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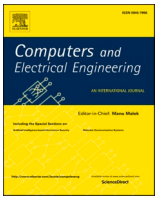

Applications of cognitive internet of medical things in modern healthcare

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ABSTRACT

The sudden outbreak of the novel coronavirus disease in 2019, known as COVID-19 has impacted the entire globe and has forced governments of various countries to a partial or full lockdown in the fear of the rapid spread of this disease. The major lesson learned from this pandemic is that there is a need to implement a robust system by using non-pharmaceutical interventions for the prevention and control of new contagious viruses. This goal can be achieved using the platform of the Internet of Things (IoT) because of its seamless connectivity and ubiquitous sensing ability. This technology-enabled healthcare sector is helpful to monitor COVID-19 patients properly by adopting an interconnected network. IoT is useful for improving patient satisfaction by reducing the rate of readmission in the hospital. The presented work discusses the applications and technologies of IoT like smart and wearable devices, drones, and robots which are used in healthcare systems to tackle the Coronavirus pandemic This paper focuses on applications of cognitive radio-based IoT for medical applications, which is referred to as "Cognitive Internet of Medical Things" (CIoMT). CIoMT is a disruptive and promising technology for dynamic monitoring, tracking, rapid diagnosis, and control of pandemics and to stop the spread of the virus. This paper explores the role of the CIoMT in the health domain, especially during pandemics, and also discusses the associated challenges and research directions.

1. Introduction

The coronavirus disease 2019 is a respiratory sickness that is caused by the severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2), an infectious virus that belongs to the family of single-stranded, positive-sense RNA viruses termed coronaviridae [1]. The first case of this disease was reported in Wuhan, China before the declaration of coronavirus as a worldwide pandemic [2]. On 13 January 2020, confirmation got from officials that the first case of COVID-19 was reported in another country apart from China. As soon as the disease began to spread throughout the world, the WHO (World Health Organization) declared the COVID-19 outbreak a pandemic on 11 March 2020 [3]. As of 5 December 2021, COVID-19 has infected over 222 countries and territories all over the world, which resulted in over 266,00,2951 cases confirmed and a death toll of 5267,407. The common symptoms of Coronavirus which can be easily

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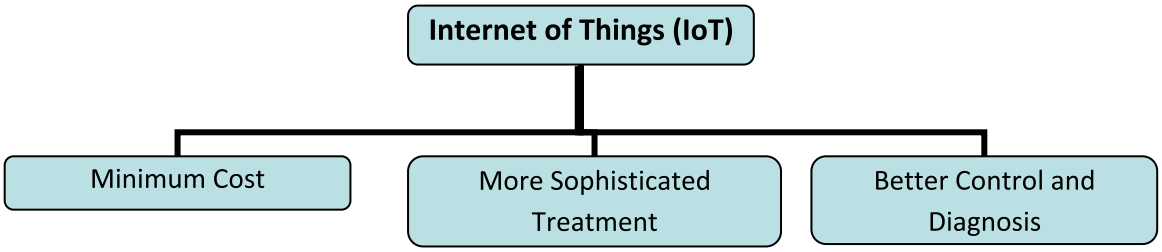

Fig. 1. Major advantages of using IoT to fight against COVID-19.

Table 1
Services offered by IoT in the health care domain.

S. No	Services offered by IoMT
1	Pediatric Services
2	Community Health Care
3	Drug Reaction
4	m-Health
5	Emergency Health Care
6	Ambient-assisted Living

Table 2.
Applications of IoMT.

S. No	Applications of IoMT
1	Blood Pressure Monitoring
2	Glucose Level Sensing
3	Temperature Monitoring
4	ECG Monitoring
5	Wheelchair Management
6	Rehabilitation
7	Cognitive Computing

identified are fever, tiredness, and dry cough; persons who are infected suffer from runny nose, body pains, sore throat, diarrhea, or nasal congestion [2]. In some cases, infected people will not have any symptoms and will not feel uncomfortable. Nearly 80% of people who get infected by this disease and are identified at the early stages can be recovered without getting specific treatment [2], but it becomes so dangerous for the age group of more than 55 years or the people with serious illness, having difficulty in breathing need proper treatment and facilities.

As of 5 December 2021, according to the official report from National Public Health Agencies 8.18 billion doses of COVID-19 doses are registered throughout the world and around 55% of the global population received at least one dose, 42.7% of the population are fully vaccinated. According to CDC (Centers for Disease Control and Prevention), in comparison with fully vaccinated people, unvaccinated people have 5 times more chances of getting infected, 10 times more of getting hospitalized, and 11 times more chances of death. On the other hand, non-pharmaceutical interventions also help to reduce the severity of this pandemic. A survey [4] discovers that implementing social distancing strictly can result in a 60% diminution of COVID-19 infections successfully [4]. The other non-pharmaceutical practices such as self-isolation and banning of public activities have also reduced the spread of this virus effectively in some regions of China and Europe [5]. Even though, these non-pharmaceutical practices are necessary for COVID-19 prevention and control, at the same time it is important to highlight the facts such as extended self-isolation and lockdowns have seriously influenced the individuals' mental and physical health along with the economy of the nation [5]. So, it is the need of the hour to develop an intelligent and more efficient non-pharmaceutical system for ensuring COVID-19 control effectively which minimizes the serious impacts on our lives [5].

In the present scenario, the latest information technologies have discovered a new door for innovation in our lives. Among these technologies, the IoT (Internet of Things) is a rising technology that provides improvements and more effective solutions in the healthcare field such as keeping the medical records properly, sampling, devices integration, and disease causes [6]. In simple words IoT refers to the connection of physical objects with each other via the internet and the data can be sent/received via the internet. Fig. 1 presents the key merits of implementing IoT for fighting against COVID-19. Some of the key elements for implementing the IoT in the field of medicine include different sensors, artificial intelligence, medical devices, latest imaging devices, and diagnostic. IoT interlinks all computing, digital and mechanical technologies for transferring data via the internet without any manual efforts. IoT technology is very useful in maintaining healthcare during the COVID-19 pandemic [6]. IoT devices have powerful sensing ability due to which human features like health conditions, activities, and important signs are captured and the analysis is done on these features in the

platform of IoT [5]. An IoT-based healthcare system enables diverse applications and provides a variety of healthcare services. Services offered by IoT in the healthcare system are listed in Table 1.

Internet of Medical Things (IoMT) offers a wide range of applications. These applications are directly used by patients and users. Some remarkable applications of IoMT are highlighted in Table 2.

IoMT is the integration of IoT and medical devices to provide cost-effective health care solutions. The general architecture of IoMT consists of three layers, such as (1) Cloud Layer, (2) Fog Layer, and (3) Things Layer. Leading emerging technologies used in IoMT to include software-defined networking, artificial intelligence, physically unclonable functions (PUN), and blockchain.

This research study reviews the role of IoT/IoMT, its applications, and various technologies implemented to control the COVID-19 pandemic.

The remainder of this paper is organized as follows: Existing technologies related to IoMT are discussed in Section 2. Applications of IoT in the medical field were discussed in Section 3. Section 4 discusses the role of IoT during a pandemic. IoT technologies to tackle pandemics are discussed in Section 5. CIoMT is discussed in Section 6. IoT-enabled technologies are discussed in Section 7. Concluding remarks are summarised in Section 8.

2. Related work

This section explores various existing models that have been developed and or implemented with the help of IoT, IoMT, and CIoMT in the health care domain.

Jung and Agulto [7] proposed a Public Platform for Virtual IoT-Based Monitoring and Tracking of COVID-19. The main aim was to develop a platform that can be accessed by anyone for monitoring and tracking information for the COVID-19 patients and the service like real-time information is provided to the global centers for Disease Control and Prevention (CDCs). The CDC maintains a list of people who require to be monitored. It also forcefully installs COVID-19 vIoT (virtual Internet of Things) as an application on their smartphone. The objective of this platform designed is to assure the services like authentication and confidentiality providing various secret keys to everyone.

Otoom et al. [8] proposed a framework based on IoT to decrease the effect of transmissible diseases. This framework provides the information related to the COVID-19 cases which are confirmed for developing a predictive model based on the machine-learning to analyze the response of the treatment. By using the predictive model, the suspected cases can be confirmed by sending the results of patients to the healthcare physicians so that the confirmed cases can be isolated with proper health care. An experiment was carried out on the COVID-19 dataset by testing with eight machine learning algorithms: Support Vector Machine, Naïve Bayes, Decision Tables, OneR, ZeroR, Neural Network, K-Nearest Neighbor, and Decision Stump. The results depicted that all algorithms except OneR, ZeroR, and Decision Stump obtained more than 90% accuracies. The accurate and effective identification of COVID-19 cases can be provided with the help of these five best algorithms.

Mohammed et al. [2] proposed a smart helmet that is mounted with a thermal imaging system based on IoT. The system is designed in such a way that it detects COVID-19 from a thermal image. The smart helmet is integrated with the thermal camera technology also combined with the IoT technology to monitor the process of the screening to obtain real-time information. Additionally, the proposed design is also equipped with one more technology of facial recognition which displays personal details automatically. The proposed work has great demand in the healthcare systems and potential help for the prevention of COVID-19 spread.

Singh et al. [9] outlined the advantages of implementing the IoT for reducing the cost of treatment. The research study outlined and discussed twelve major applications of IoT to handle the COVID-19 pandemic. Darwish et al. [10] suggested a CloudIoT-Health model that combines IoT with Cloud Computing in a health field based on the related literature. The paper highlighted the challenges faced by the integration along with the latest trends in CloudIoT-Health. The challenges are categorized into three levels: communication and networking, technology, and intelligence.

Din and Paul [11] proposed an architecture based on IoT which monitors and manages the health of an individual smartly. The architecture comprises three levels. The first level is the generation of data using the battery-operated medical sensors and processing, the second level is the processing on Hadoop, and the last level is the application layer. As the batteries have a limited capacity to charge the sensors, an energy-harvesting method with the help of piezoelectric devices is connected to the human body. Vaishya et al. [12]; determined seven important AI applications to detect the COVID-19 cases infections along with the future prediction incidences of this contagious disease by the analysis of the earlier data.

Siriwardhana et al. [13] addressed the deployment of the IoT and 5G-related technologies for fighting against the Coronavirus pandemic effectively. In addition to this, a few use case scenarios and their challenges on how IoT and 5 G could be a platform for creative approaches in various fields to overcome this pandemic are provided. Similarly, a thorough review of how the technologies like AI, IoT, UAVs, 5 G, and blockchain are developing to mitigate the COVID-19 pandemic is presented. Hussain et al. [14] presented the importance of deploying AI in fighting against the Coronavirus pandemic. The research study provided a survey of various intelligence methodologies which can be deployed for different categories of medical data. The authors have also categorized the present AI techniques of clinical data analysis into neural systems, edge significant learning, and SVMs (Support Vector Machines). Lastly, various merits of AI in battling similar types of viruses are presented.

In [15], the authors have developed a monitoring model based on IoT to keep track of the location and medical resources. This model helps the patients monitor their heart rate and temperature. This model is built with the integration of sensor networks and Radio Frequency Identification (RFID) technology.

Ammae et al. [16] developed a model to determine the quality of sleep. This model senses and monitors locomotive movements for wireless signal strength. The IoT-based smart doctor kit was designed by [17]. This doctor's kit is intended to help intensive care unit

(ICU) services to optimize health-related risks and reduce healthcare costs. In [18], the authors created a smart healthcare system with the help of an IoT smart healthcare system designed for automatic screening and classification of X-ray images of COVID 19 patients. Deep learning is employed to classify chest X-ray images. Keshary et al. [19] designed an IoT-based model for Elderly Diabetic Patients. The proposed model monitor oxygen saturation level and heart rate. Model is built with temperature sensor and pulse oximeter sensor.

In [20] authors proposed a framework FETCH: A Fog Enabled Technique for Clinical Healthcare system that integrates IoT, edge computing, and deep learning to monitor heart disease patients. Ali and Ghazal [21] proposed a framework to collect the patients' data through cell phones via voice control to enable patients' health data. The proposed model uses software-defined networks (SDN). This paper explores the latest applications of CIoMT in pandemics.

3. Role of IoT in the medical field

IoT possesses an excellent ability to produce great results using creative and advanced technologies. In the medical field, innovative approaches are developed which offer the best services to coronavirus patients by performing precise surgeries [6]. The cases which are used to be complicated earlier have now become easy to handle and control digitally [6]. The new challenges are taken by IoT in the field of medicine to develop a support system for patients, doctors, and surgeons [6]. For example, to know whether an individual is infected or not the first step is to monitor the patient's temperature. It can be known with the help of wearable IoT devices such as the heart rate of the patient, blood oxygen level, blood sugar level, etc. without any human interaction. Not only this, IoT has provided various other services in the healthcare sector [6].

Sensors are helpful for sensing and capturing the data of the patient's disease/health and obtaining the required information. Here each physical object is internet-connected (networked), and devices display the continuous monitoring of a process. The necessary data is provided instantly to designated doctors according to their requirements [6].

4. IoT applications during COVID-19 pandemic

As information and communication technologies are getting advanced, the techniques based on IoT have raised the interest among the developers of healthcare applications [3]. The IoT devices are integrated with smart sensors and algorithms in the area of medicine, which are connected to an application through the Cloud and various connected devices, which have been very useful to overcome this COVID-19 pandemic. The technologies of IoT can be used to trace the infection of COVID spread pattern, offering services of tele-medicine, robotic sanitization, privacy, and protection of data in the sector of healthcare. The following subsections outline the various applications of IoT for managing coronavirus disease.

4.1. Contact tracing

The quarantine period for COVID-19 ranges from 1 to 14 days. But an asymptotic individual can also transmit the virus to another person. As this virus spreads so faster within no time, it is necessary to find the people who have had contact with the infected person within this quarantine period. IoT technologies enabled for contact tracing enhance the efficiency in many ways such as automatic processing, and immediate response and the most important thing is that it maintains the infected person's privacy [2]. With the help of wearable IoT devices like smartwatches and smart thermometers, infected people can be detected by tracking their temperature because fever is the initial symptom of coronavirus. These data can be collected and analyzed with the help of AI and Big Data. Thereby, the areas which are affected mostly can be separated from other areas, and appropriate methods can be implemented for quarantine and isolation for controlling the virus spread effectively.

Additionally, RF-based signals like RFID, Bluetooth, and Wi-Fi are used for the detection of proximity. Adame et al. [15] proposed Bluetooth Low Energy (BLE) for performing contact tracing based on the detection of proximity. It also discusses the issues related to the privacy and security of contact tracing methods. Ammae et al. [16] proposed a scheme based on IoT for coronavirus contact tracing known as IoTrace. IoTrace also utilizes the BLE for determining distance same as the earlier work. The uniqueness of this work is that it implements a decentralized model that overcomes the issues of disclosure of location.

4.2. Telemedicine

For preventing the spread of this virus, satisfactory healthcare is required to be given to COVID-19 patients remotely. Telemedicine is the process of data collection of patients from remote places as patients do not require visiting the hospital. Because of lockdown and social distancing implemented everywhere, telemedicine is the safer method to seek medical help. It is also cost-effective as the travel cost is eliminated and patient engagement is increased. Various health sectors are aiming to develop chatbots for automatic disease screening and follow-ups according to the schedule [3]. Vici InTouch is one of the telemedicine carts based on robotics that is used to monitor patients remotely [3]. Many hospitals in the USA treat patients in ICUs by using bi-directional audio and video interactions [3]. Based on the detailed review of IoT Product Development after COVID-19, wearable devices are helpful in the following ways.

- Patient Monitoring: For monitoring the temperature, blood pressure, and sugar levels of a patient.
- Heart rate monitoring: For accurately measuring the heart rate without affecting the mobility of a patient.
- Mood monitoring: For understanding the mental state of a patient.

4.3. Robotics, drone, and UAV for fighting against the pandemic

Robotics has been coming into the spotlight in the field of medicine. This is due to the capabilities of robots to assist while performing highly complicated tasks like treatments of cancers and surgeries. Besides that, robotics has a vital role in sanitizing hospitals and affected areas where human interference can be reduced to the maximum extent. Robots can also be used for reminding users of social distancing and to use masks and gloves [3]. Facial emotion recognition training can be given to robots for identifying the stress of health workers who require further attention [3].

The infectious nature of this COVID-19 forces many health-related activities to monitor remotely which results in the stress on the current connections of Wi-Fi. As a result, alternative technologies of communication like Long Range Wide Area Network (LoRaWAN) can be used [3]. For instance, UAVs (Unmanned Aerial Vehicles) are proposed to enhance the reliability of information exchange between devices of LoRA connected to the users who are infected and the base station [3]. The approach uses the control algorithm of the distributed topology for updating the UAV-based topology depending on the mobility of LoRA devices that enhance the reception rate of packets at the base station [3].

Similarly, drone technology is useful for solving various challenges of technology rising in the pandemic. There are various applications where a drone is helpful such as, delivering life-saving medicines to remote hospitals, delivery of food, and automatic parcel deliveries [3].

4.4. IoT for diagnosis of COVID-19

Technologies of IoT can enhance the accuracy, pace, and efficiency of the diagnosis of COVID-19 and the process of treatment. According to [17], the authors proposed an application based on the Cloud which integrates Treatment Assistant Program and Intelligent Diagnosis for COVID-19 [3]. This application uses medical records electronically and ML (Machine Learning) approaches for automatic diagnosis. It assists the authorities of health by collecting data from patients; coordination is managed and enables self-diagnosis. This application is based upon 5 G technologies which incorporate the higher bandwidth and communication efficiency of networks [17]. It enables good coordination between treatment and diagnosis using WeChat and a common platform is built for medical scientists, doctors, and healthcare workers [3].

4.5. Vaccine cold chain monitoring

In poor nations, the delivery of required vaccination services in this ongoing COVID-19 pandemic is a bigger problem. IoT and Mobile technologies can optimize the delivery chain of vaccination [18]. With the help of IoT sensors present on the vaccine, cold chain data loggers transfer the accurate data of condition logs to the Cloud through wireless data networks [18]. eVIN is an IoT-enabled mobile-based technology invented by the United Nations Development Programme (UNDP) and an Indian government, offering real-time management of logistics throughout the vaccine cold chain [18]. The application- attached to IoT sensors put on the vaccine-traces the temperature, location, and level of vaccine stock available, ensuring a safe and reliable supply [18]. The usage of eVIN in India results in an 80% reduction in the vaccine inventory [18].

5. IoT technologies in healthcare during the COVID-19 pandemic

Depending upon the requirements of a COVID-19 patient, IoT may link devices medical instruments, and machines for creating smart information systems [6]. Technologies of IoT have a significant impact on medical devices that help for providing a customized solution for COVID-19 patients [6]. They identify the changes in patient data for determining the related information [6]. Various IoT technologies are discussed in the following subsections which are useful in the field of healthcare during a pandemic.

5.1. Big data

In earlier days, medical data was stored in files that require extra cost but now the data is stored in a digital form which is cost-effective. Big data technology can be used to store, capture, and analyze COVID-19 patients' data at a quick speed [6]. It stores the data in a systematic order which immediately offers the best solution in the healthcare sector [6].

5.2. Cloud computing

Cloud Computing refers to the delivery of various services via the internet, services including data storage, networking, database, and many more. It can share the details of a COVID-19 patient instantly via the internet which in turn helps a doctor to proceed further in an efficient manner [6]. It enhances the quality of data with a reduced data storage cost.

5.3. Smart sensors

In the medical field, smart sensors play a vital role in communicating with a digital network for generating correct and reliable results [6]. It keeps track of all parameters of the patient's health and controls them. It easily monitors the temperature, blood pressure, sugar levels, and oxygen concentrator of a patient suffering from COVID-19 [6]. Smart sensors are useful for obtaining information on

Table 3
The summary of various research contributions made in IoT to handle the COVID-19 pandemic.

S. No	Refs. No.	Domain	Contribution
1	[19]	Use of UAVs and Drones for fighting against the pandemic	Application of LoRaWAN technology is used for monitoring COVID-19 patients remotely.
2	[20]	IoT for the diagnosis of COVID-19 patients	WeChat application is used for improving the coordination between diagnosis and treatment of COVID-19 patients.
3	[21]	IoT for the services of telemedicine in COVID-19, wearable technologies for the prediction of COVID-19 enabled by IoT	Demonstration of monitoring wearable devices remotely in COVID-19.
4	[22]	Efficient and Secure Contact Tracing	Discussion based on the solution of privacy-preserving contact tracing and challenges faced by it.
5	[23]	Use of UAVs and Drone for the protection in this pandemic	Potential technologies like AI, ML, and IoT in the field of health care are reviewed for the prediction of the pandemic, disease analysis, delivery of medicine, etc.
6	[24]	Contact tracing via TraceTogether App	Demonstration of a mobile application enabled by IoT for contact tracing of a coronavirus disease.
7	[25]	Current contact tracing techniques	IoT technology is implemented for improving the contact tracing efficiency
8	[26]	Classification of contact for the sake of contact tracing	Demonstration of classification of contact based upon Bluetooth messages
9	[27]	Contact tracing with the help of DP3T (Decentralized Privacy-Preserving Proximity Tracing)	Demonstration of contact tracing solution safely and securely in a decentralized way.
10	[28]	Efficient and Secure Contact Tracing	By using Bluetooth technology, privacy preserved contact tracing solutions are demonstrated.

Table 4.
CIoMT Applications to tackle pandemic diseases.

S. No	Application	Purposes
1	Real-time tracking	Tracking of infected people with the virus
2	Remote monitoring	Remote Monitoring of patients by health care workers
3	Diagnosis	Rapid diagnosis of people with the use of IoT-enabled devices
4	Contact tracing	Contact tracing of patients
5	Prevention and control	The spread of the virus can be controlled by the timely intervention of health care workers by using IoT-enabled technologies
6	Screening	Automatic screening of COVID-19 patients
7	The workload of health care workers	The CIoMT-enabled system will help in reducing the workload of the lab technicians

health states, defective bones, and biological tissues [6].

5.4. Artificial intelligence

AI is very useful in performing, evaluating, validating, predicting, and analyzing data in a pre-defined environment [6]. It has an exceptional capability for predicting and controlling the spread of the virus. By using AI doctors and surgeons acquire enhanced efficiency and accuracy in treating patients [6]. It estimates the pain of a patient suffering from COVID-19 with modifications in medication.

5.5. Augmented/ virtual reality

The integration of humans with electronic systems is the best way of providing real-time information [6]. Virtual reality is useful for enhancing the planning quality, and safety of a patient and treating COVID-19 patients effectively [6]. Augmented reality is also useful for providing digital data of life in the form of digital sound/imagery.

5.6. Actuators

It refers to a mechanism that establishes the motion in controlling the system for acting in an environment [6]. The major applications of medical actuators are accuracy maintenance and controlling necessary parameters [6]. They are useful in designing the

Table 5.
IoT-enabled Devices used during pandemic diseases.

Technology	Examples	Remarks
Smartphones and Wearable devices	Smart helmet, Smart thermometer, Easy band, Selfie App, Arogya Setu App, TraceTogether App	Used to track the patients, monitoring patients who are infected with the disease.
Drones	Surveillance drone, medical drone, disinfectant drone, thermal imaging drone, multipurpose drone	Internet of drone things is used to perform a variety of tasks.
Robots	Autonomous robots, social robots, telerobots	Internet of Robot things was used to make tasks easier during the pandemic time.

hospital bed which lowers or raises its height according to the need of a COVID-19 patient [6]. Table 3 briefly describes above mentioned IoT applications in handling the COVID-19 pandemic.

6. Cognitive Internet of Medical Things (CIoMT)

Cognitive radio based IoT (CIoT) uses radio channels to connect objects which can be used to tackle COVID-19-like pandemic diseases. CIoMT is an emerging technology used for Rapid diagnosis, tracking and monitoring, contact tracing, and prevention and control of pandemic diseases. Applications of CIoMT are illustrated in Table 4.

CIoMT is the integration of communication, sensors, and automatic processing. CIoMT can be extensively implicated in tackling the COVID-19 pandemic. CIoMT reduces the demand for bandwidth requirements. CIoMT helps to manage the pandemic and provides solutions to the challenges posed by this global crisis.

7. IoT-enabled technologies used during pandemic diseases

Since 2020, the world has been fighting a pandemic disease caused by a novel coronavirus. There is an urgent demand to use emerging technologies to tackle pandemic diseases. IoT has been widely used to monitor patients during this pandemic. Various IoT-enabled technologies have been used during the pandemic. Table 5 shows the IoT-enabled technologies that are used during COVID-19.

8. Conclusion and future work

As the world is facing a battle against the COVID-19 virus and at the same time IoT technologies are developing at a faster pace to monitor and reduce the spread of the virus. Various medical devices are internet-connected and in emergencies, these devices deliver a message to health workers. Infected cases are handled properly even in remote places by using teleservices. With the help of statistical-based methods, IoT is useful in predicting the future state of a disease. This paper reviewed the role of IoT, its applications, and the IoT technologies implemented in this COVID-19 pandemic. Moreover, by implementing IoT technology properly doctors, academicians, government, and researchers can build a good environment for fighting with COVID-19 pandemic. There are certain concerns to be taken care like Privacy of the person's data and safeguarding from malicious attacks. CIoMT provides efficient and reliable service in tackling the pandemic. This technology can be used as a framework for pandemic diseases to stop the spread of the virus by early detection. Through this paper, researchers will get an insight into the applications of IoMT and CIoMT and new will get ideas for further research. In the future, more concentration should be given to data security and privacy which is a very sensitive and challenging issue in implementing IoT in the healthcare domain. Designing low-power and energy-efficient CIoMT are prime concern in future aspects.

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.

Data availability

No data was used for the research described in the article.

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