Journal of Harbin Engineering University
ISSN: 1006-7043

Vol 45 No. 5
May 2024

COVID-19's Effects on the Adoption of IoT in Transportation, Industry, Smart Buildings, Smart Houses, Smart Cities, and Hospital

Tin Fuk Yeung,
City University of Hong Kong, MSc,

Abstract
Normal life has been disturbed by COVID-19, which has also significantly altered people, organisations', and authorities' policies, priorities, and actions. These modifications are turning out to be a spur for creativity & development. This article examines how the pandemic has affected the uptake of the Internet of Things (IoT) across several major domains, including transport, industrial IoT, automated structures, intelligent houses, and smart towns and cities. This paper offers the first thorough analysis of the major IoT innovations that have affected Covid-19 in the areas of mobility, contact tracing, and healthcare during the epidemic. Every industry is thoroughly examined, and possible uses, the effects on society and the economy, and obstacles to widespread adaption are all covered in great detail. Our examination of the influence on IoT adoption is based on an extensive evaluation of the research information available, a close inspection of papers from top firms of consultants, and discussions with a number of industry professionals. The ability to rigorously manage physical proximity is the key advantage that people who use IoT services during pandemic scenarios enjoy. The biggest issue that individuals are facing, though, is that using IoT devices makes them more socially isolated and less likely to communicate personally. Online questionnaires were used to gather data, and a practical random sampling technique was also employed. Following a three-fold verification process, 260 respondents' correctly formatted responses were examined. The research approach used was empirical and quantitative. While some research has been done on the potential of IoT in China, none has particularly examined the advantages and difficulties of IoT services in various Chinese industries in light of the new normal COVID-19 scenario. Academic researchers, business executives, organisations from various industries, and anybody else interested in learning how IoT services affect pandemics can all benefit from the findings.

Keywords: COVID-19, IoT Services, Transportation, China, Healthcare, Personal Communication, Maintain Physical, Adoption, COVID-19 Situation, Beneficial, Mass Adaptation, Consulting Firms, Barriers, Policies.

I. Introduction

A network of billions of sensors, communicators, and data-sharing devices is called the Internet of Things (IoT). These devices can detect, interact with one another, and exchange data, which can be processed to reveal a wealth of intelligence helpful for administration, planning, and decision-making processes [1]. IoT holds great potential for many industries, including manufacturing, transportation, health care, and agriculture. The Internet of Things has gained popularity, but adoption has proceeded far more slowly than anticipated despite the benefits that have been touted. Several of the principal causes of this include:

- Concerns about trust, policy, protection, and private;
- The lack of specialised labour, lengthy capital cycles, and organisational inertia required for the successful implementation of IoT; [1], and
- Some industries lack compelling use cases with evident returns on investment (ROI).

Since COVID-19 has affected people from all walks of life, the status quo may never fully return. Because COVID19 has broadened or generated novel applications and use scenarios for digital technology, this pandemic is turning out to be a catalyst for the digital transformation. Additionally, it has compelled governments, organisations, and people to modify or adapt their operating procedures, priorities, [1, 2], and opinions on social and ethical concerns. In numerous instances, this has solved or lessened a number of the previously identified causes of the IoT's slower-than-anticipated adoption across numerous verticals. To counteract COVID-19, for instance, authorities have poured enormous sums of money into IoT and related technology. The COVID-19-related modifications to the lifestyle, [2], such as the ability to operate a business from home, have also given rise to new IoT use cases with a definite return on investment, such workforce tracking, remote asset control, and remote collaboration among workers. As a result, a lot of organisations have accelerated their IoT projects and raised their investment in IoT. Fighting COVID-19 has led to a more lenient attitude towards privacy concerns, increased faith in technology, and expedited approval processes [3].

Additionally, this is opening doors for IoT adoption across a range of verticals. The use of IoT in automated structures is also being accelerated by changes to regulations, such as more stringent cleanliness and surveillance standards for commercial buildings [3]. This article examines the possible effects of Covid-19 on the Internet of Things (IoT) adoption across many industries, including transportation, the industrial IoT, connected structures, smart homes, and smart cities. In order to achieve this, we have looked through studies from Gartner, [3, 4], Yole, McKinsey, and other consultancy organisations as well as a thorough analysis of recent pertinent research material. We discover that, at least initially, COVID-19 has not always had a favourable effect on the uptake of IoT across all industries [5]. For instance, most automakers are unable to allocate money to IoT projects mostly as a result of the disaster.

To the greatest extent of our expertise, this is the initial study that describes how COVID-19 has affected the uptake of IoT across various industries. Numerous articles addressing the intersection of IoT and COVID-19 have been out released since the start of the pandemic. Nonetheless, our approach differs greatly in the following key areas. First off, the vast bulk of published publications only address IoT in the healthcare sector. Given that COVID-19 is a health emergency, this is not surprising [5]. But COVID-19 has affected nearly every part of our lives, and here is the first report regarding how it has affected IoT across a range of significant industries, including medical [4, 5]. Secondly, the majority of research that has already been done focuses on the ways in which COVID-19 can be fought using IoT and other technological advances [6]. However, in addition to giving a summary of current IoT projects in various industries following COVID-19, we also talk about how COVID-19 has affected the uptake of IoT in these areas. To put it another way, although the works that have already been done concentrate on how IoT may or may effect COVID-19, [6], we also consider how COVID-19 is affecting (or is predicted to affect) the IoT sectors [6, 7].

Lastly, a large number of the published papers only address current and/or prospective Internet of Things uses for COVID-19. The influence of COVID-19 on the implementation of IoT and the research problems that require to be addressed to promote IoT adoption in various sectors are also covered in this study [7]. The remainder of the document is structured as follows: We give a summary of the research that has already been done on COVID-19 and digital technology, with an emphasis on the Internet of Things. The effects of COVID-19 on several IoT industries, including healthcare, transport, smart buildings, smart homes, smart cities, and industrial internet of things, are covered in detail in Section 3 [7]. We also talk about noteworthy recent actions that were implemented in each of these areas following COVID-19 [7, 8].

During pandemics, it's critical to be able to identify early instances, track down, and quarantine affected individuals. For companies to remain operational and for clients and staff to remain functioning properly, a system is required. Improved solutions for the situations mentioned above are made possible by Internet of Things technologies as RFID as a technology Near Field Communication (NFC), Wi-Fi, Bluetooth Low Energy, [8], or BLE for and GPS technology. In recent years, tiny, practical, and compact devices are integrated into these technologies. The material and technology utilised in a device can affect its ease of use, coverage, cost, processing time, usage of energy, and data rate. In addition to meeting patient needs, IoT assists in controlling pharmaceutical inventory control systems, tracking tagged equipment, such as oxygen reservoirs and nebulizers, and helping healthcare professionals resolve machinery problems more quickly [9, 10].

Since COVID-19 has affected people from all walks of life, the status quo may never fully return. The digital revolution is being sparked by this worldwide epidemic. Additionally, it has compelled governments, organisations, [10], and people to modify or adapt their operating procedures, objectives, and opinions on issues of society and ethics. This has frequently dealt with or lessened the impact of several of the factors cited above that contribute to the IoT's sluggish adoption across numerous verticals [11]. To counteract COVID-19, for instance, governments have made significant resource investments in the Internet of Things and related technologies. As a result of COVID-19-related changes in lifestyle, [12], such as the ability to work and study from to your home, [12], new IoT use cases with demonstrable return on investment, like remote asset control, workforce tracking, and remote employee cooperation, are emerging. As a result, a lot of businesses have accelerated their IoT initiatives and raised money to invest in IoT [12, 13]. Additionally, the battle against COVID19 has led to a less harsh attitude towards privacy concerns, increased technological confidence, and expedited approval processes. Additionally, this opens the door for implementation of IoT across a range of verticals to happen more quickly. The use of IoT in intelligent buildings is also being accelerated by regulatory developments, such as more stringent housekeeping and tracking demands from enterprises. The influence of COVID-19 on the widespread implementation of IoT in many areas, particularly transport, industrial Internet of Things,[13, 14], intelligent structures, smart homes, and smart neighbourhoods, is covered in this study [14, 15]. As explained in Section III, in order to gain a better understanding of how COVID-19 affects the adoption of IoT, we conducted in-depth interviews with over 20 experts from a variety of industries, carefully analysed the most current writing by searching for "COVID-19" and "IoT" on various academic databases, including the search engine Google Scholar, and looked through previously published reports from consulting firms like Gartner, Yole, McKinsey, and others as well.

The Internet of Things is being used in numerous distinct settings. The automation of wearable objects at home is where the application starts. Important information about the emerging field of client relationship management (CRM), with a focus on IoT use in China. Additionally, they helped to create an efficient method of integrating IoT to link customers and businesses. To address issues during COVID-19, an automated and transparent remediation mechanism is being implemented. The step-up procedure for implementing IoT in the healthcare industry is depicted in process Fig. 1, [15], which has been made public. There are a few benefits of IoT use in the healthcare sector.

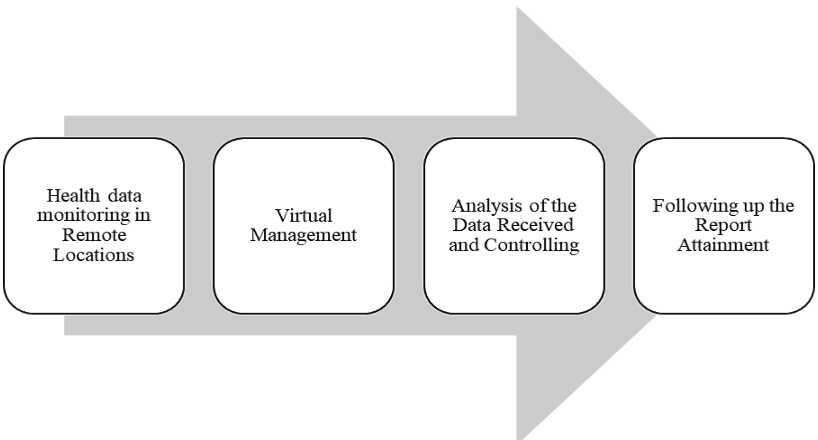

Fig. 1 The IoT-Based Covid-19 Fight Procedure for Health Care Administration.

During COVID-19, it is also being practiced all throughout China. The Internet of Things revolution is incorporating economic, technological in nature, [15], and social changes into our present healthcare system. The health care system is changing from a traditional model to one that is more personalised and allows for simpler surveillance of patients, diagnosis, and therapeutic interventions thanks to connections to the internet of things. In addition to its direct usage in healthcare, wearable technology, [15, 16] freelance employment, automation, drones, selling goods, storage and safety of information devices, tools for communication, online banking, online shopping, and other uses are also making use of it. China is a developing nation, therefore utilising Internet of Things technologies in the midst of a pandemic presents both potential and problems. The applications of Internet of Things across several industries in China are well-known in COVID-19. Next, we will look at the advantages and drawbacks of utilising the IoT's services, which will help us understand the prospects and difficulties associated with IoT devices in China [16].

1.1 Covid-19's Effect on IoT and New Schemes

As a socioeconomic shock, COVID-19 has had a tremendous influence on people's behaviours as well as forcing governments and organisations to reassess their goals and strategies. IoT and other technology adoption is being accelerated by this, particularly in the fields of medical services and smart cities. However, in some industries, [16], including transport, the economic strain brought on by the worldwide financial crisis has had a negative short-term influence on the adoption of technology. But as financial strain lessens in the medium to long run, this pandemic is predicted to hasten the adoption of IoT across a wider spectrum of industries [16].

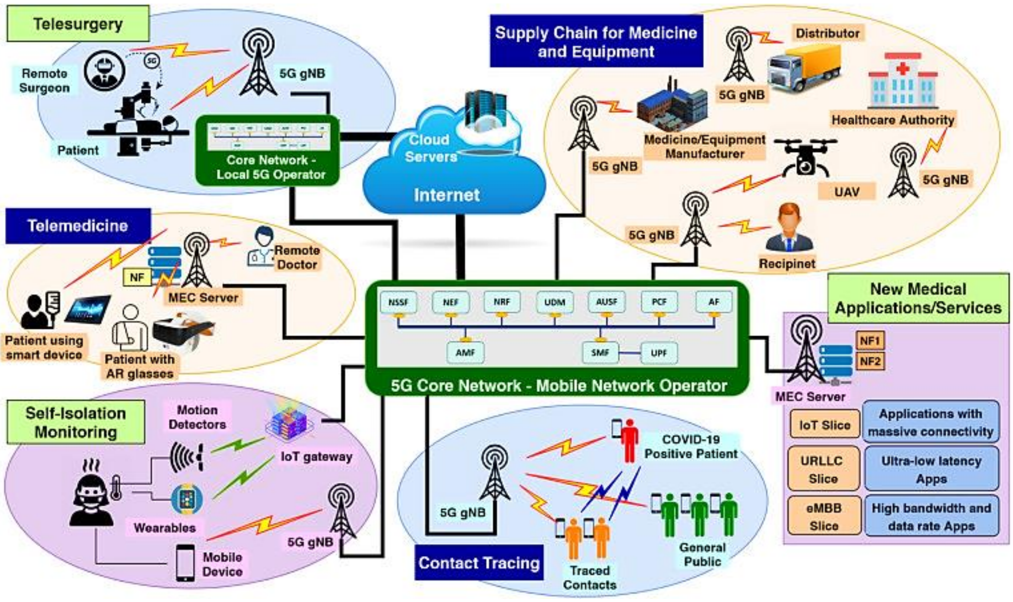

Fig. 2 An illustration of the impact of COVID-19 on IoT research and development [17].

There are many potential to embrace IoT for imaginative ways to get ready for the new normal as a result of alterations in government laws, organisational priorities, and consumer behaviour. It is imperative for investigators and creators to produce new services and products that correspond with the evolving customer habits [17, 18]. Organisations will be forced to revaluate their R&D resources in order to fit with new research topics as a result of the increased needs for products and services. An illustration of how COVID-19 is influencing IoT research and development may be found in Figure 2. The effects of COVID-19 on the adoption of IoT in the fields of medical care, transportation, intelligent structures, intelligent homes, intelligent cities, and manufacturing are discussed in the following paragraphs. We also go over the most noteworthy recent actions that have been made in each of these sectors following COVID-19. We spoke with over 20 experts from various companies to have a better understanding of the wider effects of COVID-19 on various sectors [18].

We note that several of the industries we cover in this article overlap (smart houses or smart transit are frequently regarded as being a part of smart cities). Themes that we think are most closely relevant to the industry are highlighted in each area; for example, in-cab air quality analytics for public transportation is covered in transportation rather than the area of smart cities.

A. Healthcare

Since COVID-19 is a medical emergency, its direct effects on medicine are more evident. According to a recent Juniper Research study, the rapid adoption of IoT platforms in the healthcare sector is predicted to drive a 20% growth in platforms revenue, which will reach $66 billion in 2020 from $55 billion in 2019. Three primary themes are driving the adoption of IoT in the health care sector.

B. Smart Homes

Despite the COVID-19-related economic upheaval, ABI studies indicate that revenue from connected homes will reach $85 billion in 2020, up 4% from 2019 [16]. This, however, is a far cry from the pre-pandemic estimate, which projected a 20% growth in 2020. Fortunately, it is anticipated that these short-term negative effects will pass and that the pandemic will eventually result in positive effects, with income rising to $317 billion by 2026—a 5% rise over before the outbreak estimates. This is mostly due to the fact that adoption-promoting lifestyle and consumer behaviour shifts are here to stay, regardless of whether the pandemic is ended.

C. Smart Buildings

The impact of COVID-19 on construction settings has been significant. Strict security measures have drastically decreased customer foot traffic in constructions, leading to the insolvency of some prominent offline retailers, such as Brooks Brothers Inc. and Ascena Retail Group. The main reason malls are being turned into warehouses is the rise in online shopping following the worldwide epidemic. Simon Property Group, [17], one among the biggest owners of property in shopping centres in the United States, has been in discussions with Amazon regarding the conversion of its anchor department shops into Amazon fulfilment centres. Microsoft Azure had a lack of data centre capacity in Europe. As a result, additional information centres are currently being built to accommodate the growing "x from home" demand. The manner that buildings are supposed to function has also been significantly altered by COVID-19. Examples of these changes include separation from society, population tracking and surveillance, smart HVAC (heating, ventilation, and air conditioning) infrastructure, and more stringent cleaning regulations. Because smart buildings may enable more efficient facility administration and assist promote healthy and secure working conditions, this has led to a major increase in the importance and demand of IoT in the construction sector. Nevertheless, despite the growing significance and consumer demand, [18], short-term investment in smart buildings has primarily suffered because of the strain on organisations' finances. As such, the global smart construction market is anticipated to contract from $49.23 trillion in 2019 to $41.72 billion in 2020. But by 2023, this should have recovered to $54.94 billion.

D. Smart Cities

Numerous aspects of urban life have been impacted by Covid-19, such as decreased use of publicly accessible transportation and traffic, altered patterns of electricity consumption, problems with supply chains, and increased online traffic, among other things. In an effort to combat COVID19 and its effects, municipalities are working to strengthen their technological evolution and resilience to urban hazards, according to a recent analysis by ABI Research. Digital twins, driverless freight, real-time visualisations, drones, and new forms of spying are a some of the innovations that are being used for the new use cases that the epidemic has brought forth. Government are making significant investments in technological advances to assist battle COVID-19 despite the financial impact [18]. For instance, the Government of Singapore proposed a 30% increase in its investment in digitalization, rising from a total of $2.7 billion in 2019 to a whopping $3.5 billion in 2020, in an effort to strengthen the economy and assist businesses in recovering from COVID19. Additionally, China has declared a sharp rise in spending on IoT and associated technologies including 5G, data centres, and smart electricity networks. Figure 5 provides an overview of COVID-19's effects on smart cities.

E. Transportation

Prior to COVID-19, the smart transport market was expected to grow at a significant rate, rising from $94.5 billion in 2020 to $156.5 billion by 2025. This substantial anticipated expansion is threatened by COVID-19, which has previously hindered the market's growth. Over the past year or two, there has been a noticeable decline in the number of trips taken on public transit. There is also a noticeable drop in the number of commuters using subways [19]. Furthermore, there have been reports of shipment delays as a result of port closures in other nations. Road transport continued to run, but with fewer routes. The European Road Freight Rates Benchmark Q1 2020 study states that as a result of these modifications, freight prices have become more volatile.

F. Industrial IoT

Decrease in economic activity due to COVID-19 will have an adverse impact on factory automation as many companies are cutting on their industrial IoT (IIoT) budget. That being said, in mid- to long-term, IIoT is expected to see significant growth due to its importance especially during pandemics or other disasters. A recent McKinsey survey found that 93% of supply chain and manufacturing professionals plan to focus on smart and resilient solutions. A report on India's initiatives for IIoT in wake of COVID-19 focuses on supply chain visibility and sustainable IIoT solutions. It also shows how IIoT can have a bigger impact on returning industries back to normal as compared to other technologies like AI and Big Data [19, 20]. Thus, despite an adverse impact on IoT adoption in industries in the short-term, this pandemic is expected to result in accelerated growth of IIoT in the long run. According to a research analysis, IIoT market will reach $263.4 billion by 2027. Similarly, Juniper Research forecasts that the number of IIoT sensors will increase from 17.7 billion in 2020 to 36.8 billion in 2025.

1.2 Objectives of the study

- Examine the growing utilisation of IoT in residential environments, with a focus on home automation, health monitoring, and remote work.
- Look into how COVID-19 has affected the uptake of IoT in healthcare environments, especially in hospitals.
- Identify the main obstacles that the pandemic has caused in the adoption and application of IoT technologies.
- Propose methodologies for continued investigation into the long-term effects of COVID-19 on IoT adoption.

II. Literature Review

(Abdalla, W., 2023) [21] The timely response and implementation of proper knowledge management methods, together with the facilitation of successful decision-making and management efforts, are essential for the successful handling of the coronavirus disease 2019 (COVID-19) and the pressing need for improved epidemic prevention. The growing utilisation of Smart Cities (SC) technology presents an array of tools that facilitate the collection, appropriation, exchange, and conveyance of information. Nonetheless, handling the massive amounts of data produced by the many SC systems presents a number of difficulties for information management professionals and decision-makers. Filtering, cleansing, preserving, and disseminating only relevant data is essential for managing knowledge connected to COVID-19. Thus, this paper's goal is to examine COVID-19 knowledge management from a SC perspective.

(Bazel, M. A., 2021) [22] A severe crisis in the health and financial markets has resulted from the emergence of the new coronavirus pandemic (COVID-19), which has prompted healthcare providers, health organisations, scientists, and the governmental sector to act quickly. Health care facilities around the world have been severely and unexpected impacted by the COVID-19 pandemic, which has forced current health care systems to operate at full capacity and with limited resources in order to treat individuals who are afflicted. It has become imperative to create swift and creative solutions in light of an ongoing global health catastrophe and the existing scarcity of medical supplies. Consequently, it is now imperative to use cutting-edge technology to combat COVID-19 and fulfil the demands of the pandemic, including detection, monitoring, diagnosis, assessment, surveillance, monitoring, and awareness-raising. Understanding how the health care sector uses these new tools to combat the pandemic is the main goal of this research.

(Sharifi, A., 2020) [23] The community of scientists has been working tirelessly to provide light on a number of topics since the beginning of the COVID-19 crisis, including the processes causing the virus to propagate, its effects on both society and the environment at large, and the plans and policies that will be required for recovery and adaptability. Cities are frequently hotspots of COVID-19 infections due to their dense population and commercial activity. In order to comprehend the effects of COVID-19 on cities, numerous researchers are discovering it difficult to investigate the trends surrounding the worldwide outbreak in urban areas. In this study, we evaluate the literature published during the first eight weeks following the initial confirmed incidents being reported in Wuhan, China, in an effort to present an overview of COVID-19 research connected to communities.

(López-Vargas, A., 2021) [24] Not all nations have been impacted by COVID-19 equally; emerging nations have been more negatively impacted. The COVID-19 pandemic has compelled a reversal in the direction of global progress and the achievement of the Social progress Goals (SDGs). These three SDGs—work, health, and education—are the most severely impacted by the epidemic. The effect of the Internet of Things (IoT) following the establishment of COVID-19 is then examined, with relation to the SDGs, as well as the additional issues that developing nations now confront. During the epidemic, IoT solutions implemented in poor nations have been recognised and examined. Promising Internet of Things for Developing (IoT4D) initiatives have been highlighted with respect to the SDGs. Then, the new social and technological difficulties that the pandemic has brought about for IoT4D are examined. This study recommends that, in the wake of COVID-19, the future of IoT4D should concentrate on the adoption of inexpensive IoT devices for the SDGs that are most impacted by the current pandemic.

(Jiang, H., 2023) [25] When it comes to smart city implementation, urban officials tend to prioritise the technology sector. This frequently results in the treatment of urban challenges in a rather consistent, technocratic, and corporate-led manner. On the other hand, the issue of whether smart city technologies are acceptable deserves more focus. This means that relatively similar urban problems in various circumstances require different methods, and thus, diverse smart city technologies. Put differently, the selection of certain smart city technology is heavily influenced by the setting, as is the choice of the urban issues themselves and the methods by which they are ‘solved' or governed. This study looks at how context affects how technology for smart cities are used to handle urban issues in three different smart city projects: Singaporean Smart Nation, Hangzhou City Brain (China), and Rotterdam Smart City (the Netherlands).

(Foth, M., 2021) [26] Over 2.96 billion people have died and 137 million individuals have contracted the COVID-19 virus globally thus far. Everyone's life has been touched by the swift and comprehensive response to COVID-19 in one way or otherwise. This work conducts a horizon scan to find some of the following the pandemic impacts on design research, adding to the community and reflective assessment of COVID-19's influence. Following a brief examination of some broad ramifications, we go into two main areas: Two main issues are supply chain interruptions and after the pandemic cities. Our study indicates that, despite the possibility of some actions remaining ad hoc and transitory, it is critical to extract a legacy and learning dividend from this deeply upsetting and frightening event. In light of this global catastrophe, we finish with some observations on community action and how design may change to produce more socially and environmentally equitable practices and products.

(Ahmed, S., Yong, J., 2023) [27] The technologies included in this study, which include intelligent machines and the Internet of Things (IOT), are crucial for lessening the negative consequences of this illness as well as encouraging its recovery. It first looks at the financial effects of COVID-19 before hearing about emerging innovations and possible remedies. The goal of the research was to develop a method for using individual cell phones along with private data for self-diagnosing monitoring themselves, and managing yourself of COVID-19. This method made use of cloud services and smartphone apps, as well as a smart Internet of things system, machine learning, robotics, and 5G connectivity. An inventive method is the suggested self-diagnosis-based solution, which uses handsets alone to provide low-cost stored in the cloud data analytics without posing any danger to user data. Global social, economic, spiritual in nature, and cultural frameworks and timetables have suffered since the COVID-19 pandemic. The situation was exacerbated by the anxiety and terror brought on by the new disease, about which the world knew very little. Epidemiologists are and researchers have located the site of the first COVID-19 epidemic in Wuhan, China. A detailed analysis of the virus's genetic composition revealed that it is zoonotic, which means that it originally infected animals before spreading to humans.

(Dionisio, P., 2022) [28] The AIOTI WG Healthcare vision and contributions to the European talks on AI methods applied to the health sector are introduced in this white paper. This paper's primary goal is, using best practices from AIOTI WG Health members, to assist in identifying and resolving any challenges that may be impeding the broader use of AI technology in the healthcare industry. To sum up: In the post-COVID-19 age, the healthcare industry offers a special chance to support the broader deployment of AI. As a matter of fact, the healthcare industry is under tremendous strain as a result of significant internal and external changes that are driving a growth and alteration of its dynamics. AI has the capability to significantly contribute to this transition process by streamlining the distribution of financial and human resources and enhancing the administration of healthcare treatment.

(Akinola, A., 2021) [29] Since the COVID-19 outbreak began, thousands of people have died and life has come to an abrupt halt throughout the planet, placing everyone in an unprecedentedly tough predicament. As of April 26, 2021, the total number of affected infections and fatality tolls from COVID-19 have increased to 146,841,882, and 3,104,743, respectively, due to the virus's global expansion across 212 countries. This poses a serious threat to the nation's health care system. This research provides a new design for satellite-based internet of things (IoT) applications that track using frequency-domain configurable antenna at Ku and K-bands. Four distinct switch techniques are put forward to enable four programmable antennas. Additionally, four-stage switches are utilised to modify the directional antenna surface's resonance frequency in relation to the Ku- and K-bands.

(Shaikh, T. A., 2022) [30] Technologies for extending reality (XR) are quietly developing, and research is already being done on their innovative applications, especially in the medical field. The global market for extended reality is projected to reach a valuation of $209 billion by 2022. Promising outcomes have been observed with XR-assisted remedies for a number of ailments, including Alzheimer's, Schizophrenia rehabilitation following a stroke, recuperation injuries to the head, realistic 3D visualisation, touch-free interactions, educating interpersonal abilities to autistic children, and rehabilitation trauma to the brain. Video gaming therapies like EndeavorRx from Akili Interactive, which was previously licenced by the FDA as an intervention for children with Attention Deficient Hyperactivity Disorder (ADHD), have been utilised to achieve similar benefits. Though there has been encouraging comment on these developments, the field of XR-assisted treatments for patients is still relatively new.

(Heidari, A., 2022) [31] The COVID-19 outbreak has devastated each facet of human existence and caused innumerable fatalities since December 2019. The World Health Organisation (WHO) has declared COVID-19 an epidemic, which has put a great deal of strain on almost all nations, particularly those with underdeveloped health care systems. Deep Learning, or DL, has been utilised in the medical area for many detection applications, such as thyroid evaluation, lung nodule acknowledgment, foetal localization, and retinopathy from diabetes identification. Moreover, multiple clinical imaging modalities, such as Computed Tomography (CT), MRI, and X-ray, make DL an ideal method to combat the COVID-19 pandemic. Motivated by this fact, a significant body of study has been performed.

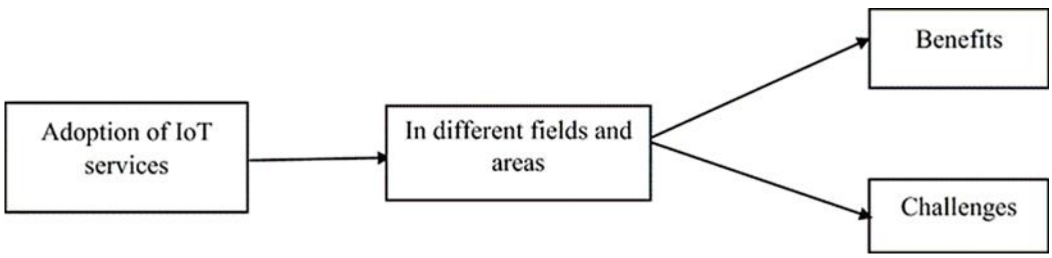

Fig. 3 Research framework.

III. Research Methodology

This section tries to discuss how this survey was created, the number of components it has, how the preciseness of the data it collects is validated, [32], the collection of samples techniques, the parameter and statistical methods for the information obtained, respondent demographics, and reliability and validity evaluations for research musical instruments [32, 33].

3.1 Evolution of instruments

An organised survey was used to gather the primary information for this investigation. The poll included demographic data in addition to three main sections [33, 34]. There are four primary questions in the section on demographic data: Participants' gender, year of birth, work, and degree of education.

3.2 Data and sample gathering

An online planned survey was used to gather data for the present research in May and June of 2021. Convenient sampling was used in the sample process to identify IoT users across various industries. To verify the correctness of the questionnaire data, three confirmation have been carried out. We obtained 0.8960, 0.8491, and 0.3398 as the outcomes [35]. Threefold efficiency means that 74% of the total correctness is represented by the mean of 0.987. A total of 500 respondents completed the internet-based surveys; of these, 70% were men and 30% were women, reflecting the greater participation of men in the nation's many sectors. A response rate of almost 53% was obtained from the 310 questionnaires that were returned, of which 260 were completely answered [36]. The response rate is 35% female and 65% male responders. In terms of age, the majority of responders (53%) fall within the 26 and 35 age group.

3.3 Appraisal technique

Version 28 of the IBM Statistical Package for Social Science (SPSS) was used to evaluate the data gathered for this study. Initially, tests were conducted on both the reliability and validity of the data components. Corrected item-total correlations and Cronbach alpha values were used to assess each construct's reliability and consistency [36, 37]. For every item within the constructs, an exploratory factor analysis was also performed to check the validity of the constructions. Second, using a Likert scale with five points as the level of agreement, descriptive analyses were performed to calculate the rate that this means for each item inside categories [37].

IV. Result

4.1 The demographic profile of the participants

Table 1 shows the respondents' demographic characteristics.

Table 1 Each respondents' profile.

Questions		Frequency (n=260)	Percentage
Gender	M	160	68.79%
	F	100	36.98%
Education	Bachelors	117	43.64%
	Master	128	48.96%
	PhD	15	2.9%
Field and area of use		40	21.96%
Medical		31	22.6%
Wearable devices		94	54.9%
Work place		166	65.9%
Education		24	21.6%
Merchandise		75	64.89%
Bank		41	22.69%
Smart home		18	14.69%

It is clear that most of the respondents were under 35 years old. Of the male attendees, only 5%, 3%, and 2% were underneath 45, below 55, and above the age group, respectively. Of the male individuals, 21% were below 25, 31 percent were below 35, and 5% were below 25. Nevertheless, just 4%, 2%, and 1 percent of female participants were below 45, below 55, and above 55 years of age, respectively, [37], whereas 11% of female responders were under 25 years old, 18 percent were under 35 years old, and so on. Table 1 shows that 35% of participants were female and 54% were male. Table 1 shows that of the 260 subjects, 47% had a bachelor's degree, 48% had a master's degree, and 8% had a doctorate. Respondents were given the task to identify sectors of expertise (not just one field) in which they were utilising IoT services. Table 1 reveals that the majority of participants (63%) worked in the field for learning, 36% utilised IoT services at their places of employment, [38], 29% were bank employees, and 14% were medical professionals.

4.2 The validity and dependability of the research methodology

Reliability is a measure of how well scale elements are consistent within a construct. The level of error-freeness of the study tools is guaranteed by reliability testing. A popular metric for assessing scale dependability and item consistency within is Cronbach's alpha (α). Cronbach alpha can be calculated by comparing the variability from individual item scores to the relationship between each scale's score and the total score of each witness. As can be seen in Table 2, the Cronbach's alpha coefficient values for the advantages and drawbacks of adopting IoT services were 0.7983 and 0.587, [38], respectively. Reliability data supporting the internal homogeneity of measuring scales is provided by Cronbach's values greater than the alpha coefficient of 0.7.

Table 2 An overview of the outcomes of the reliability tests.

Construct	No. of items	Mean	Cronbach alpha	Cronbach's alpha range if one item is removed	Range of the item-total adjusted correlation
Advantages of IoT services	10	3.968	0.569	0.969-0.549	0.549-0.590
Issues with IoT services	12	3.896	0.695	0.648-0.974	0.628-0.419

Table 3 shows that the item-total relationship values of 11 items ranged from 0.407 to 0.617, with the exception of 1 item (adjusted item-total correlation = 0.246) in the first construction used. With the exception of one item (adjusted item-total correlation = 0.465), Table 4's second utilised construct showed that the item-total correlation values of nine items varied between 0.797 to 0.467 [39]. The correlation coefficient for all items should be no less than 0.56. Good internal consistency among the majority of the scale items utilised is indicated by the corrected item total coefficients of the greatest number of items (20 items) from 22 items in two components being above 0.40.

Table 3 Participants' perspectives on the benefits of using IoT.

Items	Mean	Factor Loading	connection between items and totals	Rank
Physical distance is beneficial.	4.89	0.596	0.596	1
Time is saved.	4.59	0.249	0.549	2
Simple to employ	4.41	0.529	0.529	9
Information that is easily accessible	2.59	0.526	0.219	6
Makes Communication Easier	6.49	0.583	0.239	8
It makes contactless operation possible.	2.14	0.698	0.219	3
Decreases Manual Labour	6.69	0.497	0.274	5

Makes Location-based services easier to access	3.59	0.269	0.695	4
It reduces expenses.	2.65	0.659	0.529	7
Services are offered whenever you need them.	6.49	0.549	0.649	10
Services are easily accessible.	6.89	0.699	0.698	11
Guarantees Transaction and Data Processing Security	1.59	0.529	0.396	12

Table 4 Perceptions of participants on the difficulties encountered when utilising IoT services.

Items	Mean	Factor Loading	Item-total correlation	Rank
It widens the social divide.	3.95	0.596	0.529	1
It reduces interpersonal communication.	4.59	0.549	0.695	3
Growing Quantity of frauds	6.59	0.689	0.549	2
Technical Difficulties	3.96	0.649	0.978	4
Fewer employment opportunities or job losses	3.21	0.597	0.696	6
Unauthorised data access	3.96	0.589	0.289	5
Mobility issues	3.56	0.398	0.359	7
Data privacy is jeopardised.	3.89	0.548	0.489	9
Insufficient adaptability	3.54	0.968	0.596	8
It appears intricate.	3.96	0.696	0.896	10

V.Result Analysis And Discussion

5.1 Applications of the Internet of Things (IoT) across industries

Participants in the research were asked to choose how Internet of Things (IoT) services might be used in various industries. According to Figure 3, [39], the majority of people (67%) in the school sector use internet of things services during COVID-19. In offices, almost 35% of users use IoT. The financial industry accounts for a significant portion of users (29%) and the medical industry (14%).

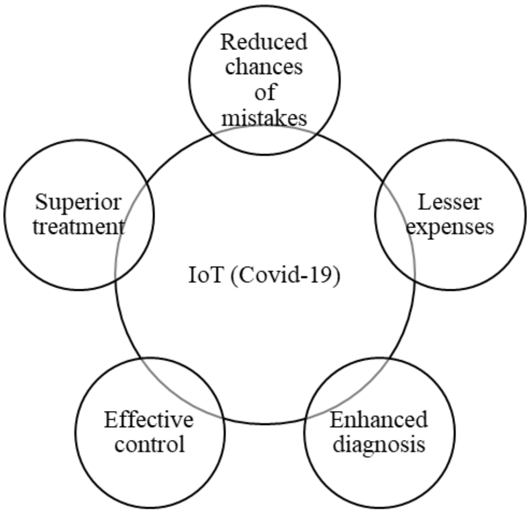

Fig. 4 Principal benefits of IoT use.

5.2 Types of Users

A new type of user appears in F-commerce, also and E-commerce during the pandemic, which makes up around 28% of the total. Nonetheless, [40], just 5% of the workforce is employed in the retail industry.

5.3 Advantages of Using Internet of Things Services

12 elements make up the structures used to investigate the advantages of utilising IoT services. These twelve items were rated by the respondents on a Likert scale of one to five, with 1 denoting significant disagreement and 5 denoting strong agreement".

The greatest advantage of adopting IoT services, according to the results, is "It helps keep a precise physical distance" (Mean = 4.21). This finding validates the theoretical advantages mentioned in multiple research on the significance of utilising the Internet of Things to preserve physical distances during COVID-19.

5.4 Difficulties Met While Utilising IoT Services

Ten things make up the construct that was used to look at the difficulties people encountered when using IoT services. According to the findings, which are displayed in Table 4, "increasing social distancing" (Mean = 3.64), is the difficulty that users of IoT services encountered during COVID-19 the most frequently. The majority of respondents concurred that social alienation is rising as a result of IoT use. The results of IoT use that is prone to social estrangement are corroborated by this top problem [41. The second major obstacle to implementing IoT services in pandemics has been identified as "reducing personal communication" (Mean = 3.64). Numerous individuals reported that one of their biggest challenges is that their usage of IoT has resulted in fewer human connections with others.

These results blatantly contradict the hundreds of studies that have been published discussing technological and technical obstacles to IoT services. The flexibility and complexity of IoT are posing less of a problem to users.

Furthermore, as covered in 3.5, loading of factors is employed to validate study constructs. Additionally, the values of the items-total correlation are above 0.20, indicating a strong association between each item and the final score [39, 40].

VI.Challenges And Key Research Directions

COVID-19 has created numerous possibilities and significant obstacles for the deployment of IoT. Macro economically speaking, IoT adoption must adapt to the significant cultural and economic shifts brought about by COVID-19. A significant change has occurred in the attitudes of people, organisations, and neighbourhoods since the start of the global pandemic. Furthermore, not all of this transition will be reversed in the upcoming years or even later.

a. **Financial Constraints:** One major obstacle impeding the widespread acceptance of IoT is the financial difficulty that many businesses, organisations, and individuals are experiencing. Numerous companies have cut back on or discontinued funding a number of recent or upcoming projects, including Internet of Things ventures. An additional financial burden brought on by COVID-19 is the rising cost of labour for installing devices in areas with limited interaction with others [41, 42].

b. **Privacy and Security of Data:** During the worldwide epidemic, many nations implemented a variety of precautionary measures, including restrictions on people's travel, social distance requirements, and laxer privacy laws [42, 43]. These laws will need to be closely examined after the pandemic is finished to guarantee that people's rights and privacy are upheld.

c. **Context-Aware Sensors Integration of Data:** The awareness of context is a crucial feature for robots and other intelligent equipment. Effective integration and analysis of data collected and gathered from many sources is necessary to achieve this. To detect and clean the places that persons with raised temperatures visited, [43], for instance, disinfection robots can be programmed to use data from other in-building sources, such as CCTV, swipe cards, access databases, sensors that measure temperature, and GPS coordinates from mobile phones and computers.

VII.Conclusion

COVID-19 is demonstrating its ability to stimulate technological advancement and adoption. In order to assess how COVID-19 would affect the widespread implementation of IoT, we have conducted in-depth interviews with numerous industry experts, carefully reviewed and assessed most recent publications, and looked over studies from top consulting companies. Our research on the effects of COVID-19 on the adoption of IoT in several industries, including health care, transportation, industrial IoT, smart buildings, smart homes, and smart cities, is presented in the following article. The findings indicate that a younger demographic—those under 35—is more likely to employ Internet of Things services across various industries. People are mostly using the Internet of Things (IoT) for banking, medical, business purposes, and educational (as educators and learners) during the epidemic. The biggest advantage that people find when adopting IoT services in pandemic conditions is that it makes it easier to rigorously maintain geographic separation. The benefit that consumers value the least, nevertheless, is security-related.

Additionally, we identify a number of issues that require resolution and significant research avenues that require consideration in order to promote faster adoption of IoT in various industries.

VIII.References

[1] Javaid, M.; Khan, I.H. Internet of Things (IoT) enabled healthcare helps to take the challenges of COVID-19 Pandemic. J. Oral Biol. Craniofacial Res. 2021, 11, 209–214.

[2] Chhikara, P.; Singh, P.; Tekchandani, R.; Kumar, N.; Guizani, M. Federated Learning meets Human Emotions: A Decentralized Framework for Human-Computer Interaction for IoT Applications. IEEE Internet Things J. 2020.

[3] Barriga, A.d.C.; Martins, A.F.; Simões, M.J.; Faustino, D. The COVID-19 Pandemic: Yet another catalyst for governmental mass surveillance? Soc. Sci. Humanit. Open 2020, 2, 100096.

[4] Fan, K.; Ren, Y.; Wang, Y.; Li, H.; Yang, Y. Blockchain-based efficient privacy preserving and data sharing scheme of content-centric network in 5G. IET Commun. 2017, 12, 527–532.

[5] Metcalf, D.; Milliard, S.T.; Gomez, M.; Schwartz, M. Wearables and the internet of things for health: Wearable, interconnected devices promise more efficient and comprehensive health care. IEEE Pulse 2016, 7, 35–39.

[6] Hall, M.L.; Harty, C.; Knutsen, H.; Yoo, J. Wearables for health: developing designs for functional practicality. In Proceedings of the 2019 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2019 ACM International Symposium on Wearable Computers, London, UK, 11–13 September 2019; pp. 1034–1036.

[7] Ruth, P.S.; Cao, J.; Li, M.; Sunshine, J.E.; Wang, E.J.; Patel, S.N. Multi-Channel Facial Photoplethysmography Sensing. In Proceedings of the 42nd Annual International Conference of the IEEE Engineering in Medicine Biology Society (EMBC), Montreal, QC, Canada, 20–24 July 2020; pp. 4179–4182.

[8] Siche, R. (2020). What is the impact of COVID-19 disease on agriculture? Scientia Agropecuaria, 11(1), 3–6.

[9] Hobbs, J. E. (2020). Food supply chains during the COVID-19 pandemic. Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie, 68, 171–176.

[10] Pu, M. , & Zhong, Y. (2020). Rising concerns over agricultural production as COVID-19 spreads: Lessons from China. Global Food Security, 26, 100409.

[11] Poudel, P. B. , Poudel, M. R. , Gautam, A. , Phuyal, S. , Tiwari, C. K. , Bashyal, N. , & Bashyal, S. (2020) COVID-19 and its global impact on food and agriculture.

[12] S. Stahie. (2020 (accessed December, 2020)) COVID-19 pandemic increased iot adoption, research finds.

[13] J. O'Halloran. (2020 (accessed December, 2020)) Nearly half of firms to increase investments in iot despite the impact of COVID-19.

[14] M. Ndiaye, S. S. Oyewobi, A. M. Abu-Mahfouz, G. P. Hancke, A. M. Kurien, and K. Djouani, "IoT in the wake of COVID-19: A survey on contributions, challenges and evolution," IEEE Access, vol. 8, pp. 186 821–186 839, 2020.

[15] L. Bai, D. Yang, X. Wang, L. Tong, X. Zhu, N. Zhong, C. Bai, C. A. Powell, R. Chen, J. Zhou et al., "Chinese experts' consensus on the internet of things-aided diagnosis and treatment of coronavirus disease 2019 (COVID-19)," Clinical eHealth, vol. 3, pp. 7–15, 2020.

[16] R. P. Singh, M. Javaid, A. Haleem, and R. Suman, "Internet of things (IoT) applications to fight against COVID-19 pandemic," Diabetes &

Metabolic Syndrome: Clinical Research & Reviews, 2020.

[17] D. S. W. Ting, L. Carin, V. Dzau, and T. Y. Wong, “Digital technology and COVID-19,” Nature medicine, vol. 26, no. 4, pp. 459–461, 2020.

[18] M. S. Rahman, N. C. Peeri, N. Shrestha, R. Zaki, U. Haque, and S. H. Ab Hamid, “Defending against the novel coronavirus (COVID19) outbreak: How can the internet of things (IoT) help to save the world?” Health Policy and Technology, 2020.

[19] Otoom, M.; Otoum, N.; Alzubaidi, M.A.; Etoom, Y.; Banihani, R. An IoT-Based Framework for Early Identification and Monitoring of COVID-19 Cases. Biomed. Signal Process. Control 2020, 62, 102149.

[20] Alam, M.M.; Malik, H.; Khan, M.I.; Pardy, T.; Kuusik, A.; Le Moullec, Y. A Survey on the Roles of Communication Technologies in IoT-Based Personalized Healthcare Applications; IEEE Access: New York, NY, USA, 2018; Volume 6.

[21] Abdalla, W., Renukappa, S., & Suresh, S. (2023). Managing COVID-19-related knowledge: A smart cities perspective. Knowledge and Process Management, 30(1), 87-109.

[22] Bazel, M. A., Mohammed, F., Alsabaiy, M., & Abualrejal, H. M. (2021, September). The role of internet of things, blockchain, artificial intelligence, and big data technologies in healthcare to prevent the spread of the Covid-19. In 2021 International Conference on Innovation and Intelligence for Informatics, Computing, and Technologies (3ICT) (pp. 455-462). IEEE.

[23] Sharifi, A., & Khavarian-Garmsir, A. R. (2020). The COVID-19 pandemic: Impacts on cities and major lessons for urban planning, design, and management. Science of the total environment, 749, 142391.

[24] López-Vargas, A., Ledezma, A., Bott, J., & Sanchis, A. (2021). IoT for global development to achieve the United Nations sustainable development goals: The new scenario after the COVID-19 pandemic. Ieee Access, 9, 124711-124726.

[25] Jiang, H., Geertman, S., & Witte, P. (2023). The contextualization of smart city technologies: An international comparison. Journal of Urban Management, 12(1), 33-43.

[26] Foth, M., Caldwell, G., & Fredericks, J. (2021). A COVID-19 horizon scan looking for post-pandemic implications for design. Foth, M., Caldwell, GA, & Fredericks, J.(2021, Jun 8-11). A COVID-19 Horizon Scan Looking for Post-Pandemic Implications for Design. In Proceedings of Cumulus Roma.

[27] Ahmed, S., Yong, J., & Shrestha, A. (2023). The integral role of intelligent IoT system, cloud computing, artificial intelligence, and 5G in the user-level self-monitoring of COVID-19. Electronics, 12(8), 1912.

[28] Dionisio, P., Nikolov, R., Gyrard, A., Petelova, K., Eberle, W., Sanjuan Vinas, L., ... & O’Murchu, C. (2022). AI for better health: AIOTI WG Health white paper.

[29] Akinola, A., Singh, G., & Ndjiongue, A. (2021). Frequency-domain reconfigurable antenna for COVID-19 tracking. Sensors International, 2, 100094.

[30] Shaikh, T. A., Dar, T. R., & Sofi, S. (2022). A data-centric artificial intelligent and extended reality technology in smart healthcare systems. Social Network Analysis and Mining, 12(1), 122.

[31] Heidari, A., Navimipour, N. J., Unal, M., & Toumaj, S. (2022). The COVID-19 epidemic analysis and diagnosis using deep learning: A systematic literature review and future directions. Computers in biology and medicine, 141, 105141.

[32] Fizza, K.; Banerjee, A.; Mitra, K.; Prakash, P.; Rajiv, J.; Pankesh, R. QoE in IoT: A vision, survey and future directions. Discov. Internet Things 2021, 1, 4.

[33] Hameed, S.; Khan, F.I.; Hameed, B. Understanding Security Requirements and Challenges in Internet of Things (IoT): A Review. J. Comput. Networks Commun. 2019, 2019, 1–14.

[34] Rahmani, A.M.; Mirmahaleh, S.Y.H. Coronavirus disease (COVID-19) prevention and treatment methods and effective parameters: A systematic literature review. Sustain. Cities Soc. 2021, 64, 102568.

[35] Wala Vera, J.M.; Tobón, L.E.; Gómez, J.A.; Culman, M.A.; Aranda, J.M.; Parra, D.T.; Quiroz, L.A.; Hoyos, A.; Garreta, L.E. Review of IoT applications in agro-industrial and

environmental fields. Comput. Electron. Agric. 2017, 142, 283–297.

[36] Kamal, M.; Aljohani, A.; Alanazi, E. IOT Meets COVID-19: Status, Challenges, and Opportunities. arXiv 2020, arXiv:2007.12268.

[37] Bahuguna Y, Verma A, Raj K (2018) Smart learning based on augmented reality with android platform and its applicability. In: 2018 3rd International conference on internet of things: smart innovation and usages (IoT-SIU), pp 1–5.

[38] Bai L, Yang D, Wang X, Tong L, Zhu X, Zhong N, Bai C, Powell CA, Chen R, Zhou J, Song Y, Zhou X (March 2020) Chinese experts' consensus on the internet of things-aided diagnosis and treatment of coronavirus disease 2019. Clin eHealth 6(111).

[39] Bassam N, Asif H, Qaraghuli A, Khan J, Sumesh E, Lavanya V (2021) IoT based wearable device to monitor the signs of quarantined remote patients of COVID-19. Inform Med Unlocked 24:100588.

[40] Bluetooth (2020) Fighting against COVID-19 via privacy-first Bluetooth tracing.

[41] Cascella ACSCDM, Rajnik M, Napoli RD (2020) Features, evaluation and treatment coronavirus (COVID-19)

[42] Chai PR, Zhang H, Baugh CW, Jambaulikar GD, McCabe JC, Gorman JM, Boyer EW, Landman A (2018) Internet of things buttons for real-time notifications in hospital operations: proposal for hospital implementation. J Med Internet Res 20(8):e251.

[43] Chakraborty I, Maity P (2020) COVID-19 outbreak: migration, effects on society, global environment and prevention. Sci Total Environ 728.