Internet of Things for Managing Global Pandemics: Lessons from COVID-19 Pandemic

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***Abstract* - The Internet of Things, often known as IoT, is an innovative technology that connects digital devices all around us, allowing Machine to Machine (M2M) communication between digital devices all over the world, owing to the technological advancements in the 21st century. Due to the convenience, connectivity, and affordability, this IoT is being served in various domains including healthcare where it brings exceptional benefits to improve patient care, uplifting medical resources to the next level. As of now, the IoT is served in various aspects of healthcare making many of the medical processes much easier as opposed to the earlier times. One of the most important aspects that this IoT can be used is, managing various aspects of healthcare during global pandemics, as pandemics can bring an immense strain on healthcare resources. As there is no proper study is done with regards to the proper use of IoT for managing pandemics, in this regard, through our study we aim to provide a comprehensive analysis of various use cases of IoT towards managing pandemics especially in terms of COVID-19 owing to what we are currently going through, along with key challenges and future directions. In this regard, we are proposing a contextual framework synthesizing the current literature and resources, which can be adopted when managing global pandemics like COVID-19 at the national and global levels.**

Keywords - IoT,COVID-19,Pandemic,Healthcare, Internet of Things,Technology

I. INTRODUCTION

The Internet of Things (IoT), as we all know, connects all of the things around us, creating a massive omnipresent network that allows these linked things to communicate with one another. This ubiquitous nature of IoT offers convenient access, fast information dissemination, and high affordability for many of its end users. As of now, this IoT is highly used in healthcare for the enormous benefits it yields, which act as the main enabler for global healthcare [1]. Through the immense benefits that IoT offers, it is evident that it gives us the flexibility for managing lack of medical resources such as infrastructure and medical staff, management of chronic diseases, solving medical issues associated with aging populations, and managing pandemic events [2],[3]-[5]. During the course of a pandemic, the role of smart hospitals (hospitals that automate most of their tasks using IoT), and the role of various smart IoT devices, that can be used towards providing community support, tracking patients, monitoring the patient condition, and capturing and analyzing real-time data is significant for mitigating and controlling most of the adverse effects associated with pandemics, that can control to an acceptable or a minimum level [1].

The aim of our study is to identify and discuss the role of IoT in healthcare towards managing global pandemics, as by the time that we are writing this, we all are still being suffered from the novel coronavirus, termed as COVID-19 virus, where we lost almost over 4 million lives as of now [2]. As in the 21st century, the faith of humanity is mostly dependent on evolution and the development of the novel technologies [3]-[9], we believe, that this IoT has a huge potential for fighting against these kinds of global disasters, owing to its omnipresent nature. This instills motivation for us to investigate how this IoT can be used towards managing global pandemics especially in terms of COVID-19, highlighting its various solutions and applications along with associated challenges and future directions.

Nevertheless, while the entire world fights with the COVID-19 pandemic, which has infected over 157 million people and caused to the death of over 4 million people worldwide, researchers and industry are stepping up their efforts to find effective solutions for managing virus propagation and bringing the pandemic under control, where this IoT based healthcare solutions are increasingly becoming a viable choice [10]. As of now, it is evident that almost every country in the world is looking for adoption of this novel and

emerging technology; IoT, owing to its ubiquitous nature and the cost-effectiveness [11]. Hence, our research aimed to raise awareness about this cutting-edge IoT technology and its potential applications in the COVID-19 pandemic.

The following is the breakdown of the paper's structure. As the basic foundation of our study, we present a brief review of what is a pandemic and on the COVID-19 pandemic in the second section. Next, in the third section, we discuss about IoT. Next, in the fourth section, we discuss, how various applications and services of IoT can be used towards managing global pandemics, highlighting current research contributions. In the fifth section, we discuss the contextual IoT framework that we are proposing towards managing pandemics; also highlighting the current research contribution. In the sixth section, we highlight the challenges associated with the effective use of IoT against pandemics, and in the seventh section, we highlight the anticipated future directions. Finally, we conclude our paper with the conclusion.

II. BACKGROUND

Before discussing how the pandemics can be managed, first, we need to understand what exactly means by this pandemic and how they spread across nations. In simple terms, a pandemic is a contagious disease outbreak that spreads over a vast geographic area and affects a larger proportion of the population, when people have less immune and on the other hand no cure, such as vaccines, is available [3]. It can also spread quickly from one individual to another. An ***epidemic***, according to [9], is a disease that affects a significant number of people in a given location or population, but a ***pandemic***, unlike an ***epidemic***, is an ***epidemic*** that spreads over numerous countries or continents [3],[8],[9].Hence if not managed and controlled, a disease outbreak in a specific region could progressively become a ***pandemic*** with time. All pandemics bring disastrous consequences resulting in loss of lives and social chaos if not managed well.

Throughout the course of human history many pandemics have happened and was brought many adverse consequences to mankind, namely; AIDS pandemic and epidemic (1981 to present); H1N1 Swine Flu pandemic (2009 to 2010); Ebola epidemic (2014 to 2016), and Zika Virus epidemic (2015 to present) [8]. COVID-19 was declared a global pandemic by the World Health Organization (WHO) in March 2020, resulting in approximately 4 million deaths to date. It has quickly spread over the world, with an extremely high worldwide infection rate and death toll.

COVID-19 stands for "Coronavirus Disease-2019," a respiratory ailment caused by the severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2), an infectious virus belonging to the coronaviridae family of single-stranded and positive-strand RNA viruses. SARS-CoV-2, like the typical influenza virus, targets the respiratory system and causes symptoms such as cough, fever, tiredness, and shortness of breath [12],[13]. This was originally reported in December 2019 in Wuhan City, Hubei Province, China. Since then, the COVID-19 has spread like wildfire over the rest of the world in a much shorter time, resulting in the deaths of many people [13].

COVID-19, like all other virus epidemics, poses significant hurdles, including identifying the source of the pandemic (patient zero), minimizing virus dissemination, and incorporating sufficient medical resources to treat all patients with severe symptoms in a timely way [1]-[3].On the other hand, the demand for medical resources would also be increased, owing to the strain created by the pandemic growth. The best example for this is, how the second and third wave of coronavirus in India has created an overwhelming strain on national healthcare facilities, owing to the shortage of oxygen supply and medicines [14]-[25].

The management of pandemics clearly necessitates the identification of infected persons, as well as the tracking and implementation of relevant measures such as social distancing and the use of Personal Protective Equipment (PPE). Recent COVID-19 experiences demonstrate the need of taking a wise and speedy approach to dealing with pandemics to prevent putting an undue burden on healthcare systems/resources and reducing loss of human lives [8].

Since the discovery of the COVID-19, it has been able to spread across all continents, causing many challenges highlighting the need for scalable ways to mitigate such kinds of disastrous pandemics. It is clear that tracing the source of an outbreak, quarantining potentially infected patients, treating seriously ill patients, and preventing cross-infection between medical staff and patients all require a significant amount of human resources, and an accelerated epidemic will put even more strain on medical resources, highlighting the need for a practical and scalable solution [14]-[20], where this IoT comes in to play. Hence, in the next section, we provide a brief review of the pervasive IoT ecosystem.

III. WHAT IS IOT?

The Internet of Things, or IoT, is a scalable and automated solution that has seen spectacular growth in the 21st century, with applications in a wide range of industries, including automated manufacturing, wearable consumer electronics, and asset management [1].Currently, the IoT market is expected to be worth $243 billion by 2021 according to the latest reports [3],[5]-[10]. A typical IoT system comprises several functional components that specialize in ***data collection, data transferring, data analytics, and data storage.*** Data is acquired most of the time by a variety of IoT sensing devices. Following the data collection, the data is transferred to cloud storage for data analytics, which is subsequently used to make decisions [16]-[21].

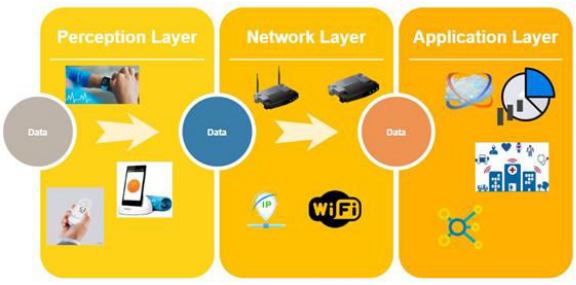

Fig. 1. The IoT architecture

As on Fig. 1, the typical IoT architecture comprises three layers, that is; the perception layer, the network layer, and the application layer. Even though based on the literature there are many representations have proposed, as the basic IoT architecture, the most common and widely available architecture is the three-layer architecture [21]-[24].

Firstly, the perception layer holds the responsibility for the collection of data from a variety of IoT sensing devices; such as smart mobile devices, wearable devices, wristbands, and so on. Secondly, the network layer, which comprises various wired and wireless network connections, processes the data and then transmits the collected data to the application layer. Lastly, the application layer aggregate all these data and then store and process this data in the cloud and provides various services based on its end-user needs. Nevertheless, these IoT devices are embedded with specific IoT protocols that are best suited to the resource-constrained nature of IoT, which hold a key place in the IoT technology stack. These protocols enable IoT hardware to exchange data in a structured and meaningful way, making IoT deployments profitable and successful. Such protocols include Constrained Application Protocol (CoAP), Message Queuing Telemetry Transport (MQTT), and other related lightweight networking protocols [25]-[29].

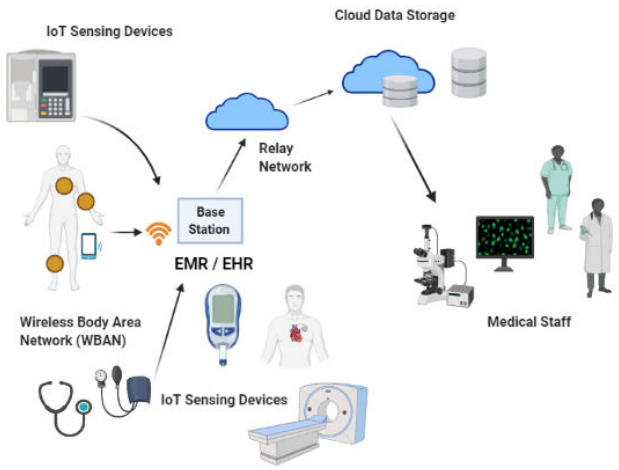

Fig. 2. The typical structure of IoT enabled medical setting.

For better understanding, in Fig. 2. We depict the typical structure of an IoT-configured medical setting. A collection of Body Area Network (BAN) and other IoT monitoring devices first collect patient pathological details and saves them in Electronic Medical Recording (EMR) or Electronic Health Recording (EHR) systems. Then through the base network station and forwarding through the internal medical network, collected data are then saved in the cloud or medical data servers, where medical staff and relevant stakeholders can access these collected data for diagnosis and decision making [8]-[10].

IV. THE APPLICATIONS OF IOT FOR COVID-19

According to [9], the authors have mentioned that the severity and the consequences of the virus depend on several factors. Firstly the population density; when the population is high, higher the disease spread. Secondly, the way that viruses transmit as viruses can spread through, physical contact, some through body fluids and others through air. Thirdly the time that virus can stay contiguous and lastly the social dynamics, where people with bad hygiene firstly affect by the disease outbreak. Hence all these factors affect the widespread of disease. The rapid spread of the COVID-19 pandemic has had negative implications, particularly in developing countries like India, where the death toll is rising by the day, raising serious concerns about how to handle the problem. As a result, most governments set out to find effective strategies to contain the virus and lessen its impacts such as recognizing the source of the pandemic, fast testing, and identification of specific individual patients, and then restricting the spread of the infection by tracking and implementing appropriate measures such as increasing public awareness, social distancing, and facemasks.

In terms of COVID-19, it clearly shows us, that a rapid and robust response approach is needed to lessen most of the deadly challenges associated with pandemics and to minimize the overwhelming strain that is created upon healthcare resources. Also when managing pandemics like COVID-19, as it spread over physical contact and by been in close proximity with an infected individual, recommendations were already developed to avoid crowd, wear face masks and wash hands frequently, whereby practicing these habits infection rate and the disease spread can be reduced to an acceptable level. By doing so, it would give more time to examine the nature of the pandemic and find effective ways to manage the pandemic [8],[9].Towards managing pandemics, IoT provides a ubiquitous platform to collect data about individual patients who are being infected, who are being tested, and tracing the individuals who may have been infected by being in contact or in close proximity with infected individuals. On the other hand wearable IoT devices like smart watches, fitness trackers can be used to continuously monitor vital pathological details (temperature, blood pressure, SPO2 level, heart rate) remotely, reducing the rate of cross-infection of medical staff. Thereby IoT act as a powerful platform for collecting a vast amount of pandemic data, including the data of infected patients [8]-[10]. As of now, researchers worldwide have proposed various approaches using IoT-based wearables, mobile devices, drones, surveillance cameras to monitor various aspects, during a pandemic. Furthermore, devices that use Long-range low-power communication protocols (LPWANs) have enabled data gathering and monitoring to be carried out across vast regions. As the virus spreads over these places, these traits become an important surveillance tool. Software defined wireless sensor networking (SDWSN) in combination with LPWAN technologies, on the other hand, has improved the management and control of thousands of heterogeneous IoT devices, which has the potential to enable health workers to collect data and monitor the coronavirus spread across multiple locations and large communities in a shorter time [6]-[15].

For the time being IoT is already used to manage many aspects of COVID-19 by easing most of the manual efforts to

automate tasks and facilitating for tasks that are difficult for humans to perform or important for ensuring the safety of ones. Following, we highlight these important aspects featuring IoT applications, which could use towards managing pandemics, based on the state of the art, and to the best of our knowledge.

A. Remote patient monitoring

IoT powered remote monitoring or well known as ***Telemedicine*** helps medical staff and caregivers to monitor patient conditions remotely, where most of the IoT devices first gather pathological details from patients and send them to medical staff or caregivers in remote locations for their recommendation, attention, and treatment, so they can take timely actions [1],[3]. This is highly useful in monitoring the condition of patients, who are located in rural areas during a pandemic; that are otherwise hard to reach and to monitor the condition of contagious patients maintaining appropriate social distancing. In this regard, HIPAA compliant video-conferencing tools or wearables IoT devices are being used [3]-[8].

B. Medical management

In terms of the management of healthcare resources during a pandemic, the scalability of IoT is playing a vital role when monitoring patients remotely and managing medical resources such as hospital beds. Gauteng health services in South Africa, for example, implemented an Electronic Bed Management System (eBMS) to determine the availability of beds across several facilities in order to determine resource availability [4],[5]. Further as maintaining social distancing is vital during a virus outbreak daily patient checkups can be easily done using this IoT, as patients themselves can take their temperature, blood pressure and upload the data to the cloud for the attention of caregivers even when they are at their homes. This will also reduce the workload of medical staff and reduce the possibility of cross-infection of medical staff during a pandemic [3],[23],[24].On the whole, IoT would ease the management of healthcare facilitates during a pandemic.

C. Medical supply chain monitoring

In case of a virus outbreak, vaccines are essential as that is the only way to get rid of the virus infection by strengthening the human immunization system. Hence ensuring proper immunizations service is deemed essential for totally eradicating the virus outbreak. As of now, these immunization services have become a challenging issue, especially in developing countries owing to the supply chain logistics issues as most of the vaccines need to keep in a cold environment even during the transportation. To address this problem, the UNDP (United Nations Development Program) and the Indian government collaborated to create an Electronic Vaccine Intelligence Network (eVIN); a mobile-based IoT-enabled solution that provides real-time logistical management across the vaccine cold chain [4],[5].Moreover, GPS-powered tacking and monitoring devices are also found to be helpful in these situations [6].

D. Dissect the virus outbreak

Because of the omnipresent nature of IoT, it can be utilized to track down the source of the outbreak, where during an outbreak, the IoT offers various applications to dissect an outbreak with the use of Artificial Intelligence (AI) technologies (e.g.: Machine Learning and Deep Learning), thanks to the vast datasets collected by IoT sensing devices such as mobile phones . For example, MIT researchers recently used aggregated mobile phone data to track dengue fever's spread in Singapore between 2013 and 2014 [3],[4].

E. Delivery drones

IoT-enabled drones have proven to be effective in identifying patients who violate quarantine regulations (for public surveillance) and bringing medical supplies to hard-to-reach locations, particularly in rural areas. In studies [4] and [5], the authors have discussed how IoT is used to distribute medicines and other critical medical supplies to people in developing countries, especially in Rwanda and Ghana [5].

F. Ensure the compliance with quarantine

IoT could be used to ensure patient compliance with quarantine rules once the potentially infected people have been quarantined. Officials from the Department of Public Health will keep track of which patients have been quarantined and which have not. The IoT data would also help them figure out who else might have been affected [3],[4], and keep track of patients' whereabouts in real time, who are under quarantine. Moreover, various researchers [10], have pointed the efficacy of IoT, towards tracing and tracking people and to get to know whether they are adhering to social distancing guidelines or not.

G. Medical robots

IoT-powered medical robots are often used in clinical settings to perform tasks that are otherwise hard to perform for medical staff such as performing high precision surgeries. This enables us to achieve medical procedures with high accuracy. It is evident that, medical robots are currently being deployed in COVID-19 detection centers to automate most of the operations procedures. According to [6], Patients' temperature can be measured, medicine can be sent to those in quarantine, and even rooms are disinfected with the aid of medical robots.

H. Applications of big data

The term "big data" is one of the most often used buzzwords with the IoT. This concept refers to the vast amount of data that interconnectivity can collect to the point where it is "unprocessable" manually [6]-[8]. In terms of public health, big data technologies have already been employed by China, South Korea, and Australia to create epidemiological maps and monitor transmission chains. In the case of China, IoT-based big data applications are used to assess, if social isolation has been reached or not [6].

I. Related work / Research contribution

The aim of this section is to provide readers with a brief understating of what exact research contributions have made by other researchers and academics with regard to the use of IoT for pandemic management and to reveal the current state of the research. Hence in the following Table 1, we discuss information about the contributions made, with regard to pandemic management from a border perspective.

TABLE I. RELATED WORK / RESEARCH CONTRIBUTION

Ref.	Year	Application / Contribution
[7]	2020	The authors of this study examine the issues faced by fast-moving consumer goods supply chains , as a result of the pandemic lockdown policy, which might be bolstered by various IoT technologies.
[8]	2020	This paper explains how to use smart technologies like the IoT, Mobile Edge Clouds (MEC), and Artificial Intelligence to effectively handle pandemics.
[10]	2020	This paper examines how a worldwide pandemic like COVID-19 has influenced the world of IoT technologies, as well as the contributions that IoT and related sensor technologies have made to virus tracing, tracking, and spread reduction.
[11]	2011	Owing to the reason of lack of adequate and timely medical resources in developing countries, especially in the rural areas, authors propose a corporative IoT approach for better management and control of health in rural areas, which collect health paraments like blood pressure, blood sugar, hemoglobin level, blood sugar and so on.
[12]	2020	In summary, the authors discussed a variety of IoT applications, that can be used to subside the effects of a pandemic; further, in that regard, they discuss 12 IoT applications in particular.
[13]	2020	In a summary, the authors explore how IoT, Unmanned Aerial Vehicles (UAVs), Blockchain, Artificial Intelligence, and 5G technologies can be leveraged to assist lessen COVID-19's impact. Furthermore, they have offered a thorough analysis of the COVID-19 virus epidemic, including information on the infection and its consequences.
[14]	2020	This research shows how 5G and IoT-related technologies can be used and developed effectively to combat the COVID-19 pandemic.
[15]	2021	Because drones or Unmanned Aerial Vehicles (UAVs) have proven to be extremely useful in dealing with the COVID-19 pandemic, this study investigates drone-based systems in pandemic situations and proposes an architecture for dealing with pandemic situations in real-time and simulation-based scenarios.
[16]	2020	In summary , this study discussed how IoT based medical things can be used in an pandemic situations.
[17]	2020	This study provides a review of how emerging technologies and collation of these technologies can be used to manage pandemic, highlighting key challenges and opportunities
[18]	2020	A full examination of Industry 4.0 and its applications in the COVID-19 pandemic is offered, based on relevant search terms in PubMed, SCOPUS, Google Scholar, and Research Gate databases.
[19]	2020	The authors propose a brief review of the general use of IoT solutions in health care, starting with early health monitoring solutions based on wearable sensors and progressing to a discussion of the latest trends in fog/edge computing for smart health, as well as their application in pandemic situations.

V. CONTEXTUAL IOT FRAMEWORK FOR PANDEMIC MANAGEMENT

As discussed above, the IoT utilizes its ubiquitous and interconnected nature for effective data gathering, retrieval, and exchange. This nature of IoT enables necessary stakeholders (medical staff, government officials, social workers, and volunteers, civilians) to always keep on alert and stay connected. Hence employing necessary IoT tactics during the COIVD-19 pandemic; such as tracing patients, monitoring patients would ensure effective utilization of medical resources, where it will lead to subside the strain on healthcare, during a pandemic [1],[3],[11]. With this regard, in this section, we propose a policy-based contextual IoT framework that can be adopted at the national and global level to successfully managing global pandemics like COVOID-19. Firstly, we highlight the current research contributions before highlighting our work to deepening the understanding.

Tangcharoensathien et al. [21], have proposed a framework towards pandemic management, consolidating crowd-sourced ideas from various stakeholders; such as policymakers, medical staff, researchers, students, academics, and other concerned stakeholders. The analysis team, compiled suggestions into a set of fifty proposed actions for a framework for handling pandemics in health emergencies, resulting in six policy implications, based on the crowd-sourced ideas. The WHO's COVID-19 Strategic Preparedness and Response Plan (SPRP) and Monitoring and Evaluation Framework (COVID-19 M&E Framework) outlines critical public health and vital health services and systems indicators to track preparedness, response, and situations during the COVID-19 pandemic in [22]. Reimers and Schleicher hope to use their research to aid in the development and implementation of effective COVID-19 pandemic education responses in [26]. It is evident, that during a pandemic, a lot of strain would create upon the medical resources, such as high demand for hospital beds, trained medical staff, medications such as drugs, vaccines, oxygen, and laboratory testing. Simultaneously frontline medical workers would be under immense pressure due to their heavy workload. As a result in the long term, it will affect their mental health. However, it is evident that many health systems lack a practical model for providing mental health support to frontline staff engaged with the pandemic. Thereby, Adibe et al. [27], described; simple, easy-to-follow framework as an interdisciplinary, proactive effort that promotes staff well-being during COVID-19 developed by Rush University Medical Center in Chicago, Illinois. Ye et al.[28], developed a technical framework to respond to the COVID-19 from a health informatics perspective; to facilitate monitoring, detection, early warning, prevention and control of pandemic. Abdel-Basset et al. [31], present a framework that uses disruptive technologies such as IoT, Medical Internet of Things (MIoT), Big Data, Virtual Reality (VR), AI, and 5G for analysis of COVID-19. The proposed framework restricts the spread of COVID-19 outbreak and ensure the safety of the healthcare teams and maintains patient's physical and psychological healthcare conditions.

After summarizing the current contributions, then in the following, we would like to highlight our contextual IoT framework in Fig 3.

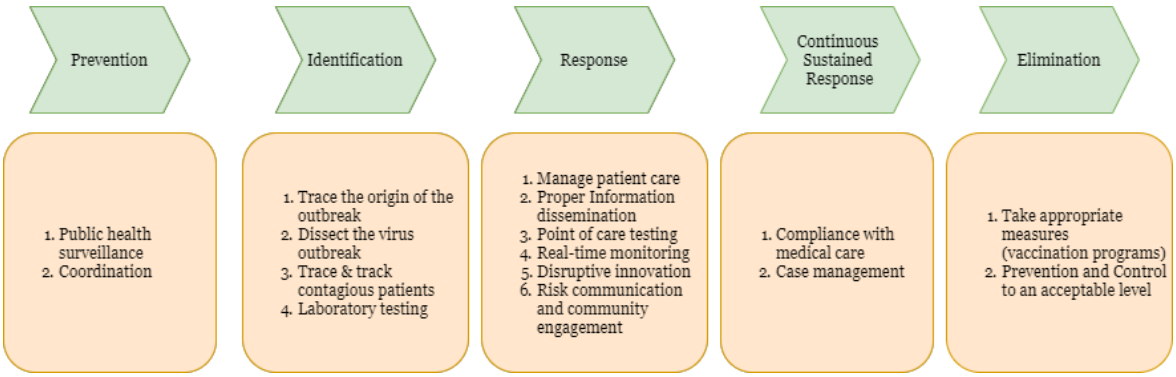

Fig. 3. Contextural IoT Frameowrk

As depicted in Fig. 3, we have apportioned the stages in our framework into five stages that are ***prevention, identification, response, continuous sustained response, and elimination.*** A pandemic should go through many chronographic phases during its formation from simple epidemic in to a global pandemic, which is evident through the literature review we have done. Therefore, we could harness the power of Internet-connected things and accompanying technologies to manage the pandemic appropriately, bring it to an acceptable level, and finally eliminate it from the face of earth. As a result of all of this, we've divided our framework into five phases and identified appropriate policy actions that can be implemented at the national and global levels for each phase.

In the prevention phase, we could take steps to improve national and global public health surveillance by collecting, reviewing, and evaluating health data on a regular basis to identify and track any unusual health incidents, allowing the virus to be tracked, traced, and eradicated at the earliest possible stage, preventing the virus from transforming in to a epidemic and then in to a pandemic. Therefore effective and timely coordination is essential between the ground level medical workers and the policymakers of nations to prevent the virus outbreak, before transforming into a pandemic. In the identification phase, in case that the virus is transformed into an epidemic and then into a pandemic; we can take measures to trace the origin of the outbreak, such as analyzing mobile phone data to identify the spread of the virus; and then dissect the virus outbreak (we can use AI and epidemic simulations) and track the contagious patients and perform continuous laboratory testing for identifying the root cause for the creation of the pandemic.

In the response phase we could take measures as managing the patient care, ensure proper information dissemination among all sort of people in the country, continuous point of care testing, then real-time monitoring, encourage innovation in the community and also risk communication and community engagement. Next in the continuous sustained response phase, we can continuously do all the above-explained measures along with paying higher attention about the compliance with medical care to make sure there is no room for error in the national or the global response strategy against the pandemic and managing the medical cases that may arise , appropriately.

Lastly, by ensuing continuous sustained response and taking deemed essential measures such as continuous vaccination until all the people in the country are vaccinated, we can prevent and control and pandemic to an acceptable level and then eliminate it totally. By adopting all these measures and customizing the measures depending on the needs, we believe this would give strength for successfully manage any sort of pandemic.

VI. CHALLENGES

With regard to the challenges, that IoT may pose, when used for pandemic management, as usual, challenges can be expected around computing power, memory capacity, and storage due to the intrinsic and miniaturized nature of IoT [20]. On the other hand, due to the miniaturized, cheap nature and easy deployment schemes of IoT sensing devices, compared to standardized devices it would make them more worthy in a disastrous situation like a pandemic. Also, the ubiquitous nature of IoT gives the ability to connect to any of the wireless networks resulting in overall effectiveness [26]-[30]. Nevertheless, in a typical medical setting, it totally relies on the transmission of a variety of medical data including patient pathological data from source to destination, where it would make doubt about the security and privacy of underlying medical data that is being transferred. However, most IoT applications in healthcare come with constraints by default; for example, most medical images and footages are of poor quality when transmitted over a communication channel or used in for telemedicine. Hence this can be strengthened with the help of mobile and broadband operators. Furthermore, the key worry when using IoT in the current COVID-19 pandemic situation is the security and privacy of the data that is being shared, which is unique and critical from the patient's perspective [12],[38].

Furthermore, implementing IoT solutions and adopting related technologies typically necessitates a significant shift in

the healthcare workplace. As a result, resistance may occur on both an individual and organizational level, needing careful preparation as well as timely communication with key stakeholders [3].

VII. Future directions

Even though there are a lot of challenges and limitations, day by day IoT is becoming a disruptive technology, offering a wide range of benefits for the betterment of the human race. The disruptive, intrinsic interconnected nature of IoT would make it a viable solution, that people can have a lot of benefits. In the following, we highlight the anticipated future directions of IoT that we can see in the coming years that would be highly beneficial in terms of pandemic management [30]-[37].

- Incorporation with enabling technologies

  In order to increase the performance, communication latency, security and quality of service, the IoT in healthcare would incorporate with innovative and intelligent enabling technologies like AI, VR, Blockchain, Fog, Edge computing and so on, which are are only a few of the enabling technologies that will further fuel and expand the usage of IoT in healthcare that could use to subside the strain on healthcare during pandemics [3],[5]-[10].

- Rise of AI based IoT solutions

  AI-based, machine-learning, and deep-learning technologies are increasingly being employed in the pharmaceutical business in the development of effective medications and clinical trials [13],[39]. Furthermore, by combining satellite and geographical data, these AI-based technologies will be utilized to track and predict epidemics around the world [3].

- Rise of IoT wearables

  The wearable's have been sky rocketed in to the top of the healthcare market in recent years, owing to its convenience, highly mobile nature and popularity. For the time being, Apple, Fitbit, and BlackBerry are creating and upgrading their genuine wearables, adding new health-monitoring functions [3],[10]-[20],[40]. The nature of wearables would be highly beneficial during pandemics as the devices can be used for remote monitoring of the patient condition and tracking the patient location.

- Rise of remote monitoring

  It is evident that, doctor visits could be reduced with the help of telemedicine and related solutions, which become more prevalent. Physicians may examine the pathological aspects of their patients remotely, even during a pandemic, without being exposed to potentially contagious patients. The data made available to health care providers will allow them to fine-tune daily treatment plans on a regular basis, resulting in better overall patient care performance during a pandemic [3],[30],-[35].

VIII. Conclusions

Up to the moment that we are writing this, the impact of the COVID-19 virus extends even beyond our imagination posing many adverse effects forming its third wave. Many of the developing nations especially, India severely affected by this third wave, where more than 6000 deaths happened daily. This would get more worsen if the virus continues to spread further by mutating its genetic sequence. It is evident that the IoT and the associated technologies capable of enabling global medical systems to deal with virus outbreaks already exist; but the important thing is no one can guess the emergence of the next pandemic, as the threat is imminent. Therefore, the important thing is having adequate infrastructure and components for scalable service before the next pandemic, so that the services can be scaled up and expand for disease tracking, patient tracking, and patient care whenever needed. In summary, through our study, we provide a comprehensive analysis about the COVID-19 virus outbreak, its implications, the use of IoT technologies, and its application we can use to fight against the pandemic. Nevertheless, we also proposed a contextual customizable IoT framework that can adopt at national and international levels to eliminate the pandemic, highlighting current research contributions along with key challenges and future directions.

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