

The role of contemporary digital tools and technologies in COVID-19 crisis: An exploratory analysis

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Abstract

Following the COVID-19 pandemic, there has been an increase in interest in using digital resources to contain pandemics. To avoid, detect, monitor, regulate, track, and manage diseases, predict outbreaks and conduct data analysis and decision-making processes, a variety of digital technologies are used, ranging from artificial intelligence (AI)-powered machine learning (ML) or deep learning (DL) focused applications to blockchain technology and big data analytics enabled by cloud computing and the internet of things (IoT). In this paper, we look at how emerging technologies such as the IoT and sensors, AI, ML, DL, blockchain, augmented reality, virtual reality, cloud computing, big data, robots and drones, intelligent mobile apps, and 5G are advancing health care and paving the way to combat the COVID-19 pandemic. The aim of this research is to look at possible technologies, processes, and tools for addressing COVID-19 issues such as pre-screening, early detection, monitoring infected/quarantined individuals, forecasting future infection rates, and more. We also look at the research possibilities that have arisen as a result of the use of emerging technology to handle the COVID-19 crisis.

KEYWORDS

artificial intelligence, augmented reality, big data, blockchain, cloud computing, COVID-19, deep learning, intelligent Mobile apps and 5G, internet of things, machine learning, robots and drones, sensors, virtual reality

1 | INTRODUCTION

Very recently, a novel severe acute respiratory syndrome coronavirus 2 (SARS-COVID-2) triggered COVID-19, a global pandemic infectious disease (Whitelaw et al., 2020). This new virus and the disease caused by the virus were unknown before the outbreak began in Wuhan, China, in December 2019. Since then, COVID-19 has become a pandemic affecting many countries globally. The history and timeline details of this virus can be found in Alam (2020b).

We can say that the year 2020 and 2021 have been being heavily reliant on emerging technology and trends to address the major issues associated with the management of COVID-19 problems and diseases. (Ting et al., 2020). These emerging technologies include the internet of things (IoT) and sensor technology with next-generation communication networks (5G), big data analytics, artificial Intelligence (AI)-driven machine learning (ML)/deep learning (DL) tools, blockchain technology, augmented reality (AR)/virtual reality (VR), and so on. These technologies are intrinsically linked. The proliferation of IoT and sensors in healthcare institutes contributes to the establishment of an integrated digital environment that enables large-scale real-time data collection. The amount of real-time data would be enormous, and it could then be stored in the cloud for long-term and reliable storage. AI and ML/DL techniques can then use this data to identify healthcare patterns, model risk associations, and predict outcomes. Furthermore, Blockchain

technology, which is a structure for creating and maintaining a cryptographically safe, shared and distributed ledger for transactions, can be used to ensure that data is copied securely and traceably in various physical locations. When it is necessary to avoid human interaction, robots and drones may assist. Autonomous vehicles can transport contaminated patients without endangering the lives of healthcare staff. Robots may be used to distribute groceries, clean hospitals and patrol the streets (Chettri et al., 2020). The activities like food deliveries, tracking population, carrying test kits and medicines to quarantine locations, thermal scanning to identify infected people, spraying disinfectant and many more can be carried out using drones.

During the COVID-19 crisis, the aforementioned innovations proved to be necessary tools for ensuring the provision of vital public services. As the Corona virus spreads across the world, governments imposed significant restrictions on people's travel, the operation of utilities, and physical separation laws, among other things. In this context, digital technology can have a significant impact on societal lives by ensuring people have access to health care, information, and contact with competent authorities, among other things. Governments have turned to digital technology to track, anticipate and influence disease transmission, provide education to students who are unable to attend school, and promote social cohesion by respecting physical distance. The global pandemic of COVID-19 has given a much-needed impetus to the global adoption of emerging technologies. People seeking new solutions to fulfil their everyday needs as a result of lengthy lockdowns, such as online classes, food/medical deliveries, and consultations with their physician and so forth. Hence, COVID-19 crisis presents itself as an interesting challenge for digital technology and the related industries.

Furthermore, there will be an emphasis on the ethical and legal constraints of deploying emerging technology and resources for disease surveillance and control. These constraints include problems with accuracy, safety, protection and data quality, as well as interoperability issues and risks. In this report, we also discuss these concerns.

We authors would like to contribute to society's response to the COVID-19 crisis by investigating various applied emerging technologies as well as future technologies that have not been widely used in the past but could aid in pandemic control.

The rest of the article is organized as follows: in Section 2, we present a brief list of various digital technologies that are addressed in this review. Section 3 presents the strategies adopted to include and exclude the review articles in this study. How each of the recent digital tools and technologies has demonstrated its potential during COVID-19 crisis to bring down the immediate problems is explored in Section 4. Section 5 presents the findings from the review and how technologies can be further explored to provide safe living to society. The conclusion is given in Section 6.

2 | RESEARCH MOTIVATIONS

Detecting and preventing the spread of the Corona virus, as well as assisting medical practitioners, nurses and healthcare professionals, among others, in providing productive and reliable services to patients, is a difficult task at present. This article discusses and presents recent research activities conducted using different emerging tools to combat the pandemic. Figure 1 depicts the main emerging technologies used to battle COVID-19, which include big data AR/VR, 5G, IoT, robots/drones, AI, cloud computing, blockchain, and I-Apps.

Below, we present a list of activities/ways by which digital technologies could help in the containment of this pandemic and Figure 2 projects these activities.

1. Timely detection and diagnosis of the infection
2. Prevention of /controlling the spreading of the infection
3. Tracking the quarantined / infected patients
4. Contact tracing of infected persons
5. Prediction of future cases and mortality rates
6. Vaccine and drug development
7. Assisting healthcare workers
8. Supply of medicines and medical equipment and food items
9. Clinical management
10. Remote monitoring the patients' health condition including patients with other medical issues.

In this study, we review the efforts carried out by the research community to provide abovementioned services. In Section 4, we discuss how these technologies help in addressing various issues and challenges during and after COVID-19 outbreak.

3 | METHODOLOGY

In order to identify the efforts related to the proposed study, we adopted the following search strategy.

- i. Identifying the appropriate digital libraries to search for the articles related to the proposed study: The following digital libraries have been searched for.

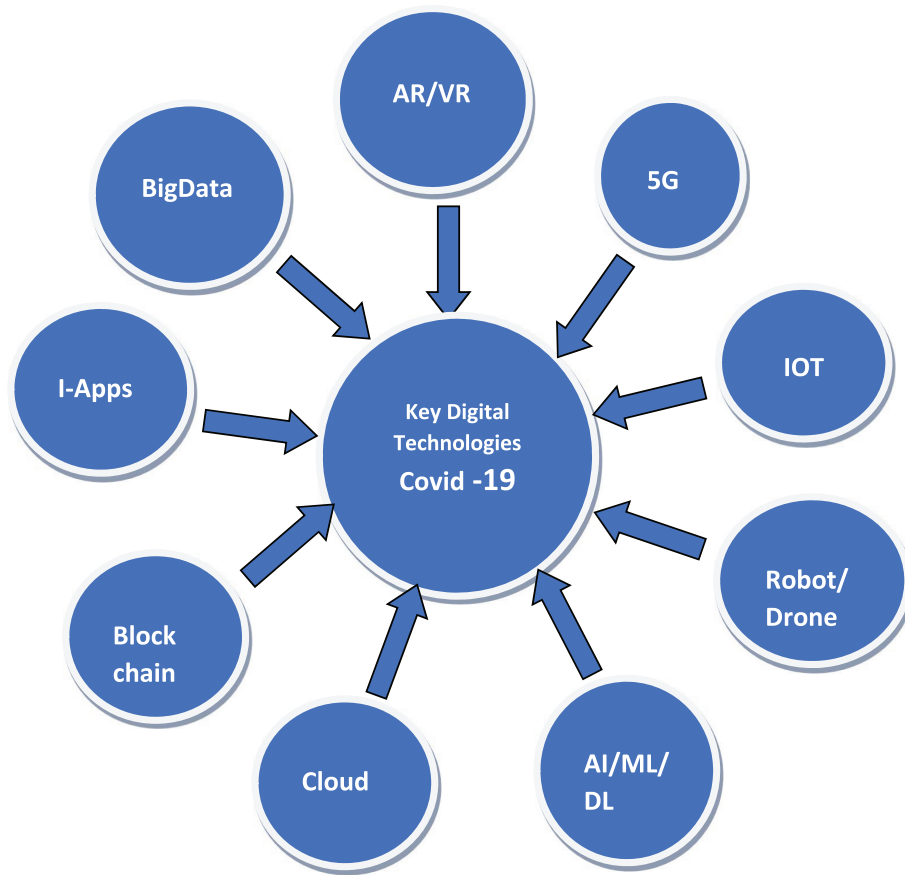


FIGURE 1 Key digital technologies to combat COVID-19

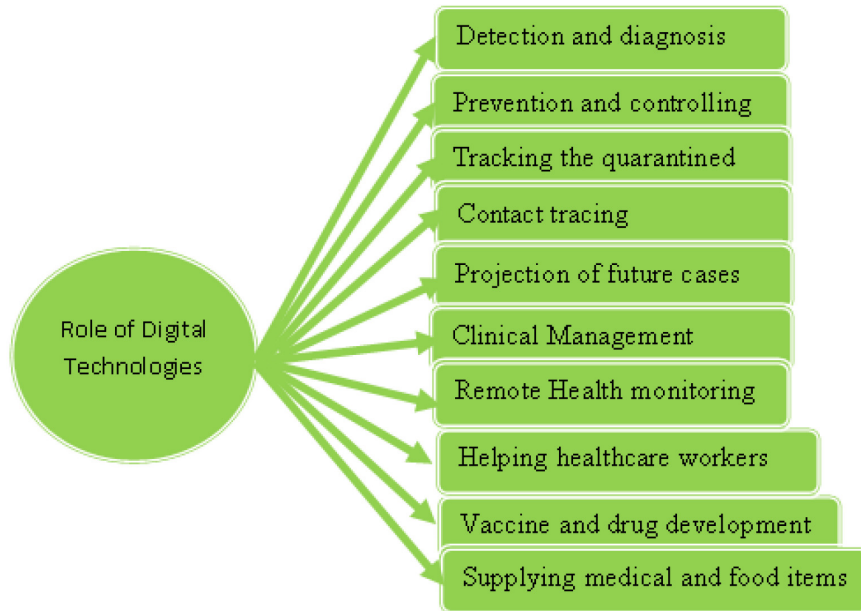


FIGURE 2 Role of digital technologies in COVID-19 pandemic

Elsevier (<https://www.elsevier.com/>)

Science Direct (<https://www.sciencedirect.com/>)

IEEE Xplore (<https://ieeexplore.ieee.org/>)

Web of Science (<https://apps.webofknowledge.com/>)

Scopus (<https://www.scopus.com/>)

Wiley (<https://onlinelibrary.wiley.com/>)

ResearchGate (<https://www.researchgate.net/>)

Hindawi (<https://www.hindawi.com>)

MDPI (<https://www.mdpi.com/>)

<https://dl.acm.org/conference/ccs/proceedings/>

<https://dblp.org/> (include all conferences)

- ii. Identifying the key terms related to the proposed study: The main search word was chosen based on the topic under consideration. To find the articles for this study, we used search words like “COVID-19,” “Internet of Things,” “Cloud Computing,” and “Robots.” Since the Corona virus swept the globe and piqued the attention of the research community in 2020 and 2021, the publications from 2020 and 2021 have been chosen. This search yielded a large number of articles, which we sorted out based on various domains.
- iii. Examining the title, abstract and methodology used in the articles downloaded from digital libraries and deciding to include them for review: During the initial selection, the title and abstract of each article downloaded from digital libraries were reviewed and shortlisted based on the topic under review. The technique used in the shortlisted papers was investigated for further screening. The inclusion criteria are focused on the role that digital technology played in combating COVID-19.

4 | ROLE OF KEY DIGITAL TECHNOLOGIES AND TOOLS IN COVID-19 PANDEMIC

The relationship between humans and emerging digital technologies has been thoroughly recorded in recent decades, but it has yet to be examined in light of the on-going global pandemic crisis. This analysis compiles the use of emerging technologies in the current COVID-19 pandemic. This review addresses the following three issues: (1) the emerging digital technologies that were used, (2) the impact and benefits of these digital technologies on humans during the pandemic, (3) how could we further utilize these technologies by addressing the limitations.

In Table 1, we summarize all recent research efforts on combating the COVID-19 pandemic using significant digital technologies, and we present the primary technologies used and their roles in combating the COVID-19 pandemic by each of the research attempts.

Apart from the research efforts, there are a huge number of IoT products, robots, drones and so forth, available for managing the pandemic. (Gore, 2020) described an IoT device called ‘Suraksha Kawach’ for tracking of corona infected patients and their surveillance developed by Defence Research and Development Organization (DRDO), India. This is an arm worn device and a GSM/GPS- based for real-time tracking. Figure 3 shows a sample Suraksha Kawach device. Temperature sensors are used to measure temperature of COVID-19 patients and depicted in Figure 4.

Then there are wearable devices. These instruments assist in the measurement of parameters such as temperature, heart rate, and pulse rate, among others, so that appropriate steps can be taken for early diagnosis. Figure 5 depicts a smart band as an example of a wearable system. It sends out a warning when the body temperature rises above a certain level and is often used to maintain social distance.

IoT buttons are also IoT devices that aid in the efficient management of diagnosis, such as generating warnings about cleaning and maintenance problems. Another programmable button is the AWS IoT Button, which can be used to count or monitor objects, call or warn, order service, and so on. Figure 6 shows several examples of IoT.

We also present a case study on drones used during the pandemic. During the COVID-19 outbreak, many countries used drones for delivery and transportation. Some conducted it as part of their experimenting and testing, while others continued with their usual drone delivery operations. Since the beginning of the pandemic, three nations in Sub-Saharan Africa, notably Rwanda, Ghana, and Malawi, have reported the usage of Ziplines drones to carry routine medical consumables, COVID-19 supplies, and medical samples. Prior to the COVID-19 pandemic, all three countries had drone operations; thus, drone operations were changed in all three countries to respond to the increasing need for medical commodities and COVID-19 supplies. While COVID-19 has effectively halted surgeries, robotic-assisted surgery (RAS) has aided the patients critically. A robot guides a surgeon's actions in RAS, making surgeries more accurate, lessening the impact of the surgery on healthy tissues, and lowering the chance of potential human errors. These operations are safer, faster, and aid in the recovery of patients. Da Vinci surgical system, as shown in Figure 7, is one such RAS which provides physicians with a sophisticated collection of instruments to perform robotic-assisted minimally invasive surgery. The risks in robotic surgery are similar to those of open surgery, but they are significantly lower. In addition, they are of higher costs.

Global medical devices sales are estimated to increase 6.4% annually from 2016 to 2020, reaching nearly \$440 billion according to the International Trade Administration (<https://mercercapital.com/article/five-trends-to-watch-in-the-medical-device-industry/>). While the Americas are projected to remain the world's largest medical device market, the Asia/Pacific and Western Europe markets are expected to expand at a quicker pace over the next several years. From the Figure 8, it can be seen the medical devices market is increasing gradually. Compared to 2019, year 2020 has its highest market value.

TABLE 1 Contribution of digital technologies in COVID-19 pandemic

Authors	Year	Key technology addressed	The role played by the technology in addressing the COVID-19 pandemic
Rajvikram et al. (2020)	2020	AI, ML, IoT, drone and robotics, mobile applications	Predicting and predicting infection rates, as well as disease diagnosis Providing high-quality treatment (e.g. drug delivery at home) Transportation and surveillance, eliminating labour-intensive tasks such as nursing and tracking infected individuals Providing medical assistance ubiquitously
Pratap et al. (2020)	2020	IoMT	Remote monitoring of patients suffering from orthopaedic problems
Vaishya et al. (2020)	2020	AI	Detection and diagnosis of infection in its early stages Treatment monitoring Individuals' contacts are traced Case and mortality projections Drug and vaccine production Streamlining the workload of healthcare professionals Disease prevention
Javaid et al. (2020)	2020	Industry 4.0 technologies (IIoT)	Telemedicine service for effective virus prevention and control Predicting outbreaks and containing or even preventing the virus's spread Surveillance to ensure the quarantine and mask-wearing procedures are followed
Pratap et al. (2020)	2020	IoT	Discussed hospital with Internet access Consultation via telehealth Rapid examination Intelligent monitoring of infected individuals Virus forecasting Real-time data on the infection's spread
Iyengar et al. (2020)	2020	Mobile apps	Clinical assessment Disease diagnosis Appropriate advice and prescription Patients are monitored from their homes and in remote areas.
Mohanty et al. (2020)	2020	IoMT	Monitoring in real time Patient monitoring via remote access Rapid diagnostic evaluation Tracing of contacts Examination and surveillance Disease prevention and control
Chamola et al. (2020)	2020	IoMT AI Robots and Drones 4. Mobile Apps Blockchain 5G	Remote monitoring of patients Keeping track of prescription orders Wearable devices that relay health data to the appropriate health care professionals. Disease surveillance, risk assessment, medical diagnosis and screening, and curative research Treatment of patients and reduction of healthcare workers' stress levels Noncontact ultraviolet (UV) surface disinfection methods operated by a robot Tracing of contacts Increasing the frequency of testing and reporting Providing supporters with a secure donation platform Keeping supply chain disruptions to a minimum Recording of patient information in a secure manner Virus tracking, patient management, data collection, and interpretation have also been enhanced.
Rahman et al. (2020)	2020	IoT	Surveillance in real time via wearable health monitoring devices Remote health testing via the cloud Data processing in real time Utilizing travel history data to rapidly diagnose infected patients and forecast the possibility of disease transmission to other locations
Kumbhar et al. (2020)	2020	IoT and deep learning	Detection of violations of social distance using CNN. Tracking by area dependent on the user's cellular activity Detection of infected individuals within a geographic region. Identification of individuals with serious symptoms by the use of wearable devices Contact tracing of individuals in high-risk areas Appropriate acts and alerts against isolation

(Continues)

TABLE 1 (Continued)

Authors	Year	Key technology addressed	The role played by the technology in addressing the COVID-19 pandemic
Yang et al. (2020)	2020	IoMT	Implemented point-of-care (POC) diagnostics and the IoMT to build a network that enables patients to access proper healthcare at home and a disease management database for government and healthcare organizations. Monitoring disease progression and administering appropriate medical treatment while avoiding the spread of the viral infection to others.
Singh et al. (2020)	2020	IoT	Developed an IoT-enabled wearable quarantine band capable of detecting and tracking absconders in real time
Lin & Wu (2020)	2020	IoMT	Distribution of critical drug products efficiently Monitoring of medical supply production and demand
Ding et al. (2020)	2020	Wearable sensors and telehealth	Various parameters such as Oxygen saturation, respiratory rate, and others are monitored in the general population and quarantined patients. Unobtrusive sensing systems for detecting the disease and tracking patients with relatively mild symptoms whose clinical condition may deteriorate unexpectedly Telehealth technologies for remote monitoring and diagnosis of COVID-19 and related diseases
Ahmed et al. (2020)	2020	Mobile apps	Attributes and examples of contact tracing applications
Nasajpour et al. (2020)	2020	IoT, robots, drone, intelligent apps	Early detection, quarantine period, and post-recovery.
Kamal et al. (2020)	2020	IoT	Deployment and organizational difficulties, as well as future opportunities for more pandemic control Ambulances equipped with the Internet of Things, and wearable health tracking devices Artificial intelligence-assisted forecasting and social distancing education and conferencing through the internet
Ye et al. (2020)	2020	5G-based robotic technology	Cardiopulmonary examinations of COVID-19 patients
Rahman et al. (2020)	2020	B5G (beyond 5G) and DL	Remote monitoring and diagnosis by the use of mobile edge devices equipped with deep learning models
Soldani (2020)	2020	5G	To enhance diagnostic capabilities in high-risk areas by identifying infected subjects as soon as possible Tracing their contacts and determining the source of the infection as soon as possible
Yu et al. (2020)	2020	5G	Two cases of SARS-CoV-2 infection were evaluated using remote robotic ultrasound operated by 5G, and the benefits of 5G were discussed. COVID-19 case diagnosis and monitoring in clinical practice.
Tuli et al. (2020)	2020	ML and cloud computing	Proactively forecasting the epidemic's development Predicting the potential threat posed by COVID-19 and deploying on a cloud-computing platform to allow more precise and real-time forecasting of the epidemic's growth activity.
Lalmuanawma (2020)	2020	ML and AI	SARS-CoV-2 and its associated epidemics: screening, prediction, forecasting, touch tracking, and drug creation
Ghoshal & Tucker (2020)	2020	DL	Detecting COVID-19 in X-ray images
Narinv et al. (2020)	2020	DL	Detection of a patient with Corona virus pneumonia using a chest X-ray radiograph
Punn et al. (2020)	2020	ML and DL	Prediction of the COVID-19's potential reachability using real-time data from the Johns Hopkins dashboard.
Hussain (2020)	2020	AI and DL	Early warnings and alerts about COVID-19 COVID-19 prediction and monitoring in its early stages. Prognosis and diagnosis in the early stages. Distancing and regulation on a social level. Early diagnosis and care.
Naudé (2020)	2020	AI	Tracking and forecasting the spread of COVID-19 Disease diagnosis and prognosis
Alimadadi et al. (2020)	2020	AI and ML	Classifying and predicting individuals according to their susceptibility or resistance to COVID-19 infection

TABLE 1 (Continued)

Authors	Year	Key technology addressed	The role played by the technology in addressing the COVID-19 pandemic
			Detection and tracking of COVID-19 patients automatically over time Rapid development of automated diagnostic systems in order to improve predictive, diagnostic, and therapeutic methods for possible pandemics such as COVID-19.
Pham et al. (2020)	2020	AI and big data	Developing effective diagnostic and treatment approaches, as well as early detection and prediction of infection, in order to determine the magnitude of COVID-19, COVID-19 detection and diagnosis, and detecting, monitoring, and predicting the outbreak Outbreak prediction: to forecast outbreaks using large-scale data analytics, to monitor the spread of COVID-19, and to assist in the diagnosis and treatment of COVID-19. Discovery of vaccines/drugs
Pratap et al. (2020)	2020	VR	Pain management by physical therapy Patients that need prolonged in-hospital care will benefit from a VR-based stay. Medical personnel education Patient care Medical marketing Public understanding of disease
Proniewska et al. (2020)	2020	AR (holography)	Using augmented reality lenses, displaying patient details and confidential information just in front of the doctor's eyes
Woolliscroft (2020)	2020	AR and VR	Virtual medical Hospital in own house Diagnostic and therapeutic advancements, Virtual health education for authorities, academic medical centres, faculty, and students
Imperatori et al. (2020)	2020	VR	Treatment of psychopathological symptoms associated with stress, as well as trauma associated with the effects of the COVID-19 pandemic, both in health care staff and the general population
Gao et al. (2020)	2020	VR	Determine the feasibility of using virtual reality exercise as a coping strategy for the promotion of health and wellness in older adults during the COVID-19 pandemic.
Ecclestona et al. (2020)	2020	VR and AR	The public health implications of COVID-19 for patients with chronic pain are discussed. The repercussions of failing to treat these patients during the pandemic's uncertain period are illustrated. Remote evaluation and management options are demonstrated. Additionally, clinical evidences demonstrating the efficacy of remote therapies are discussed.
Bragazzi (2020)	2020	Big data	In real time, reconstructing the outbreak's early epidemiological history, spreading the outbreak, and preventing and controlling infectious diseases Identification of possible therapeutics and vaccine candidates Facilitating the application of interventions in public health.
Wang (2020)	2020	Big data	Real-time warnings during a hospital visit based on travel history and clinical symptoms to assist with case detection QR code scanning and online monitoring of travel history and health symptoms to identify travellers' infectious threats based on origin and recent travel history.
Lin & Houc (2020)	2020	Big data and AI	Tracing the person who has come into contact with infected individuals COVID-19 epidemic risk management using self-reported health status and travel history from aviation, railway, and land transportation networks, as well as social media, contact tracking, and strict quarantine compliance
Ienca & Vayena (2020)	2020	Big data	Identifying individuals who have travelled to places where the disease has spread through prediction and surveillance. Identifying and isolating contaminated people's contacts
Zhou (2020)	2020	Big data	Rapid aggregation of multi-source big data for disease knowledge visualization Cases that have been verified are being tracked in space. Transmission forecasting in the area
Torky & Ella (2020)	2020	Blockchain	Detecting unknown contaminated cases, as well as predicting and measuring the COVID-19 epidemic's contagion risk for populations in real time.

(Continues)

TABLE 1 (Continued)

Authors	Year	Key technology addressed	The role played by the technology in addressing the COVID-19 pandemic
Xu et al. (2020)	2020	Blockchain	Tracing knowledge sharing in order to reduce the harm COVID-19 causes humanity and to save lives and money without infringing on fundamental human rights to privacy.
Bansal et al. (2020)	2020	Blockchain	“Immunity certificates” or “Immunity licences” i.e. document that certifies an individual has been infected and is immune to coronavirus disease 2019 Combating two challenges while using immunity certificates namely the falsification of information and people seeking out for COVID-19 infection
Nguyen et al. (2020)	2020	Blockchain	User privacy is protected when monitoring outbreaks. Day-to-day activities, such as medical supply chain and donation monitoring, must be kept secure.
Chang & Park (2020)	2020	Blockchain	Infectious disease reporting systems, as well as the rapid and reliable exchange of patients' medical information in a safe manner.
Mashamba-Thompson & Crayton (2020)	2020	Blockchain	Low-cost blockchain and AI-connected mHealth connected self-testing and monitoring systems are being developed and deployed.
Khatoon (2020)	2020	Blockchain	Encourage patients to share their medical records freely and securely with physicians, hospitals, research agencies, and other stakeholders while maintaining complete control of their medical data's privacy.
Alam (2020a)	2020	Blockchain	Four-layer architecture that uses IoT and Blockchain to detect and prevent the spreading of COVID-19 infection
Warren & Skillman (2020)	2020	Cloud	Using cloud computing services, analysed a publicly accessible mobile device location dataset and discovered drastic improvements in mobility due to COVID-19.
Gong et al. (2020)	2020	Cloud	A cloud-based hardware to solve the problems unique to the COVID-19 epidemic A data model has been developed to store the data on the cloud and to provide different levels of access to the data, data security and privacy protection
Maghdid et al. (2020)	2020	Cloud	Using built-in smartphone sensors, a new AI system is proposed to detect COVID-19. The developed Artificial Intelligence AI-enabled system reads the signal measurements from smartphone sensors to predict the severity of pneumonia as well as the disease's outcome. The proposed system gathers data from a variety of users or patients, allowing the dataset to expand and form a broad data set. The registered data as well as the prediction's outcome are saved in the cloud.
Bai et al. (2020)	2020	Cloud	The COVID-19 Intelligent Diagnosis and Care Assistant Program (nCapp) has been suggested as a way to detect COVID-19 sooner and improve treatment. COVID-19 is better managed, regulated, and diagnosed with the help of nCapp. In real-time online contact with the cloud, the following functions are introduced. Patient registration: the patient's basic information is entered into an online database. Start consultation. Diagnosed with intelligent assistance; treated with intelligent assistance. A treatment recommendation is provided depending on the seriousness of the disease. Self-control: this section contains useful knowledge on self-control. Information about COVID-19 cases in the user's area is given through a map.
Bogue (2020)	2020	Robots	Reducing the risk of infection transmission by limiting inter-personal communication By performing such regular tasks, you can free up medical professionals. Aid and expedite the delivery of food and medical supplies. Keep an eye on public areas. Educating the public about the importance of social distance Enable those who are alone to communicate with friends and family.
Jaiswal et al. (2020)	2020	Robots, Drones	Thermal imaging is used to determine the temperature using a thermal camera. To avoid the danger, keep a social distance near the affected area by using a loudspeaker-equipped drone system. For the containment of COVID-19, assistance in quarantine and a variety of other functions are needed.

TABLE 1 (Continued)

Authors	Year	Key technology addressed	The role played by the technology in addressing the COVID-19 pandemic
Tavakoli et al. (2020)	2020	Robots	Reduce the risk of infectious disease transmission to frontline healthcare workers by allowing them to triage, assess, track, and treat patients safely from a distance.
Zeng et al. (2020)	2020	Robots	The roles of various types of robots are illustrated. Described how robotic technology can be useful in a variety of settings such as hospitals, airports, transportation, recreation and scenic areas, hotels, and communities in general.
Khan et al. (2020)	2020	Robots	The roles of various types of robots such as receptionist, washing, disinfecting, nursing, ambulance, and telemedicine robots are presented. These robots can help with effective COVID-19 management and reducing the number of infected patients and casualties.
Gore (2020)	2020	Robots, drones, mobile apps	Assistive hospital care robotic devices are intended to assist frontline soldiers in keeping a safe distance from Corona virus-infected patients. Teleoperated robots to navigate the quarantine zone and distribute food, water, medication, and other necessities to anyone in need. Robots are now being developed that can be used at the entrances to office buildings and other public places to dispense hand sanitizer and send public health messages about the virus. Robots may also be used to transport drugs and food in hospital isolation wards. Drones help to clean public spaces, hospitals, and tall buildings. Mobile apps for monitoring social distancing, conveying COVID-19 information, and patient tracking are discussed.
Aymerich-Franch (2020)	2020	Robots	Reduce the disadvantages of separation by facilitating physical distancing.
Malik et al. (2020)	2020	Robots	The role of cobots in the pandemic, specifically increasing ventilator output, repurposing existing non-ventilator (e.g. car) production to ventilator production, and maintaining social distancing, is addressed.
Vafea et al. (2020)	2020	AI, big data, IoT, robots, drones	Predict the outcome of COVID-19 infections in order to predict the mortality risk of a COVID-162 patient. Predict and assist in the early detection of critically ill patients Execute efficient clinical techniques Using COVID-19, take regular temperature measurements in inpatients. Distribute medical supplies and test kit equipment to hard-to-reach locations.
Zampolli & Rodriguez (2020)	2020	Robots	In urology surgery, robots are used to prevent viral transmission.
Ruiz Estrada (2020)	2020	Drone	Aerial monitoring of the impact of post-epidemic infectious diseases Infectious disease epidemics have hampered logistics and freight distribution. Post-aerial evaluation of major epidemic infectious diseases
Kumar et al. (2020)	2020	Drones	Simulated a drone-based device for surveillance, control, thermal imaging, sanitization, social distancing, medicine, data analytics, and statistics generation. In COVID-19 hotspots, a real-time drone-based framework for sanitization, tracking, vigilance, face recognition, thermal scanning, and other purposes were implemented.
Parker et al. (2020)	2020	Mobile apps	The ethical consequences of using cell phone applications to combat the COVID-19 pandemic are discussed.
Oliver et al. (2020)	2020	Mobile apps	Discussed how mobile phone data will assist government and public health officials in deciding the best course of action to contain the COVID-19 pandemic and evaluating the efficacy of control measures such as physical separation.
Banskota et al. (2020)	2020	Mobile apps	During COVID-19, various forms of apps such as social networking apps, prescription management and telemedicine apps, health and wellness apps, food and drink apps, and apps for visual and hearing disability are addressed.
Javid & Khan (2021)	2021	IoT	To track and regulate all medical temperature, sugar level, blood pressure, and information about COVID-19 patient health clinical operations, drug distribution, patient care, laboratory testing, and medication management During the COVID-19 Pandemic, various IoT technologies for use in healthcare were also discussed.

(Continues)

TABLE 1 (Continued)

Authors	Year	Key technology addressed	The role played by the technology in addressing the COVID-19 pandemic
Filho et al. (2021)	2021	IoT	PAR, a network for remote patient and environment monitoring, patient healthcare data management, patient health condition management, and emergency and crisis management, was created.
Dong & Yao (2021)	2021	IoT	COVID-19 symptom diagnosis, quarantine monitoring, contact tracing & social distancing, COVID-19 outbreak forecasting, and SARS-CoV-2 mutation tracking were all demonstrated as part of a potential fog-cloud combined IoT network for COVID-19 prevention and control.
Rathee et al. (2021)	2021	IoT	Developed an AI-based device to diagnose COVID-19 symptoms such as fever, bleeding, and sore throat, among other things.
Wang et al. (2021)	2021	AI	In order to rapidly diagnose COVID-19 pneumonia, an AI system that analyzes CT images automatically and measures the risk of infection was deployed.
Chassagnon et al. (2021)	2021	DL	Artificial intelligence and medical imaging are being used to study disease quantification, staging, and outcome prediction.
Mushtaq et al. (2021)	2021	AI	COVID-19 CXR results were classified and quantified, the relationship between initial CXR severity and clinical outcomes was examined, and the use of an AI system as an initial COVID-19 prognostic method was evaluated.
Abdel-Basset et al. (2021)	2021	AI, IoT, VR, big data, 5G, robots and drones, blockchain	proposed an intelligent framework to reduce COVID-19 outbreaks Keeping the medical teams safe, maintaining the patients physical and psychological healthcare conditions; managing a severe shortage of PPE for the medical team; reducing the massive pressure on hospitals Tracking recovered patients to treat COVID-19 patients.
Christopher & Valérie (2021)	2021	Drones and robots	Demonstrated that mobile remote presence systems (MRP), also known as telepresence robots, can be used effectively in some forms of medical consultations, such as remote consultations with nursing home residents.
Huang et al. (2021)	2021	AI	Discussed clinical applications of machine learning and deep learning, such as clinical features, electronic medical records, and medical images (CT, X-ray, ultrasound images, and so on).



FIGURE 3 Suraksha Kawach IoT device

5 | FINDINGS AND DISCUSSION

In the fight against COVID-19, a range of emerging technological developments such as AI, ML, DL, IoT, 5G, big data, robots, drones, and blockchain have made a difference. This study looked at recent research attempts that used these technologies to combat COVID-19's war and mitigate its effects. In this section, we recommend some of the insights on the utilization of these technologies further to manage this COVID-19 pandemic.



FIGURE 4 Temperature sensor (source: <https://www.geospatialworld.net/blogs/how-iot-can-help-fight-COVID-19-battle/>)



FIGURE 5 Smart band



FIGURE 6 IoT buttons. Source: <https://aws.amazon.com/blogs/aws/aws-iot-1-click-use-simple-devices-to-trigger-lambda-functions/>, <https://aws.amazon.com/iotbutton/>

5.1 | Internet of things and sensors

Despite its utility in the COVID-19 pandemic, IoT faces several challenges when used for COVID-19 containment. A few of them are mentioned below.

The use of IoT in the battle against this global pandemic can be applied to many sectors such as healthcare, logistics, and others that play a critical role in reducing the risk of corona virus outbreak. For the successful management of the COVID-19 crisis, IoT employs a large number of interconnected sensors. Scalability is a major challenge in this pandemic as the number of IoT devices in IoT grows exponentially. Scalability, in particular, raises the energy demands of these machines. As the number of IoT devices grows, high bandwidth is needed to transmit all data from sensors to the cloud. IoT devices currently use 4G/LTE networks to complete their tasks. This issue can be easily resolved soon after the use of 5G.

The next concern is the protection and privacy of data created by a large number of devices. The data collected from Corona infected people, such as temperature, heart rate, pulse rate, and so on, must be accurate and safe. It is important to ensure that data forgery and interception are not possible. Since IoT devices have constraints such as low power and low processing speed, standard encryption algorithms such as DES, 3DES, and AES appear to be infeasible. As a result, energy-efficient security algorithms that are lightweight and have low computational complexities must be designed.

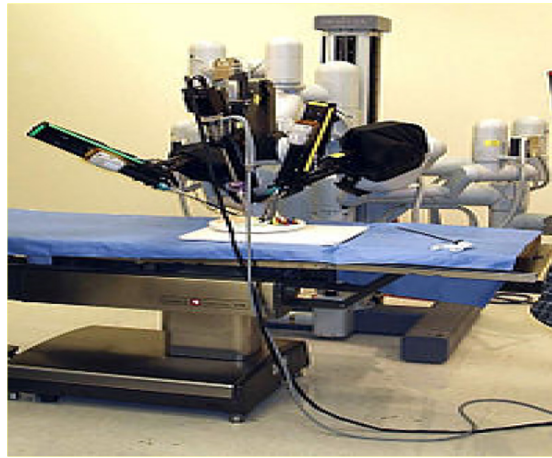


FIGURE 7 Da Vinci surgical system. Source: https://en.wikipedia.org/wiki/Da_Vinci_Surgical_System

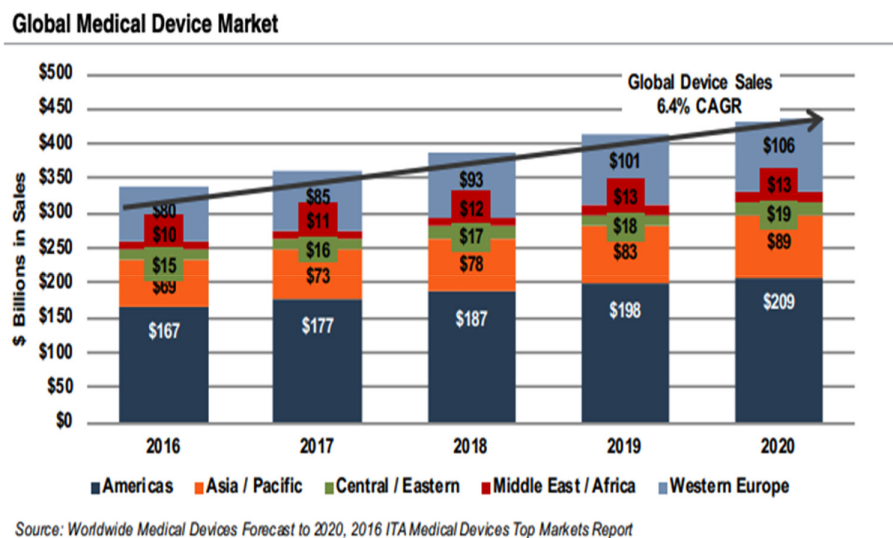


FIGURE 8 Global medical devices market

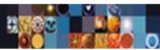
5.2 | Robots and drones

From the articles that demonstrated the role of robots and drones for the containment of COVID-19, we understood that the robots and drones help to diminish the chances of spreading the infection by reducing inter-personal contact, free-up medical professionals by conducting certain routine tasks and a lot more.

Still, many opportunities are available in the design and operation of robots such as a cyber-physical system for ensuring the security, power management for long life using optimized algorithms and renewable energy sources, fault-tolerant systems for reliable and safe operations within the healthcare facilities.

5.3 | Artificial intelligence/machine learning/deep learning

The COVID-19 pandemic has destroyed lives all over the universe, but AI/ML/DL has been found to greatly minimize its effects. According to the efforts (Alimadadi et al., 2020; Ghoshal & Tucker, 2020; Hussain et al., 2020; Lalmuanawma et al., 2020; Narin et al., 2020; Naudé, 2020; Pham et al., 2020; Punn et al., 2020; Tuli et al., 2020), AI/ML/DL could help in a variety of ways, including enhancing risk stratification, categorizing patients for the type of treatment they will receive based on infection incidence, and so on. As a result, in the light of this crisis, we have discovered that AI/ML/DL is being used in the following three big ways: Virus research and production of medicines and vaccines, management of



resources and services in healthcare facilities, and data analysis to support crisis management decisions such as confinement measures. The current urgency, however, necessitates greater applicability of these techniques with high precision in screening and forecasting the SARS-CoV-2 to combat the pandemic.

5.4 | 5G

According to the articles we reviewed on the use of 5G technology to combat the COVID-19 crisis, the healthcare system has benefited from increased response times, patient tracking, data collection and analytics, remote analysis, remote screening, and a variety of other benefits. Ye et al. (2020) looked into the potential use of a 5G-based robot assisted remote ultrasound system to examine COVID-19 patients and to evaluate the severity of COVID-19 remotely.

However, we believe that the success of 5G applications in the public health domain could spark interest in other domains such as education, transportation, security, and patrol in public places in order to capitalize on 5G's popularity. To the best of our knowledge, these domains have yet to be discussed, and they will undoubtedly help with COVID-19 prevention and control, as well as post-COVID activities.

5.5 | Augmented reality and virtual reality

Virtual education is one of the important areas where VR and AR can make a significant contribution, and these technologies have the potential to prepare, handle and facilitate digital transformation needs for the education sector, as well as assist educational institutions in shifting their emphasis from conventional learning methodologies to digital.

We found a few efforts (Niranjan, 2020; Rapanta et al., 2020) that encourage the use of online teaching during this crisis. As far as we know, there is a few articles reviewed the use of VR and AR technologies/tools for the education sector and real-time scenarios during COVID-19. The use of virtual and/or augmented reality technology in remote learning for higher education and its impact on learning outcomes are discussed in Nesenbergs et al. (2021). Teachers must experiment with digital technology and methods to continue their students' education in light of the Corona virus pandemic. As a result, traditional in-person schoolroom education would need to be replaced with novel learning approaches ranging from live broadcasts to virtual reality experiences. Catchy Words AR, Devar, Figment AR, Google Translate AR, Narrator AR etc. are some of the AR and VR learning immersive tools that are now used in education. In general, we agree that VR and AR technologies must be extensively researched during the COVID-19 crisis in order to reap their benefits.

5.6 | Big data

Big data has recently played an important role in analysing data about observed pathogens, disease modelling, monitoring human behaviour, and data visualization. Based on our analysis of the efforts related to this technology, we determined that the main advantage of this technology is the ability to evaluate decision-making based on data in near real-time.

It is also critical to use the gathered data and algorithms in a safe and responsible manner, in accordance with data-protection legislation and with due regard for privacy and confidentiality. Failure to do so would undermine public confidence, making people less likely to obey public-health advice or guidelines and more likely to have adverse health outcomes. More research is needed to investigate how to use big data while protecting privacy and maintaining high standards. There are many ways to make big data more impactful in circumstances such as COVID-19, but we have yet to successfully harness the power of Big Data in the quest for a solution for the COVID-19 catastrophe.

5.7 | Blockchain

According to the findings of this report, blockchain technology is widely used for protecting patients' health information, monitoring outbreak data, contact tracing, donation tracking, and addressing supply chain failures revealed by the COVID-19 pandemic. However, a few issues must be addressed before this technology can be widely adopted.

The first issue is trustworthiness in the release of funds by governments through smart contracts. For example, a government will prepare to raise relief funds and ensure that the funds can be used in the event of a disaster such as COVID-19. However, the question is whether people can depend on their government's word. This is where Blockchain comes into play. Since its implementations necessitate dedication, blockchain will assist the government in will its trustworthiness. We could not find any papers relevant to this particular problem when looking through the research works on using Blockchain technology for COVID-19.

Furthermore, another technology known as distributed ledger technology (DLT) is not being used to resolve the crisis during COVID-19. DLT is a digital system for tracking the details of asset/fund transactions in various locations at the same time. This DLT principle can be very useful during the COVID-19 outbreak. Let us cite an example for the use of DLT. To support the livelihood of the people below poverty line, the Government offers them relief fund. In order to ensure that the fund reaches the right person, the Government transfers the amount directly to their accounts. DLT can help in this process. All those who are involved have control of their data, that is, the power remains with all people who are supposed to receive the relief fund. DLT allows the recipients of the funds to have their individual wallets. This kind of application is not explored in the recent efforts that use Blockchain technology for COVID-19. This type of application has not been investigated in recent efforts to use blockchain technology for COVID-19. Although the potential of blockchain is undeniably disruptive, it is still in its infancy.

5.8 | Cloud computing

While reviewing the articles related to the role of cloud computing in COVID-19, we found only a very few articles (Westmonroeparteners 2021; Gong et al., 2020; Maghdid et al., 2020; Warren & Skillman, 2020). These articles focused on storing the huge volume of health data of the patients and analysing the data for prediction of infection, analysis and treatment.

Furthermore, fog computing offers a real-time solution with extremely low latency. Fog computing combined with AI can aid in the early diagnosis of patients and the processing of clinical data with ultra-low latency. It is suited for applications that require real-time processing, fast reaction times, and minimal latency. A variety of medical IoT devices collect real-time dynamic data. This real-time data is sent to the fog nodes, where AI is applied through various classification methods. Their current health status is characterized as COVID-19 infected or non-infected, allowing necessary action to be taken.

Cloud computing has been used as a technology enabler for many years. However, it is generally accepted for large-scale companies. Aside from the numerous benefits, there are still several obstacles to cloud computing adoption. The probability of security risk is the most significant impediment to cloud adoption in healthcare. Since health data is sensitive, cloud-hosted healthcare data must be protected from cyber-attacks. Encryption and access control systems, among other things, may be used to ensure the confidentiality of sensitive data. One method of providing protection is to use Blockchain technology. Another consideration when hosting data in the cloud is adhering to data regulation laws such as HIPAA and GDPR. Even though downtime is uncommon in the cloud, there should be a strategy in place to deal with it. These three issues, as far as we know, have not been prioritized in the efforts we examined. These should be taken into account for potential extensions. The convergence of cloud and fog computing and other emerging technologies would undoubtedly increase efficiencies and open up new avenues for solving problems not just in healthcare, but also in other domains such as logistics and transportation. As a result, cloud computing has a long way to go in the healthcare field.

5.9 | Mobile apps

According to the research on the use of mobile apps, the use of these apps to allow authorities to contact health workers remotely and to alert authorities and officials about monitoring infected persons, number of cases, symptoms, and preventive measures are a few examples of measures that have been efficiently used in the COVID-19 crisis. Some of the apps include CovidSafe, MyTrace, AArogya Setu and so forth. As it has been mentioned in Parker et al. (2020), there are ethical considerations that need to be focused in the use of mobile apps for public health monitoring.

Based on our review on the effectiveness of intelligent mobile apps during COVID-19 epidemic, we identify the following issues and challenges that need to be focused further. Mobile apps can harmonize but never replace regular contact tracing efforts. Since everyone will not have a smart phone, especially the elderly people, and will not have downloaded the tracing app, the use of mobile apps during this pandemic is a big question. In addition, it is important to know that many mobile applications may lack in parameters which make them more secured, reliable and viable tools. These apps collect the users' location information periodically using GPS, Bluetooth and so forth. The various concerns involved in using these apps include the collection of users' information like age, mobile number, profession, travel history, current location and so forth. All this information is stored in a server and the government has the control over the information. This leads to the loss of privacy of users' information.

Intelligent smartphone applications, like other digital health breakthrough technology, are no exception. These apps face concerns about privacy and data ownership. Based on the analysis, we conclude that the most successful implementation of digital technology for communication tracing, tracking quarantined individuals, social control and many more is dependent on two factors. The first factor is people's willingness to embrace new technology, and the second is the digital infrastructure required for these technologies. To counter the consequences of COVID-19 and potential public health pandemics, the digital infrastructure must be strengthened. Perhaps, the constructive impact of these digital technologies will further hasten the adoption of innovations in healthcare. Nonetheless, innovations still need to focus on safety and security. Furthermore, we found that Gasser et al. (2020) have contributed to address the legal and ethical issues related to the risks of deploying digital public

health technologies in response to COVID-19. The various legal and ethical challenges include ensuring public benefit, validity and accuracy of data, privacy and autonomy protection, avoiding discrimination and so forth. In order to address these challenges, Gasser et al. (2020) have proposed a navigation tool to assist decision makers in ensuring procedural robustness and minimizing ethical breaches while deploying digital public health technology.

6 | CONCLUSION

The COVID-19 pandemic has generated an enormous demand for digital technology solutions and has resulted in effective solutions such as early detection and diagnosis of infection, tracking of treatment and quarantined individuals touch tracing of individuals, projection of cases and mortality, assisting healthcare staff and so on. Digital technology tools and trends have encouraged pandemic strategy in ways that were previously difficult to accomplish manually. We examined technologies such as IoT, AI/ML/DL, big data, AR/VR, robots, drones, cloud, blockchain, and 5G, which are key enablers for radically changing the current crisis scenario and management of the COVID-19 outbreak.

We anticipate a dramatic change in the use of emerging technology for COVID-19 containment. The effectiveness of these emerging innovations is heavily reliant on our acceptance of them. To conclude, while the world continues to depend on conventional public-health interventions to combat the COVID-19 pandemic, there is now a wide variety of emerging technology available in 2021 that can be used to complement and improve these public-health scenarios. The immediate use and active deployment of emerging technology to address the COVID-19 global public-health challenge in 2021 will most likely increase public and governmental acceptance of such technologies in the future for other areas of healthcare, including chronic illness, as well as other domains such as transportation, logistics, digital marketing, and so on.

ACKNOWLEDGEMENT

The authors extend their appreciation to the Researchers supporting project number (RSP-2021/314) King Saud University, Riyadh, Saudi Arabia.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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How to cite this article: Subramanian, M., Shanmuga Vadivel, K., Hatamleh, W. A., Alnuaim, A. A., Abdelhady, M., & V E, S. (2022). The role of contemporary digital tools and technologies in COVID-19 crisis: An exploratory analysis. *Expert Systems*, 39(6), e12834. <https://doi.org/10.1111/exsy.12834>