregates the results of multiple decision trees. It makes final predictions, to avoid overfitting, by averaging the randomized decision trees on different subsamples of the data set [58]. The ET classifier uses the entire sample of data set and randomly chooses root nodes rather than the best one. This is the reason why the ET is considered as an extremely randomized tree classifier.

VC is the ensemble of models that predicts final output on probability scores of different base learners. The base learning model results are aggregated to make final predictions. In VCs, the output is obtained by two ways: 1) hard voting and 2) soft voting. In hard voting, the final output is selected on majority votes of classifiers while in soft voting, the output with high probability is selected after taking the average of each model. Soft voting is used in our case. We combined LR and SGD as a VC. LR [59] is a statistical model and uses a logistic function to model a dependent variable. It is a linear method that uses probabilities to make predictions. It explains the relationship between dependent and independent variables and can be used for regression and classification tasks. Gradient descent refers to the taking derivative from all training data while SGD refers to the taking of derivative from each instance of training data. SGD is introduced as a variance reduction method [60]. LR and SGD are well known techniques used for classification tasks in machine learning.

VII. Results and Discussion

Table II compares the performance of five machine learning models. It shows the accuracy, precision, recall, and f1 score of each classifier. The results presented in Table II and Fig. 15 suggest that models AdaBoost, gradient boosting, RF, ET, and voting (LR+SGD) used in our experiments are effective in predicting the severity level of COVID-19 confirmed patients. Among all algorithms, RF shows the highest results in terms of all evaluation measures with 0.754 accuracy, 0.794 precision, 0.810 recall, and 0.802 *F*-score.

However, from results, it is concluded that all tree-based models can be effective and feasible for predicting severity level of COVID-19 patients. This study investigated the usefulness of five machine learning models and found RF as more appropriate for the analysis of data. RF, an ensemble model, uses few parameters for tuning and deals with multidimensional data in a better way by modeling categorical data. The ensemble model will be incorporated in a data warehouse component of the proposed framework where data are collected by sensors and uploaded to data centers. It will help in making informed decisions to control the outbreak of the disease. The results suggest that our proposed IoT-based framework could use the RF model for the classification of severity levels of infected persons.

TABLE II
Performance of Machine Learning Models

Classifiers	Accuracy	Precision	Recall	F-score
AdaBoost Classifier	0.604	0.712	0.781	0.746
Voting Classifier (LR+SGD)	0.592	0.702	0.769	0.735
Gradient Boosting Classifier	0.671	0.782	0.771	0.776
Extra Tree Classifier	0.697	0.748	0.784	0.766
Random Forest Classifier	0.754	0.794	0.810	0.802

VIII. Significance of Using IoT

IoT applications will significantly contribute to control COVID-19 pandemic by identifying patients, locating them, and monitoring their data real time. IoT provides a transparent setup and can locate fraud information sources in the system.

When an epidemic or pandemic spreads rapidly in any place, early diagnosis, tracing infected patients, and isolating them are very critical steps. IoT-based devices are getting attention to provide solutions for these challenges. This research aims to provide IoT-based solutions to fight against COVID-19 by highlighting wearable technologies. The main target is to identify infected cases, eliminate the spread, and reduce the impact of contagious disease.

The use of IoT in a proper way will help in treatment and future decision making. The data captured by IoT tools can be used to predict future situations and enable medical professionals and government and other policy makers to plan during pandemic conditions.

IX. Conclusion

IoT enables devices to connect over networks in the hospital and other planned locations to control the COVID-19 pandemic. IoT devices will help patients, doctors, and the health management system to identify patients from their symptoms and manage positive cases globally in a better and efficient way. It can make the whole pandemic control management process fast, effective, and will save time.

In this article, an IoT-based framework has been proposed to reduce the outbreak of infectious disease in less time. The proposed framework collects data of patients and health centers and saves it to the data warehouse for analysis purposes where machine learning models are deployed to predict disease severity. The framework also communicates these results to health professionals where quick response for isolation or treatment can be provided to patients. We conducted experiments to test five machine learning models [AdaBoost, VC (LR+SGD), gradient boost, ET, and RF] on a real-time data set of COVID-19 patients. The results showed that RF identifies the severity of COVID-19 infected patients with high accuracy.

IoT-based devices in the proposed framework are monitoring COVID-19 patients during different phases of the disease. Our proposed IoT framework will help management, health professionals, and patients to investigate the symptoms of contagious disease and manage COVID-19 +ve patients. Deploying this model on a real-time framework can help to reduce the outbreak in an efficient way. Our proposed framework has the ability to follow up steps and to understand disease symptoms in a better and efficient way.

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