



# Smart technologies driven approaches to tackle COVID-19 pandemic: a review

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## Abstract

The novel coronavirus infection (COVID-19) is not diminishing without vaccine, but it impinges on human safety and economy can be minimized by adopting smart technology to combat pandemic situation. The implementation of new innovations and novel tactics has proven to be effective in curbing the risk of COVID-19. The present study covers the role of smart technology in mitigating the spread of COVID-19 with specific focus on advancement in the field of drone, robotics, artificial intelligence (AI), mask, and sensor technology. The findings shed light on the robotics and drone technology-driven approaches that have been applied for assisting health system, surveillance, and disinfection process, etc. The AI technology strategies and framework is highlighted in terms of bulk data computing, predicting infection threats, providing medical assistance, and analyzing diagnosis results. Besides this, the technological shift in mask and sensor technology during the pandemic have been illustrated, which includes fabrication method like 3D printing and optical sensing, respectively. Furthermore, the strength, weakness, opportunities, and possible threats that have been shaped by the rigorous implementation of these technologies are also covered in detail.

**Keywords** COVID-19 · Robot · Drone · Artificial intelligence · Mobile apps · Sensor

## Introduction

Coronavirus 2019 (COVID-19) is a human infectious disease linked with severe respiratory distress. Seeing the impact of COVID-19 infection on human health and its outbreak, since 30 January 2020, World Health Organization (WHO) recognized it as Public Health Emergency of International Concern (PHEIC) (WHO 2020). Considering the rapid transmission of infection among masses, COVID-19 has been given a status of pandemic disease (Lai et al. 2020). According to WHO, the best solution to curtail its widespread is by adopting precautionary measures at the early stage. To tackle the pandemic, the main focus of healthcare systems is to implement large-scale testing and effectively treating the infected individuals. Furthermore, to mitigate the infection and bring the sustainability in current pandemic situation, the other best solution at which governments are unanimously focusing is imposing lockdown in infection concerned regions. Thus, to simultaneously meet the requirement of the health system and implement the lockdown, a certain framework for shaping the society is required. Under these circumstances, smart technologies

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have made their impact in various sectors like healthcare, government, public and industries, etc. (Elavarasan and Pugazhendhi 2020). The sudden shift toward the techno-driven approaches has accelerated the demand for innovations and alternative strategies, and has pushed the limits of the technologies in almost every field (Javaid et al. 2020; Kumar et al. 2020; Singh et al. 2020). To handle the burden of frontline health system warriors, technologies like telehealth (STAT 2020), artificial intelligence (AI) (Alsuliman et al. 2020; Nguyen 2020), robotics (European Parliament 2020), and drone (dJI enterprise 2020), etc. have gone up multiple folds during the pandemic. Drone and robot technology has been configured to assist in the disinfection process, delivery of medical supply, surveillance, and screening of individuals for early detection of infection, etc. Moreover, the robotics has been widely applied in providing medical consultation to patients and healthcare workers. The rapid increase in the COVID-19 cases and it impinges on human safety has created a necessity to analyze bulk data for making protocols to tackle the pandemic situation. Under the context, the AI and data-driven applications have encouraged the development of strategic framework to enhance the detection, tracking, and data analysis, which has a direct influence on mitigating the spread of infection (OECD.AI 2020). With ability to work autonomously, self-learn to improve with addition of new data set and draw imperatives in short span of time, AI has been implemented in predicting regions with infection threats, medication, and computing diagnosis results, etc. Even mobile phone network is trusted as one of the key avenues in tackling the pandemic situation. In recent time, mobile phone technology is spread all across the cities and virtually connects person to larger masses. Seeing mobile phone network as the veins of cities smartphone applications (Apps) has been utilized as perfect template to communicate with larger masses. Various mobile Apps were developed to spread awareness among people, provide medical assistance, and most important to curb the spread of COVID-19 through contact tracing. As we prepare to step out and bring normalcy in the daily life, authorities are focusing on the implementation of protective measures and rapid testing methods. In this regard, the use of face mask has proven to be effective in limiting the spread of the COVID-19. As a result, a sudden surge in the demand of mask has led to novel innovations in the mask fabrication technology. On the other hand, worldwide researchers are engaged in developing point-of-care products that will assist in rapid testing of COVID-19 (Udugama et al. 2020). The combined effort from various sectors, implementation of technologies, and effective governance together has created a defense line to fight against COVID-19. Seeing the astonishing contribution of the technologies in combating COVID-19 infection, it becomes essential to understand how these innovations are synergistically helping to overcome the pandemic situation.

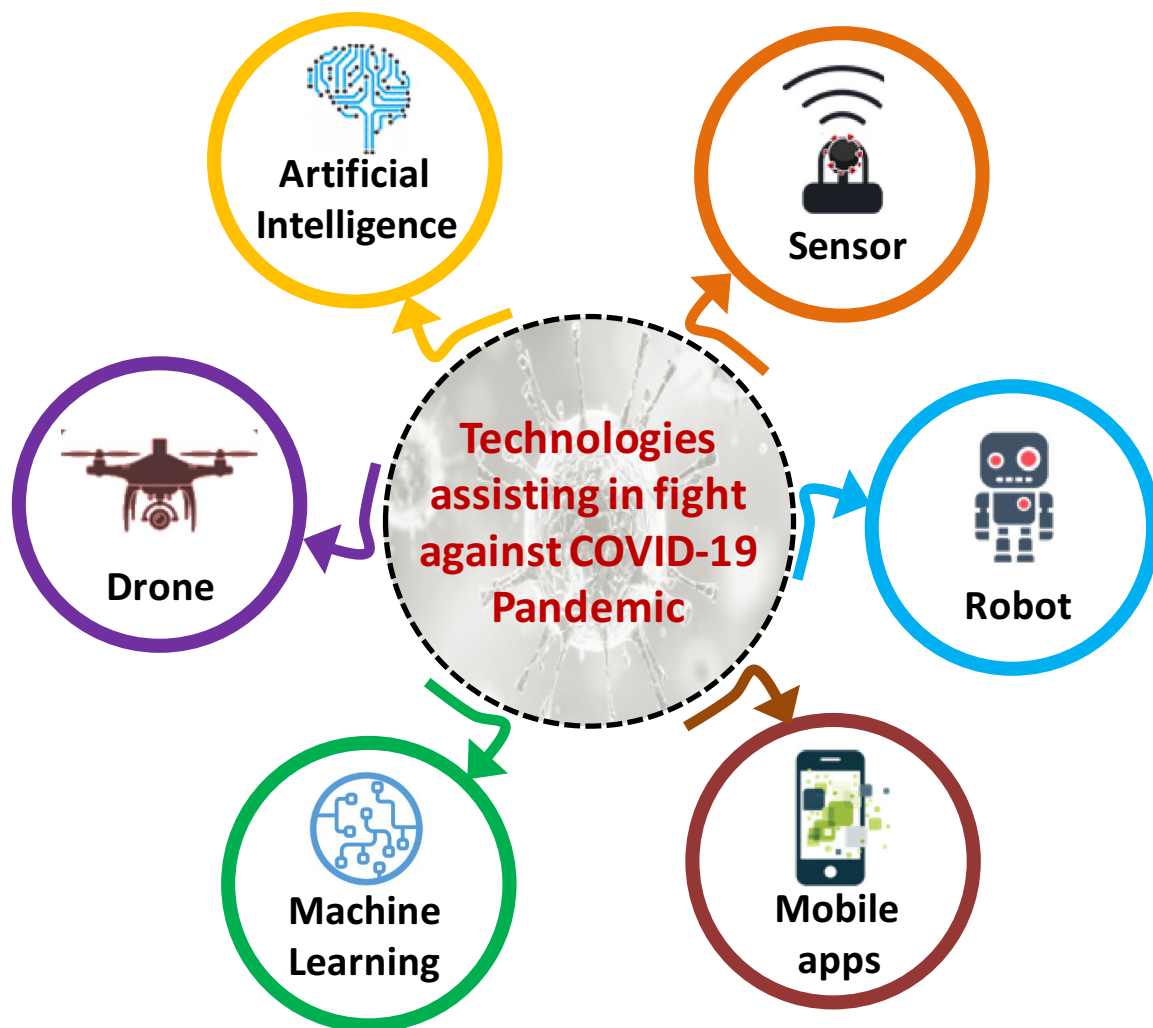
The present review highlights the hidden roles of smart technologies and reveals its potential in controlling the pandemic situation (see Fig. 1). The study includes a detailed investigation of viable technologies based strategies that are influencing in controlling the pandemic along with the changes that these technologies have undergone to exploit their potentials to the fullest. The article helps scholars, professionals, and readers to recognize how the implementation of technologies is synergistically assisting in controlling the spread of the coronavirus infection and, also, persuade the implementation of these technologies in current or future emergency situations.

## Drone technology

The use of technology such as drones (autonomous machines) has a crucial role in responding to the COVID-19 pandemic. Drones assist authorities and people in different ways to prevent the spread of coronavirus infection and stop unwanted movements of peoples during the lockdown. Authorities are using drones for purposes like medical supply, surveillance, disinfection, screening infection symptoms, and public awareness etc., as shown in Fig. 2. Drones technology is feasible to carry all these tasks and even enables its service in interior regions without any person-to-person contact.

## Delivery

In the coronavirus pandemic situation, drones have been extensively adopted for faster and safe transfer of essential products. The delivery approach can be classified in two perspectives, first is supply of food items/basic needs and second is delivering health care facilities, which include test samples to labs, medicines and personal protective equipment (PPE) kit, etc. (Poljak and Šterbenc 2020). To reduce the load on the healthcare system, drones are applied for collecting test samples from localized/remote areas and transport them to the nearest testing lab. This approach makes the transportation faster and even minimizes the risk of virus spread. A more-advanced and potential concept called 'lab-on-a-drone' is suitable where the delivery of diagnosis equipments is difficult and for laboratories that are located in a remote area. The 'lab-on-a-drone' technology couples drone with sample preparation and diagnostic platforms, which intern reduces the testing time (Priye et al. 2016). A startup company in California named 'Zipline' has been actively using drone technology for the past few years to deliver medical supplies in regions like Ghana and Rwanda (Bloomberg 2020). During the COVID-19 outbreak, under national pilot programs, the Chinese government accelerated the use of drones to deliver tons of medical supplies



**Fig. 1** Schematic showing various smart technologies assisting in mitigating COVID-19 pandemic

and parcels in virus-infected areas (Twitter 2020a). Drones helped in quick diagnosis by delivering test samples to laboratories (BBC 2020a) and are much safe to transport medical supplies into hospitals treating COVID-19 patients (Nikkei Asian Review 2020). Moreover, drone-based delivery approach took humans out of the process which helps in curtailing the spread of coronavirus and also reduces delivery time. The various drone technology-assisted delivery strategies adopted by different countries are listed in Table 1.

### Surveillance and broadcast

Most countries took measures like closing non-essential public places, ban mass gatherings, and social distancing policy to limit physical contact. The major issue is how governments, organizations, and societies should perform surveillance with minimum effort and without any physical contact. In this regard, authorities are using drones to

monitor people's movement and avoid social gatherings that could pose a risk to society (Vacca and Onishi 2017). Drones are being used in broadcasting messages and imparting awareness among the public through loudspeakers and even digital displays are widely used in many countries (Mishra et al. 2020). Using a global positioning system (GPS) enabled drone management system; authorities can easily detect unwanted activity even in the crowded areas.

### Disinfection

Till now, no medicine or vaccine has been developed for curing COVID-19 infection, and as a result, authorities are much focused on prevention methods. Controlling coronavirus infection by prevention methods is a gradual process and may take months, and thus, to bring stability in the economy, governments are giving relaxation in lockdown. As we prepare to step out and bring normalcy in daily life, it becomes



**Fig. 2** Schematic showing the implementation of drone technology in various fields to combat COVID-19 pandemic

even more important to frequently disinfect places of high-risk like parks, public transport, and open market, etc. To implement it, authorities have come up with a solution of deploying agriculture spraying drones for frequent disinfection of high-risk area within short span of time (China Daily 2020; Clay and Milk 2020). The area covered and the speed by which these drones can disinfect are unparalleled compared to other spray techniques.

### Screening

One of the common ways of coronavirus transmission is a person-to-person interaction. Thus, it is important to identify the infected person and the possible infected person due to contact at an early stage. The idea is to perform bulk and rapid screening around the regions with minimum human-to-human interaction. Under the context, drone technology has emerged as a game changer and assisted in symptom-based bulk screening of individuals.

These drones are installed with the temperature sensor to screen the people from their homes. They are also equipped with the camera to take pictures of the person and GPS to track the location. To enhance the screening accuracy, technology that remotely monitors the respiratory conditions is coupled with drones and is referred to as “Pandemic Drone” (HIT consultant 2020a; Forbes 2020). Originally, the pandemic drones were developed for remote monitoring in natural disasters and war zones. The unique technology incorporated computer vision system and specialized sensor to monitor respiratory rates, heart rates, temperature, as well as coughing in crowds. To combat the global spread of coronavirus in the United States of America, authorities have deployed a pandemic drone named ‘Draganfly’ that remotely monitors and detects people with infectious and respiratory conditions (GPS World 2020b). The technology offers health assessment at a large area within short duration of time and a large number of persons can be monitored frequently and on a daily basis.

**Table 1** List of various countries using drone technology for delivering medical supply and other essential products

Country	Function	Information	References
Australia	Medical supply	Skyrocket, a Google project initiates cargo drone deliveries	Twitter (2020b)
Canada	Medical supply	Drone Delivery Canada (DDC) Sparrow, a multi-task drone transports hygiene kits, PPE, COVID-19 test swabs and can carry about 10 lb of payload	Inside unmanned systems (2020)
Chile	Medical supply	High-tech drones transport sanitizer, masks, and medications across the rural South American nation and in remote areas	Reuters (2020)
China	Medical and commercial products	JD Logistics drones deliver commercial cargo and medical supplies	Supply Chaindive (2020)
China	Medical supply and Test sample	Antwork uses cargo drones to deliver supplies to quarantine people and also medical samples for test	GPS World (2020a)
Estonia	Test sample	Threed Systems and The North Estonia Medical Center use drones to transport COVID-19 samples to labs	ERR.ee (2020)
Germany	Test sample	Becker and Kollegen and Quantum Systems use a drone to transport COVID-19 samples to the Munich laboratory	Quantum systems (2020)
Ghana	Medical supply and Test sample	Zipline drones transport around 200 medical products that include health facilities, PPE, plasma, blood and vaccines, etc	The World (2020)
Ireland	Medical and other supply	Health Service Executive is working with Manna Aero to transport essential supplies and medicines	BBC (2020b)
Italy	Medical supply	Industrial drones deliver medicines and COVID-19 test swabs	UAS magazine (2020)
Poland	Test sample	Warsaw, Central Clinic Hospital uses Hermes V8Mt drones to transport patient samples for testing	La Opinion (2020)
Scotland	Medical supply	Wingcopter drones deliver PPE and test kits	The guardian (2020)
Singapore	Medical supply	Drones deliver medicines to cargo ships	We Robotics (2020)
South Korea	Medical supply	In response to the coronavirus pandemic, hydrogen powered drone transports protective masks	H2 view (2020)
Turkey	Food supply	In a lockdown, a bakery owner uses a drone to deliver food items to the customers	Twitter (2020c)
United Kingdom	Medical supply	National Health Service (NHS) delivers medical supplies using drones	BBC (2020c)
United States of America (USA)	Medical supply	Zipline and Matternet use drones to supply medical deliveries in North Carolina	Fierce Electronics (2020)

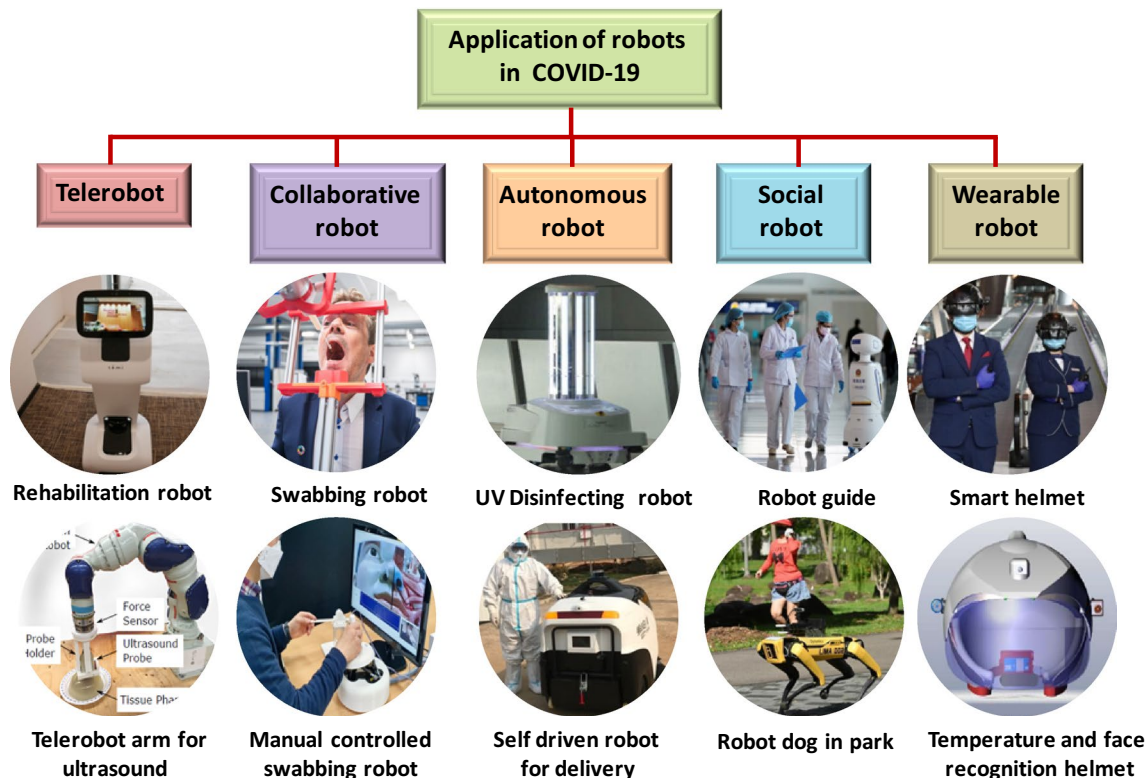
## Robot technology

Robotics has proven its caliber in many fields and can assist in many ways. The technology has proven its potential in many aspects like delivery of medicine, surveillance, screening of patients and disinfection, etc. The application of robots in healthcare systems has shown encouraging solutions for preventing the escalation of COVID-19. With the simultaneous incorporation of machine learning algorithms and AI, robots have turned out to be more effective in the treatment and diagnosis of infection. For instance, robots are used for bulk screening and acquire data to interpret the health report of individuals. In pandemic situations like coronavirus, autonomous robot system has provided substantial support to health workers by performing repetitive

tasks with a low margin of error. Robot technology can be classified based on the effective level of communication between robots and humans. Figure 3 shows the classification of robot technology along with examples depicting its application in the COVID-19 pandemic. A detailed discussion of the various robot technologies listed in Fig. 3 is carried out in the next section.

## Tele-robot

Tele-robot is the technology that can be used to handle robot from distance using a wireless communication network like Internet. During the COVID-19 pandemic, assisting the healthcare system with human-operated tele-robots has proven to be much safer and effective technology. The robots



**Fig. 3** Schematic representing the classification of the robot technology along with examples illustrating their application in the COVID-19 pandemic

can be easily sterilized from time to time, which makes their use effective during screening and intake of patients. The ‘Intuitive’ made ‘daVinci Surgical Robot’ has received much attention in this field and works with a surgical software console that can be operated by a physician (Intuitive 2020). Another example is using a teleoperated robot arm to perform ultrasound examinations (Carriere et al. 2019). Along with this, by clubbing tele-robots with mobile phone software, it is possible to use the instrument for a regular check-up of blood oxygen level, pulse, blood pressure, and temperature, etc. Apart from this, tele-robots are used in hospitals and in the community for secondary healthcare operations like screening, redirecting patients for isolation, and providing assistant during rehabilitation. Tele-robotics assisted tele-rehabilitation is employed to connect with patients at residence and guide them with their cognitive or physical rehabilitation activities (Agostini et al. 2015; Fong et al. 2019; Tao et al. 2020). Using this technology, people with a high risk of getting affected can remain at their home and can receive rehabilitation therapy through a distance.

### Collaborative robot

Collaborative robots are intended to augment the human-operated process and work in close proximity to physically

interact with humans. Compared to tele-robots, the collaborative robots do not have the capability to work in isolation without human intervention, but have the ability to adapt with task changing dynamics. Collaborative robot can be incorporated for initial testing like collecting and testing oropharyngeal and nasopharyngeal swabs (Evening Standard 2020). This will reduce the risk, speed up the process, and allow bulk testing. Under this context, a team at the University of Southern Denmark has developed a robot that collects the swab from the throat interior and deposits it in the sample box (Healthcare Packaging 2020). Collaborative robots with augmented reality (AR) technology serve as trainers/simulators for training healthcare workers and quickly assist them in various target activities. The robotic task simulators are used in the COVID-19 pandemic to train medical staff on highly dynamic procedures or technical protocols.

### Autonomous robot

Autonomous robots are proficient enough to make decisions independently and accordingly take actions without any human intervention. During COVID-19, the most common and widely deployed autonomous mobile robot is UV sterilization robots. A wheeled UV disinfecting robot is used at places like hospitals, airports, shopping complexes and

stores, etc. (Simple Flying 2020). Apart from this, wheeled autonomous robots are also used for visiting patient rooms and interact with them to record vital health information. On coupling these robots with manipulators, they can even perform some medical treatment (Tavakoli et al. 2020). A self-driving autonomous robot is used for supplying PPE, medication, equipment, and food supply, and can do other logistic work (Nikkei Asian review 2020b).

### Social robot

Social robots have the ability to communicate and interact with persons and their surrounding environment. To make effective interaction with humans these robots are equipped with different types of actuators and sensors. Social robots are designed to resemble humanoids or toys with a head and can speak to interact with users. The motive of this kind of robots is to engage with persons in isolation, elderly persons, and persons with disabilities to provide them medical/mental assistance. These robots measure the infection symptoms, stress, and other vital signs via sensors embedded in them. In the COVID-19 pandemic, social robots are used for social interaction and guiding peoples in the hospital (The Peninsula 2020). Along with this, these robots are used at public places to help people follow the guidelines like social distancing and wearing face mask, etc. (Ecns.cn 2020).

### Wearable robot

Wearable robot technology mainly refers to electronic devices that can be worn on the body and has the ability to perform an action and take decisions while assisting humans in computing, examining, and communicating the data. In the case of COVID-19, measured data can be a body activity corresponding to vital signs of symptoms. One such example is the use of thermal imaging helmets at places that confront a large number of visitors on daily basis (International Airport review 2020). Recently, Mohammed et al. proposed a smart helmet for temperature monitoring and even facial-recognition technology to display the pedestrian's personal information (Mohammed et al. 2020).

### Artificial intelligence

Artificial Intelligence is considered as an emerging opportunity in the era of the Internet and virtual world. Many countries are leveraging AI to observe COVID-19 infections, inform healthcare systems, and set up rapid actions to curb its spread.

### AI-based data science modeling methods for COVID-19

To monitoring and combat the pandemic, the world is exploring robust technology areas particularly in AI and statistical science. Recently, Australian Census-based Epidemic Model (ACEMod), previously used for influenza pandemic simulation (Zachreson et al. 2018; Cliff et al. 2018), was modified and calibrated for modeling the COVID-19 pandemic across Australia (Chang et al. 2020). Allam and Jones recommend the use of AI for managing health system and regulating protocols (Allam and Jones 2020). China adopted a deep learning-based autoencoder model to speculate real-time COVID-19 cases in the infected regions (Hu et al. 2020). Even, an AI-based model called as 'α-Satellite' is projected to analyze the possible spread of the infection in an assigned area (Ye et al. 2020). The various immediate facts like death counts, public awareness through social media (Mirza and Osindero 2014), visitor's density, and demographic data are collected to assess the threat of infection in a region. Maghdid et al. proposed a framework to screen COVID-19 infection by clubbing built-in smartphone sensors with AI technology (Maghdid et al. 2020a, b). The intended AI-enabled protocol analyzes the smartphone sensor's data to estimate the infection severity in the user. In another work, deep learning method was employed for diagnosis by acquiring data and performs analysis corresponding to disease symptoms. For instance, videos and images obtained from smartphone camera or data screened through installed inertial sensors were studied for detecting human fatigue levels (Karvekar 2019; Roldán Jiménez et al. 2019). Likewise, condition of cough can be detected from the audio recorded through smartphone microphone (Nemati et al. 2019; Vhaduri et al. 2019). Even, the video obtained through smartphone can assist in the prediction of nausea (Story et al. 2019). Recently, a joint venture between India and Japan aims to hasten human health sector with novel innovation in smart technology system (Salzburg Global Seminar 2020). The association will focus on the development of autonomous system, robotics, AI, and blockchain technologies to deal with the challenge of health systems. The Canadian startup 'BlueDot' has developed an AI enable framework that precisely perceives the risk of the infection and level of hazard in a demographic region (Bluedot 2020). On a similar note, the healthcare analytics and solution corporation 'Cotiviti' is now using AI and fitness data to predict future coronavirus hot spots around the USA (TechRepublic 2020). To forecast the possible infection hubs, an AI model that computes the data based on Susceptible-Infected-Recovered-Dead (SIRD) protocol was used in Hubei, China (ET Healthworld 2020). Meanwhile, there are a lot more technologies that are under

development process and yet to come in support of dealing with pandemic situations like coronavirus.

### AI working on coronavirus medication

Artificial intelligence and data science have become critically important in pandemic situations such as COVID-19. Google's 'Deep Mind' division has used its latest AI algorithms to understand the proteins and genetics of the coronavirus (ZD Net 2020). It has published its findings to help others develop treatments and understand more about the virus. 'BenevolentAI' has been using AI models to develop drugs that can cure the most challenging diseases and even putting efforts to medicate COVID-19. With the help of the AI module within the initial weeks of the pandemic itself, it proposed prevailing drugs that might be useful in curing coronavirus infection (Benevolent 2020). The supercomputers and cloud computing resources around the world are being employed to ventures possible breakthrough in the development of coronavirus vaccine. These systems can run calculations and model solutions at a much faster rate than standard computer processing. Ke et al. used AI to test and specify already existing drugs with positive effects against coronavirus (Ke et al. 2020). Continuous efforts are going on to establish clinically achievable permissible doses against SARS-CoV- 2.

### Pandemic tackling mobile applications

Since the commencing of COVID-19 pandemic, many smartphone Apps have been developed, some of them operate through public authorities and others in collaboration with private companies. Worldwide governments and agencies are relying on smartphone Apps to provide contemporary coronavirus information, monitor quarantine of people, give healthcare services, and assist self-assessment. Based on the task which they perform, mobile Apps can be classified into information Apps, self-assessment Apps, and contact tracing Apps.

### Informational apps

These Apps do not require a great deal of customization as they are meant to provide information rather than to interact. These applications give the latest information related to COVID-19 like breaking news, fact sheets, and guidelines, etc. Table 2 summarizes the list of informational mobile Apps used by various countries in coronavirus pandemic.

### Self-assessment apps

COVID-19 self-assessment Apps for mobile phone helps people to evaluate their health and receive instructions/recommendations on COVID-19. The aim is to offer a degree of understanding to people, who seem to have infection symptoms and favor ailment through an easy set of questions. It also acts as a tool to educate people on how this disease spreads and guides them with preventive measures. The secondary objective is to lessen the flooding of health care centers with people having minor symptoms. Table 3 summarizes the list of self-assessment apps used by various countries during coronavirus pandemic.

### Contact tracing apps

Contact tracing and warning has played an important role in all phases of the outbreak. The purpose of contact tracing and warning is to point out infection suspected person and ask them to self-quarantine or isolate if they show symptoms. The contact tracing also helps in aggregated facts to monitor infection spreading patterns in society. The various contact tracing Apps work on technology like Bluetooth specification, cryptography specification, and application program interface (API) framework. The Chinese authorities have developed a monitoring App known as 'Health Code' that performs massive statistics to figure out the level of risk associated with the person (Business Insider 2020). The Indian authorities have launched a smartphone App known as 'Aarogya Setu' to assist coronavirus patients and provide statistical data on the number of infected person in close vicinity of the user (Google Play 2020h). The 'Covid-Safe' App launched by Australia approves the fitness of the users and gathers data to confirm whether they have come in contact with an infected person (Australian Government Department of Health 2020b). As the outbreak of COVID-19 is escalating across the world, the number of software employed for contact tracing will also increase across the nations. The brief detail of contact tracing Apps used by different countries is listed in Table 4.

### Technology-based X-ray and CT image analysis

One emerging solution to fasten the medical treatment is AI-driven image analysis. During COVID-19 infection screening and treatment, a large number of X-ray and computed tomography (CT) images are taken, and manually analyzing these images requires terrific effort. Under the context, AI can help via quantitative analysis and adjusting treatment plans according to reports of the patient. COVID-19 detection neural network (COVNet) is a deep learning



**Table 2** Informational mobile Apps used by various countries in the COVID-19 pandemic

Country	Application name	Function	References
Bolivia	Bolivia Segura	The latest updates of professional communications, statistics on care, prevention, symptoms of disease and emergency numbers, etc. are being provided via this App	Google Play (2020a)
Brazil	Coronavírus-SUS	The App is launched by the Brazilian Ministry of Health to unfold recognition among humans about the outbreak	Google Play (2020b)
Cambodia	Khmer Education COVID-19 App	The Ministry of Education, Youth and Sport has launched a competition to inspire public and students to send data about the virus	The Phnom Penh Post (2020)
Cuba	InfoCU	The Ministry of Health has launched this App to supply residents with applicable data about the COVID-19 pandemic	CubApk (2020)
Guatemala	COVID-19 en Guatemala	Institute of Research and Projection for Science and Technology (Incyt) and Rafael Landívar University developed the tool to update data on the number of infected persons, deaths and recovered people, etc.	PlazaPublica (2020)
India (Kerala)	GoK direct	The App presents formal information of the pandemic in a particular region	Google Play (2020c)
Indonesia	PikobarJawa Barat	The App is beneficial for residents to request logistical help and get entry to emergency, etc.	Google Play (2020d)
Mauritius	beSafeMoris	The App provides users a real-time statistics, obtained from health organizations. Users can assist recommendations and locate a list of various fitness centers	Google Play (2020e)
Namibia	Covid-19 Namibia	The Namibia University of Science and Technology (NUST) designed an internet site and App for providing records related to COVID-19 disruption	NUST (2020)
Portugal	Estamos ON	Application updates the country's epidemiological bulletin, news related to government's feedback on pandemic	Google Play (2020f)
Vietnam	NCOVI	The Ministry of Health and The Ministry of Information and Communications have launched an App to notify the coronavirus statistical data and other essential information	Google Play (2020g)

algorithm-based AI module that screens the CT images to diagnose the coronavirus infection in patients (Li et al. 2020). Figure 4 shows a schematic of pre-trained models that analyze the X-ray images to differentiate between COVID-19-infected persons and normal person (Narin et al. 2020). Another deep learning framework based on the concatenation of three dimensional CNN ResNet-18 network (He et al. 2016) and location-attention method is proposed to analyse pulmonary CT images for identifying COVID-19 infection (Butt et al. 2020). A company named Infervision has developed an AI-based platform that helps healthcare people to effectively screen out the suspected individuals (ITN 2020a). Alibaba an e-commerce company has built an AI-enabled analysis machine that is estimated to be 96% correct in figuring out the virus-infected person (Technology Org 2020). A gadget named 'Coronavirus Chest CT Smart Evaluation System' developed in Shanghai can diagnose the suspected persons within seconds (Synced 2020). Wang et al. developed a clinical diagnosis for COVID-19 by employing a deep learning method to monitor radiographical deviation in CT-scan images with a comparison accuracy of 89.5% (Wang et al. 2020). Yuan et al. examined the CT-scan images of coronavirus infected persons and analyzed them

to be associated with the mortality of the sufferer (Yuan et al. 2020). Companies like Thirona and Delft Imaging have collectively developed a CAD4COVID screening platform built on the CAD4TB software for screening of COVID-19 (ITN 2020b). In line with the work described above, a list of research applying deep learning for COVID-19 prognosis is given in Table 5.

## Mask technology

To control the spread of respiratory infection, use of face masks by patients is a well-recognized strategy. The asymptomatic patients in SARS-CoV-2 are unaware of their infection and become active carriers of the infection. During breathing and talking, the resultant aerosol dispersion and droplets becomes the prime route of transmission. Thus, to prevent the spread and inhalation of these droplets, it is recommended to use the mask in public. Surgical masks are effective in preventing from spray and inhalation of droplets in the range above 5  $\mu\text{m}$ , but have limited ability to filter submicron-sized droplets. Studies have shown that surgical masks and N95 are effective in intercepting respiratory

**Table 3** Self-assessment mobile Apps used by various countries in the COVID-19 pandemic

Country	Application Name	Function	References
Argentina	COVID-19 Ministerio de Salud	The self-testing web application is regulated by Argentina's Secretariat of Public Innovation	Argentina.gob.ar (2020)
Australia	Australian Government	The Australian Government has launched the App to make citizens up to date with the pandemic situation. By the usage of this App, a citizen may also self-analyze their symptoms to apprehend whether they require medical help services or not	Australian Government Department of Health (2020a)
Belgium	Move-UP	The move-UP App is for the rehabilitation of COVID-19 patients. Doctors can also use this App to maintain records of their patients	moveUP.care (2020)
Brunei	Health Info	The self-assessment tool has been developed for the citizens by the Ministry of Health of Brunei Darussalam	Kementerian Kesihatan (2020)
Bulgaria	Virusafe	The App has the feature of symptoms based self-assessment and can also track one's health status	Scalefocus (2020)
Canada	Canada Self-Assessment Tool	The App allows users to receive the latest updates and self-assess their health symptoms	Government of Canada (2020)
Colombia	Coron App	The App works by monitoring the symptoms of users and generating their reports based on the analysis	ApkPr.com (2020)
France	French Government online test	The French Government running App analyzes a person based on a self-evaluation online test, which asks about signs and symptoms of COVID-19 (if any)	Gouvernement. (2020)
France	Covidom	The App has features for home monitoring of COVID-19 infected patients. Simultaneously, medical assistance is provided by professionals	Frandroid (2020)
Ghana	Redbird	The App tracks the patient's symptoms through self-assessment. The motive of this App is to provide a digital alternative for patient's screening and daily follow-up	Redbird (2020)
Guyana	COVID-19 Response App Home Page	The Ministry of Public Health's Information System offered this App as a self-screening tool so that precautions are followed and people can monitor their symptoms	Moph Information System (2020)
India	Coronavirus risk scan	The AI-driven COVID-19 risk scan App has been launched by the chain of Apollo Hospitals. They have created an online self-assessment platform that conducts a preliminary check at home. The application is outfitted with a chatbot using the AI technique	Apollo (2020)
Ireland	HSC	The Health and Social Care Board (HSC) uses this App to aid in COVID-19 by providing vital advisory and information. This App additionally helps in self-evaluation of symptoms	App Store (2020a)
Japan	by Agree	Japanese clinical company named 'Agree' has created an App that connects residents with physicians and assesses their health symptoms	The Japan times (2020)
Philippines	FightCOVID	Fight COVID-19 App is launched to decrease flocking in hospitals and health centers	Fight covid (2020)
Oman	Tarassud	While imparting all the vital information of pandemic, users can additionally self-assess their symptoms and ask associated queries	App Store (2020b)

Table 3 (continued)

Country	Application Name	Function	References
Saudi Arabia	Mawid	The App offers all required consultation to the public. It additionally has guidelines on how to act during an emergency	App Store (2020c)
South Africa	Corona Fighter	Online tracking and monitoring of symptoms are done. Also user gets recommendations on request	Corona Fighter (2020)
Spain	Spanish Government App	Professional App from the Spanish government appraises user's health and gives general guidelines or recommendations	Government of Spain (2020)
Uruguay	App Coronavirus UY	The App forwards the records supplied by the user to professionals and also offers functions to contact a medical doctor through video conferencing	Gub.uy (2020)
Uganda	Zoctu	To avoid creating a rush at hospitals, the App has been rolled out by Uganda's Nurses and Midwives Union. This App makes a connection between patients, nursing staff, and healthcare professionals	New Vision (2020)
USA	COVID-19 screening tool	In association with the Centres for Disease Control and Prevention (CDC), the government of the USA has started the COVID-19 screening tool which helps people to self-assess their symptoms	Apple (2020)

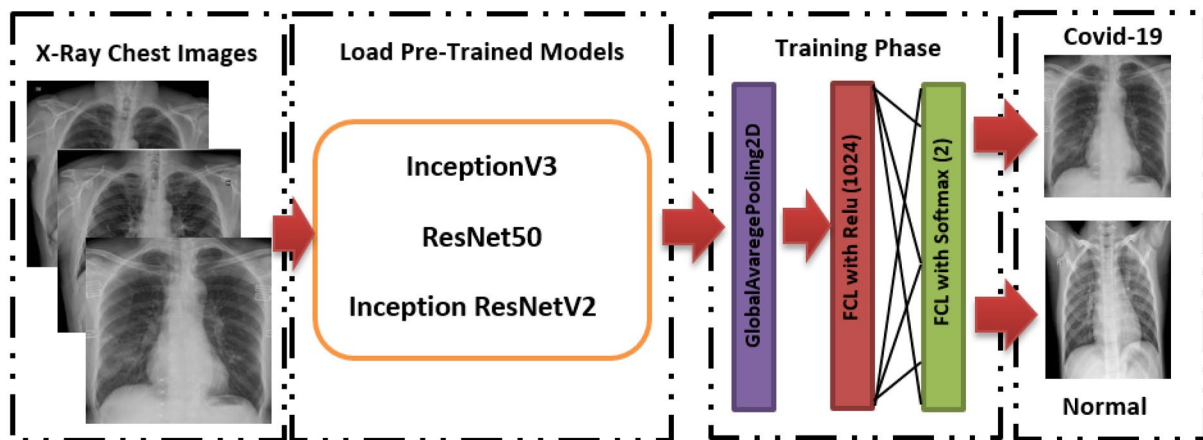
infection and can even prevent the spread of coronavirus through coughing. The European standard FFP2 and American standard N95 mask perform well as PPE, and are recommended for health workers dealing with sample collection and clinical care of COVID-19 patients. With an increase in the spread of the COVID-19, the global shortage of these PPE masks is a major concern. Thus, research is much focused on implementing the reuse of masks through disinfection methods and even to fabricate a cost-effective mask with self-disinfecting properties. Recently, Schwartz et al. adopted hydrogen peroxide vapor exposure as a method to decontaminate N95 mask and powered-air purifying respirators (PAPRs) masks, as shown in Fig. 5a. The study revealed that even after 50 cycles of disinfection, the N95 respirators retain their filtering capability (Schwartz et al. 2020). It is well known that UVC exposure has the ability to disinfect the surface more efficiently compared to other exposure methods. On a similar note, a smart UVC treatment-based hygiene product is launched by 'Cleanbox Technology'. The patented technology is based on UVC treatment for disinfecting point of use protective products that are not feasible to clean by a solution-based process. The technology is capable to safely eliminate 99.99 + % of fungi, bacteria, and viruses within seconds (Clean Box 2020). In another study, scientists have developed a special self-disinfecting mask that can give enhanced protection against the virus. The mask contains ~ 150 µm-thick outer porous coating of modified polysulfone material, and can kill the virus having a size of ~ 60 nm and above (The Times of India 2020). A washable mask that would kill 99% of bacteria and viruses has already stepped into the market. Extensive research has been done by the University of Arizona to fabricate mask with the ability to neutralize all kinds of pathogens that come in contact with the mask surface. Moreover, these masks can be washed with soap and water up to 30 times and are effective for up to 2 years. The effectiveness of mask was tested against many viruses, including the nearest to COVID-19—the 229E coronavirus (The National 2020). In another study, Marchese et al. suggested the use of a special device to be applied to the patient face during upper endoscopy, and this can minimize the aerosolization at the time of treatment (see Fig. 5b) (Marchese et al. 2020). During this global revolution in mask technology, 3D printing has emerged as an attractive tool to produce mask with improved disinfecting efficiency and tailored designs for enhanced comfort. A 3D-printed unique film called 'Maya sticker' can be attached to a face mask to increase its protective capabilities, as shown in Fig. 5c. The 3D-printed sticker has nanoscale fibers coated with disinfectants that enhance the capture and neutralization of nanoscale particles, respectively (Breaking Defense 2020). Ishack et al. displayed how 3D printing can be used to make customize face masks. In the study, they showed how 3D laser scanning can be implemented to scan exact

**Table 4** Contact tracing Apps used by various countries in the COVID-19 pandemic

Country	App Name	Function	References
Austria	Stopp Corona	The Austrian Red Cross and Uniqa-Stiftung have launched a utility program to track humans that have come in contact with Covid-19 carriers	Stopp Corona (2020)
Brazil	DESVIRALIZE	This online platform affords local monitoring for COVID-19. The application also indicates the symptoms of people around the user and who are parts of their networks	Desviralize (2020)
China	Health Code	The utility lets in residents to check if they have been in contact with a person identified with COVID-19. The user is assigned with color QR code that indicates their health status	Business Insider (2020)
China: Hong Kong	StayHomeSafe	Proposed software primarily tracks the contact of persons associated with compulsory quarantine. If residents are obliged to do the quarantine, they ought to put on a wristband and setup the App	The Government of Honkong (2020)
Cyprus	COVTRACER	The software is capable to track infection carriers and persons in contact with them	Rise Up (2020)
Czechia	eRouška	The software uses facts from the phones of COVID-19 positive users and tracks their movement	Erouska (2020)
France	Stop COVID	The French authorities launched this App to track the individuals and limit the spread of COVID-19 by instructing them at times	Techcrunch (2020)
Ghana	GH Covid-19 tracker	Tracking of individuals in close contact with infected person is carried out through this App	News Ghana (2020)
Germany	GeoHealthApp	The App identifies individuals that have been in contact with an infected person within past 14 days. A map marks the region with excessive infection rates so that users can take precautions	GeoHealthApp (2020)
India	MahaKavach	Maharashtra State Innovation Society developed an App to manage COVID-19 through contact tracing of the residents	SensorTower (2020)
Israel	Hamagen	Based on the details of the user, the App compares the actions of a person recognized with COVID-19	Google Play (2020i)
Kazakhstan	Smart Astana	This App consistently monitors the actions of the individual in a quarantine period. Using the user's whereabouts, the App additionally approves users to access public services	Google Play (2020j)
Norway	Smittestopp	The Norwegian Institute of Public Health in collaboration with regional company Simula, launched an App for contact tracing. If an individual is found infected, the software records can be used to point out persons in close contact	Helsenorge.no (2020)
Philippines	RC143	The Philippine Red Cross (PRC) has developed a portal that uses geo-location for contact tracing. The idea is to help users to stay away from the high-risk area	ABS-CBC News (2020)
Poland	Home Quarantine	The software is designed to monitor people returning from abroad during their quarantine period. The App requires reference pictures, phone numbers, and day to day check-ins	Gov.pl (2020)
Qatar	Ehteraz	Qatar introduced an application that makes use of GPS based technology and Bluetooth to tracks the movement of users in quarantine	Gulf Times (2020)
Singapore	TraceTogether	The Singapore Ministry of Health, along with SG United and GOVTECH Singapore, has launched this App to track persons infected with COVID-19	Tracetgether (2020)
South Korea	Corona 100 m and Corona Map	The Korean App makes use of GPS to track quarantined citizens. Get push notifications if the individual using the App is 100 m away from the infected person	Android freeware (2020)

**Table 4** (continued)

Country	App Name	Function	References
Thailand	MorChana	This tool helps in contact tracing and prevents transmission especially to healthcare professionals	App Store (2020d)
UK	(in development) NHSX	The health service's digital transformation arm is developing an App to keep track of close contacts with infected persons	NHSX (2020)
UAE	Stay Home	An App name 'Stay Home' is launched by the Ministry of Health, Abu Dhabi. By monitoring the user's location, their purpose is to maximize the gain of self-isolation and curtail the spread of coronavirus infection	Emirates News Agency (2020)

**Fig. 4** Schematic representation of pre-trained models for the prediction of COVID-19 patients and the normal person (Narin et al. 2020)

facial parameters and how these parameters can be used to design an N95 mask template (Ishack and Lipner 2020). Even 3D-printed face mask is being developed that has ability to deactivate virus residing on its surface. The mask consists of copper nanostructure incorporated 3D-printed strips that has the ability to trap exhaled microbes (Medical Expo e-mag 2020; Copper 3D 2020). Figure 5d shows copper nanostructure and simulated design incorporated during 3D printing of the mask.

## Sensors

Currently, the world is facing a pandemic situation caused by the spread of novel coronavirus. Worldwide organizations are doing a large number of tests to track the spread of SARS-CoV-2 and isolate infected persons. This highlights the importance of testing in this pandemic situation. Various diagnostic testing methods like qRT-PCR and serologic antibody tests, etc. are currently being used to confirm the coronavirus infection (Udugama et al. 2020). These diagnostic methods are precise, but require considerable time to confirm the test and are costly. Besides this, as these testing

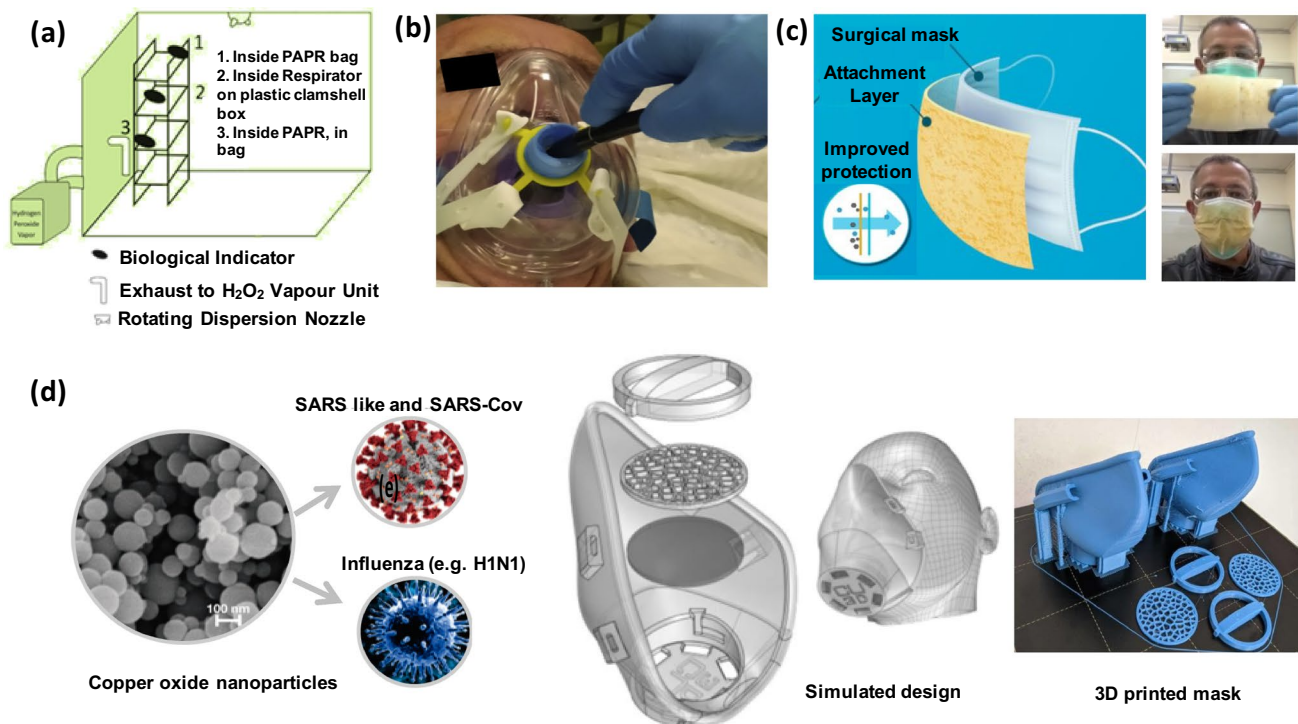
procedures require lab setup and technical staff, the number of tests conducted on daily basis is limited to certain fixed numbers. Knowing the fact that early detection of disease is a paramount for proper treatment of patients; researchers are working toward developing smart sensors for quick and instant detection of the infection. In response to tackle the coronavirus pandemic, worldwide scientist and various companies are developing a new point-of-care biosensors to detect coronavirus as soon as it is present in the human. Qiu et al. reported a plasmonic-based biosensor as a promising and alternative solution for the detection of COVID-19 infection (Qiu et al. 2020). A dual-functional sensor combines the localized surface plasmon resonance (LSPR) and plasmonic photothermal (PPT) sensing methods for diagnosis, as shown in Fig. 6a. The sensor has DNA receptor functionalized 2D gold nanoisland film that performs a sensitive detection through nucleic acid hybridization. The dual-functional LSPR biosensor can measure and determine SARS-CoV-2 sequences down to the concentration of 0.22 picomolar (pM), and can even precisely detect the specific target in a multigene mixture. In another optics-based detection method, an ultrasensitive laser sensor is proposed for the earliest point of infection detection within a minute. Here,

**Table 5** List of research work applying deep mastering for COVID-19 prognosis using radiology image

AI Technology	Data analysis	Results	References
A new CNN and pre-trained AlexNet with transfer learning	170 X-ray images and 361 CT images of COVID-19 from 5 different sources	Accuracy of 98% on X-ray images and 94.1% on CT images	Maghdid et al. (2020a, b)
ResNet-50	CT images obtained from 157 patients (China and the U.S.A)	–	Gozes et al. (2020)
COVNet	4,356 chest CT tests from 3,322 sufferers at 6 medical centers: 1,296 tests for COVID-19, 1,735 for CAP and 1,325 for non-pneumonia	–	Li et al. (2020)
AlexNet, ResNet-18, DenseNet-201, SqueezeNet	1,341 normal, 1,345 viral pneumonia and 190 COVID-19 chest X-ray images	Accuracy of 98.3%	Chowdhury et al. (2020)
Re-trained ResNet-50	Chest X-ray pictures of 50 normal and 50 COVID-19 sufferers	Accuracy of 98%	Narin et al. (2020)
Drop-weights based Bayesian CNNs	5,941 Posterior-anterior chest radiography images across 4 classes (normal: 1,583, bacterial pneumonia: 2,786, non- COVID-19 viral pneumonia: 1,504, and COVID-19: 68)	Accuracy of 89.9%	Ghoshal and Tucker (2020)
2D deep CNN	970 CT volumes of 496 COVID-19 sufferers and 1,385 terrible instances	The efficiency of 94.98%	Jin et al. (2020)
Multilayer perception and LSTM	Clinical data and a series of chest CT data were collected at different times on 133 patients. Out of which 54 patients progressed to severe/critical periods	–	Bai et al. (2020)
Shuai Wang	Deep-learning method to extract the COVID-19 radiographical modifications in CT-scan pictures to grant prognosis	Inside validation confirmed 89.5% accuracy and exterior validation achieved an accuracy of 79.3%	Wang et al. (2020)
Delft Imaging and Thirona	CAD4COVID is developed on identical technology as CAD4TB, which has contributed to the screening of 6 million humans throughout 40 international locations	–	ITN (2020b)

the test sample is saliva or nasal swab, which passes through receptors (like DNA strands and antibodies) that recognizes the antigens of the virus capsid. This intern results in the change of refractive index and laser light passing through the sample slightly change its travel direction. On comparing with the set of existing values, the change in light direction can be measured precisely with high sensitivity. The lower detection limit of the sensor lies in the range of pM to attomolar (aM) (EE news Europe 2020). A field-effect transistor (FET)-based biosensor for rapid detection of COVID-19 from human nasopharyngeal swab sample is reported by Seo et al. (see Fig. 6b) (Seo et al 2020). The sensor consists of SARS-CoV-2 spike protein sensitive antibodies that are coated on the surface of graphene sheets. The fabricated sensor could detect the virus concentrations of 1 fg/mL in phosphate-buffered saline. Also, the limit of detection in clinical samples is  $2.42 \times 10^2$  copies/mL and that in culture medium is  $1.6 \times 10^1$  pfu/mL.

Another non-invasive point-of-care detection method is breath fingerprinting. The exhaled breath contains various gases and volatile organic compounds that can be used as a signature to detect the disease present in the human body. The breath fingerprinting has already been implemented in the detection of diseases like diabetes, liver infection, and renal infection, etc. By systematically analyzing the interaction mechanism of the coronavirus with the human cell and its effect on the biological activity of the body, it is possible to identify the new compound or compound whose proportion in the exhale breath is affected. Worldwide various companies are working on the detection of coronavirus by breath fingerprinting. On a similar note, a new hand held gas sensor for SARS-CoV-2 detection within a few seconds through exhaled breath fingerprinting is proposed by Nian Sun et al. (North Eastern University 2020). The proposed electrochemical sensor is expected to have several advantages like a fast response, low cost, ultra-high selectivity, and



**Fig. 5** Mask technology during the COVID-19 pandemic. **a** Setup for disinfection of the mask using H<sub>2</sub>O<sub>2</sub> vapors. The figure shows the placement of biological indicator at different sections of the disinfecting chamber (Schwartz et al. 2020). **b** A modified mask to be used during the upper endoscopy of patients (Marchese et al. 2020). **c** A

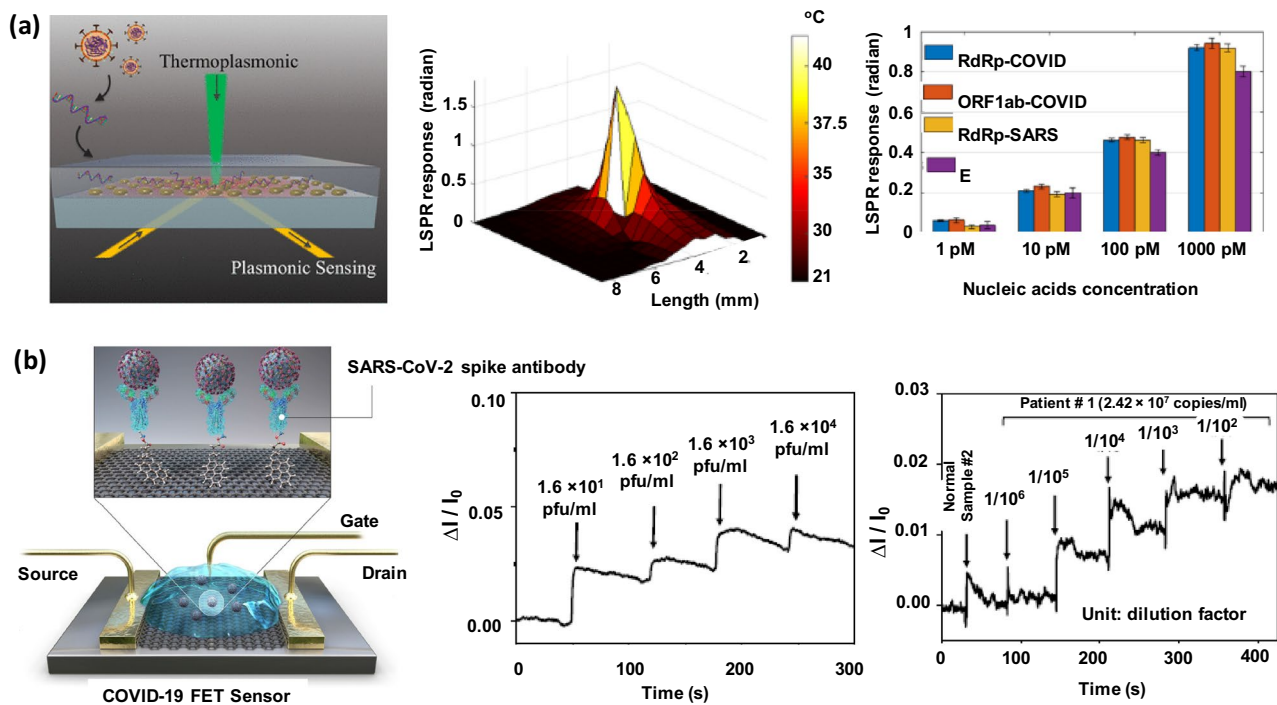
unique porous self-disinfecting layer fabricated using a 3D printer, to be used as a sticker on any mask (Breaking Defense 2020). **d** Copper nanoparticles (left) and physical design (middle) used in the fabrication of 3D-printed mask along with copper nanoparticle incorporated 3D-printed face mask (right) (Copper 3D 2020)

extreme sensitivity in the range of sub-part per quadrillion (sub-ppq). In a recent report, Next-Gen and Scentech Medical have jointly worked on a coronavirus detecting breathing device that can detect the virus infection (LabMedica 2020). Likewise, Grolltex develops a graphene-based virus testing platform for COVID-19 detection. The sensor employs functionalized gold nanoislands deposited on a monolayer graphene sheet. The sensor is fabricated on a plastic chip and requires a very small biological sample; as a result, it can perform 12 viral tests at a single time (GROLLTEX 2020). To aid in the fight and slow down the spread of infection, Vayyar, an Israel-based company, has developed a touchless remote monitoring sensor (HIT consultant 2020b). The intelligent sensors provide real-time monitoring of vital signs of COVID-19 symptoms which include respiratory rate, heart rate variability and pulse rate, etc. On a similar front, a tiny flexible throat sensor powered by AI technology that can track respiration rate, body temperature, and coughing is developed by researchers at Northwestern University in collaboration with the Shirley Ryan Ability Lab (Medgadget 2020). The device has to be stuck at the throat and assists in the continuous detection of any changes in the patient condition. Likewise, wearable sensors and IoT technology-based monitoring of COVID-19 patients are employed by

the Shanghai Public Health Clinical Center SPHCC (Mobi Health News 2020). The technology helps to receive real-time patient data from the sensors and wirelessly transmit these data for continuous monitoring. Researchers at the University of Utah are working on a sensor that communicates with a smartphone through Bluetooth link and assists in the detection of COVID-19 (7 NEWS 2020). The sensor performs breath rate analyses and could also test swab containing samples when placed on the sensor. The test results will be displayed on a phone screen within a minute and the reusability of the sensor is ensured by disinfecting the sensor with small electric current. The smartphone gateway also adds features to send users test reports and location to concerned authorities.

## SWOT analysis of the technologies to tackle COVID-19

The fourth industrial revolution has boosted globalization and seen an exponential growth in technology, which in turn played a critical role in advancing digital and manufacturing systems (AIMaadeed 2020). During coronavirus pandemic, already existing technologies and technologies under



**Fig. 6** Sensors for COVID-19 detection. **a** Schematic diagram of the COVID-19 plasmonic sensor (left). Mapping of temperature distribution around the PPT heat source (middle). Concentrations of various viral oligos measured using the dual-functional LSPR bio-

sensors (right) (Qiu et al. 2020). **b** Schematic diagram of the FET sensor (left). Real-time response of fabricated FET toward SARS-CoV-2 cultured virus (middle). Real-time response of FET toward the SARS-CoV-2 clinical sample (right) (Seo et al. 2020)

development have aligned themselves to meet the demands and tackle the health emergency. In the context technological progress is skipping development stages and advancing at a much faster rate. This provides great strength and opportunities to solve issues concerning pandemic, but has some weakness which may directly or indirectly pose adverse effects in long terms. Figure 7 represents the strength, weakness, opportunity, and threats that technological progress in COVID-19 can pose in the near future. The main strength that technologies have provided in COVID-19 is the development of a strong health emergency system. The healthcare services have swiftly been tailored to increase their patient handling ability, and also the telehealth system is improved to increase the interaction capacity and reduce the workload. Moreover, the development of new testing methods and technology-driven diagnosis facilitates bulk testing in the pandemic situations.

Crisis may happen and impose immediate challenges, and to be sustainable, it is important to develop technologies that has long-term effectiveness. Lack of long-term vision and the absence of a continuity plan for these technologies could potentially be a weakness on the economic front. Even the effectiveness of various technologies involved in tackling the coronavirus outbreak has not been evaluated. Thus, there is an urgent need for regulations and standardizations of technologies that are being used in infection control systems.

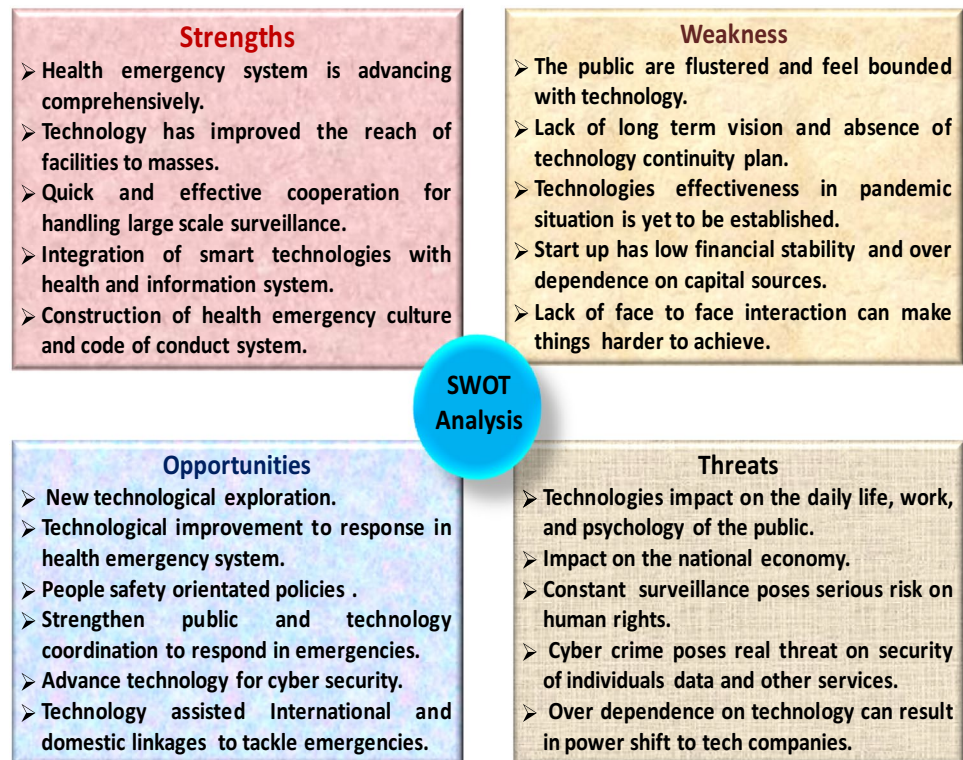
The involvement of technology in people's life has increased during a pandemic; this might change their perception and response toward the use of technology in the near future. The pandemic has created a lot of challenges, which inter has generated opportunities, especially in the technology sector. While providing health services and contact tracing, authorities are collecting a huge amount of data related to their citizens, which imposes a serious concern for cyber security. This is one of the major threats that have been created, while it also creates opportunities for cyber security providing companies to enter the market and deliver solutions to government. Moreover, to ensure continuity, industries have been forced to digitally transform and innovate technologies on an unprecedented basis. The role of technology in tackling coronavirus pandemic is unparalleled, but there is a need to have balance in considering the involvement of these innovations. The incorporated changes in the current pandemic situation might have an influence on how we will live and work in near future.

## Conclusion

The emergence of COVID-19 has pushed the limits of technologies and accelerated innovations in every field. The support of technology in managing the pandemic



**Fig. 7** SWOT analysis of technological development during COVID-19 pandemic



situation is irreplaceable. The modifications in already existing drone, robotics, and artificial intelligence technology along with the framework in which they are applied to combat the pandemic situation have been discussed in detail. The findings establish how the smartphone applications that connect large masses can be configured to tackle emergency situations. The review gives deep insight on new innovations in the mask and sensor technology that has been globally investigated during the course of pandemic. A broader picture of how the various technologies are implemented and changes that they have undergone across the globe to directly or indirectly assist in the pandemic situation is represented. Alongside, the impact of these technologies on society in numerous aspects has been summarized. Thus, the finding helps in understanding the impact of the technology on the society and how these innovations can further be tuned to response in an emergency situation.

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### Compliance with ethical standards

**Conflict of interest** On behalf of all authors, the corresponding author states that there is no conflict of interest.

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