IoT in Combating COVID-19 Pandemics: Lessons for Developing Countries

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1 Introduction

The outbreak of COVID-19 from Wuhan, China, has led to several countries imposing lockdown in the hopes of containing the spread of the virus. In most countries, schools, businesses and several industries have been severely affected, and this have created an atmosphere of economic instability with most countries reviewing their initial budget plans for the year to consider the impact of the virus spread [18, 54]. After the declaration of the situation as being a pandemic, the race to contain as well as develop technologies and vaccines to combat COVID-19 became fiercer. Several techniques have been proposed in dealing with the impact of the virus, some vaccines have been tried with both positive and negative outcomes, tracing applications have been developed as well as other developments which will be detailed in proceeding sections [11, 21]. However, till date, there has been no confirmed vaccine that can alleviate the current condition. For countries with very little technological might, more focus is being shifted towards damage control, contact tracing and prevention of further spread through leveraging on technologies such as smart systems and Internet of Things (IoT) [48]. COVID-19, which is a virus

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Fig. 1 Total confirmed virus cases as on June 2020 [65]

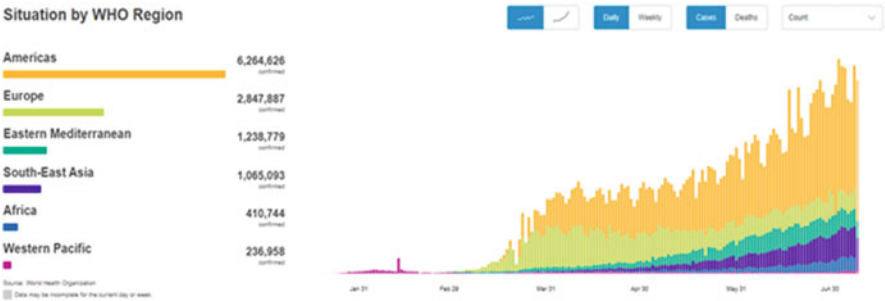

Fig. 2 Total infection by region (June 2020) [65]

that attacks the respiratory system [1], has spread round the globe with the United States being the worse hit region as of the time of this report. According to the World Health Organization (WHO), the total global confirmed cases in April 2021 reached approximately 135 million with 108 million recovered and about 2,927,442 deaths [65], which was on record as seen in Fig. 1. Of the total cases, the United States alone accounts for 32 million cases which translate to a whopping 24% of the total world cases. This unprecedented increase in cases therefore requires that immediate action needs to be taken as a countermeasure of the side effect of the outbreak (Fig. 2).

Mobility has become universally prohibited in a view to limit the spread of COVID-19. Physical contact too is considered as a heinous crime [45, 49]. As a result, people were forced to meet and chat with each other through virtual means like skype, zoom, webax and other convenient methods to interact and comfort each other instead of having physical meetings and get togethers. Healthcare professionals too have sought the assistance of technology in monitoring and controlling the infectious spread [21, 55, 56]. Their fight on COVID-19 has been propelled hugely thanks to IoT which has eliminated the risk of infection as humans get exposed to infected patients. IoT easily tracks the spread of the virus and

pinpoints high-risk patients crucial in containing infections instantaneously. One advantage of IoT is that it forecasts the risks of death by sufficiently examining data previously provided by the patient. The main applications of IoT in the fight against COVID-19 are characterized as (1) early detection and diagnosis where inconsistent symptoms and other critical signs are communicated to health professionals to take action, (2) monitoring the treatment where IoT builds data platforms for automated predictions and tracking on a daily basis provides vital information on infected patients, (3) contact tracing of individuals where patients released into the communities are traced to identify who has contact with the patient, (4) projection of cases and mortality where IoT can monitor and predict the virus based on the information at hand and other social and mainstream media outlets, (5) reducing work hours for healthcare providers where information is gathered through digital modes by utilization of IoT devices resulting in less hours worked and limited exposure and contact with patients maintaining social distancing protocols and (6) prevention of the disease where availability of timely data IoT enables real-time information for prevention of the virus [61]. Meanwhile, in Australia, the risk of contraction is increasing by the day, forcing health professional to accept the use of virtual care models to monitor and track patients [6]. The applications of IoT can potentially boost the research in development of vaccines, prevention of infections, managing of infected people as well as prevention of virus contractions through development of smart devices such as smart social distancing glasses, cloths, etc. Therefore, given the current pandemic stage of the virus, this paper highlights the role of IoT in overcoming the previously mentioned problems. It is also projected that demand for IoT devices will climb to 10 percent in 2020 placing the number of devices at 718 million as Australia confronts COVID-19 [43]. In this regard, the current research has been carried out to explore

- the potential usage of IoT in combating the Pandemic
- various challenges in implementing IoT-enabled services
- the success stories of IoT in various areas

2 Problem Statement

With the continuous increase in the infection rate of the virus, there is also a desperate need to develop solutions towards containing the pandemic in a manner that can be easily managed. A need of technologies such as real-time information and data exchange is essential for getting a reliable vaccine more achievable in the shortest possible time. The practical implementation of technology-based remote patient monitoring system is also essential to safeguard the frontline medical personnel engaged in treating asymptomatic COVID-19. Further, monitoring and tracking exercise are required to furnish throat swabs, personal and contact particulars and travel details so that health authorities can track and trace those who have made contact with travellers displaying symptoms of COVID-19. This can only be

achieved using bug data, cloud technology and Internet of Things for the purpose of faster data processing as well as for determining efficient and effective methodology of managing the current situation. The insertion of sensors and connection of care devices like smart watches, heart rate monitors and glucose monitoring devices and other life-saving devices emanating remote signals to technological gadgets of healthcare professionals to act speedily to save lives has transitioned health care from being a responsive medical-based system into a more hands-on wellness-based system [60].

3 Literature Review

Internet of Things (IoT) has revolutionized the way in which different organizations have conducted their activities. Consequently, their dependency on IoT has increased over time as industries look for better ways to cut costs and increase profits. Therefore, the end of 2020 will witness installation of more than 24 million IoT devices with estimated revenue of more than 300 billion dollars [60] for businesses globally. Particularly, infusing sensors into everyday usable items like TV remote controls and more sophisticated devices like smart offices designed to save energy costs by controlling the electricity or temperature has increased the level of dependency of businesses on IoT. The use of sensors has gained industry-wide popularity guaranteeing its wide deployment and adoption because of the sensors' significant qualities such as (1) low prices, (2) capability and (3) size.

The vast range applications of IoT are forecasted to transform ordinary everyday objects to valuable intelligent devices that disseminate vital data for effective decision making. IoT is deployed in various forms and devices solely aimed at offering users with real-time information that is crucial for all aspects of life. Therefore, IoT's deployment is evident in (1) wearables such as heart rate monitors for people with acute cardiac difficulties, smart watches for sports people and others to monitor their body's functionality and glucose monitoring devices for patients with diabetes, (2) smart home applications whereby energy usage and temperature levels are controlled to save energy costs, (3) healthcare application where patients' care devices are connected to a network that send signals to care givers' mobile devices, (4) smart cities applications where IoT is used in traffic lights controls, providing important data on cleanliness of water and air in the periphery of the city, for instance, in Palo Alto, California, USA, in order to reduce traffic congestion, sensors are installed in parking areas that alert motorist of occupancy status, (5) agricultural applications where smart greenhouse allows bountiful harvests by managing environmental factors like climate and plant requirements, (6) industrial application like automation where IoT enables faster developments of products and yields high returns on investment as factories become more digitalized, effective monitoring of product flows, better inventory management, assuring safety and security, efficient quality control, packaging optimization, and logistics and supply chain optimization [60]. Therefore, making industries more efficient supersedes

production costs which lead to profits because organizations target cost reduction in all areas while maximizing profits. Hence, different industries have jumped on the IoT bandwagon because it provides (1) manufacturing efficiency by eliminating bottlenecks and minimizing wastage and time, (2) energy efficiency whereby sensors observe lightings, temperature and energy usage in a plant, (3) agricultural efficiency by scientifically detecting soil humidity, anticipating weather changes, ensuring smart irrigation systems to water plants and eliminating water wastages, (4) inventory efficiency by assigning radio frequency identification (RFID) tags on every single product designed to track its location and movements within the inventory management system right up to purchase by customers, (5) improving healthcare systems' efficiency by intensifying surveillance, monitoring, tracking, detection and prevention of viruses and diseases.

IoT defines a system of interconnected devices inclusive of hardware and software such as computers, digital and mechanical devices which are connected together through the Internet for the purpose of monitoring, control, data transmission, etc., which is meant to achieve certain set of objectives without necessary interference from humans at various levels. This has been successfully integrated in our everyday life that most people make use of IoT unknowingly. A simple task as controlling home security, lighting and cooling system amongst other is a very typical application of IoT [28, 42]. It is therefore needless to say that such interesting technology can be used in times of crisis as in the case of the present COVID-19. Several researches earnestly kicked off in the early stage of the pandemic and so much money was invested by government agencies as well as private organization in a bid to handle the situation. This led to some interesting applications of IoT from researchers of engineering and physical science background in an attempt to tackle the challenge by exploring untapped areas and developing new theories and concepts which adapted IoT.

One of the aforementioned developments in the application of IoT is readily seen in India. A group of researchers developed "ArogyaSetu" [51] which is a smartphone-based application to connect the people to the relevant medical services required; similarly, several applications have been developed to tell the proximity of a user to a positively identified patient [29]. Furthermore, Beark et al. [7] have previously developed a smart chair for patients' health monitoring. Their design involved IoT application in remote transfer of data relating to heart rate and blood pressure monitoring. Similar mobile-based applications have been used in scheduling hospital visits [27], fall detection of elderly [36], etc. Majorly, this IoT drive seems to be caused by the expenditure cost relating to medical services, need for solutions to cover up lapses, expanding growth of wireless connectivity and the overall requirement of precise and efficient healthcare targeted to take care of all individuals without bias [46].

Of recent, the expansion of cloud-based computing and analytics of big data have also seen an increased application in the fight against the pandemic. Nowadays, a massive amount of data could be collected with the application of smart technologies such as phones to gather data in real time. Mostly, this have rendered the older methodologies used extremely obsolete to the point that countries with

limited knowledge and capacities have a hard time keeping up. This application of cloud computing and data analysis has been practically implemented by Taiwan. Their adopted model was based on the militarization of case identification as well as suppression and provision of resources. Their methodology was based on the use of big data in acquiring records of personnel immigration history which analysed the data to predict and provide real-time alerts to hospitals when anyone went for clinical visits based on the travel history of the individual and symptoms identified. This was aided by the use of QR codes and connected reports, etc. [63].

In addition to these recent applications, wireless in the medical field is not a new phenomenon. This technology has always been used in fatal electrocardiograms [58], monitoring of patients' breathing parameters [15] and condition in real time, monitoring of ICU patients [9], assistive identification of apnea, stethoscope applications, to mention a few [57]. Similarly, the use of wireless or cloud-based computing has been applied in data storage such as taking record of physiological conditions such as breathing rate, temperature, heart rate, blood pressure, etc. [35]. This has further been enhanced with the increasing development of nanotechnology which has been applied in the development of smart shirts [23] which incorporates an array of sensor networks for monitoring conditions such as heart rate, lung functions as well as other body parameters.

Going by further review of more recent works, we see that smart technologies, which are meant to be less intrusive, interconnected, dynamic and intelligent, are now moderately being developed by less technologically advanced countries as can be seen in smartphones, watches, devices, etc., which is capable of meeting the minimum requirement for effective usability. This therefore explains the predominant adoption of mobiles and smart watches in medical monitoring which in effect boosts the increasing interest in these smart devices. It is now easy to integrate these smart networks in medical applications such as interconnected healthcare services using sensors such as GPS receiver to provide real-time data on the location of users, vision systems for remote connections between medical services and users, and mobile sensors such as accelerometer, gyroscope, etc. could also provide valid data relating to a multi-faceted surrounding situation. More often, these mobile smartphones work in tandem with smart watches [16], smart glasses or other smart devices which can account for the lapses in gathering sufficient data by a single device (Table 1).

As seen in the table above, medical care mobile applications could be designed to support a wide range of functions for varying medical conditions. Of these applications, the major classifications are the apps which provide functions based on embedded sensors to monitor and keep track of health conditions such as heart rate, pulse, oxygen level, etc.; secondly, other apps are based on recommending activities to the users with respect to but not limited to health, nutrition, available stores, etc.; thirdly, other apps provide medical-related tips, advice and other related services in contrast to medical care applications which can be used to schedule clinical appointments or place order for drugs prescription. The potential application of IoT which is categorized under 3 sections as shown in Table 1 could be helpful for supporting disjointed branches of the medical system [59]. However, recent

Table 1 Sample functions of medical care application

Users function	Medical services function	System admin function
Medication compliance	Receive alerts	Resource and communication
Users condition monitoring	Connected medical reference	Sensors data acquisition
Remote care	Remote diagnostic	Health information extraction
Managing conditions history	Health record access	Cloud storage
Wellness/fitness tracking	Time management and scheduling	Adaptive visualization
	Communications and consultation	System management
	Real-time management and monitoring	Optional services (intelligent alerts, recommendations and guidelines, etc.)
	Related education and training	
[17, 19, 30]	[34, 40]	[5, 10]

occurrence has spurred the urgent need as a peer collaborative system working hand in hand to offer a robust model of medical care.

Looking at past emergency preparedness and response, the adoption of smart devices and big data analytics is now being used to interconnect laboratories working on possible vaccines as medical devices. Advancements also include the capability of these wearable sensors to measure cardiac rhythms, biometric data, etc., which increase the ability of these devices to predict or diagnose some existing conditions which may be present as well as for remote patient monitoring in the case of severe conditions which needs to be monitored in real time [54–56]. This potentially maximises the hopes of quickly developing and improving technologies [2]. There is also an overwhelming multitude of open source articles, codes and designs available on the Internet as part of individual's contribution. This has seen the use of thermal imaging, IoT and even ventilators development to assist in rural communities with limited manpower and resources. Although the implementation of thermal imaging is not self-sufficient in adequately detecting possible infection, the combination of this technology with artificial intelligence (AI) and IoT offers endless possibilities [8] provide that there are more accurate and comprehensive real-time information on outbreaks as well as the infection dispersion tracking. This will definitely make the risk management more effective and manageable (Table 2).

Table 2 Current IoT applications in fighting COVID-19 [51]

Methodology	Remark
Interconnected hospitals	This integrates various functions within the hospital facility
Emergency alerts	Allows for quick medical response when required
Treatment management	Unbiased treatment, method selections, etc.
Assignment scheduling	Assists medical personnel in management of duties and work functions
Remote monitoring	This enables remote patient in getting the possible best medical assistance through connected communications service as well as remote medical equipment control
Wireless identification	Application of mobile applications in identity authentication for secure access to facilities, that is, barcodes, etc.
Contact tracing	Applications of internet and GPS services in tracing patients.
Information sharing	Connected real-time and validated information sharing channels.
Rapid screening	Efficient and effective diagnosis through applications of smart devices.
Research	Application in vaccines research, monitoring, etc.
Connected hardware	Connections of medical equipment and other device for real-time information management.
Prediction	Uses statistical analysis to identify and predict future conditions for medical staffs, government agencies, data analyst as well as researchers.

4 Methodology

A subject advances when prior studies are synthesized logically based on the findings of prior studies [31]. Hence, this research is conducted for extracting and analysing literature pertinent to IoT application from various journals and other published articles. This could be helpful for both the practitioners and academicians in formulating a response tailored to the societal needs. Literature reviews, as a research methodology [53], contribute significantly for conceptual, methodological, and thematic development of different domains [24, 39].

In the preparation of this paper, the main source of information was collected from published journals from the database of SCOPUS, Google Scholar and Research Gate coupled with other sources from credible organizations' reports and blogs such as the world health organization, etc. The major key words used in the search were "Internet of Things (IoT)", "Coronavirus", "COVID-19", "Artificial Intelligence (AI)", "Pandemic", etc. Finally, a comparison of the methods applied were made based on information obtained from the journals.

5 Practical Applications of IoT in Combating COVID-19

Given that we are in a digital age surrounded by advancing technology, IoT has a lot of advantages to offer in the way of combating the pandemic. There is an increasing amount of data that needs to be analysed all ranging from immigration records, medical symptoms, transport, entertainment, health sector, etc., and in the case of COVID-19, such analysis becomes critical and needs to be executed without compromising efforts put in place to contain the virus spread. With a large number of IoT devices now in circulation, there is a possibility of a large number of interconnected devices which can be used to form proper management systems in handling the virus effect as well as for making proper decision. Some of the possible applications are briefly summarized below.

5.1 Prediction and Spread Prevention

Early enough in the initial phase of the virus spread from Wuhan, China, smart hospitals were integrated such that they provided additional functions such as the combination of AI and IoT to assist in monitoring incoming patients' conditions such as temperature, oxygen levels, etc. [12]. Other robots were designed to prevent contact between the infected patients and the medical personnel. These robots were tasked with essential services such as in medicine and food delivery, etc. This function highlights the enhanced accessibility and availability towards information related to healthcare system management such that patient's medical information and images, etc. were possible to be stored in the cloud for unobstructed access by designated medical personnel attending to the patient from mobile smart platforms such as phone, etc.

Furthermore, the use of contact tracing applications has seen huge adaptation in most western countries which are mostly hit with the pandemic such as the United States. Contact tracing applications in this case refers to mobile applications that are developed with the sole purpose of tracing and identifying individuals who have been exposed to an infected individual at any point in time while taking into consideration the virus incubation period. This app aims to reduce the data processing cycle and identify connectivity between apps supporting healthcare system. They are also capable of warning, tracing and quickly identifying all persons who have come in contact with an infected patient at one point of another. In less developed countries, most of the tracing is done manually and a major issue with this system is that most of the time, the infected patient may not remember everyone they have been in contact with over a period of time. This application is therefore useful in identifying infection hotspots, isolation setup and diagnosis. The process involved in tracing contacts is initial identification of close contact with and infected person, detailed information of people in contact and finally setting up testing of those individuals as quickly as possible.

Additionally, geo-fencing, which is an existing technology [62], has been previously used in monitoring prisoners [38]. This system combines the use of IoT with wireless network as well as a geographical fence to reduce the number of agents monitoring a group of isolated people. In practical relation to COVID-19 control, when abnormal traits are noticed within an isolated group, it becomes easy to mobilize for transfer and immediate treatment; these are additional steps that can be implemented to prevent virus spread.

Recent data on coronavirus show that there are some cases where patients who are infected might be asymptomatic. This makes early detection more difficult. Moreover, almost eighty percent of infected individuals recover from the virus without any form of medical intervention or specific treatment [64]. However, for the older population, there is a higher risk of the occurrence of complications. To prevent this, it is imperative that alternative and more efficient and effective systems for early detection are implemented. IoT can be combined together with other equipment such as thermal imaging and optical cameras which gathers data for remote post processing which can help in rapid identification of infected patients.

5.2 Treatment

Due to the successful reduction in the total cases in China, other countries have now adopted the use of IoT, thereby bringing it to the forefront of the pandemic fight. According to Forrester's analysis [25], the application of IoT in the Asian healthcare system prior to the virus was estimated to be 7%, and this number has sharply risen with the mandatory implementation of smart systems for measuring people's vital signals such as temperatures in most open spaces and business facilities such as restaurants, train stations, airports, etc. Most of this setup are often analysed in real time.

Given the increasing rate of infection in other regions, prevention and treatment become more strained. This is where IoT comes to play. Technologies such as real-time information and data exchange make the prospect of getting a reliable vaccine more achievable in the shortest possible time. The practical implementation of remote patient monitoring has also assisted frontline medical personnel in treating asymptomatic COVID-19 patients remotely. This has tremendously helped in decongesting medical facilities for more critical cases. This technology implements IoT in monitoring patient's health conditions using wireless sensors [50].

In the process of developing suitable vaccines in fighting the pandemic, AI and IoT are combined to aid the research effort such that possible outcomes can be predicted before trial commences. Similarly, this technology is applied in designing efficient drug delivery system which exponentially increases the drugs testing phase in real time as compared with the standard methodologies previously implemented [13, 22]. This study also studies the reaction to certain drugs based on patient's behaviour and body response [52]. Finally, once a vaccine has been discovered, there will be significant pressure due to the large demand for the

vaccine. This will present a problem at that stage, and hence, there will be need for accelerated mass production of vaccines. Thankfully we are closer to the reality of a commercial vaccine due to advancement in physical, biological and chemical modelling of data toward computer-aided research for potential drugs, and for efficient delivery, AI and machine learning techniques can be deployed for a predictive and prescriptive analysis of the vaccine production. Now scientists and engineers can monitor production parameters through specific location of sensors throughout the whole production process for real-time analysis in ensuring constant research and development, quality control as well as an optimized product [44].

Similarly, in COVID-19 treatment, IoT is currently playing a big role by utilizing AI algorithms as well as interconnecting computing power in others to increase research ability. This can be practically seen in Googles DeepMind which is a platform where findings related to treatments of COVID-19 are constantly being published. Similarly, Benevolent AI is an artificial intelligence system which is purposely set up for the treatment of severe cases of diseases. It is used in building suitable drugs that aid the ongoing search for a vaccine [47]. Furthermore, robots are now being deployed in hospitals which assist medical personnel in the treatment of infected patients. This relieves the overworked staffs as the cases continue to surge.

The use of IoT along with Cloud and AI are leading the way to combat the crisis especially in the United States, Britain, Germany and elsewhere. With the help of global information systems (GIS) on IoT-assisted epidemiologist to track and monitor high-risk infected patients on their mobile data usage which helped in the process of identifying people they have come into contact with and allowing healthcare professionals to adequately act to contain the spread of the deadly virus [20]. IoT was infused into wearables, electrical gadgets and such as smart suits, IoT buttons and electrical thermometers. Smart suits are designed to monitor the human body and signal the patient of changes in body temperature exceeding 37.5 degrees while also analysing the movements of the body. IoT buttons provide advice of any cleaning or maintenance needs that pose grave danger of people contracting the virus as they come into contact with surfaces handled by patients. Electrical thermometers are connected to energy sources which are employed in checking and screening patients and staff for any deviations in temperature as they enter and exit quarantine and hospital facilities [20].

5.3 Direction and Prospect of IoT

Continuous advancements in technology relating to wireless technology, Internet of Things and artificial intelligence have led to the emergence of an hyper-connected world which have attracted practitioners and researchers to develop ways for the practical implementation of these technologies in healthcare services [55, 56]. As of now, the current IoT implementation in the medical field is still at a young stage with promising future prospect if fully developed. The use of this technology however should be based on the main aim of preventing, treating and research towards human

health. This would require more adaptation to other technologies such as machine learning, computer vision for a broader application as well as the development of more secure communication and consultation platform. Finally, future prospect should yield an effective system with a robust quality control across all the nodes of the health sector. Future solutions should also address the issue of interoperability of devices as well as security of user's data.

The future of IoT in health care looks more promising with potentially new frontiers to be discovered in the interaction and connectivity of medical professionals, technology and devices purposed to make the healthcare system smarter and even more successful by ensuring that medical devices are all connected to a network, tracking and monitoring of patients progress, video- and ID-enabled security systems, tagging and tracking of vital assets and organs and effective maintenance of essential equipment done without hampering medical care are the trends in healthcare attributed to IoT. However, certain setbacks have thrown caution in the wind where healthcare administrators are working round the clock to ensure that the extraordinary depth of data available, hurdles of managing and operating network infrastructures and heighted security problems associated with the unprecedented charter of information delay effective implementation of IoT [26].

In the treatment of COVID-19, there have been extensive development and experience gained from the application of Augmented Reality (AR) technology in the study and management of the lung's nodules. This is the integration of virtual information with IoT and can utilize a variety of data streams such as three-dimensional models, registration details, real-time tracking, etc. in the diagnosis and treatment models which are applied towards the treatment of pandemic-infected patients [32, 33]. Additionally, since the COVID-19 is a viral infection affecting the lung and leading to Acute Respiratory Distress Syndrome (ARDS), this means that addressing the symptoms as quickly as possible increases survival rate. Therefore, IoT systems can be tasked with early support for treatments and monitoring of patients which would relieve pressure of medical staffs.

6 IoT—Challenges and Opportunities

While the use of data is crucial to the success of the IoT system, there are a lot of concerns about data management such as the way these data are being collected and managed in terms of storage, processing and accessibility by selected users [2–4]. Needless to say, these concerns are not baseless and must be adequately addressed going by previous experiences with security breach and selling of user's data to government organizations without permission. One major issue regarding data access is the political factor. This is due to the fact that data have now become a gold rush given its potential in influencing geopolitical standings in both government and private corporations. Hence, there is a rush to control this flow of data. This is very obvious in the recent fallout between the United States, United Kingdom and China

in the planned implementation of 5G networks in the country's infrastructure which have generated huge pushback pioneered by the United States [14].

Similarly, this has pitted the famous mobile application TikTok in the middle of a battle between countries due to political reason. Although the Internet services such as the 5G network offers a vast opportunity presented in the form of increased Internet speed, this therefore means more handling of user's data. This political quest to control data will clearly affect the adaptation of interconnected IoT device at an international level. Furthermore, some countries tend to be more critical of others in terms of approach and methodology of handling the pandemic rather than focussing on the productive application of technology in containing the spread. A practical example of this is the obvious disparity in the COVID-19 data of both the United States and China. The virus originated from China with a population of 1.34 billion residents. Common logic would expect that the infection and death rate should be extremely high given the condition of living of its residents as well as it being an epicentre of a novel virus which means it took some time to identify and formally declare emergency. On the other hand, the United States with a mere fractional population of 311 million when compared with China's population accounts for the highest infection and death rate in the world despite the fact that they had enough time to put in place preventive measures. Of course, there might be other factors which accounts for these disparities, we simply cannot ignore the fact that the adoption of these aforementioned technologies had an important role to play in containing the pandemic in China. Due to this geopolitical fight for data control, it is obvious that certain economies will push for their dominant control of critical information which will in turn slow down the international effort geared at controlling the pandemic and developing vaccines if critical information regarding COVID-19 is not freely shared.

Additionally, in implementing a smart interconnected mobile health system, this will require the use of some custom sensors which might be embedded for adaptability. These systems must remain interconnected at all time to ensure a robust and intelligently functioning system [59]. The main issue here is the fact that mobile sensors and applications can only provide limited amount of information. For more critical cases as in remote monitoring of patients, the use of mobile applications to measure parameters such as heart rate, pressure, etc. might not be feasible or entirely inadequate. Also, different healthcare facilities are very much against the idea of data sharing or interconnected scheduling. Furthermore, it becomes a burden for physically disabled individuals to utilize some of these IoT systems set up for monitoring; also, given that some health monitoring applications employ the use of short surveys in determining the well-being of users, this is subject to misinformation being that sometimes, it is not convenient or the users are not in a right mind frame when filling those details [41].

Developed countries such as New Zealand and Australia are also facing challenges that thwarted their best efforts in mitigating the impacts of COVID-19 as the number of new cases surges. COVID-19 has introduced a new trend to business vocabulary which is "stay-at-home-economy" where more businesses and people are taking advantage of social distancing limitations by conducting business while

at home. This new trend has caused a surge in the shipment of IoT devices to 718 million units in 2020 alone from China despite the anxiety and threat of COVID-19. Other similar technologies on high demand are smart personal audio devices which rose to 15.5 percent and wearable bands to 3.8 percent in 2020 alone [43]. These surges in the demand for IoT gadgets will stress the current technological capability and burdening the existing infrastructure as more people are using IoT devices. This will certainly pose monumental challenges like (1) unreliability of the network as more people are connected using more than one IoT devices, (2) huge number of data flowing at any one time making analysis and interpretation difficult reducing real-time application, (3) use of multiple devices creates confusion in tracking, detecting and preventing the rapid spread of COVID-19 and (4) elimination of the human component of the healthcare system affects patients who have the virus.

Irrespective of these issues, there are lots of opportunities which can be leveraged on if the adaptation of IoT is successfully implemented in the fight against COVID-19. Technologies such as cloud computing where data can be processed and stored online offers a unique advantage. This is because it does not require a lot of effort to set up or maintain and IoT enabled health services could be hosted on platforms like this. Also, with the introduction of 5G networks, this greatly increases the speed at which information can be processed online and improves the efficiency of remote patient monitoring as well as other medical services such as contact tracing, testing and even treatment.

7 Conclusion

The advantages of IoT in saving time and money make IoT unavoidable as organizations prioritize their efforts to ensure that effective adoption of IoT is vital for organizations. Therefore, IoT cannot be ignored nor dispensed by organizations but incorporated into their activities to minimize costs and maximize revenues. The long awaited overhaul of the healthcare system through the integration of IoT has taken place as healthcare professionals seek new ways of incorporating IoT in their practices by building infrastructure that can enable implementation of IoT and health care. IoT facilitates connection of medical equipment with Internet and aids in collection and sharing of important information regarding health condition of patients, their life style and treatment process [56]. As a result, vital patients' needs are communicated through a network to the devices of health professionals, which allows them to offer customized services to patients' special needs. IoT has become pivotal in the fight against COVID-19 as governments and health professionals attempt to curb the steady increase of the deadly virus in the efforts to detect, control and predict the spread of COVID-19. By providing an integrated network for healthcare professionals by maintaining connectivity with devices during the critical situation with the virus, vital information is passed on to health professionals which

enables them to act adequately in their pursuit of provided relief and solution to this deadly enemy.

Although smart technologies and IoT have been introduced to the medical sector, there are still several ways that this methodology has not been adequately explored for better services. Drawing from the contents of the preceding sections, it is obvious that IoT is capable of delivering an extensive interconnected system which can be optimally used in tackling the pandemic. This application ranges from infection identification, tracing of infected individuals, management of hospital and healthcare services as well as inter-health service communications for management and research purpose. Though major cities around the world were prepared for potential outbreak of COVID-19, it was observed that these cities had varying policies pertaining to the pandemic control, which led to eventual collapse of the approved protocol that could potentially be avoided if there was a global and unified approach towards research and treatment of the virus. The sharing of data in critical situations will enable a proactive approach in identifying and setting up better measures to combat health-related issues.

This study has highlighted the potential applications as well as the challenges in the implementation of IoT. It is important to note that an unobstructed service is key for the successful implementation of IoT in the fight to contain the virus. Additionally, due to the successful applications in western countries, this model of service can be applied to obtain similar improvement.

8 Limitations and Scope of Future Work

Various challenges of IoT adoption in healthcare practices have been highlighted in this study. The current work doesn't reveal whether the challenges encountered during IoT implementation have equal impact on it or not. In future studies, multi-criteria decision making (MCDM) tools such as analytic hierarchy process (AHP) could be employed to rank these challenges. This would be helpful for organizations interested in IoT integration in their operational practices to rationale their resources [37].

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