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Survey

Study on IoT for SARS-CoV-2 with healthcare: present and future perspective

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Abstract: The ever-evolving and contagious nature of the Coronavirus (COVID-19) has immobilized the world around us. As the daily number of infected cases increases, the containment of the spread of this virus is proving to be an overwhelming task. Healthcare facilities around the world are over-burdened with an ominous responsibility to combat an ever-worsening scenario. To aid the healthcare system, Internet of Things (IoT) technology provides a better solution—tracing, testing of COVID patients efficiently is gaining rapid pace. This study discusses the role of IoT technology in healthcare during the SARS-CoV-2 pandemics. The study overviews different research, platforms, services, products where IoT is used to combat the COVID-19 pandemic. Further, we intelligently integrate IoT and healthcare for COVID-19 related applications. Again, we focus on a wide range of IoT applications in regards to SARS-CoV-2 tracing, testing, and treatment. Finally, we effectively consider further challenges, issues, and some direction regarding IoT in order to uplift the healthcare system during COVID-19 and future pandemics.

Keywords: IoT; healthcare management; MIoT; SARS-CoV-2 (COVID-19)

1. Introduction and motivation

The SARS-CoV-2 originated in Wuhan, the capital of Hubei Province in China, and has since spread across the world, with many mutations altering the virus's existence. The first patient admitted to the hospital had acute pneumonia and the cause was unknown. Researchers then studied the symptomatic traits of the affected individual and identified the reason behind pneumonia and a similarity with SARS-CoV [1]. Then it started to spread to other countries of the world with different levels of severity. The nature of the virus is changing over time. Initial statistics revealed the virus affected people with comorbidity and elderly people above 60 years, [2] but current evidence indicates the spreading of the virus amongst children as young as 6 years [3]. There were 133,718,495 cases found until April 82,021, of which 107,839,091 were recovered with the death count rising to 2,901,600. The spread of this virus is swift because it can be transmitted from an infected person to a healthy individual through droplets [4]. However, it can be transmitted indirectly as well without touching an infected one. On top of that, the Personal Protective Equipment (PPE) used to protect frontline workers from the virus may be another cause of infection, according to the author in [5]. One hope is that the droplet cannot last forever in the air and cannot spread over a distance of more than six feet [6]. In order to contain the virus, several strategies such as isolation or lockdown [7], ensuring set distance protocols, and wearing of masks and other safety measures were introduced [8]. But lockdown is not the ultimate solution. Prolonged lockdown has severely hampered industrial activity, and crippled the economic infrastructure of several countries around the world. In this regard, researchers are attempting to discover ways to keep the economy spinning, to prevent health workers from being contaminated quickly, and to control the healthcare system's overall resources.

As seen in the above case, the internet of things may be a viable option for dealing with COVID-19's implications, such as maintaining social distance, ensuring face mask usage, allowing work from home, and so on. The basic idea behind the Internet of Things is that it can link a large number of sensors, computers, and networking devices to form a networking structure. With the incorporation of cloud infrastructure, no physical movement is needed in this networking framework, and data can move back and forth [9]. Prior to the COVID situation, IoT was being used in many aspects of everyday life, such as smart cities, smart education [10], smart business, smart appliances, and so on, and had grown in popularity due to the ease with which users could access and monitor the systems [11].

At present, healthcare services are deteriorating due to the pandemic. The growing struggle is clearly visible as the impact of coronavirus worsens. Decision-makers are trying to find solutions that are effective, safe, and, at the same time, cost-effective. People with potential COVID symptoms are suffering due to limited access to doctors because of the contagious nature of the disease. In certain instances, there is no one to take a suspected patient to the hospital to get medical advice [12, 13]. In such cases, IoT can be useful by providing telemedicine service, so that people with a smartphone can receive expert advice without going to the hospital physically. In the medical field, IoT can be an effective option for proper quarantine monitoring, tracking the community to identify the origin of the virus and the high and low-risk zones, and taking initial preventive measures at every office [14], building [15], or healthcare facility by checking the temperature, ensuring mask for every individual and sanitizing by automatic control without physical contact [16].

Based on the above discussion, the research contributions are mentioned below:

- We provide an intelligent integration between IoT and healthcare for the COVID-19 pandemic

with a detailed review.

- We comprehensively discuss applications of IoT in the SARS-CoV-2 environment, including—testing, managing, and tracing systems efficiently.
- Furthermore, we consider various platforms, smart products, and existing IoT based research schemes for the COVID-19 pandemic as well as competently utilizing medical data applications in multi-domain.

To aid in comprehension of this manuscript, we included a list of abbreviations and their definitions in Table 1. The rest of the study has been structured as follows: we discuss an overview of the background knowledge and preliminary concept of IoT, healthcare, and the COVID-19 pandemic in Section 2. In Section 3, we integrate the concept of IoT and healthcare properly. Then, we present the applications of IoT in the COVID-19 pandemic in Section 4. Moreover, Section 5 focuses on the different platforms, services, and research projects where IoT is used for the SARS-CoV-2 situation. Further, we convey some discussion regarding medical data in Section 6 for various applications efficiently. More importantly, in Section 7, we elaborately discuss open challenges and issues, and future plans for IoT in healthcare for the COVID-19 environment. Finally, we conclude this article in Section 8.

Table 1. Technical terms and abbreviations.

Notations	Definition
AI	Artificial Intelligence
BC	Blockchain
CNN	Convolutional Neural Network
COVID-19	2019 Novel Coronavirus
CP	Control Plane
DL	Data Learning
DP	Data Plane
IoMT	Internet of Medical Things
IoT	Internet of Things
IR 4.0	Industrial Revolution 4.0
ML	Machine Learning
QoS	Quality of Service
RFID	Radio Frequency Identification
SARS-COV-2	Severe Acute Respiratory Syndrome Coronavirus 2
SC	Smart Contact
SDN	Software Defined Networking

2. Background and basic concepts (on IoT technology)

2.1. IoT in COVID-19

After the outbreak of coronavirus, depending upon the nature of the spread; researchers continue to pursue several methods to figure out a possible solution to limit the spread of the virus as well as

provide possible solutions to the problems that have arisen due to the outbreak. Basically, IoT refers to the Internet of Things. The fundamental principle of IoT is that several devices can be linked together to create an intelligent network, and devices to transmit cloud information [9]. It is incorporated to limit the spread of COVID-19 in line with this theory. The virus spreads through droplet or aerosol, which means when someone gets close to a COVID patient, the risk of getting infected becomes higher. In order to limit the spread, many tasks that can be accomplished from home are encouraged to be performed online. This is how researchers interconnected the IoT to fight against SARS-CoV-2. Figure 1 illustrates the interconnection of the COVID-19 issues to the applications of IoT. The advantages of treating COVID-19 with IoT are huge.

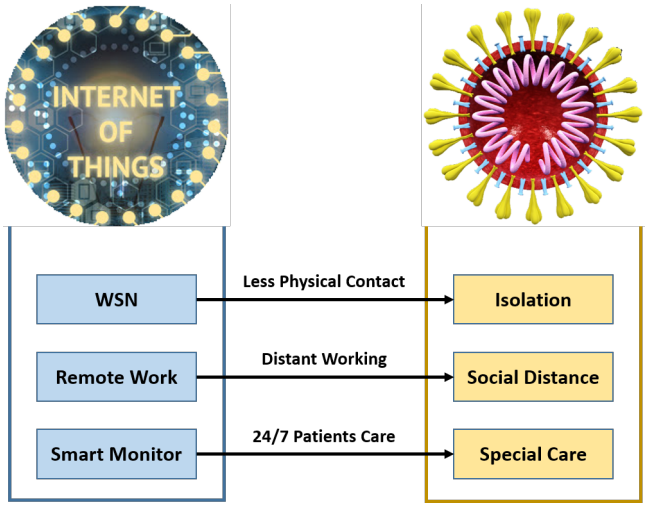

Figure 1. Relationship between IoT and COVID-19.

2.1.1. Reduce risk

IoT based system helps to reduce the risk of being infected. Through online platforms, a person is able to accomplish almost every task from home. From daily groceries to bill payments, all things are possible in this era of automation. Even the education system has been substantially reformed to accommodate learning from home during this pandemic. Online learning has gained popularity amongst students [17]. Students can now attend interactive sessions using online platform, and teachers can evaluate them online as well. Online business meetings and other tasks that can be done without going outside are performed through the help of the Internet [18]. Thus, by minimizing the movement of people, IoT is helping to reduce the risk of getting infected.

2.1.2. Less expensive

The spread of the coronavirus can be effectively restricted to alleviate the worst-case scenario such as the need for ICU support. The sensors of IoT can initially identify the suspected individual with the virus using a temperature sensor. Cameras for face recognition are a cheaper alternative but can be effectively deployed to control the initial spread by transferring suspected patients to quarantine zones or isolating them from the community.

2.1.3. Effective control

In order to contain the transmission of coronavirus related illnesses, IoT can assist with effective control procedures. With the help of IoT sensors such as optical cameras, temperature detectors, heart rate detectors, the detection of suspected COVID patients can be assisted, and thus the spread of the virus can be controlled effectively. For example, in a transportation system; to detect the temperature and the face of a person, multiple sensors can be used, and the data collected from the sensors can be transmitted through the gateway to the cloud. The data stored in the cloud can be easily used further to identify the same person moving to another location. Thus, the spread can be controlled at a primary stage [19].

2.2. Healthcare with COVID-19

With the outbreak of coronavirus, the worldwide healthcare system was affected significantly. The alteration of the virus is unpredictable and spreading rapidly. As a result, healthcare systems are challenged constantly to uplift the standard of their services [20]. In the present situation, the hospital management are trying their best to increase the bedding capacity to accommodate more patients.As a result, there has been a noticeable increase in the recruitment of more doctors and medical personnel and a considerable increase in the usage of safety equipment such as PPE, masks, gloves, and so on [20]. Despite several measures taken by the hospital and the government, the number of patients admitted to hospitals keeps on rising in countries like Bangladesh, Italy, and Brazil due to the highly infectious nature of the disease [21]. On top of that, the risk of medical staff being affected is high. Statistics show a growing number of deaths amongst doctors as they remain the front line workers in this battle [22]. So encompassing financial support, increasing the bedding capacity, and providing safety equipment will not be adequate to tackle the situation. A simple snap of the situations of healthcare systems during the pandemic is shown in Figure 2.

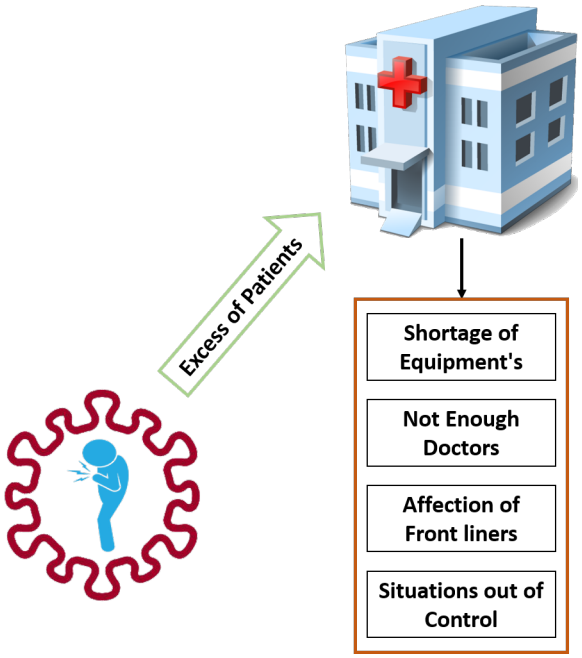

Figure 2. Situation of Healthcare during COVID-19.

2.3. IoT with COVID-19 for healthcare management

In the present situation, healthcare system up-gradation has became a necessity. According to the authors in [23], the incorporation of IoT in the medical sector will help in efficient decision-making for management and will efficiently reduce expenditure.

2.3.1. Connected hospitals

During this outbreak, almost every hospital is working at full capacity. In order to understand the pattern and determine the severity index and other symptoms amongst infected individuals, it is required to connect the data from all hospitals together. Information such as treatment procedures, death rates, number of seats available for a new patient can be readily accessible via this platform. The data stored in the cloud can be accessible to the system which is connected to the same network [24,25].

2.3.2. Telehealth

Some cases can be treated by taking care of patients at home. In such cases, access to a doctor to seek medical advice or get the name of the medicine or other measures to take proper care by staying at home remains essential. In such a scenario, in order to make the telemedicine system more efficient, IoT is being integrated with the communication system [26].

2.3.3. Contact tracing

Contract tracing is another way to trace the region or community from where the spread started. In this system, a cellular network, or wifi, or even a Bluetooth system can be used to transfer the data. Such a system can alert users when a person is in close proximity with an infected person by generating an alarm. IoT provides a better and more efficient way in the era of digital contact tracing, with the advantage of automation and a scalable system that handles the load of the data produced and transfers it accordingly [27].

2.3.4. Remote monitoring

The IoT architecture is subdivided into three layers. Among the three-layer, the sensors that are responsible for collecting information perform their task in the detection layer. The second one is the transport layer that connects the system and the cloud infrastructure by transferring sensor data. Moreover, the application layer processes the information [28, 29]. Thus, with the combination of IoT and healthcare systems, physicians can easily get the sensor data from the cloud and can monitor the health condition of the patient remotely [30, 31].

Summarizing of the background: in this section, the authors have focused on the IoT technology and its integration, particularly emphasizing COVID-19 pandemic situation. Wide-scale application of IoT to uplift the standard of e-medical services bears significant importance. Related contents between IoT and COVID situation has been discussed while we highlighted the healthcare management scenario during this viral attack. Taking the challenges of healthcare on account, we depicted the applications of IoT for SARS-CoV-2.

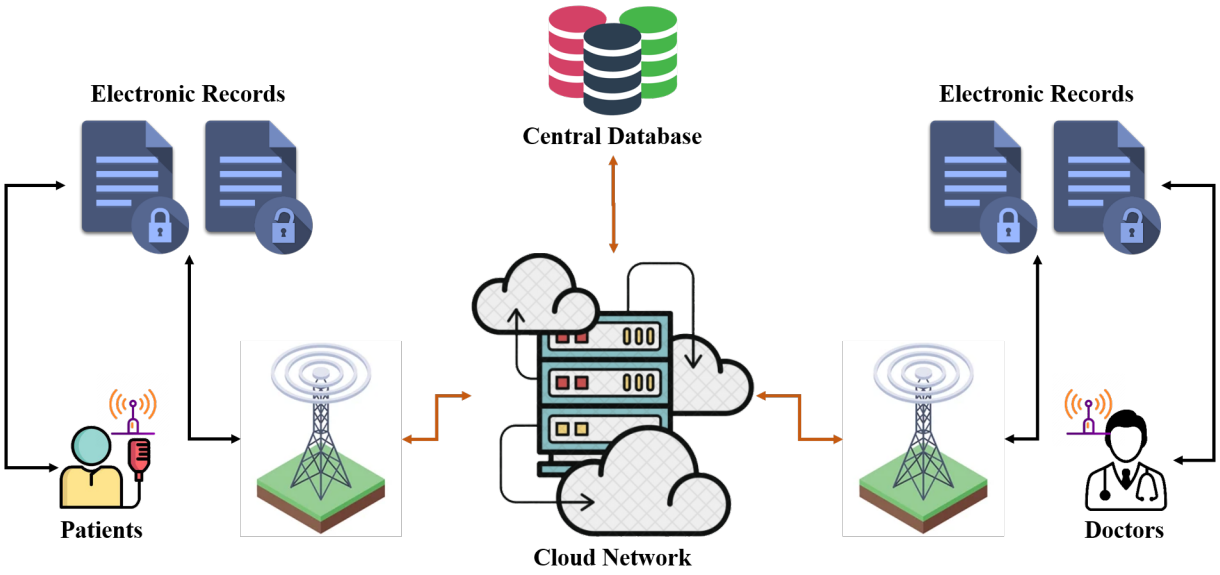

Figure 3. Integrating scenario of IoT and health.

3. IoT and health: drivers for integration

A basic and simple architecture is depicted in Figure 3 to establish the integration of the Internet of Things and the Health Care Systems. The information from the patients side is stored in the form of electronic records into a central database with the help of cloud network. Some recent technologies are used in the cloud for better security and quality of service. The database could be accessed by the doctors and researchers too. After processing the data by a medical person, report will be generated and transferred to the patients with medical advice and suggestions.

However, the idea behind merging IoT with the health industry is basically because of the advancement of this sector by incorporating technologies—SDN, Blockchain, Machine Learning, and advancement of sensors and cloud infrastructures [32]. Valanarasu et al. [33] proposed an AI integrated IoT system that is capable of reducing paperwork by replacing the traditional system with a centralized database from where the load of the hospital management staff is reduced. The proposed system being automated further minimizes the working load for the physicians and nurses. Additionally, Alamri et al. in [34] developed a system for remote monitoring of patients by incorporating an IoT system into the electronic records of a healthcare facility. In this work, the author proposed the use of semantic analysis to merge IoT medical data methods with the EHR system. Wu et al. [35] provided an architecture that can transmit physiological data wirelessly where encryption at both ends ensures the security of the data in the IoT-based healthcare system. Again, data transmission suffers from critical issues, such as similarity of data, which can be solved using NLP-based semantic methods. Zhang et al. [36] proposed a method by integrating knowledge-based graph and word embedding based methods to find out the similarity between the words in the health data. Selvaraj et al. [37] studied the aspects of the IoT-based healthcare system such as consumption of electricity, efficiency, and management of data, with both benefits and disadvantages mentioned in this work. Gupta et al. in [38] researched the technological mechanisms to monitor the health and diagnostic system efficiently within a low bud-

get by analyzing the data gained from sensors used in IoT. In another work, [39] proposed a method for managing and recording health data by leveraging features of IoT and private blockchain that ensures trustworthy data transfer within a specified time-frame. Again, the IoT-based healthcare system serving in the present pandemic scenario with the features it. Javaid et al. in [40] comprehensively studied and indicated crucial methods of the internet of things that can assist the healthcare system in the pandemic situation. Again, Filho et al. [41] proposed an IoT-based patient monitoring method for those who suffer from COVID-19 in the ICU, where entry is restricted and proper safety measures need to be maintained. In another related study, [31], patient data through remote patient monitoring is used to detect and forecast the status of a patient's health condition using IoT. Islam et al. in [42] used UAV to collect data from patients and, using blockchain, the security of data is ensured, thus human involvement is reduced. In another related paper, Islam et al. in [43] proposed a system that ensures low human engagement for monitoring the outbreak with a drone based automatic pandemic tracking system. Blockchain together with AI assits the automatic monitoring procedure through swarm drones.

In an IoT-based healthcare system, confidential data is passed through the internet, which needs to be protected from being attacked or altered by intruders. Elhoseny et al. in [44] proposed an encryption mechanism based on integration of discrete wavelength to convert the data to be transferred covered by gray and color images. Furthermore, Pirbhulal et al. [45] proposed a machine learning-based architecture for ensuring security by dividing the process into training and testing phases, with the user's identity being checked in the testing phase using biometrics created from ECG. Furthermore, the data produced and used by the hospital's management is private and confidential. In order to retain a low-cost operation while also ensuring better privacy, a paper cited by [46], Saha et al. proposed an access control scheme leveraging private blockchain technology to shield an IoT-based hospital management system from attacks. However, to provide better security to the IoT-based medical care unit, Sahoo et al. [47] proposed a 3-factor authentication system, where a new cryptography system known as Elliptic curve, known for higher-level privacy, is used. In this work, the mutual authentication system is being implemented. Again, as the data is transmitted via the cloud architecture in order to ensure confidentiality and validate the authenticity of the data, Hussain et al. in [48] proposed a safe method by leveraging IoT protocols such as CoAP and MQTT, which protect the data by ensuring end to end privacy measures.

In sum, as discussed in earlier research work, the integration of IoT and healthcare necessitates applications of fundamental technologies. We illustrated a probable scene in Figure 3. To process and control the myriad of data, SDN can be used. On the other hand, Blockchain and some sorts of cryptography can be utilized for security purposes. In order to make the system intelligent, machine learning models and NLP could be used to monitor and take decisions based on situations.

4. Applications of IoT to COVID-19

The global impact of coronavirus has affected human civilization in many ways. There is a constant pursuit using several approaches to return to the lifestyle that existed before the pandemic. Several technological platforms are used to reduce the severity of the COVID-19 pandemic. IoT-based applications merged with state of the art communication technologies are considered a vital means of uplifting the standards of medical healthcare. As per the Centers for Disease Control and Prevention (CDC), the use of these technologies can significantly improve the performance and efficiency of healthcare facilities [49]. IoT, now merged with conventional medical equipment's, has introduced

the Internet of Medical Things (IoMT), which tries to reduce the burden of the traditional healthcare facilities by introducing AI, big data analytics, 5G, and other communication technologies [50]. The following section explores the impact of IoT on mitigating the severity of coronavirus related illnesses and discusses the applications of IoT for 3 primary tasks, including—testing, tracing, and treatment of coronavirus-related diseases.

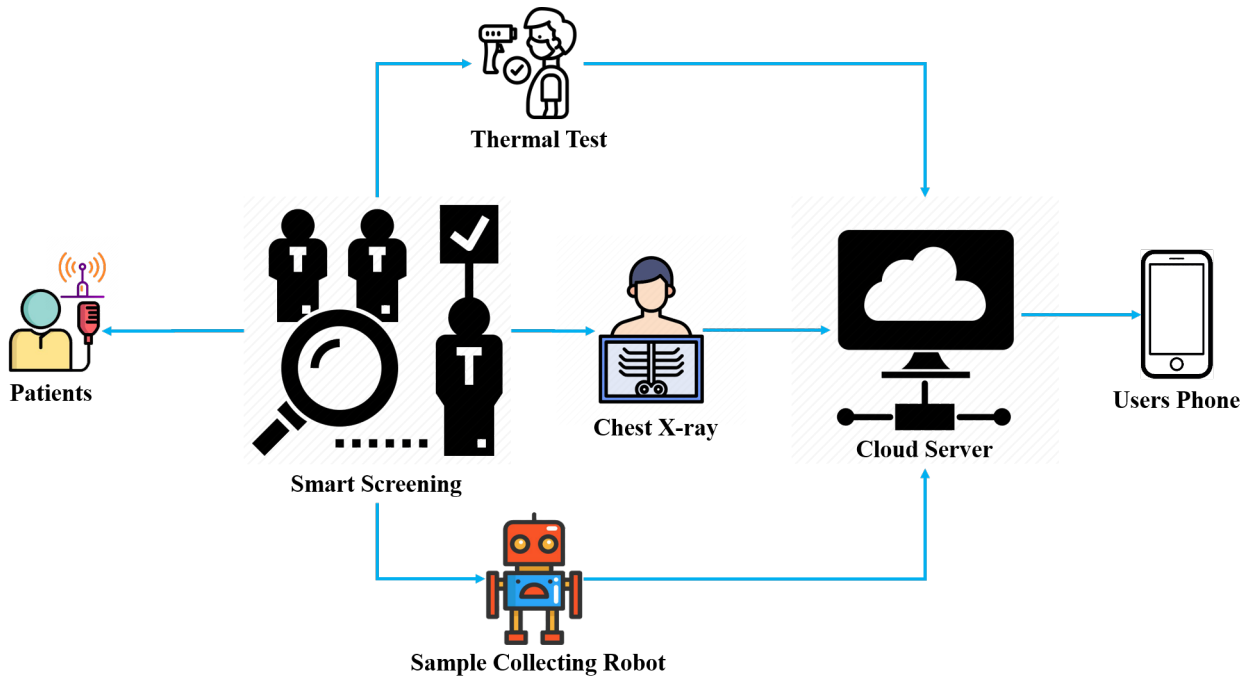

Figure 4. Testing scenario.

4.1. IoT for the testing of COVID-19

There are several methods of diagnosing a patient with COVID symptoms. Amongst them, the PCR test stood out as the most fruitful and popular method of testing a patient with corona symptoms. However, due to the scarcity of adequate test kits, computational systems have emerged with a potential solution towards the screening of suspected individuals [51]. Several machine learning algorithms are also being deployed to decipher thermal images which yielded successful test results for COVID [16]. [52] introduces the concept of deep learning AI technologies for diagnosing suspected patients by analyzing CT scans and X-ray reports. Furthermore, an attempt to deploy robots capable of collecting nasal samples for laboratory testing is also considered [53]. Again, big data is used to establish a cloud-based system for clinical tests, including pathogen detection and relevant testing, in Zhongnan Hospital of Wuhan University [54]. Computation-based technique Convolutional Neural Network (CNN) has been utilized for diagnosis of several illnesses via CT image. In [55], a study conducted on the CT images of lungs of several patients with the positive COVID test result and other patients with similar pneumonia like symptoms resulted in the training of identification of COVID cases. Again, machine learning has the potential to identify patients with COVID traits via X-ray images of lungs, as proposed in [56]. Another study conducted by Carnegie Mellon University based on deep learning and machine learning algorithms is used to predict COVID cases by recognizing the sound

detection method [57]. Researchers in [58], proposed a deep learning-based technique for COVID detection using convolutional neural networks on X-ray images of the chest. Another Taiwan-based company has introduced robot technology to assist in the nasal swab testing of suspected individuals with COVID symptoms [59]. This ensures minimal to no contact with the patient being tested by a Nasal Swab Robot (NSR). Another team of researchers from the University of Southern Denmark has emerged with a robot with the ability to collect samples from the throat and test them for coronavirus detection [60]. A growing effort towards developing intelligent robots capable of detecting COVID in early stages is discussed in [61]. Another testing method of SARS-CoV-2 is the use of a wearable biosensor patch that monitors the respiration and ECG rate in real-time and allows the user to see any irregularity [53]. The data is transmitted to the user's smartphone, allowing them to take the necessary measures towards treatment and quarantine. Again, AI-based sensory technology is deployed in several public venues to utilize face scans and detect individuals with high-temperature [62]. A similar approach is adopted by the Tampa General Hospital in the USA, to detect high temperatures of individuals [63]. Bayesian Health, a start-up company in the USA, has used AI technology to detect early symptoms of respiratory-related illnesses, which is critical for detecting COVID patients [64].

In Sum, the testing scenario based on IoT can be illustrated as shown in Figure 4. It shows a clear backdrop that we have already discussed in the above portion of this section.

4.2. IoT for the tracing of COVID-19

Several devices are in use and being developed continually to combat the existing situation of the pandemic. In order to contain the spread of the coronavirus, it is essential to identify and locate the individuals suffering from symptoms. Several countries around the world have relied on IoT-based devices to trace the red zone (high number of infected individuals) and locate individuals with distinguishable features in public places. Some of the devices that are being used are listed below, and Figure 5 shows a clear illustration of the technologies used to trace the disease.

4.2.1. Smart thermometers

In order to effectively identify patients with SARS-CoV-2 symptoms, smart thermometers were introduced by Kinsa, an American-based company [65]. This technology is successfully deployed in the USA to identify and isolate affected regions. These smart thermometers are further connected to cellular devices via apps and can actively transmit data to the central control unit about the health condition of an individual. This initiative has successfully assisted the government to isolate and lockdown particular zones showing an increased number of cases of high fever and similar symptoms. In [66], several smart wearable thermometers are reviewed, which could be vital for detecting the temperature of suspected individuals.

4.2.2. Drones

Several countries have adopted drone technology to monitor and survey areas with huge gatherings and also to provide a public announcement to the general mass. These drones are further equipped with infrared cameras to monitor the health conditions of people and trace down potential red zones infected with the virus [67]. Another joint venture between the University of South Australia and DraganFly (A Canadian-based drone company) is exploring the possibility of introducing a drone

capable of recording heart rate and temperature data simultaneously [53]. These technologies can also be implemented to trace and locate people with infected respiratory tract [68]. Another thermal imaging drone based on IoT is proposed to identify rising body temperatures at public locations. In [69], an IoT-based drone is proposed to spray disinfectant in public places, ensuring minimum human contact.

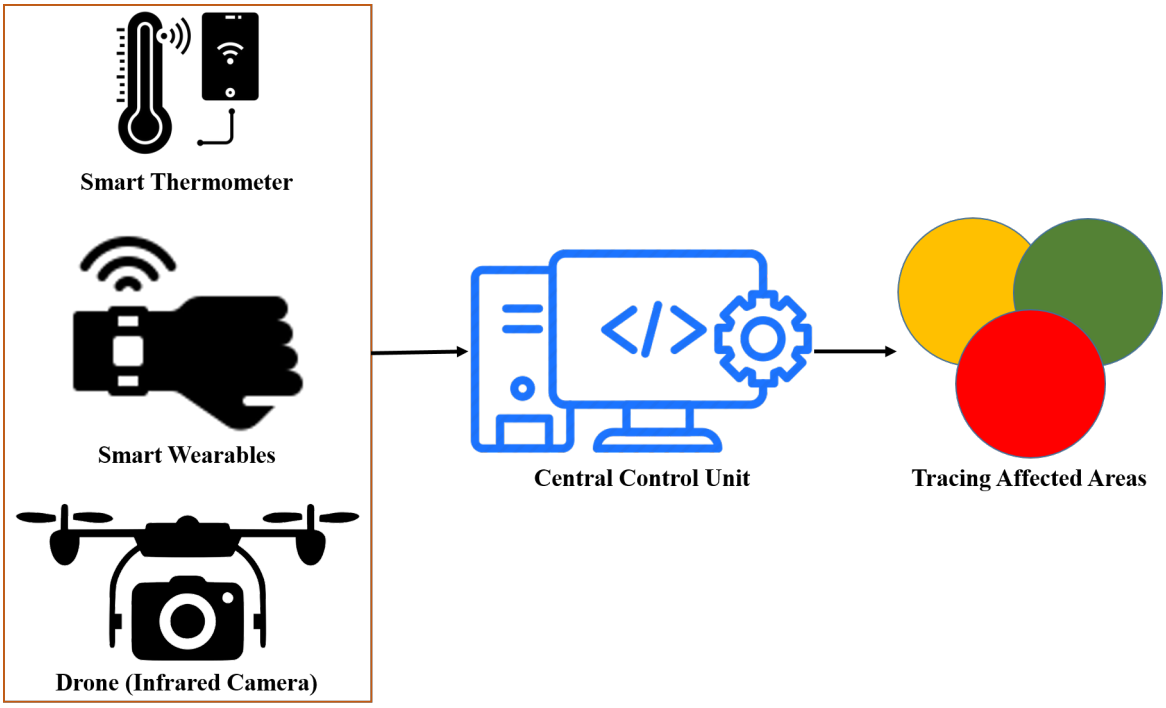

Figure 5. Tracing scenario.

4.2.3. Wearables

Wearable devices such as smartwatches, glasses, and similar technologies are defined as the merging of electronics and sensory devices to record specific data from the subject [60]. These devices have the ability to receive and process input data when the patient is wearing them. Primarily used for improving fitness and lifestyle, wearables are now being considered as a potential device to remotely monitor the health condition of an individual with COVID symptoms. There is also a growing trend to invest more in wearable technologies to ensure secure monitoring of patients health, as reported in [60]. The devices associated with wearables include smart helmets, [16] and eyewear [70], and other tracking devices together with smartwatches and bands. A USA-based company, in collaboration with Central Queensland University, has developed a strap band that collects physiological data, including respiratory issues, from patients who have tested positive for the COVID test [71]. This allows monitoring of the patient's health status. Another company, Estimote, has developed wearables in order to monitor the health status of employees in an office environment to ensure containment of the virus [72].

4.2.4. IoT buttons

IoT buttons have facilitated improved cleaning, particularly in hospitals, to prevent the spread of diseases. These devices operate by using a programmable button connected to the cloud server via

wireless communication, and are in service in several hospitals in Canada [73]. When activated, these devices alert the authorities to send cleaning or other maintenance teams to the area in need of attention. Another feature of this button is its ability to conduct certain tasks repeatedly and its inherent adhesive property regardless of the surface. An IoT button, Wanda QuickTouch, was introduced by Visonstate Corp. to alert authorities about the need to attend a particular place within the facility and ensure rapid deployment of personnel to the area [61]. Another company called Sefucy has developed IoT buttons that are used in healthcare facilities to ensure a prompt response from healthcare attendants [60].

4.2.5. AI technology

AI technology has the potential to combat coronavirus and can be implemented effectively in several spheres of the current pandemic situation. Tracing using AI involves several aspects, including surveillance, suspected carrier identification, to imply lockdown protocols, etc. AI can also be successfully deployed to alert relevant authorities about the possibility of an outbreak. Canadian-based company BlueDot successfully used AI based on machine learning to inform about the possible outbreak of coronavirus before it was announced on a global scale [74]. Applications based on AI are used to learn the travel history of individuals from the red zone or highly infected areas, and the information is delivered to relevant authorities [75]. AI can also be used to successfully forecast the possibility of getting infected or analyze the seriousness of a patient who might undergo critical conditions in the near future. Authors in [76, 77], have proposed a Blockchain and machine learning-based procedure to develop an index parameter for individuals who are likely to be infected by the coronavirus. AI can also be deployed to predict the effectiveness of a vaccine on a specific group of people.

4.2.6. Smart phone-based apps

Several countries, including India and China, have launched mobile apps to create awareness amongst the general population about the possibility of coming into close proximity to a COVID-infected person. In China, a mobile app termed "Close Contact" is used to alert people of a COVID infected patient within their vicinity [9]. Smartphones equipped with a camera, accelerometer, temperature monitoring, and GPS services have the potential to identify the location of an infected patient. Mobile phone-based applications are also being used by governments in some countries with the aim of tracking down people who have tested positive for the COVID test [78]. In several cities in China and some European countries, biosensors and cameras from mobile phones are utilized to record data such as heart rate, cough-like symptoms, and relevant data. These data are then transmitted to the cloud system, where they are processed for deep learning and pattern recognition [54]. Several research towards developing an innovative mobile phone equipped with capabilities to perform clinical diagnostics [79]. Another app known as Civitas developed by a Canadian-based company, is used to limit the impact of the pandemic by restricting COVID positive individuals movement and offering telemedicine services [80]. Another platform, MiPasa, is used in combination with IBM blockchain and cloud services to identify the location and health status of an affected individual [53]. A mobile app developed by Israel's Health Ministry called HaMagen is becoming increasingly popular for contract tracing and alerts the user about the presence of infected individuals within their vicinity [81]. The Singapore government introduced the app known as TraceTogether to enable contract tracing using Bluetooth technology [82]. In Russia, a social monitoring app has been launched to locate the user

who tested positive for the COVID test [83].

4.3. IoT for the treating of COVID-19

IoT-based technology is also being implemented to treat COVID-affected patients [84]. Since the disease is highly contagious, it is of paramount importance to limit contact with infected patients. Several IoT-based technologies are actively used to elevate health care facilities and to ensure minimal contact between healthcare workers and patients. Some of them are listed below:

4.3.1. Telemedicine

The use of telemedicine enables monitoring of patients remotely. This technology further promotes a reduced burden on the healthcare facilities as the patients can receive treatment from specialized doctors without being in physical contact with them. Since the outbreak of the virus, an increased number of individuals have opted for treatment via this platform, as reported in [73]. JD Health, an e-commerce platform, has observed a rapid surge in demand for consultations with doctors. Another, USA-based telemedicine company called Teladoc [85], saw a similar pattern in their company's demand for expert consultancy. The true impact of telemedicine can be further analyzed by merging sensory devices with drones, smartwatches. Several hospitals in the USA have used telemedicine strategy to provide expert medical advice to patients [53]. India has also approached a similar telemedicine strategy to reach out to people living in remote areas of the country [86].

4.3.2. Drones

Drone technology has the potential to be utilized for both tracing and treatment during the COVID pandemic. Drone technology has been successfully implemented to deliver necessary medical equipment. Several drone technologies are also adapted to deliver medicine to remote areas or highly infectious zones. Researchers in Ireland have successfully sent medicine for a diabetic patient from Galway to a remote island using drone technology [87]. Widescale adaptation of this technology could successfully eliminate the workload on healthcare facilities. In particular, aged people who are required to receive treatment from their home can access this technology to access all the necessary medical requirements. Another similar attempt was made when a drone traveled to supply medicine from a disease control center to a hospital in Xinchang, China [88]. An Indian company, named Marut Drones, has successfully implemented drone technology towards sanitization, medicine delivery, and temperature monitoring in an attempt to reduce the impact of the coronavirus [53]. Another USA-based company, Zipline, is considering the possibility of using the drones to supply and deliver medicine to people in contaminated areas using drone technology [89].

4.3.3. Robots

The concept of using robots to treat infected patients is being considered and undertaken in some countries of the world. A medical facility in Kerala, India has already adopted the use of these technologies to deliver medicine and serve food in the wards with COVID patients [90]. Robots with the capability to spray disinfectants within hospital areas to contain the spread of infectious diseases are discussed in [53].

4.3.4. H-IoT

Healthcare data management facilitates patient's health monitoring by contacting healthcare services remotely [52]. These services remotely monitor the real-time health condition of an individual and predict a patient's future health condition based on vital signs and other readings.

4.3.5. Mobile apps

There are several apps used to assist healthcare workers to respond to a significant number of requests. Specifically, healthcare apps such as the Salesforce Care Solution is one of the platforms used to process requests from patients with feverish and relevant symptoms [91]. Another platform called ArogyaSetu, launched by India, allows healthcare workers to connect with patients and access treatment [92]. Another app known as ncapp, developed in China, is used to update patients health information and provide specialized consultancy to patients in need of treatment [93].

4.3.6. Blockchain and 5G

Blockchain technology, [94] is rapidly establishing its presence in crucial spheres of everyday life, including the healthcare sector. This technology gives access to individuals to be part of a vast interconnected network using secured data sharing, eliminating redundant or unwanted data, and initiating barriers to unauthorized access. Blockchain enables monitoring of COVID patients by recording all the physiological details of the affected individuals. It can also be implemented to manage the lockdown protocols, promote an increased amount of testing and reporting to the relevant authority. The authority involved can devise a plan to contain the spreading of the virus. Blockchain platform enables users to update and process data from a single network. The data available in this media cannot be manipulated and is a reliable source of information for all parties concerned. 5G technology is yet another revolutionary achievement that offers speed in data transmission, lower latency, and improved reliability. This sector remains relatively unexplored but has the potential to significantly improve healthcare facilities when coupled with AI. In China, 5G technology has already been deployed to combat the pandemic by relaying information such as monitoring health conditions, tracking of the virus, and data mining and processing [95]. The adaptation of 5G technology means the telemedicine service can improve dramatically as the platform offers high speed and improved bandwidth, thereby providing a high quality of live conferences. Another example is the use of 5G technology at Kunming Medical University in China, where an online platform based on 5G is being used for the diagnosis and treatment of SARS-CoV-2 [53]. The technology is also being implemented in thermal and medical imaging to detect individuals with COVID symptoms and reduce the workload on frontline workers. In Thailand, 5G network at a hospital is used to perform telemedicine services using robots [53]. 5G-enabled robots are also being used in hospitals in China to perform several functions, such as sanitization, delivering food and medicine, and recording temperature [96, 97].

4.3.7. Vaccine development

AI-based machine learning is vital for the development of vaccines and has been successfully implemented in past pandemics. In the current context, machine learning and similar tools can be utilized to develop a potential vaccine against the coronavirus. AI technology has the potential to assist in performing optimal trials of vaccines. The use of Electronic Health Record (EHR) for patients affected by

COVID symptoms further allowed to carry out large-scale data analysis and develop methods of treatment using highly reliable big data analytics [98]. Several institutes are relying on big data analysis to facilitate vaccine production [54, 99].

We can sum-up this section by highlighting some of the prominent areas of IoT to uplift healthcare facilities during the COVID-19 pandemic. Starting from the testing of this disease to the stages of treatment, IoT can significantly contribute to every sphere of treatment for the affected patient. Thermal and robotic technologies can test a patient and notify an individual by updating the data in the cloud database (Shown in Figure 4). Smart wearable devices and drones can detect the patients condition and keep track of the potential infected zones (Figure 5). Telemedicine services, drones, mobile apps and similar technologies are striking methods to provide treatment.

5. Platforms, services, products, and research projects where IoT are used for COVID-19

The IoT-based products currently available in the market to combat the current pandemic situation are listed in Table 2.

5.1. Research projects using IoT to combat the COVID-19 pandemic

Researchers have proposed several methods in an attempt to detect, trace and provide treatment for the COVID pandemic. Several AI and machine learning technologies are implemented to diagnose patients using x-ray and CT scans. Again, some authors proposed using sensory devices or wearables to locate or trace individuals with corona symptoms and alert relevant authorities to take necessary action to limit the spread of the coronavirus. Researchers in [98] mentioned the use of microcontroller-based technology to locate the patient and record their ECG rate and health status. AI based technology is used to detect a cluster of SARS-CoV-2 cases in [108]. A smart chair with the capability to measure ECG and ballistocardiogram is presented in [109]. A smart IoT system to monitor patient health and alert healthcare workers of critical conditions is discussed in [110]. [111] proposed a large cloud system based technology on a large dataset to predict the future health condition of the patient. A condition monitoring system based on IoT is proposed in [112] to monitor the health status and administer treatment based on requirements, while ensuring secure data transmission as well. Again, [56] proposed a novel technique which is based on wearable IoT devices to promote real-time solution for contact, monitoring, and tracing of spread of the COVID-19 virus. Convolutional neural network-based technology is proposed to study CT scans and detect the presence of corona symptoms in patients in [55]. The X-ray image is studied using a machine learning algorithm to detect COVID symptoms in the lungs of patients in [56]. [57] proposed the machine learning and deep learning-based algorithm for diagnosing the suspected patient using cough sounds. An IoT-based deep learning technique is used in [58] to detect the presence of coronavirus using chest x-ray images. Researchers in [113] used the artificial intelligence method to identify and segmentate the x-ray images of patients. Convolutional neural network-based architecture is considered in [114] to compare and classify patients as normal, having pneumonia symptoms or COVID cases by screening x-ray images. Again, [115] proposed a strategy to identify patients based on the ResNet-50 model on x-ray images. The patients considered in this study were again diagnosed as healthy, infected with virus or infected with pneumonia based on the results. Table 3 lists out the research projects that were performed using IoT to combat the pandemic.

Table 2. IoT based products in service to trace down and promote treatment.

Types	SI.	Country	Company	Technolog	Applications	Sources
Testing	1.	Tawian	Brain Navi Technology	Robot	Collecting samples of nasal secretion	[59]
	2.	Denmark	University of Southern Denmark	Robot	Throat swab collection	[60]
	3.	USA	LifeSignals	Biosensor patch	Monitoring real-time ECG and respiratory rate	[53]
	4.	USA	Tampa General Hospital	Camera with AI technology	Temperature scan	[63]
	5.	China	LinkingMed	AI technology	Pneumonia screening using CT scans	[62]
	6.	Canada	DarwinAI, University of Waterloo	Convolutional Neural Network	Diagnose COVID suspect using x-ray	[100]
Tracing	1.	USA	Kinsa	Smart Thermometer	Tracing of hotspot region	[65]
	2.	China	MicroMultiCopter	Drone	Monitoring crowd / large scale temperature measurement	[101]
	3.	India	Corona combat	Drone	Temperature measurement	[102]
	4.	Australia / Canada	DraganFly	Drone	Identify infectious respiratory infirmities, monitors temperature and heart rate	[53]
	5.	China	KCN901	Smart helmet	Contactless monitoring temperature and access location of infected patient	[16]
	6.	China	Rokid	Smart eyewear	Monitoring temperature	[70]
	7.	India	Cyient	Drone	Monitoring of infectious zone, prevention of mass gathering	[103]
	8.	USA	Zipline	Drone	Supply of medicine using drone technology	[89]
	9.	USA	Estimote	Wearable device	Monitoring health status of employees in office environment and prevention of spreading of the corona virus	[72]
	10.	Canada	BlueDot	AI: Machine learning and Natural Language Processing	Predicting and informing about the possibility of the outbreak of coronavirus	[74]
	11.	USA	Bayesian Health	AI technology	Early detection of respiratory illness	[64]
	12.	Canada	Civitas	Mobile application		[80]
	13.	N/A	MiPasa	Mobile application	Secured sharing of health status and location of individual	[53]
	14.	Israel	HaMagen	Mobile application	Contact tracing using GPS technology	[81]
	15.	Singapore	TraceTogether	Mobile application	Contact tracing using Bluetooth technology	[82]
	16.	Russia	Social Monitoring	Mobile application	Identify users location	[83]
Treatment	1.	E-commerce	JD Health	Telemedicine	Remote treatment	[73]
	2.	USA	Teladoc Health	Telemedicine	Remote treatment	[85]
	3.	USA	George Washington University Hospital	Telemedicine	Remote treatment	[104]
	4.	USA	Rush University Medical Center	Telemedicine	Remote treatment	[105]
	5.	India	Government Funded healthcare	Telemedicine	Remote treatment	[86]
	6.	Ireland	National University of Ireland	Drone	Supplying medicine	[87]
	7.	China	Disease Control Center	Drone	Supplying medicine	[88]
	8.	India	Marut Drones	Drone	Medicine delivery, thermal data	[53]
	9.	India	Asimov Robotics	Robots	Supplying medicine and serving food to affected patients	[90]
	10.	India	Megvil Technology Limited, Baidu, SenseTime	Body temperature measurement using AI	To identify people affected with COVID symptoms	[75]
	11.	USA	Xenex Disinfection Service	Robots	To disinfect regions within hospital area potentially reducing spreading of infections	[106]
	12.	Denmark	Odense Robotics	Robots	To disinfect contagious areas using UV light	[107]
	13.	Canada	Visionstate Corp.	IoT button	Wanda QuickTouch buttons to alert authority and ensure rapid deployment	[61]
	14.	USA	WHOOP	Strap band	Monitoring of patients health status	[71]
	15.	Thailand	Advanced Info Services	5G Technology	Telemedicine and thermal scans using robot	[53]
	16.	China	nCapp	Mobile application	Update patients health and offers consultancy based on health status	[93]

Table 3. Research projects using IoT to combat the COVID-19 pandemic.

Works	Technology Used	Major Findings	Limitations
Jaffari et al. [98]	Microcontroller ESP8266 – 01	GPS and ECG to monitor patients location and health status	Real-time testing of the proposed model on individual needs to be analyzed.
Vaishya et al. [108]	AI-based applications	Detection of cluster cases of COVID-19	Detailed analysis of the proposed AI algorithm for detection of COVID-19 should be considered.
Roy et al. [116]	IoT based system merged with healthcare server	Tracing and monitoring of spreading of the coronavirus using wearable IoT devices	Privacy and data protection needs to be analyzed.
Ardakani et al. [55]	Convolutional Neural Network architecture	Studying CT scans to detect and diagnose COVID cases	Practical implementation with economic analysis can be explored.
Elaziz et al. [56]	Machine Learning Algorithm	X-ray images to detect COVID symptoms in lungs of suspected patient	Future applications in the medical field needs to be considered.
Imran et al. [57]	Machine learning and Deep learning algorithm	Identification of COVID through cough sounds	Further analysis on reduction of misdiagnosis needs to be considered.
Ahmed et al. [58]	IoT based deep learning	Screening of X-ray images of chest region in order to detect coronavirus	Extensive data analysis and real-time implementation can be explored.
Shi et al. [113]	AI-based method	To investigate the X-ray images of COVID-19 patients	AI to enable image data and clinical lab results to obtain better diagnosis can be ventured.
Wang et al. [114]	Convolutional neural network-based architecture	Comparison of covid, normal state and pneumonia from X-ray images	Improve sensitivity for dataset analysis and further areas of application for the proposed app can be considered.
Farooq et al. [115]	ResNet - 50	Classification of patients affected with infections, viral or pneumonia symptoms, based on X-ray images	.
Sharma et al. [112]	IoT based system	Condition monitoring of patients health and register treatment, secured data transmission	Several workload analysis in a healthcare facility can be considered.
Sahoo et al. [111]	Large cloud system analysis of patient data	Predicting future health condition of a patient	Real-time data analysis in a healthcare facility needs to be considered.
BG Ahn et al. [109]	Sensory device in a smart chair	Remote monitoring: measure ballistocardiogram measurement	Further data recording and transmission to relevant health authority need to be explored.
Chiuchisan et al. [110]	Smart IoT system	Monitoring of ICU Patients and call for assist from healthcare services	Further analysis into real-time applications and use of sensory devices need attention.

Table 4. Existing work analysis is already done regarding medical data.

Work and Methods	Medical Data	Application of Medical Data
Bassi et al. [125]	Chest X-ray image	Covid-19 Detection
Tahamtan et al. [127]	Real-time data from RT-PCR	Analyzed the issues that can hamper the detection of SARS-CoV-2 from the data
Ghosha et al. [128], Deep Learning	X-Ray image	Bayesian C-NN to discover the uncertainty from the diagnosis report of the COVID-19 dataset.
Mangal et al. [129]	X-Ray image	Detection of COVID-19 from chest x-ray with 90.5% efficiency.
Vaid et al. [130], deep learning	X-Ray image	The CNN-based method was applied to the gathered data to find out the patterns or the abnormalities.
Waheed et al. [131], Data Augmentation	Chest X-ray images	Build a model by the classifier to enhance the detection of COVID-19 with 95% accuracy.
Liu et al. [132], data analysis	Statistical patient data	After analyzing the data in China it is evident that the coronavirus can cause in some cases severe respiratory issue in children also.
Alom et al. [133], Multi-task DL	X-ray and CT scanned images	An efficient way to detect SARS-CoV-2 from the chest or CT scan image.
Brunese et al. [134], Deep learning	Chest X-ray images	A method for automatic detection of COVID-19 from Chest X-ray within 2.5 seconds and with 0.99 accuracy.
Ni et al. [135]	Blood Sample data	The research work provides a better understanding of the pathogenesis of coronavirus and provided a way of vaccination against the virus.
Ismael et al. [126], deep learning	Chest X-ray image	Deep learning and texture description-based approach to detect coronavirus.
Narin et al. [136], Deep CNN	X-ray image	Automatic detection of COVID-19 with 96.1% efficiency (Dataset-I), 99.5% (Datatset-II) and 99.7% (Dataset-III).
Ozturk et al. [137], Deep NN Chest	X-ray image	An automated method to detect COVID-19 at early stage with 98.08% for binary case additionally 87.02% for multi-case detection procedure with heatmap feature to assist the physicians to locate the region.
Sethy et al. [138], SVM	X-ray image	Detection of COVID-19 using SVM with above 95% accuracy.

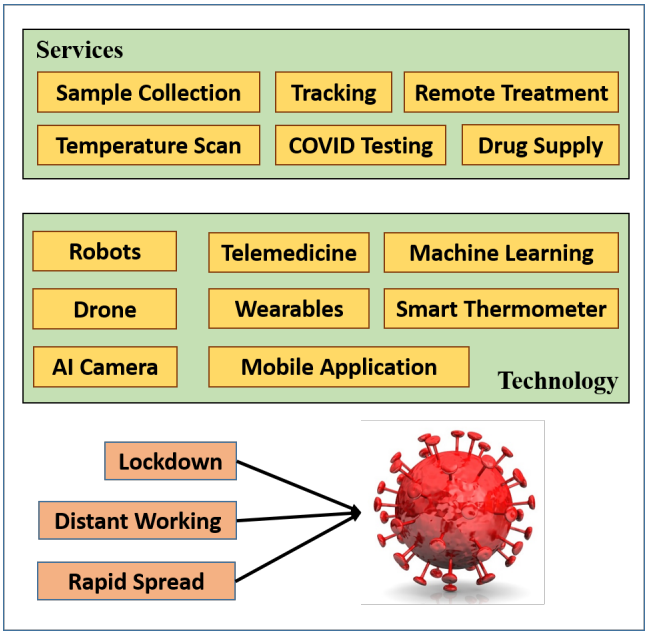

Figure 6. Overall scenario using services, platforms, and applications.

Several types of tools, techniques and numerous services are attached during the COVID-19 situation which is discussed in the above section and depicted in Figure 6 as a summary. Researchers often investigate their ideas using smart technologies and AI. The services are provided without any physical contact through telemedicine. To overcome the challenges of COVID-19 pandemic, a lots of ideas are being tested.

6. Different applications of medical data

The need for medical data is enormous for a deeper understanding of the essence of the disease and the development of a model for predicting when it will occur. By analyzing the data obtained by medical facilities or hospitals, researchers will create a precise model to predict symptoms automatically, which will reduce the doctors' burden by mitigating time spent on identifying their symptoms. As such, fast treatment can be administered as a result of early detection. Some of the examples of usage of the medical data sets include the detection of tumor from medical images that have tumor assist to build a model. In such cases, several types of images can be helpful like microwave sensors image which is considered efficient in cancer detection with better resolution and additionally provide features which are helpful in the detection process [117]. For efficient breast cancer or tumor detection, ultrasound images have also been used by researchers [118, 119]. Whole slide images used to detect tumors are considered to be more effective and efficient [120]. Again, for detection and prediction of diabetes in both cases and for the detection of the percentage of chance of a patient having diabetes, a model is trained with diabetes data [121–123]. Furthermore, in order to detect SARS-CoV-2 or to detect how COVID-19 had affected our hearts, researchers trained their model with medical image data gained from COVID and non-COVID patients [124–126]. Table 4 summarised the existing work regarding medical data.

Therefore, medical data is one of the essential components of smart systems. The main two types of medical data are texts and images. Both of them could be useful for treating patients remotely. Moreover, AI models are trained over the medical data and deployed into the system to provide amazing services.

7. Challenges, open issues, and future directions of IoT in healthcare for COVID-19

7.1. Open challenges and issues

The prior task of developing an IoT system is to deploy sensor hardware into the system. It is the primary challenge to improve the performance of the IoT sensors so that the functionalities of the network can be run accordingly [141]. Since the services need to be quick and in real-time for healthcare especially in the COVID-19 pandemic, the life-time and power consumption of a wireless sensor should be as effective as possible. Otherwise, the system will lose it's ability to serve in critical conditions. Security issue is challenging, without any doubt, as people are afraid of this viral situation and they normally do not want to share their medical condition with other people. On the other hand, someone may alter the reports of the patients willingly and that will lead the circumstances to an unsafe state.

Because of this kind of pandemic, every corner of the world is going under lockdown as social distancing becomes the only way to reduce the spread of COVID-19. So, remote healthcare systems based on IoT are gaining increasing demand. However, not everywhere is privileged with a high speed internet connection. Hence, it is an open issue for the service provider to cover such areas. Apart from this, the online process stores the data on the cloud within a shared storage so that both the patient and doctors can access it. The management of shared resources is also an intriguing phenomena in the field of IoT. However, the general public are not likely to have service from a remote distance because there exists a lack of trust. This type of application needs extra awareness and reaching out to the general public and they should be motivated to get service remotely.

7.2. Future directions

7.2.1. Machine learning

Machine learning technology remains indispensable to process the abundant amount of data [142]. Machine learning to enhance and accelerate the diagnosis, tracing and treatment of the current pandemic has received wide-scale attention. AI-based machine learning to identify and track down patients with COVID symptoms has already been implemented to counter the spread of the virus. In order to explore the full potential of machine learning technologies, considerable effort towards the development of efficient algorithms, steady performance monitoring, improved data processing, and approval to promote deployment remains latent. Another drawback of machine learning remains the ability to interpret results by healthcare professionals. Pedagogical training remains vital for healthcare facilities and laboratories to alleviate any irregularities in results achieved through machine learning. Furthermore, several institutions have developed custom analytical method which processes limited sets of data. Access to large data sets from several sources remains a stumbling block to generalize the results achieved using machine learning algorithm. These challenges must be resolved to help machine learning algorithm perform efficiently in the event of a pandemic.

7.2.2. Blockchain and software-defined network technologies

In the event of a pandemic such as COVID-19, data collection of relevant parameters using the IoT framework necessitates connections of several devices. Software defined IoT is imperative to ensure efficient performance of network management via several devices and platform [139, 140]. SDN-based IoT-related applications further allow for interchangeability with varying policies for implementation [141, 143] . Future research on the role of software defined IoT for data collection of coronavirus and relevant parameters using the IoT framework could significantly improve the e-healthcare services [144].

7.2.3. Usefulness of deep learning features

Deep learning techniques have the potential to promote intelligent solutions to the current pandemic. Previously, this technology remained limited in the application for medical image processing. Recently, several efforts have been made to combat the COVID-19 outbreak, which include prediction of an outbreak, screening, tracking, and treatment using deep learning. Initial results have been optimistic to process medical images of patients with COVID symptoms using deep learning methods. However, the technology can be further improved by collaborative work between policy researchers, policy makers, and industries. Furthermore, large data-sets remain unavailable to generate resilient predictions. Transfer learning can be another direction for future research which can be implemented to overcome the inconsistency issues in limited data-sets.

7.2.4. The role of blockchain to healthcare to control coronavirus

Optimization of blockchain platforms remains vital to improve the performance efficiency through increased data throughput, nominal delay in network and to ensure confidentiality of client data through improved security. Minimized or lightweight blockchain design in medical facilities with the ability to optimize data through local and private blockchain, remain another area of research to promote fast response.

7.2.5. Improving the patients confidentiality data through data science

Another significant sector of healthcare IoT is to maintain the confidentiality of patients general and health information. Set guidelines to ensure the security of patients information via 5G network is yet to receive detailed attention. In addition to enabling confidentiality of patient data, various other security concerns related to 5G telecommunication need to be regulated [145]. There are several technologies based on IoT supported by big data and AI that are failing to gain momentum due to the reluctance of people to share health related data or provide access to location [146]. Research towards improved data security for clients within the IoT framework is expected to uplift the confidence of general people to share health and relevant data.

7.2.6. Building a smart healthcare approach through AI and robotics technology

Smart healthcare system remains an emerging technology and poses numerous challenges to its development. Processing large and complex data-sets, compatibility issues with several platforms and devices remains some of the key area of development. Another issue that requires dire attention is the

lack of legal norms to prevent the leakage of patient information. Future research work could be directed towards a generalized technical standard to enable compatibility between devices and platforms used in smart healthcare systems. Finally, research directions towards containment of privacy breaches in smart healthcare systems need to be addressed to protect patient data.

From the above discussion, it is clear that the implementation of IoT in the field of healthcare is quite challenging, particularly for protection of patients sensitive information and other malware attacks. Researchers are still looking for innovative solutions and intend to come up with a platform which enables all security features. The ability of a system is being improved by deploying different AI models. Security issues are solved through the use of Blockchain, while the SDN controller virtually manages the data and transmits it to different systems.

8. Conclusions

This study focuses on the IoT with healthcare technology for the COVID-19 pandemic. We review some existing work regarding SARS-CoV-2 in healthcare and also present different applications through the IoT platform. Further, we discuss different techniques such as tracing, managing and testing to properly detect patients with coronavirus infection. Still, we are in the process of reviewing about how to use IoT more conveniently in the healthcare system, particularly for the COVID-19 pandemic. Eventually, to improve this system, we consider technologies such as AI, robotics, and data science applications efficiently. In the future, we will integrate some emerging technologies like SDN, Blockchain, and Network Function Virtualization (NFV) to improve healthcare facilities and provide a confidential platform for COVID-19 patients.

Conflict of interest

The authors declare no competing financial and non-financial interests.

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