Computational Intelligence and IoT-Enabled COVID-19 Response: Technology Landscape

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Abstract

The advent of IoT has catalyzed significant development in various fields of science and technology. The developments in healthcare and medical facilities have given rise to the Internet of Medical Things(IoMT). This coronavirus pandemic has shown the world how unprepared our systems are for a tragedy of this scale and a need for strong, computationally intelligent, and pervasive intervention. This research article explores the various ubiquitious IoT-enabled smart technologies that can potentially be used to respond to various facets of this growing pandemic from diagnostics and treatment to the prevention phase. The article gives a state-of-the-art survey and levels out various challenges and impediments to integration of IoT as a response to COVID-19. The composition concludes with future scope and potential solutions in reference to the challenges addressed.

Introduction

The Internet of Things (IoT) has grown into a behemoth network of well-connected smart devices that work in unison to achieve a myriad of tasks. The aim of IoT has been to integrate traditionally standalone objects through a mutual arrangement in a manner that not only makes the control aspect better but also in a ubiquitous and pervasive manner. These devices have the ability to perceive their surroundings and integrate the collected data with an Internet cloud and further enable distributed processing as per the task. Its advent has triggered development in various sectors of computing, mechanical, and information services, and IoT has emerged as a great growling engine. In addition to macro-scale industry application, IoT has been integrated with our daily functioning, and serving daily life requirements. This ranges from smart home appliances and autonomous vehicles to intelligent transportation and smart grids. The last decade also underscored the rise of IoT devices in the medical and health sector, so much so that it led to the coining of terms Internet of Medical Things (IoMT) andInternet of Health Things (IoHT), both being equivocally used to represent the usage of IoT technology in the sector. Integrating IoT medicine significantly lowers expense, ameliorates the quality of services, and diversifies the experience of its users.

The global predicament of the COVID-19 pandemic caused by the n-SARS-COV-2 virus has emerged as the most severe public health crisis since the influenza pandemic in the previous century. The WHO statistics, as of 25 August 2020, noted that confirmed COVID positive cases had crossed over 23 million and were still showing no signs of stopping. The infection, although demonstrating similar symptoms as a flu, has been particularly deadly and caught the broken healthcare infrastructure by surprise. This underscored the need to take reasonable steps to improve the situation through technological advancement in this area. In this investigatory article, we aim to determine the technology landscape of IoT-enabled innovations designed to tackle and mitigate COVID-19. The state-of-the-art architectures, ranging from wearable devices, drones, robots, IoT buttons, and smartphone applications, are a few IoT-based solutions that are discussed within the composition of this piece.

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The significance and contribution of this piece are manifold as this article not only details IoT devices but also introduces a novel sector that serves as a reference point for future innovations in the medical field. The organization of this article entails a total of six sections. We underscore the synergies in IoT and COVID, and identify impediments to the integration. We aim to present the technology landscape of IoT and COVID-related applications. We cover open challenges and potential solutions in reference to improvement.

Synergies In IoT and COVID: Potential and Impediments

The seamless integration and synergetic confluence of IoT and COVID response are proving to be a promising area and an arsenal in combating COVID-19 on multiple fronts. Figure 1 shows the various research avenues and applications of IoT in response to the pandemic. These applications can be broken down into the following key categories:

- IoT in health and data monitoring of coronavirus patients
- IoT in diagnosis and prevention of COVID-19
- IoT in the prevention of the spread of the virus
- IoT in therapeutics and treatments

Figure 2 gives us a strengths, weaknesses, opportunities, and threats (SWOT) analysis of IoT that has leveraged various pandemic response technologies to combat this growing crisis. This analysis becomes extremely important as it underscores the relevance of IoT and its landscape in reference to the pandemic and its swift implementation. This will enable the research community to harness its full potential for future applications.

Applications In the IoMT Field

The impending expansion of the IoMT ecosystem bestows a comprehensive and innovative scheme of the interlinking infrastructure of medical devices and their requisite applications that uses networking technologies to connect with health information systems (HISs). IoMT devices include wearable smart devices, smart tracking sensors, smart thermometers, smartphone applications, and others that provide better monitoring, rigorous analysis, and precise diagnostics with fewer errors. The IoMT market is experiencing rampant growth in the healthcare industry. The challenges conferred by the COVID-19 pandemic can be tackled by IoMT, which uses innovative and advanced methodologies for effective diagnosis and treatment of patients. Table 1 depicts a confluence of IoT and its response to COVID along with a comparative assessment.

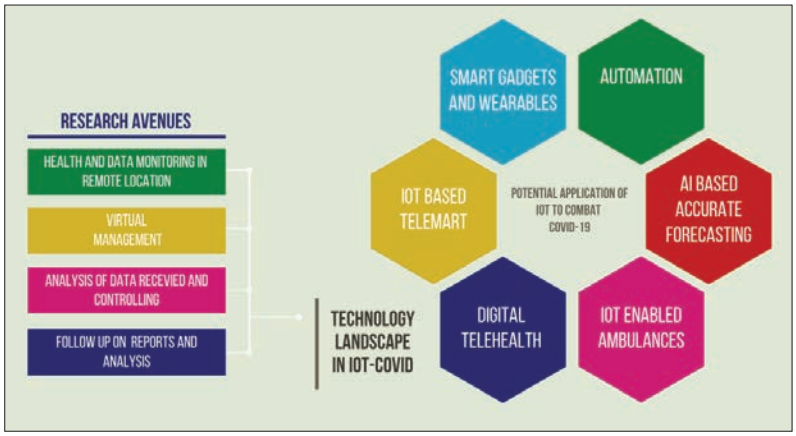

FIGURE 1. Technology landscape in IoT-COVID.

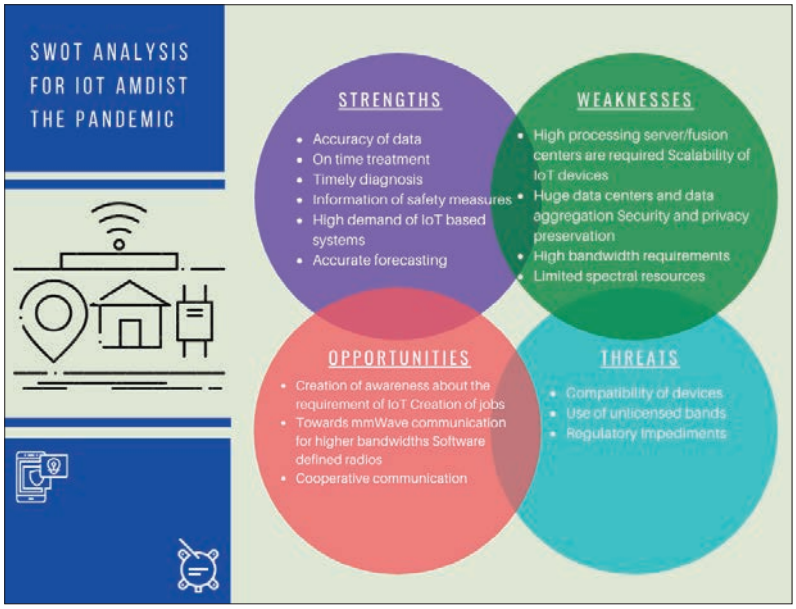

FIGURE 2. SWOT analysis of IoT amid the pandemic.

IoT Applications and Technology Landscape

Newer technologies are being deployed to tackle COVID-related issues such as diagnostics and effective treatment, but security remains an area of concern with developers taking active measures to resolve this impediment. Several mobile applications are being developed with many countries launching their applications that provide a platform for the public to detect, prevent, and eliminate the spread of the virus such as the Aarogya Setu app by India or Close Contact (English translation) by the Chinese government. Another example would be the "worldometer" that displays live updates regarding COVID-19 worldwide, including new cases per day, casualties, recoveries, and country-wise disease distribution.

Wearable Technology and Its COVID Response

The unprecedented COVID-19 pandemic has truly disrupted the world economy, and with many countries now easing the lockdown restriction in order to revive their economy, there is an urgent need for appropriate measures to be taken that help flatten the curve and further prevent spread of the virus. Smart thermometers that are connected to the Internet can be used for screening people at airports, hotels, shops, and so on, thereby limiting exposure to symptomatic disease carriers. A mobile application is connected with these thermometers, thereby allowing authorities to monitor and efficiently analyze the data [1]. A proposed comprehensive model is devised that uses the IoT framework to accumulate the requisite information from users to identify early symptoms, cognitively comprehending the data that could be used to accurately predict the COVID cases, and tracking the responses of people who have successfully recovered from the virus [2]. A set of wearable biosensors that procures the data can be deployed for the identification of symptoms such as fever, fatigue, sore throat, and labored breathing. The cloud-based infrastructure feeds the data to a data center where extensive analysis is carried out by deploying cognitive machine learning (ML) models such as support vector machines (SVMs), *k*-star, and decision stump, among others, and if the subject is suspected of being infected by the virus, he/she is swiftly attended to by physicians followed up by placement in an isolation ward or quarantine center.

Wearable devices that monitor heart rate, body temperature, and even complex evaluation of oxygen levels in the bloodstream have become a focal point pertinent to conversations regarding IoT and are rapidly transforming the healthcare industry. Reference [3] proposed an ingenious IoT-enabled smart helmet, which is embedded with thermal imaging technology for detection of COVID cases and is GPS-enabled to give real-time notifications on a smartphone. Endowed with facial recognition, it can actively unveil the specific records of the pedestrian and can also monitor their body temperature. Life Signals Inc., which is a Silicon-Valley-based startup, is coming up with their wearable product, Life Signals Biosensor 1AX and 2A, that monitors heart rate, skin temperature, respiratory rate, motion, and so on [4]. The lightweight wearable device is mounted on the chest area of a person and has a battery life of up to five days. The data procured by the devices is autonomously sent to the mobile application, and if the person is showing symptoms of COVID-19, data can be swiftly sent via a secure cloud platform to physicians. Estimote, a company that builds programmable sensor technology, has recently launched wearable products that could help mitigate the spread of the virus, and significantly boost safety and social distancing in the workplace. The proposed hardware constitutes a GPS, rechargeable battery, and proximity sensors, and is also equipped with Bluetooth [5]. To ensure a safer workplace environment, it allows the company's administrator to remotely supervise and track the dynamic status of their employees on the health dashboard that keeps a log of all contacts, which ensures better management and planning in case of any virus transmission inside the firm. As soon as the device is turned on, it searches for other similar devices and establishes interaction by collecting information like proximity distance, medical history, and health status. The company has presented three variants that have LED indicators and buttons. Employees can update their health status as certified healthy, symptomatic, or verified infected, which is registered in a database that can store the user's specifics for up to six weeks

AI-Based Approaches for Epidemiological Predictions

Comprehending that among COVID-19 cases a vast majority of patients have mild symptoms, it still behooves physicians to enforce substantially the same degree of scrupulous methods to isolate, examine, and medicate all patients. Cognitive artificial intelligence (AI) algorithms can provide great help to physicians involved in the pipeline of things, and patients are classified into three groups: 80 percent showing mild symptoms, 15 percent in the moderate group, and finally, the 5 percent that have a high risk of mortality. AI methodologies can be useful for the discovery of potential new drugs for the treatment of diseases

Model technology	Device description	Advantages	Disadvantages
IoT wearable	A wearable hardware with sensors that are connected with smartphones via applications.	Easy accessibility Improved mobility Enhanced and personalized healthcare service	Security concerns. and susceptible to leakage of data Prone to jobs reduction
Drone technology	State-of-the-art flying devices equipped with a camera, GPS, lasers, etc. and controlled remotely	Can access remote areas that are hard to access High-speed service Ensuring safety with no human-to-human interaction	Susceptible to crashing Expensive
Robots	Devices that can emulate human-like actions and perform complex tasks	Improved efficiency .Ability to work for long hours	Cannot be fully trusted Expensive
Mobile applications	Applications programmed to run smoothly on smartphones.	Reduces waiting time Personalized services Scalability	Data privacy and security

TABLE 1. Confluence of IoT COVID-19 response and comparative assessment.

that are cost-effective, with many vaccines now available and subject to mass distribution.

ML methodologies can be deployed to extrapolate the growth and monitor the effective tracking of disease, hence minimizing its impact worldwide. A study that combines ML approaches and a cloud-based framework has been proposed that predicts the total number of cases by using mathematical modeling techniques [6]. To calculate and predict COVID-19 cases, it uses the Robust Weibull model, which is premised on iterative weighting and takes factors into considerations such as populated areas, climate conditions, and medical services for better accuracy. The study indicated that their model was able to predict accurate results from a statistical point of view in juxtaposition to the baseline Gaussian model, which was showing unduly optimistic predictions. The need for an accurate model that would help physicians make optimal decisions, better forecasting of the number of cases should be underscored; it will also facilitate government agencies for better planning and handling the crisis.

Confluence of Telemedicine and IoT

With the number of cases surging at a rapid pace worldwide, all healthcare services are experiencing an immense amount of strain and facing severe issues including shortage of beds, insufficient medical staff, infrastructure impediments, and so on. Telemedicine can resolve some major challenges and help to decongest the strain that has been imparted by COVID-19. Telemedicine is the practice of myriad techniques that allows remote monitoring of patients on devices such as tablets and mobile phones, allowing physicians to assess, diagnose, monitor, and provide better access to medical services. With the outbreak of the virus, there has been a significant rise in demand for tele-health devices with many companies providing portable telemedicine kits such as ECGs for vital sign monitoring, digital stethoscopes, and high-resolution cameras. Considering the coronavirus situation, telemedicine technology can be of great help as it will ensure that there are fewer encumbrances on medical staff and that there is a lower risk of human transmission of the virus. Although this technology is experiencing rampant growth, there are some major challenges including technical training, expensive installation cost, privacy and security issues, convoluted policies guidelines and repayment rules, and others over the traditional healthcare methods that are areas of concern and need to be addressed appropriately.

Assisted Drone Technology

Drones can significantly help to tackle and resolve the unprecedented set of problems the pandemic has brought forward. Drone technology is now being used by many countries during emergency situations for mitigating the negative effects during these extenuating times. In Europe, Spain was among the first nations that deployed drones for disinfecting public areas. These drones were equipped with disinfectant sprays that were used to sanitize and disinfect common places and were able to cover large areas. This technology can be of great help, especially in alleviating the strain on health centers and hospital administrators as they can be deployed swiftly for dispatching medicines and other goods. They can also be used for monitoring of patients who are home quarantined with mild symptoms of the virus. Marut Drones, an Indian startup, is providing drones that can be used for sanitizing, medicine distribution, and crowd surveillance. In contrast to the traditional methods, these drones are much faster and can travel up to 12 km in 8 minutes [7].

IoT-Enabled Ambulances

In emergency situations where time is thin on the ground and every second plausibly could strengthen the effectiveness and efficacy leading to optimized decision making, there is a need for smart emergency vans that can be helpful for dealing with high-pressure situations that are susceptible to faults. Physicians can put forward the necessary and required steps to the medical staff who are handling a patient in an IoT-embedded ambulance. These emergency vehicles can help save the lives of patients significantly. P Manikanta proposed a model of an IoT-equipped smart emergency van in which patient data is procured by sensors and gets to physicians via a cloud infrastructure [8]. Additionally, the ambulance can control traffic lights so that it gets a clear path on the road and reaches the hospital fast.

Interventions through Robotics and Automation

Earlier, the usage of robots was restricted only to workshops and laboratories, but with the sudden spurt in the AI field, robots are everywhere and are encompassing almost every facet of life. The medical industry is no different in receiving the advantages bestowed by robot technology. Robots can ensure higher productivity, are able to work for long hours, use less space, and make fewer errors. IoT-enabled robots are now being used in hospitals for a myriad of tasks such as collecting samples, disinfecting surfaces, and conducting temperature checks. Vayyar Imaging [9] and Meditemi [10] have collaborated to develop a smart device that can scan temperature and respiratory signs and has a range of 1 m to monitor a patient. Robots can significantly help to ease the stress and workload faced by many doctors and medical staff around the globe during the COVID-19 pandemic and can also resolve major issues such as safety and shortage of medical staff.

Presented below are a few examples of how robots are used to resolve major impediments during COVID-19:

- The physiological impact of self-isolation or quarantine can have a serious impact on mental health and can give rise to various physiological illnesses. To tackle this problem, smart robots are now coming to the aid of patients facing these issues. An example corroborating the above statement is the Paro therapeutic robot, which is used in nursing homes and hospitals to alleviate stress levels and induce a calming effect [11].

Sector	Application	Domain
Hospitals having IoT connectivity	IoT connected will enhance the decision-making process and will increase efficiency leading to optimal solutions.	Diagnostics and Therapeutics
Notifying the medical staff in emergency situations	This comprehensive network will enable patients and medical faculty a more timely and rapid response.	Epidemiological Response
Limpid treatment of COVID-19	It will ensure the treatment being devoid of prejudice and partiality.	Diagnostics and Therapeutics
Ingenious tracing for individuals affected by the virus	Scaling up the process of tracing will further corroborate the service enterprises in the management of cases with increased efficiency.	Epidemiological Response
Telehealth services	Patients can remotely access and manage health care services with a higher level of flexibility and low cost.	Prevention and Healthcare
Precise prognostication of COVID-19	Analysing the available data and using statistical approaches to predict the number of cases for better management of the crisis by governmental agencies and health practitioners, academicians etc.	Diagnostics and Therapeutics

TABLE 2. Critical application for IoT in pandemic.

- A three-wheeled robot by the name of Asimov Robot is being used to assist patients who are in isolation wards. The smart robots ensure that there is minimal human contact and carry out tasks such as supplying medicines and food, thereby ensuring safety and minimizing the risk of getting infected by the virus for hospital staff [12].
- UVD robotics, a Danish firm, is providing disinfectant robots to hospitals worldwide. They emit a high-intensity UV light to sanitize surfaces by obliterating the DNA strands of the virus. The robot is also embedded with detection sensors that can detect human presence and automatically shuts down as a safety protocol. [13]

However, there are major challenges that need to be considered such as slow mobility, expensive installations, high maintenance, data security, and bias. Also, the possibility of making incorrect or non-optimal decisions cannot be discounted.

Challenges to IoT Applications in COVID

Our collective history of innovation teaches us that both implementation and integration have never been easy. There are several barriers that impede development, which are discussed below in reference to IoT technology as a response to the coronavirus pandemic. The first challenge we see is scalability of these IoT devices in use. This advent in the digital domain has caused sporadic growth in the number of IoT devices that are often used for more than one application. The scalability is especially a significant impediment to IoT's application to the fight against the pandemic as various IoMT devices are tasked with sensing the vital signs of patients and making them available on the cloud server. With the global cases of coronavirus patients soaring and hospitals brimming to capacity, IoT implementation requires the ability to deal with a scenario on such an unprecedented scale. Both the number of devices and data gathered by these devices has increased; consequently, the energy and buffer requirements have shot up due to scalability. The second big challenge we identify is that with the rise in the number of IoMT devices, more bandwidth is needed so as to facilitate data gathered through various sensors to the cloud. The technological advancement and growth in these devices has led to this increase. The issues associated with this are intermittent connectivity and latency, impeding the swift transfer of data. As with scalability, the larger number of IoT devices causes unreliability since most of these devices will be enabled by WiFi networks. The current devices make use of LTE, 3G, and 4G, whose spectrum will not be large enough to cater to the IoT devices. Amid this global pandemic, these errors and delays may cost lives; hence, larger bandwidth is a precursor for IoT's application in this fight against COVID.

Factoring in the scalability and limited energy constraints for IoT devices, we come to the conclusion that using conventional cryptographic paradigms is not viable. This brings us to our third challenge: security in the enabling of IoT devices. There is a critical need for implementation of security solutions that are sustainable for IoT-enabled networks that are computationally less complex while still offering end-to-end protection for data, privacy for users, and reliable authentication, three tenets of security. The outbreak of this pandemic has underscored the need for these security considerations, and the recent cyber-attack on COVID medical and vaccine research facilities as noted by UK's National Cyber Security Centre (NCSC) attests to the strong security consideration of any IoT-based devices. These IoHT or IoMT devices have now become critical infrastructure with the advent of this pandemic. The security considerations future lightweight security paradigms should take into account include:

- The information delivered to the sensors in direct contact to the body of COVID patient must be correct and reach the intended destination for secure end-to-end delivery.
- The information should have a secure communication path and should not be susceptible to man-in-the-middle or Sybil attacks.
- The data collected in the buffer of devices should have different levels of clearance, and should not be available to everyone and strive to keep the trust value intact.

The final challenge that we are factoring here is related to big data centers that are associated here. The data size including electronic health records (EHRs) will be enormous in size and are sent to the cloud using some designated application programming interface. Here, the big data centers need to be equipped and upgraded to handle such large volumes of data such that they do not overload, and do the requisite processing as they need to be dynamic in their operations. The lag in fetching, delivery, or processing of data can be particularly fatal when the data pertains to coronavirus patients.

Solutions and Future Perspectives

The above-discussed impediments, although inherent in IoT, are aggravated when we look at their application to combat various facets of this pandemic. These challenges are undeniable, but their solutions exist in various capacities and forms that if successfully deployed can mitigate the issues leading to smoother integration, thus bridging this gap. This section discusses these solutions, which can prove to be game-changing in harnessing IoT applications against COVID, and addresses future scope in this domain.

Due to lack of physical protection of these devices, they are easily accessible, which makes them susceptible to a lita-

ny of security issues. Hence, the security of data and provenance is crucial for implementing protection in IoT-based networks [14]. IoT devices can do that by enabling computationally lightweight security algorithms that are energy-efficient and consume less system resources. These will enable authentication, confidentiality, and data protection for users. Metrics such as information phasor, arrival angle, and strength of signals can be employed to develop these IoT security paradigms. Blockchain is one promising avenue that is gaining traction in this domain and can be used to implement connected healthcare, as illustrated in Fig. 3.

In the figure, the IoT-enabled healthcare units are linked to one another such that each unit behaves like a cohesive block, and the transfer of data is facilitated by enabling blockchain in this IoT network. For instance, the EHR of a patient is verified using hash and referencing that with present values existing in the ledger. This underscores security and preserves privacy in these IoT applications as the hash values are sent to an Internet cloud where a distributed ledger is created. This enables checking of data pertaining to EHRs and healthcare kits, pivotal in COVID-19, by officials to rule out forgery or any erroneous interventions. Its application is particularly beneficial in the supply chain, where each node in the chain is a block and contributes its hash to a decentralized ledger.

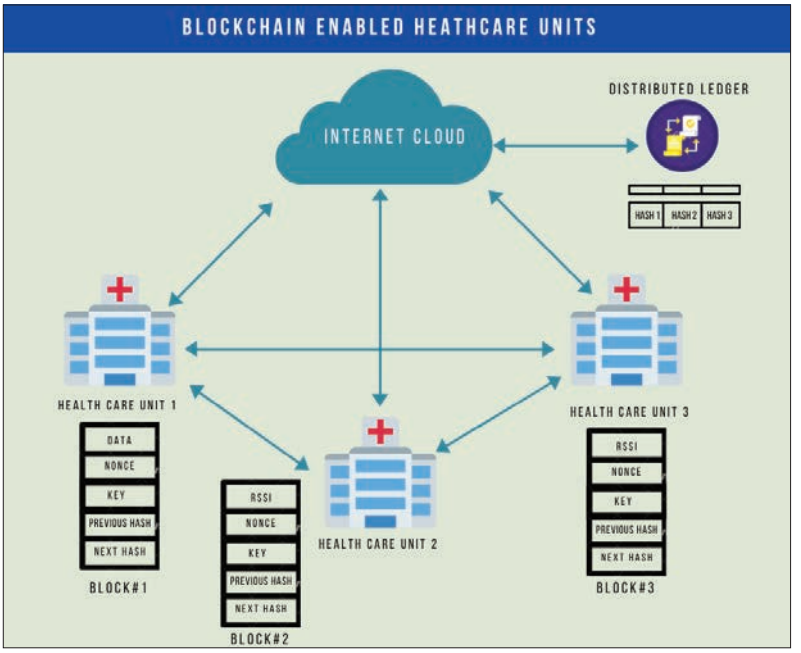

FIGURE 3. IoT-enabled healthcare units.

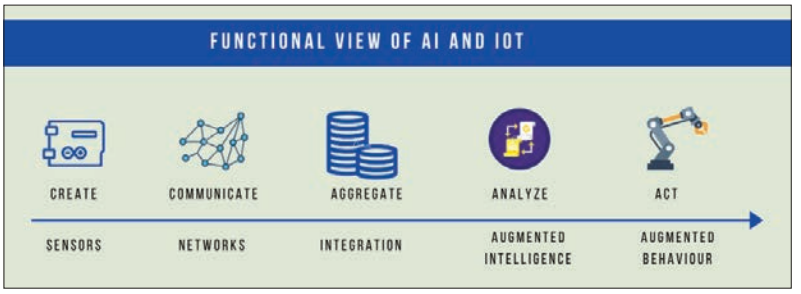

FIGURE 4. Functional view of AI and IoT.

The allocation of spectrum has conventionally been performed in a licensing-based manner, but here, the utilization is often neither complete nor ubiquitous. A confluence of cognitive radio and IoT, abbreviated as CRIoT, is used as an answer to the issue regarding reuse of frequency and utilization. Here, a three-tiered approach is used that involves spectrum sensing, spectrum mobility, and spectrum decision. In the first tier, the underutilized spectrum is sensed, and free holes from a personal user's licence are detected. Beyond this, the IoT device makes the selection of relevant spectrum as per the quality of service requirement, which is followed by the decision making aspect as per the environment of the radio signals and the statistics of the behavior of the IoT device in question. Under spectrum sharing, more nodes have access to the same spectrum; hence, collision detection and prevention becomes critical. Opportunistic resource allocation can be implemented for this purpose. Spectrum mobility ensures that the communication is maintained during the transition of the spectrum; for this, many methods are prevalent, including but not limited to detection of energy, filter matching, cyclo-stationary detection, and detection of features.

The final modality addressed in this article involves the confluence of computational intelligence and IoT devices in the medical field. The data generated by the communication devices connected over the Internet is useful and impacts the ascertaining of the behavior of the device itself [15]. AI-based pattern detections are quite useful in this regard. There is two ways this can go:

1. Predictive analysis: based on the result of the decision
2. Adaptive analysis: based on the previous behavior of the system for optimized decision making

Figure 4 illustrates the functional view of AI and IoT in the form of a process where data is created, carried, collected, analyzed, and acted upon in a stepwise manner. Interventions from AI exist at various steps, enabling a stronger learning paradigm and improvement from the status quo.

CONCLUSION

IoT as a technology has been prevalent in various fields and performs a variety of functions as per the objective, such as monitoring, tracking maintenance, delivery, and collection of information. This can augment our approach to combating various effects of this pandemic and complement healthcare systems. From early diagnosies to post-recovery, IoT proves to be extremely diverse and versatile in its approach and fight against the pandemic. This article gives the technology landscape of various IoT-enabled technologies that are responding to COVID-19 on various fronts, both directly and indirectly. In this article, the authors have addressed the synergies and impending challenges to smooth integration of IoT in the medical domain, especially from the perspective of the pandemic. Finally, this research composition concludes with various solutions to the discussed challenges and levels a future scope in this domain. With all the recent technological advancement, the future of IoMT is ripening as it assists in smarter decisions as we learn more about this relatively unknown disease.

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