Review Article

Internet of Things (IoT) Adoption Model for Early Identification and Monitoring of COVID-19 Cases: A Systematic Review

Abstract

Background: The 2019 coronavirus disease (COVID-19) is a mysterious and highly infectious disease that was declared a pandemic by the World Health Organization. The virus poses a great threat to global health and the economy. Currently, in the absence of effective treatment or vaccine, leveraging advanced digital technologies is of great importance. In this respect, the Internet of Things (IoT) is useful for smart monitoring and tracing of COVID-19. Therefore, in this study, we have reviewed the literature available on the IoT-enabled solutions to tackle the current COVID-19 outbreak. **Methods:** This systematic literature review was conducted using an electronic search of articles in the PubMed, Google Scholar, ProQuest, Scopus, Science Direct, and Web of Science databases to formulate a complete view of the IoT-enabled solutions to monitoring and tracing of COVID-19 according to the FITT (Fit between Individual, Task, and Technology) model. **Results:** In the literature review, 28 articles were identified as eligible for analysis. This review provides an overview of technological adoption of IoT in COVID-19 to identify significant users, either primary or secondary, required technologies including technical platform, exchange, processing, storage and added-value technologies, and system tasks or applications at "on-body," "in-clinic/hospital," and even "in-community" levels. **Conclusions:** The use of IoT along with advanced intelligence and computing technologies for ubiquitous monitoring and tracking of patients in quarantine has made it a critical aspect in fighting the spread of the current COVID-19 and even future pandemics.

Keywords: *Coronavirus, COVID-19, Internet of Things, systematic review*

Mostafa Shanbehzadeh, Raoof Nopour[1], Hadi Kazemi-Arpanahi[2,3]

Department of Health Information Technology, School of Paramedical, Ilam University of Medical Sciences, Ilam, [1]Department of Health Information Management, Student Research Committee, School of Health Management and Information Sciences Branch, Iran University of Medical Sciences, Tehran, [2]Department of Health Information Technology, Abadan University of Medical Sciences, Abadan, [3]Department of Student Research Committee, Abadan University of Medical Sciences, Abadan, Iran

Context

The 2019 coronavirus disease (COVID-19) is a highly contagious disease that has affected a large portion of the population. It is caused by severe acute respiratory syndrome coronavirus-2. The World Health Organization has declared COVID-19 as a public health emergency.[1-4] Currently, with the lack of approved pharmaceutical treatments or vaccines to cure this disease, there are many ongoing efforts to mitigate the spread of the virus (i.e., "flatten the curve").[5,6] Governments across the world are struggling to control the spread of the virus by issuing severe restrictions, such as implementing social distancing, contact tracing, and quarantine, and adhering to the guidelines of safety and precautions provided by the health officials. But implementing such restrictive and large-scale procedures is a huge challenge.[7] Moreover, during this pandemic, health care facilities are looking for practical and cost-effective solutions for early detection, monitoring, and tracking of infected persons in the population who can be contagious (symptomatic or asymptomatic carriers).[8-10] It is thus highly desirable to develop a smarter and integrated virtual surveillance system to ensure effective COVID-19 control and to reduce the spread across the community.[11,12]

In recent years, Internet of Things (IoT) has received significant worldwide attention and has become ever more available for predicting, preventing, and monitoring infectious diseases.[6,13] In this context, IoT technology has been shown to be a safe and efficient way of dealing with the COVID-19 pandemic due to its ubiquitous sensing ability and seamless connectivity.[14] The IoT is an advanced technology that refers to an interconnected web of real objects, sensors, and appliances for sensing, compiling, processing, monitoring, and

Address for correspondence:
Dr. Hadi Kazemi-Arpanahi, Assistant professor of Health Information Management, Department of Health Information Technology, Abadan University of Medical Sciences, Abadan, Iran.
E-mail: h.kazemi@abadanums.ac.ir

Access this article online

Website: www.ijpvmjournal.net/www.ijpm.ir

DOI: 10.4103/ijpvm.IJPVM_667_20

Quick Response Code:

How to cite this article: Shanbehzadeh M, Nopour R, Kazemi-Arpanahi H. Internet of things (IoT) adoption model for early identification and monitoring of COVID-19 cases: A systematic review. Int J Prev Med 2022;13:112.

managing a variety of information of our daily life.[15,16] Besides, the reliable IoT networks provide timely crucial information that can help in taking timely decisions.[17,18] Health care can be identified as one of the major application domains for the IoT. Internet of Health Things is a health care–specific version of IoT that aims to connect patients to health care settings for real-time monitoring and control of their clinical features such as health status, activities, and vital signs.[19-21]

In this pandemic, IoT has the potential to deal with huge amounts of data received from sensors used by a number of applications to battle against COVID-19. Our goal in this study is to review the IoT-based solutions combating this pandemic according to the "Fit between Individuals, Task, and Technology" (FITT) framework for determining its target users, technological requirements, system tasks, and processes.

Evidence Acquisition

The FITT framework provides a theoretical foundation for this comprehensive systematic literature review (SLR), and data extraction was guided according this framework. FITT technology adoption model was presented by Ammenwerth *et al.*[22], which takes into account the system individuals, tasks, processes, and technologies. Our SLR is reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standard guidelines, which describe the identification, screening, eligibility, and inclusion criteria of the articles that fall under the scope of review.[23]

Data sources and search strategy

An extensive SLR was performed using six scientific databases – PubMed, Google Scholar, Scopus, Web of Science, Science Direct, and ProQuest – from June 30 up to November 1, 2020. The following search terms were used (designed using English MeSH keywords and Emtree terms): [COVID-19 OR Novel coronavirus OR nCoV] AND ["Internet of Things" OR "Internet of Medical Things" OR "Internet of Health Things" OR "Medical Internet of Things" OR "IoT" OR "IoMT" OR "IoHT" OR "MIoT"]. After the adoption of advanced search option (search formula: combining key terms, search operators [AND and OR] and search fields: Title, Title/abstract and Topic) and applying the inclusion and exclusion criteria (via search filter or refine result), the titles and abstracts of potentially relevant studies were identified. Details of the search strategy are shown in Table 1.

Study selection

Some inclusion and exclusion criteria were determined for screening articles. Full-text articles were obtained for detailed evaluation, and eligible studies that used IoT solutions or strategies based on the FITT framework during the COVID-19 pandemic were included in the systematic review. Editorials, commentaries, conferences papers, case reports, duplicates, non-English papers, letters to editor, commentary papers, book chapters, short briefs, technical reports, and those published before the year 2020 were excluded. As COVID-19 is a rapidly evolving field, we included preprint literature.

Data extraction and quality assessment

To minimize bias, two reviewers (H: K-A and M: SH) participated independently through each phase of review and screened the titles and abstracts of articles according to predefined criteria. The authors screened the full-text reports and decided whether they met the inclusion criteria. Any vagueness during the study selection process was resolved by further discussion. The studies that met our predefined inclusion criteria were screened, and the studies that completely fulfilled our inclusion criteria were extracted for deeper analysis and data extraction.

Table 1: Search syntax

Databases	Search syntax
PubMed	((((((COVID-19[Title]) OR (coronavirus[Title])) OR (n-CoV2[Title])) AND (Internet of Things [Title/Abstract])) OR (IoT [Title/Abstract])) OR (Internet of Health Things [Title/Abstract])) OR (IoHT [Title/Abstract]) OR (Medical Internet of Things [Title/Abstract])) AND LANGUAGE: (English), limited to 2020.
Google Scholar	allintitle: "COVID-19" OR "novel Coronavirus" OR "n-CoV2" AND "Internet of Things" OR "IoT" OR "Internet of Health Things" OR "IoHT" OR "Medical Internet of Things" AND English[lang], limited to 2020-01-01 to 2020-11-1.
Scopus	(TITLE (COVID-19) OR TITLE (novel Coronavirus) OR TITLE (n-CoV2) AND TITLE-ABS-KEY (Internet of Things) OR TITLE-ABS-KEY (IoT) OR TITLE-ABS-KEY (Internet of Health Things) OR TITLE-ABS-KEY (IoHT) OR TITLE-ABS-KEY (Medical Internet of Things) AND (LIMIT-TO (LANGUAGE, "English") AND PUBLICATION YEARS: (2020)).
Web of Science	TITLE: (COVID-19) OR TITLE: (novel Coronavirus) OR TITLE: (n-CoV2) AND TOPIC: (Internet of Things) OR TOPIC: (IoT) OR TOPIC: (Internet of Health Things) OR TOPIC: (IoHT) OR TOPIC: (Medical Internet of Things). Refined by: LANGUAGES: (ENGLISH) AND PUBLICATION YEARS: (2020).
ProQuest	ti (COVID-19) OR ti (novel Coronavirus) OR ti (n-CoV2) AND ab (Internet of Things) OR ab (IoT) OR ab (Internet of Health Things) OR ab (IoHT) OR ab (Medical Internet of Things). Applied filter: time span: 2020-01-01 to 2020-11-1 AND English.
Science Direct	TITLE ("COVID-19" OR "novel Coronavirus" OR "n-CoV2") AND TITLE-ABS-KEY ("Internet of Things" OR "IoT" OR "Internet of Health Things" OR "IoHT" OR "Medical Internet of Things") AND English[lang], limited to 2020.

Summarizing results

The results were organized based on IoT adoption models (FITT framework).

Results

Characteristics of included studies

The initial search in scientific database yielded 248 citations; 142 of which remained after omitting the duplicates through the emerged endnote library (reference tools bar > find duplicates) and 53 of which remained after removing non-English, those published before 2020, and the document-type ones (editorial, commentary, report, case study, and conference paper). In the last screening phase, 28 articles were identified as eligible studies that met our criteria [Figure 1].

Table 2 summarizes the general characteristics of the included studies based on author names, country, design and setting, and IoT digital services.

All included studies are summarized in Table 3 based on the FITT model in three classes: Individual, Technology, and Task.

The analysis revealed that the IoT platforms that were used to fight against the COVID-19 pandemic were classified into three main sections as follows.

1. IoT individuals

Based on the findings of the "Individual" column in Table 3, IoT stakeholders are categorized into three classes according the degree of their interactions. In this regard, the main stakeholders of IoT for managing COVID-19 classified as first level include the health care providers[6,13,18,19,24,26,29-37,39,42-46] and society.[6,13,18,19,24,26,29-37,39,42-46] The next level of IoT stakeholders include public health authorities,[6,13,24,33,38,40,43-45,47] academicians, scientists, and researchers.[18,25,27,29-31,33,34,38,40] Finally, the third level includes educational staff,[28] IT (information technology) vendors,[25,31] economists,[18] third parties,[31] and engineering[25] [see Figure 2].

2. IoT technologies

Technological requirements that used to establish IoT for COVID-19 management are classified into five classes, which include technical platform,[13,18,19,25,30,31,34,35,40-43,47-50] processing,[6,25,31,35,36,47,49-51] network,[6,25,35,49,50] storage,[6,18,19,25,31,34,36,37,46,48] and added-value technologies[19,27,34,36,40-42,47,51] [see Figure 3].

Platform

Smart cell phones,[13,18,19,25,28,30,31,35-38,40-44,46,47,50,52] portable digital tools (e.g., microcomputers such as palmtop, tablet, notebook),[27,28,34,37,39,40,43,46,47] and wearable devices[13,18,19,25,30,31,34,35,41-43,40,47-50] are the most commonly used technological platforms in the IoT. But the application of nonportable technologies[25,36,39,41,42,45] was insignificant.

Processing

Application of location-aware technologies (e.g., GPS [Global Positioning Systems], GIS [Geographic Information Systems], remote sensing, and geofencing),[6,25,31,35,36,47,49,50,51] intelligence systems (CDSS [clinical decision support

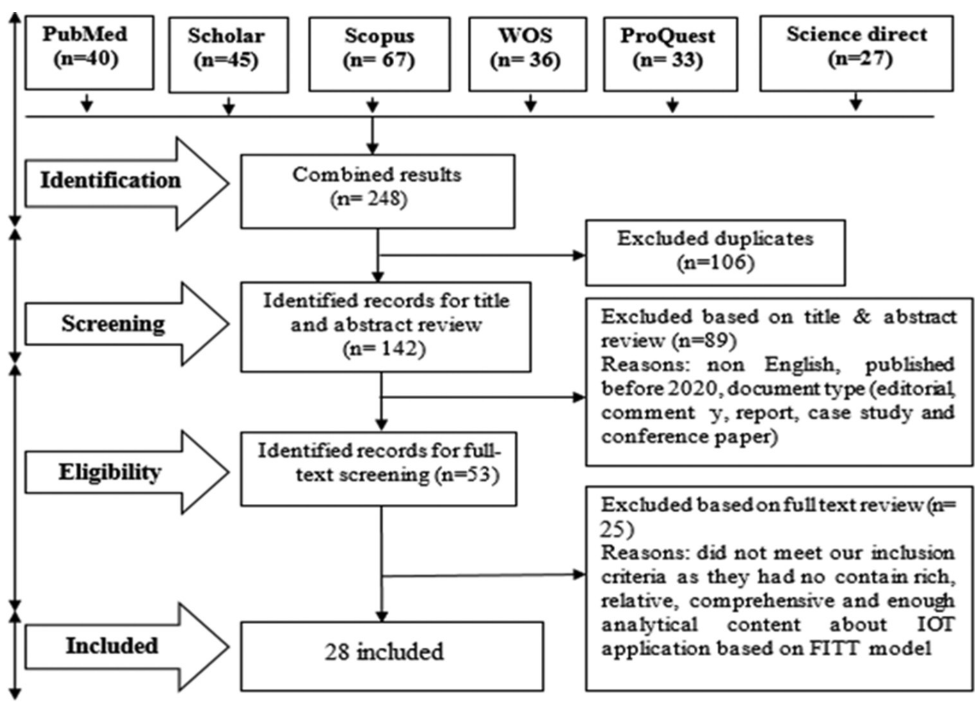

Figure 1: PRISMA chart in the study selection process

Table 2: Summary of reviewed articles

Reference	Country	Design and setting	IoT digital services
Xiao *et al*.[24]	China	Developmental	Smart real-time monitoring of physiological data
Wang *et al*.[25]	China	Developmental	Social relationships between mobile devices for geofencing
Moro Visconti *et al*.[26]	Italy	Literature review	Telesurveillance via digital public–private partnership
Vafea *et al*.[27]	USA	Review	Collaboration in the scientific community with open sharing of knowledge and expertise
Swayamsiddha *et al*.[19]	India	Literature review	Application of cognitive radio–based IoT for quarantine management and real-time monitoring
Siripongdee *et al*.[28]	Thailand	Literature review	Interaction, collaboration, and communication via blended learning technique
Pratap Singh *et al*.[29,30]	India	Review	IoMT-enabled remote tracking
Ye *et al*.[31]	China	Review	Real-time case detection and tracking through new health informatics
Rahman *et al*.[13]	USA	Review	Real-time surveillance, simultaneous reporting, and monitoring
Tripathy *et al*.[32]	USA	Developmental	Contact tracing over mobile phone location
Allam and Jones[18]	Australia	Prospective	Monitoring and management of diseases via open device connectivity
Adly *et al*.[33]	Egypt	Review	Self-quarantine and remote management and care for patients
Bai *et al*.[6]	China	Developmental	Medical IoT–aided diagnosis and treatment
Bayram *et al*.[34]	Turkey	Review	Public health decision and policy making using digital technologies
Ben Hassen *et al*.[35]	Tunisia	Developmental	Home telemonitoring (home telemetry)
Capobussi and Moja[36]	Italy	Review	Home telelaboratory and telemetry using IoT
Celesti *et al*.[37]	Italy	Developmental	Tele-medical laboratory
Chamola *et al*.[38]	India	Review	Remote thermometry and basic physiological data assessment
Chaudhari *et al*.[39]	India	Review	Real-time monitoring of the health parameters of patients and self-quarantine persons
Ting *et al*.[40]	Singapore	Review	Community-based real-time telemonitoring
Rehm *et al*.[41]	USA	Developmental	Tele-ICU monitoring of patient's vital signs (biosensors)
Kumar Singh *et al*.[42]	India	Developmental	Telequarantine management
Yu *et al*.[43]	USA	Review	Spatiotemporal outbreak detection
Mohammed *et al*.[44] Praveena and Sruthi[45]	Malaysia	Developmental	Real-time early detection and tracking (biosensors)
Oyeniyi *et al*.[46]	Nigeria	Prospective	Improving medical decision accuracy and precision (decision supporting)
James *et al*.[47]	UK	Review	Real-time monitoring of mobility and lockdown assessment

IoT=Internet of Things, IoMT=Internet of Medical Things, ICU=intensive care unit

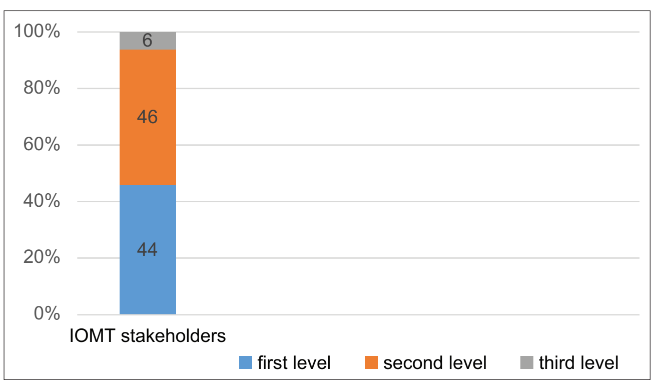

Figure 2: IoT-based COVID-19 stakeholders

system] and decision dashboards),[13,28,44,52] artificial intelligence (AI) technologies (machine learning and deep learning),[18,19,36,37,39,43-45,51] and biosensor processors such as *wearable or nonwearable* technologies,[25,41,42,45,46] special sensor (voice, image, and facial processors)[47-50] are the well-known techniques in providing added-value capabilities for real-time tracking, online telemonitoring, effective identification, and decision supports.

Exchange (Network)

According to network application in different geographical areas, we categorized Wireless Field Connectors into two classes as follows:

1. Close Area Networks such as Bluetooth,[28,30,31,37,41,42] RFID (radio-frequency identification),[6,25,35,49,50] WBAN (wireless body area networks)[1] and Zigbee[28,46]
2. Broad Area Networks such as mobile technology (GSM [Global System for Mobile Communications] or 4G and 5G networks),[6,13,19,27,28,36,43,47,52] Wi-Fi,[13,28,30,35,38,47,49-51] WSN (wireless sensor network),[39,48] WiMAX (Worldwide Interoperability for Microwave Access),[12] and internet connection.[31,36,41,42]

Storage

Using cloud storage area[6,18,19,25,31,34,36,37,46,48] and shared health databases[18,19,30,40-42,45-47] for backup and permanent accessibility to data is compatible with IoT requirements during the COVID-19 pandemic.

Table 3: IoT-based FITT model to fight against COVID-19

Reference	Individual	Technology					Task
		Platforms	**Processing**	**Exchange**	**Storage**	**Added-value technologies**	
Xiao *et al*.[24]	Providers and patients	Wearable/portable devices	Decentralized applications and smart contract	WBAN	Cloud server and EHR	Combination of IoT and blockchain	Smart monitoring of the isolated persons (geofencing)
Wang *et al*.[25]	Epidemiologists, researchers, and IT vendors	Smartphone and wearable tools	Geospatial Processor System (GPS)	Wireless network signaling (Wi-Fi)	-	Big data analysis	Real-time telemonitoring
Moro Visconti *et al*.[26]	Patients and medical doctors	Digital kiosks and m-health apps	Spatial decision support system and deep learning	GSM	Interoperable cloud databases	Machine learning and blockchains	Real-time surveillance
Vafea *et al*.[27]	Researchers, scientists, and engineering	Biosensors, Nanotechnology, mobile apps	Mathematic and computational modeling	Wireless Bluetooth and radio-frequency technology	Central cloud server	Deep learning and big data analysis	Open sharing of knowledge and real-time telemonitoring
Swayamsiddha *et al*.[19]	Policy makers and city officials	Wearable biosensors	AI	5G network, and Cognitive Radio Network	Local shared database	Blockchain and cloud computing	Remote and real-time tracking and surveillance
Siripongdee *et al*.[28]	Teachers and students	Narrowband IoT	AI	WSN, GSM	-	-	Web-based learning
Pratap Singh *et al*.[29,30]	Researchers, academicians, and scientists	Portable (mobile, wearable)/nonportable (e-kiosk)	Digital gadget, smart medicocare, and biosensors	Wireless Personal Area Network (e.g., Bluetooth) and internet)	Relational shared database	Cloud-based computing	Remote health monitoring and tracking, social distancing
Ye *et al*.[31]	Providers, patients, policy makers, IT vendors, third parties	m-health applications, wearable and portable devices	AI, in-depth mining	GSM	Personal Health Record	Drones, robots, and intelligent diagnoses	Real-time case detection and screening
Rahman *et al*.[13]	Public health and patients	m-health, social media and web-based tools	Intelligent systems	GSM	Personal smart card	Big data analysis	Predicting, preventing, and controlling
Tripathy *et al*.[32]	Society and policy makers	Telemetry based on wearable applications	Cloud computing	Wi-Fi, radiofrequencies	Centralized (state) database server	Cloud computing	Social distancing and telehealth
Allam and Jones[18]	Politicians, economists, providers, and patients	Mobile apps, wearable tools (thermal cameras)	AI and machine learning	Wireless Metropolitan Area Network	Cloud storage and local and central databases	AI and machine learning capabilities	Social distancing
Adly *et al*.[33]	Governments, researchers, and public health	Self-tracking devices and social media platforms	Biosensor processors	Wireless sensor network apps	EHR	Big data analysis and data mining	Social distancing and teletracking
Bai *et al*.[6]	Patients and providers	Intelligent Diagnosis and Treatment Assistant Program (nCapp)	RFID, GPS and core Graphics Processing Unit	GSM	Cloud base central data center	Cloud computing	Telemonitoring and tracking

Contd...

Table 3: Contd...

Reference	Individual	Technology					Task
		Platforms	Processing	Exchange	Storage	Added-value technologies	
Bayram *et al*.[34]	Society, scientists, and administrators	Wearable and implanted tools	Biosensors processors and AI	Worldwide interoperability for Microwave Access (WiMAX)	Local/central shared database	Big public health data analysis	Social distancing
Ben Hassen *et al*.[35]	Patients and health care providers	NodeMCU V3 platform	Biosensor processors	Zigbee Wireless Technology	NoSQL shared database	Fog/cloud computing	Home telemetry
Capobussi and Moja [36]	Family doctors and patients	Smartphones	-	Wi-Fi	-	Cloud computing and 3D printing	Real-time telemonitoring
Celesti *et al*.[37]	Laboratory specialists, medical doctors, and patients	Telehealthcare-based mobile phone and PDA technology using IoT	-	-	Mongo NoSQL DataBase	Blockchain engine and cloud computing	Telelaboratory or tele-medical laboratory service
Chamola *et al*.[38]	Public health authorities, researchers, and epidemiologists	Smart wearable and portable devices (thermometer) connected to cell phone for sharing and analysis using IoMT	Geofencing, GIS, GPS, voice detection and special phone base application softwares	5G network and wireless technology	Decentralized databases (local end) and centralized databases (central end)	Unmanned Aerial Vehicles, blockchain, AI	Monitoring and tracking patients from a remote location
Chaudhari *et al*.[39]	Health care team, patients, and society	Smart phone, digital platforms, and biosensors in the bed of IoT	Biosensors, GPS, and RFID	GSM: 5G network	Cloud base database	Cloud base technologies	Real-time monitoring of self-quarantine, tracking the location
Ting *et al*.[40]	Public health agencies, government, researchers, and epidemiologists	Portable smart devices in the bed of IoT Worldometer platform	-	Next-generation telecommunication networks (e.g.,, 5G) and cloud base technology	-	Big data, blockchain, AI, and deep learning	Real-time tracking and monitoring of virus spread patterns
Rehm *et al*.[41]	Providers, patients, and health administrators	PDA or smartphones equipped with sensor	Biosensors	Bluetooth, Zigbee, and Wi-Fi,	Ventilator Waveform Database	ML algorithms	Telemonitoring
Kumar Singh *et al*.[42]	Patient and health authorities	Wearable devices with the bundled mobile app	GPS units	Bluetooth and internet connection	Cloud base database	-	Quarantine management, social distancing
Yu *et al*.[43]	Public health and city officials	Spatiotemporal event detection using health sensing technology	ML, image processing, statistical and probabilistic	WSN technology	Cloud base database	Cloud computing	Timely detection of events (disease outbreak)
Mohammed *et al*.[44] Praveena and Sruthi [45]]	Patients, providers, public health and city officials	Smart helmet	GPS module and Google Location History	RFID and Wi-Fi network	Biobanks	Big data, cloud computing, and telemedicine modules	Telemonitoring, remote tracking, and telehealth

Contd...

Table 3: Contd...

Reference	Individual	Technology					Task
		Platforms	Processing	Exchange	Storage	Added-value technologies	
Oyeniyi *et al*.[46]	Patients and physicians	Smartphone apps	CDSS	GSM	-	-	Contact tracing and case tracking
James *et al*.[47]	City officials, public health	Decision dashboard	ML and GPS	Wi-Fi	-	IoT sensors, and AI	Lockdown policy and social distancing

IoT=Internet of Things, FITT=Fit between Individual, Task, and Technology, COVID-19=Coronavirus disease 2019, WBAN=Wireless body area networks, IoMT=Internet of Medical Things, IT=Information technology, m-health=Mobile health, GSM=Global System for Mobile Communications, AI=Artificial intelligence, WSN=Wireless sensor network, EHR=Electronic Health Record, RFID=Radio-frequency identification, PDA=Personal digital assistant, GIS=Geographical Information System, GPS=Global Positioning System, ML=Machine learning, CDSS=Clinical decision support system

Added-value technologies

The most prominent technologies to provide added value for IoT-based COVID-19 data processing, storage, and communication were cloud computing,[6,13,19,25,30,31,36,38,40-43,46,48-50] telehealth,[18,27,28,36,37,39,43,45,47,51] blockchain,[19,27,34,36,40-42,47,51] and big data mining.[13,27,35,37,43-45,49,50]

3. IoT tasks

The most important IoT tasks and use cases related to COVID-19 management in multiple "on-body," "in-clinic/hospital," and even "in-community" levels include real-time telemonitoring,[6,18,19,24,25,29,30,35,36,38-41,44,45] effective screening and surveillance programs,[13,19,26,31] case tracking or mobility tracing,[6,19,29,30,32,33,39,40,46] timely case identification,[31,43-46] self-quarantine and lockdown policy,[39,42,47] smart social distancing,[32,34] and smart contact tracing.[32,47] Other applications include remote education,[28] knowledge sharing,[27] and decision supports[41,46] [see Figure 4].

The IoT adoption framework for COVID-19 management is shown in Figure 5.

Discussion

Currently, given the lack of definitive and effective treatment, as well as the increase in the number of infected cases and mortalities, social isolation and containment strategy have been the best preventive interventions to limit the disease transmission.[13,18,48] Therefore, there has been an increasing demand for adoption of innovative technologies. Accordingly, many governments and policy-making agencies have emphasized on adopting innovative solutions to tackle the current health crisis, which is leading to health care's digital revolution.[29,31,34,39,46,49] In this sense, "the smart public health surveillance" is a novel concept derived from adopting advanced technologies such as IoT, which uses an internet-like structure for the integration of heterogeneous "medical objects" to address real-time screening, epidemic

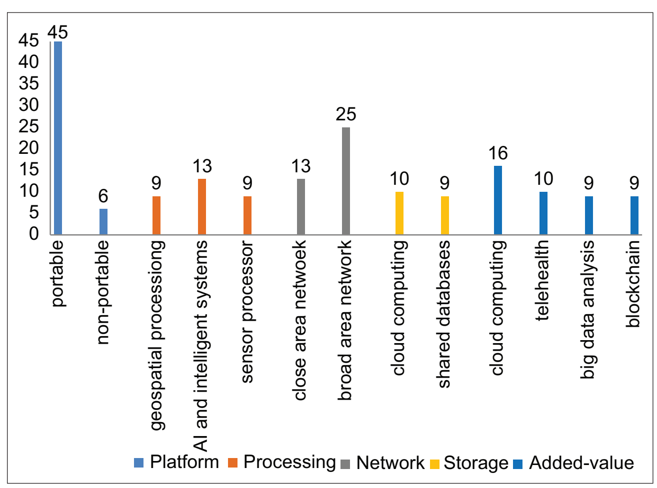

Figure 3: IoT-based COVID-19 technologies

tracing, case identification, quarantine management, decision support, and accurate predictions.[50-52] Furthermore, IoT, by providing digital contact tracing and case tracking capabilities, plays a crucial role in maintaining social distancing and implementing lockdown policies.[24,42]

In the present study, we review current literature about IoT-enabled platforms from technical requirements, expected system tasks, and target user aspects during the COVID-19 outbreak according to the FITT model. Integration of such interrelated technologies can help generate solutions within the health care sector for smart screening, prediction, and prevention of diseases.

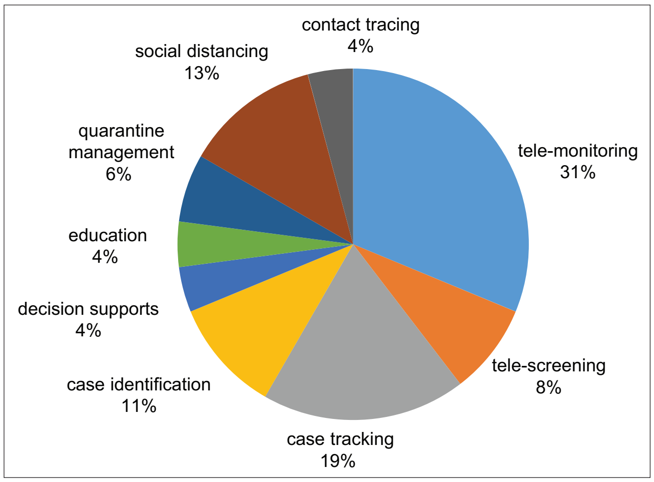

Figure 4: IoT-based COVID-19 tasks

Use of portable microcomputers, cell phones, and wearable devices equipped with wireless networks (e.g., Wi-Fi, Bluetooth, and GSM), along with added-value technologies such as new AI algorithms (e.g., machine learning and deep learning), cloud computing, and big data mining, leads to better adoption of IoT in the current and even future pandemics.[25,31] This study showed, applied to the current crisis, that IoT can be leveraged to help patients receive at-home timely monitoring and smart surveillance through mobile communications, internet connectivity, and other wireless technologies. It can also provide a comprehensive database and flexible data exchange infrastructure for governments, public health authorities, health care settings, and so on.[6,53] In addition, with regard to big data mining, there are various applications, including machine learning, deep learning, and geospatial processing, in which intelligent algorithms are used for decision making based on the data generated from IoT-enabled devices.[17-20] Moreover, this technology is also suitable to simultaneously capture the necessary physiological or geospatial data of the confirmed or suspected cases from various locations and manage the collected data in combination with GPS, AI algorithms, cloud computing, and intelligent and virtual management systems.[29,54-55]

This study also opens opportunities for health care industry in designing customized IoT-based solutions for real-time monitoring and tracking of current and probable future pandemics. However, our study also has some limitations. In future studies, with the increased usage of IoT-based smart surveillance systems, it is

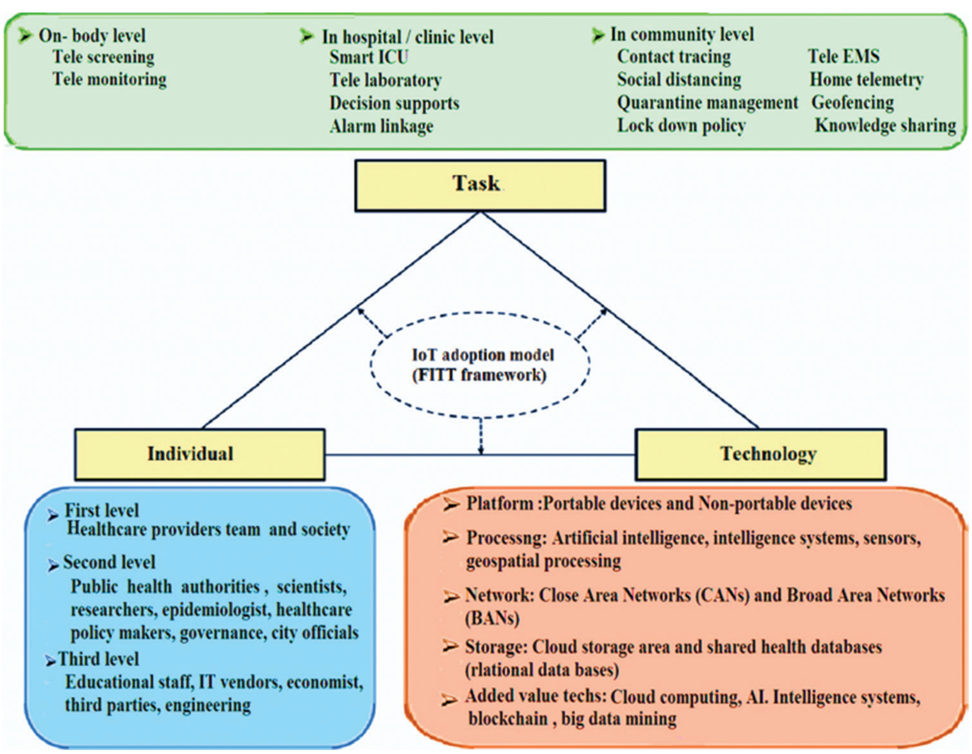

Figure 5: IoT adoption framework for COVID-19 management

important to analyze the actual use of such systems in the form of longitudinal studies rather than as review or cross-sectional study. In addition, because of our search inclusion/exclusion criteria (IoT-based COVID-19 studies conducted in 2020), we may have missed some valuable studies in this field.

Conclusion

In this article, we reviewed the IoT-enabled solutions according to the FITT framework to better understand the IoT applications to tackle the COVID-19 pandemic.

As a concluding remark, the IoT-based portable devices equipped with wireless broadband networks that take advantage of added-value and innovative complementary technologies such as new AI algorithms, big data mining, geospatial processors, and cloud computing have been broadly used in public health surveillance. Future researches should focus on novel computational and telematics approaches especially in the field of public health big data mining, deep learning, 5G/6G networks, smart implants, robotics, blockchain, and so on. These innovation technologies could be applied to diminish the destructive effects of probable future pandemics.

Acknowledgments

This article is the result of a research project approved by the research committee at Abadan University of Medical Sciences, Iran (Ethic code number: IR.ABADANUMS.REC.1399.095).

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

Received: 19 Nov 20 **Accepted:** 21 Sep 21
Published: 08 Aug 22

References

1. Peeri NC, Shrestha N, Rahman MS, Zaki R, Tan Z, Bibi S, *et al*. The SARS, MERS and novel coronavirus (COVID-19) epidemics, the newest and biggest global health threats: What lessons have we learned? Int J Epidemiol 2020;49:717-26.
2. Long C, Xu H, Shen Q, Zhang X, Fan B, Wang C, *et al*. Diagnosis of the Coronavirus disease (COVID-19): rRT-PCR or CT? Eur J Radiol 2020;126:108961. doi: 10.1016/j.ejrad.2020.108961.
3. Shi H, Han X, Jiang N, Cao Y, Alwalid O, Gu J, *et al*. Radiological findings from 81 patients with COVID-19 pneumonia in Wuhan, China: A descriptive study. Lancet Infect Dis 2020;20:425-34.
4. Guan W-J, Ni Z-Y, Hu Y, Liang W-H, Ou C-Q, He J-X, *et al*. Clinical characteristics of coronavirus disease 2019 in China. N Engl Jof Med 2020;382:1708-20.
5. Papadopoulos T, Baltas KN, Balta ME. The use of digital technologies by small and medium enterprises during COVID-19: Implications for theory and practice. Int J Inf Manage 2020:102192. doi: 10.1016/j.ijinfomgt. 2020.102192.
6. Bai L, Yang D, Wang X, Tong L, Zhu X, Zhong N, *et al*. Chinese experts' consensus on the internet of things-aided diagnosis and treatment of coronavirus disease 2019 (COVID-19). Clinical eHealth 2020;3:7-15.
7. Nguyen CT, Saputra YM, Van Huynh N, Nguyen N-T, Khoa TV, Tuan BM, *et al*. A comprehensive survey of enabling and emerging technologies for social distancing—Part I: Fundamentals and enabling technologies. IEEE Access 2020;8:153479-507.
8. Yang T, Gentile M, Shen CF, Cheng CM. Combining point-of-care diagnostics and internet of medical things (IoMT) to combat the COVID-19 pandemic. Diagnostics (Basel) 2020;10:224.
9. Bashshur R, Doarn CR, Frenk JM, Kvedar JC, Woolliscroft JO. Telemedicine and the COVID-19 pandemic, lessons for the future. Telemed J E Health 2020;26:571-3.
10. Barney A, Buckelew S, Mesheriakova V, Raymond-Flesch M. The COVID-19 Pandemic and rapid implementation of adolescent and young adult telemedicine: Challenges and opportunities for innovation. J Adolesc Health 2020;67:164-71.
11. Bhardwaj K. Digital surveillance systems to combat COVID-19 may do more harm than good. Econ Polit Wkly 2020;55.
12. Magee LA, Khalil A, Von Dadelszen P. Covid-19: UK Obstetric Surveillance System (UKOSS) study in context. BMJ 2020;370:m2915. doi: 10.1136/bmj.m2915.
13. Rahman MS, Peeri NC, Shrestha N, Zaki R, Haque U, Ab Hamid SH. Defending against the novel coronavirus (COVID-19) outbreak: How can the internet of things (IoT) help to save the world? Health Policy Technol 2020;9:136-8.
14. Ketu S, Mishra PK. Enhanced Gaussian process regression-based forecasting model for COVID-19 outbreak and significance of IoT for its detection. Appl Intelligence 2021;51:1492-512.
15. Ashton K. That 'internet of things' thing. RFID J 2009;22:97-114.
16. Dong Y, Yao YD. IoT platform for COVID-19 prevention and control: A survey. Ieee Access. 2021;9:49929-41.
17. Kamal M, Aljohani A, Alanazi E. IoT meets COVID-19: Status, challenges, and opportunities. arXiv preprint arXiv:2007.12268. 2020.
18. Allam Z, Jones DS. On the coronavirus (COVID-19) outbreak and the smart city network: Universal data sharing standards coupled with artificial intelligence (AI) to benefit urban health monitoring and management. Healthcare (Basel) 2020;8:46.
19. Swayamsiddha S, Mohanty C. Application of cognitive internet of medical things for COVID-19 pandemic. Diabetes Metab Syndr 2020;14:911-5.
20. Song Y, Jiang J, Wang X, Yang D, Bai C. Prospect and application of Internet of Things technology for prevention of SARIs. Clinical eHealth 2020;3:1-4.
21. Rodrigues JJ, Segundo DBDR, Junqueira HA, Sabino MH, Prince RM, Al-Muhtadi J, *et al*. Enabling technologies for the internet of health things. IEEE Access 2018;6:13129-41.
22. Ammenwerth E, Iller C, Mahler C. IT-adoption and the interaction of task, technology and individuals: A fit framework and a case study. BMC Med Inform Dec Mak 2006;6:3.
23. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. Int J Surg 2010;8:336-41.
24. Xiao C, Zheng L, Chen F, Xiao Y. Design and research of a smart monitoring system for 2019-nCoV infection-contact isolated people based on blockchain and Internet of things technology. 2020.
25. Wang B, Sun Y, Duong TQ, Nguyen LD, Hanzo L. Risk-aware identification of highly suspected COVID-19 cases in social IoT:

A joint graph theory and reinforcement learning approach. IEEE Access 2020;8:115655-61.
26. Moro Visconti R, Morea D. Healthcare digitalization and pay-for-performance incentives in smart hospital project financing. Int J Environ Res Public Health 2020;17:2318.
27. Vafea MT, Atalla E, Georgakas J, Shehadeh F, Mylona EK, Kalligeros M, Mylonakis E. Emerging Technologies for use in the study, diagnosis, and treatment of patients with COVID-19. Cell Mol Bioeng 2020;13:1-9.
28. Siripongdee K, Pimdee P, Tuntiwongwanich S. A blended learning model with IoT-based technology: Effectively used when the COVID-19 pandemic? J Educ Gift Young Sci 2020;8:905-17.
29. Singh RP, Javaid M, Haleem A, Suman R. Internet of things (IoT) applications to fight against COVID-19 pandemic. Diabetes Metab Syndr 2020;14:521-4.
30. Singh RP, Javaid M, Haleem A, Vaishya R, Ali S. Internet of medical things (IoMT) for orthopaedic in COVID-19 pandemic: Roles, challenges, and applications. J Clin Orthop Trauma 2020;11:713-7.
31. Ye J. The role of health technology and informatics in a global public health emergency: Practices and implications from the COVID-19 pandemic. JMIR Med Inform 2020;8:e19866.
32. Tripathy AK, Mohapatra AG, Mohanty SP, Kougianos E, Joshi AM, Das G. EasyBand: A wearable for safety-aware mobility during pandemic outbreak. IEEE Consum Electron Mag 2020;9:57-61.
33. Adly AS, Adly AS, Adly MS. Approaches Based on Artificial Intelligence and the Internet of Intelligent Things to Prevent the Spread of COVID-19: Scoping Review. J Med Internet Res. 2020;22:e19104.
34. Bayram M, Springer S, Garvey CK, Özdemir V. COVID-19 Digital health innovation policy: A portal to alternative futures in the making. OMICS 2020;24:460-9.
35. Ben Hassen H, Ayari N, Hamdi B. A home hospitalization system based on the Internet of things, Fog computing and cloud computing. Inform Med Unlocked 2020;20:100368. doi: 10.1016/j.imu. 2020.100368.
36. Capobussi M, Moja L. 3D printing technology and internet of things prototyping in family practice: Building pulse oximeters during COVID-19 pandemic. 3D Print Med 2020;6:32.
37. Celesti A, Ruggeri A, Fazio M, Galletta A, Villari M, Romano A. Blockchain-based healthcare workflow for tele-medical laboratory in federated hospital IoT clouds. Sensors 2020;20:2590.
38. Chamola V, Hassija V, Gupta V, Guizani M. A comprehensive review of the COVID-19 pandemic and the role of IoT, drones, AI, blockchain, and 5G in managing its impact. IEEE Access 2020;8:90225-65.
39. Chaudhari SN, Mene SP, Bora RM, Somavanshi KN. Role of internet of things (IOT) in pandemic Covid-19 condition. Int J Eng Res Appl 2020;10:57-61.
40. Ting DSW, Carin L, Dzau V, Wong TY. Digital technology and COVID-19. Nat Med 2020;26:459-61.
41. Rehm GB, Woo SH, Chen XL, Kuhn BT, Cortes-Puch I, Anderson NR, *et al*. Leveraging IoTs and machine learning for patient diagnosis and ventilation management in the intensive care unit. IEEE Pervasive Comput 2020;19:68-78.
42. Singh VK, Chandna H, Kumar A, Kumar S, Upadhyay N, Utkarsh K. IoT-Q-Band: A low cost internet of things based wearable band to detect and track absconding COVID-19 quarantine subjects. EAI Endorsed Trans Internet Things 2020;6. doi: 10.4108/eai. 13-7-2018.163997.
43. Yu M, Bambacus M, Cervone G, Clarke K, Duffy D, Huang Q, *et al*. Spatiotemporal event detection: A review. Int J Digit Earth 2020;13:1339-65.
44. Mohammed M, Hazairin NA, Al-Zubaidi S, AK S, Mustapha S, Yusuf E. Toward a novel design for coronavirus detection and diagnosis system using iot based drone technology. Int J Psychosoc Rehabilitation 2020;24:2287-95.
45. Praveena G, Sruthi D. Novel covid-19 detection and diagnosis system using IOT based smart helmet. JAC J Compos Theory 2020;13:457-65.
46. Oyeniyi J, Ogundoyin I, Oyeniran O, Omotosho L. Application of internet of things (IoT) to enhance the fight against COVID-19 pandemic. Int J Multi Sci Adv Technol 2020;1:38-42.
47. James P, Das R, Jalosinska A, Smith L. Smart cities and a data-driven response to COVID-19. Dialogues Hum Geogr 2020:2043820620934211. doi: 10.1177/2043820620934211.
48. Xing Y, Mo P, Xiao Y, Zhao O, Zhang Y, Wang F. Post-discharge surveillance and positive virus detection in two medical staff recovered from coronavirus disease 2019 (COVID-19), China, January to February 2020. Euro Surveill 2020;25:2000191. doi: 10.2807/1560-7917.ES.2020.25.10.2000191.
49. Ndiaye M, Oyewobi SS, Abu-Mahfouz AM, Hancke GP, Kurien AM, Djouani K. IoT in the wake of COVID-19: A survey on contributions, challenges and evolution. IEEE Access 2020;8:186821-39.
50. Yang H, Kan C, Krall A, Finke D. Network modeling and Internet of things for smart and connected health systems—a case study for smart heart health monitoring and management. IISE Trans Healthc Syst Eng 2020;10:159-7.
51. Kang M, Park E, Cho BH, Lee K-S. Recent patient health monitoring platforms incorporating internet of things-enabled smart devices. Int Neurourol J 2018;22(Suppl 2):S76.
52. Sun G, Trung NV, Hiep PT, Ishibashi K, Matsui T. Visualisation of epidemiological map using an Internet of things infectious disease surveillance platform. Crit Care 2020;24:400.
53. Joyia GJ, Liaqat RM, Farooq A, Rehman S. Internet of medical things (IOMT): Applications, benefits and future challenges in healthcare domain. J Commun 2017;12:240-7.
54. Javaid M, Haleem A, Vaishya R, Bahl S, Suman R, Vaish A. Industry 4.0 technologies and their applications in fighting COVID-19 pandemic. Diabetes Metab Syndr 2020;14:419-22.
55. Kumar K, Kumar N, Shah R. Role of IoT to avoid spreading of COVID-19. Int J Intell Netw 2020;1:32-5.