Health and Technology (2022) 12:547–568
https://doi.org/10.1007/s12553-022-00650-1

REVIEW PAPER

Digital technologies, healthcare and Covid-19: insights from developing and emerging nations

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Received: 3 September 2021 / Accepted: 23 February 2022 / Published online: 6 March 2022

Abstract
COVID-19 pandemic created a global health crisis affecting every nation. The essential smart medical devices/accessories, quarantine facilities, surveillance systems, and related digital technologies are in huge demand. Healthcare, manufacturing industries, and educational institutions need technologies that allow working from a safe location. Digital technologies and Industry 4.0 tools have the potential to fulfil these customized requirements during and post COVID-19 crisis. The purpose of this research is to provide understanding to healthcare professionals, government policymakers, researchers, industry professionals, academics, and students/learners of the paradigm of different Digital technologies, Industry 4.0 tools, and their applications during the COVID-19 pandemic. Digital technologies, Industry 4.0 tools and their current and potential applications have been reviewed. The use of different Digital technologies and Industry 4.0 tools is identified. Digital technologies and Industry 4.0 tools (3D Printing, Artificial Intelligence, Cloud Computing, Autonomous Robot, Biosensor, Telemedicine service, Internet of Things (IoT), Virtual reality, and holography) offer opportunities for effective delivery of healthcare service(s), online education, and Work from Home (WFH) environment. The article emphasises the usefulness, most recent development, and implementation of Digital technologies, Industry 4.0 techniques, and tools in fighting the COVID-19 pandemic worldwide.

Keywords COVID-19 · Industry 4.0 · Digital technologies · Healthcare · Telemedicine

1 Introduction

The Corona Virus Disease 2019 (COVID-19) named by World Health Organisation (WHO) emerged in Asia late 2019. As of 16 November 2021, 255 million people were infected and over five million people died globally [1]. The virus spread to 220 countries in Asia, Europe, North and South America, Africa, Australia, and Oceania. The ratios of infection to population and death to the population for the top 50 affected countries and a low affected country (China) are shown in Fig. 1. No countries rich or poor could escape the mayhem of COVID-19. The top 8 countries' ratio of infected people to the total population (of a country) are 20% in Georgia, 17.7% in Czechia, 14.4% in the USA,

This article is part of the COVID-19 Health Technology: Design, Regulation, Management, Assessment

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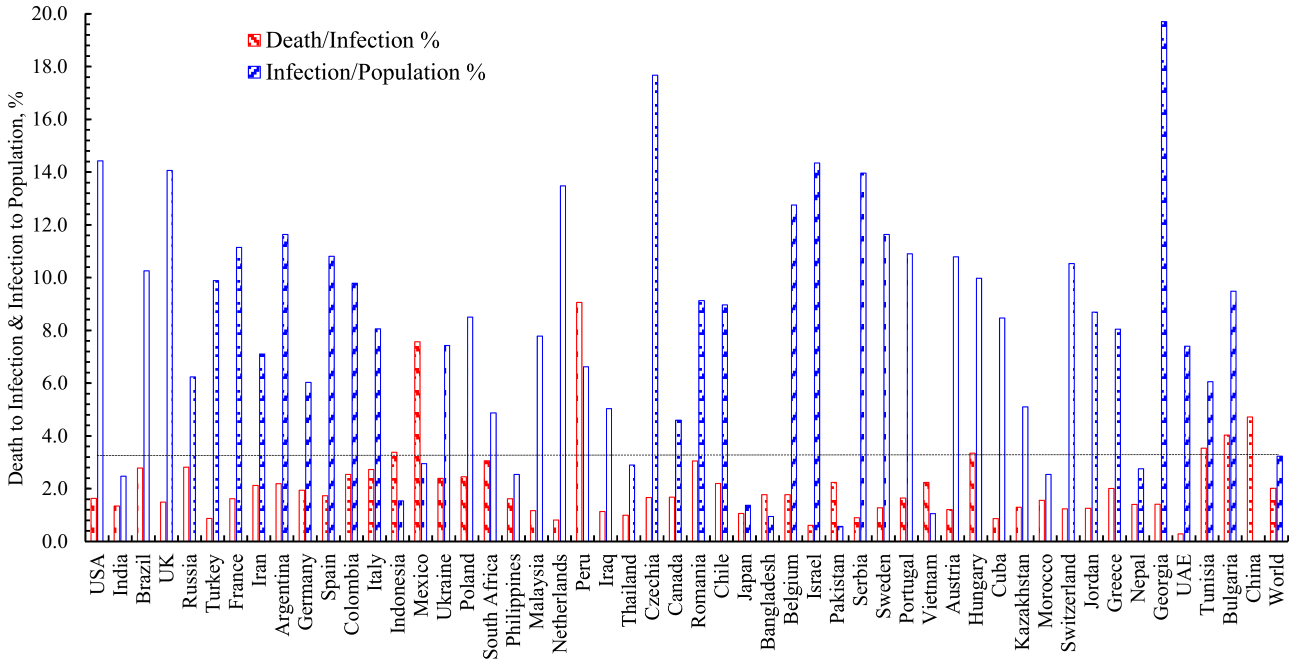


Fig. 1 Worldwide ratios of Infection to Population and Death to Infection, adapted from [1]

14.3% in Israel, 14.1% in the UK, 14% in Serbia, 13.5% in the Netherlands, and 12.8% in Belgium. Among countries with population over 100 million, China reported the lowest infection to population (0.007%) followed by Pakistan (0.6%), Bangladesh (0.9%), Japan (1.4%), Indonesia (1.5%), and India (2.5%). The highest death to infection percentage was reported in Peru (9.1%), followed by Mexico (7.6%) and China (4.7%). The world average infection to population and death to infection were 3.2% and 2.0%, respectively (Fig. 1). WHO declared COVID-19 a global pandemic as it created an unprecedented crisis in health, economy, education, global mobility, culture, sports, etc. that our human civilisation never saw from time immemorial [1]. The International Committee on Taxonomy of Viruses (ICTV) called it a severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) on 11 February 2020. To stop the spread, nationwide shutdowns were imposed in all continents disrupting nearly all physical communications and forcing them to undertake activities remotely from homes or safe places. The demand for digital access, technologies, equipment, life protecting/ saving devices, and tools was increased at an unprecedented level. Access difficulties to medical facilities and healthcare services due to COVID-19 emergencies are creating a significant impact on both healthcare service receivers/ users and service providers/ suppliers. Furthermore, digital divides among developed and developing nations, urban and rural populations, economic and cultural disparity make healthcare services more challenging and inaccessible. Available information and data on the COVID-19 pandemic affecting healthcare systems in emerging and developing countries allow evaluating digital technologies and Industry 4.0 tools that are progressively being used and can have a notable impact on healthcare delivery during the COVID-19 pandemic. Therefore, this study aims to provide understanding to healthcare professionals, government policymakers, researchers, industry professionals, academics, and students/ learners of the paradigm of different Digital Technologies, Industry 4.0 tools and their applications during the COVID-19 pandemic. The study is based on data and information collected from open and subscribed literature/ databases, individual/ personal contacts, government sources, press reports, news, media portal, and case studies.

Major indexing and search engine tools such as Google Scholar, Scopus, IEEE Xplore, Research Gate, PubMed, Academic Info, Microsoft Academic Search, JournalSeek, MEDLINE, Science Direct, Web of Science, SpringerLink, Wiley Online Library, Emerald, LinkedIn Learning (formerly Lynda.com), Factiva, ProQuest Central, IBISWorld, and data published by governments were used to get relevant information for this study. The study includes information on all advanced digital technology inventions/ innovations, development, and uses of Industry 4.0 in healthcare service delivery during the COVID-19 pandemic. Findings are expected to help healthcare professionals, academics, researchers, policymakers, industry professionals, students, and community members to understand the paradigm of Industry 4.0 and their implementation approaches during the pandemic. Advances in digital technologies in such a short interval of time can be a paradigm shift for different industries in the future. The technologies that emerged during the COVID-19 pandemic will get applications in many other areas.

2 Digital technologies and industry 4.0

Industry 4.0 or the fourth industrial revolution is the interconnection of digital technologies with modified advanced manufacturing and production systems often called “Smart Manufacturing or Smart Factory”. The Smart Manufacturing technology of Industry 4.0 has abundant potential for demand-driven supply chain services during the COVID-19 crisis [2]. Figure 2 shows four main phases of the industrial revolution.

Digital technologies including artificial intelligence, cloud computing, big-data analytics, Internet of Things (IoT), deep learning and blockchain technology can solve the major medical and clinical problems [4, 5]. Consequently, the Industry 4.0 generation can interlink the industrial revolution and medical field to fight against coronavirus by using its advanced information technology applications and modified advanced manufacturing. The demand for essential medical accessories can be mitigated using 3D printing devices and using various digital technologies. Javaid et al. [6] provided a brief overview of Industry 4.0 technologies and their applications in fighting COVID-19. Shashank et al. [7] highlighted the operational aspects of Industry 4.0 during the COVID-19 pandemic. Khan et al. [8] reviewed various smart technologies including the application of drones, robots, artificial intelligence, and sensor technology that helped in mitigating the spread of COVID-19 pandemic.

Technological innovations between the real and virtual worlds and sustainable supply chain performance during COVID-19 were studied [9]. Reviews of Digital Technologies in various domains that emerged during the COVID-19 pandemic were carried out by several researchers [10–12]. Healthcare services, educational institutions and industries have been affected the most during lockdown since March 2020. For example, apart from COVID patients, non-COVID vulnerable populations are deprived of primary healthcare services as many doctors including General Practitioners (GPs), nurses, clinics, medical centres, and hospitals, are reluctant to provide healthcare services, fearing coronavirus exposure. Healthcare professionals prefer to provide their services remotely where possible. In 2020, 1.5 billion students in 188 countries/economies were locked out of their schools [13]. In South Asia alone, over 400 million school children were locked out of schools for 19 months. Campuses are closed for university students in most countries including Australia, New Zealand, Bangladesh, India, Pakistan since March 2020. With the COVID-19 pandemic still raging, many education systems are struggling, and the situation is constantly evolving from school closures and remote learning. Commercial and industrial sectors have severely been affected by the pandemic. Continuous ‘off and on’ lockdowns and the requirement for social and safe distancing at

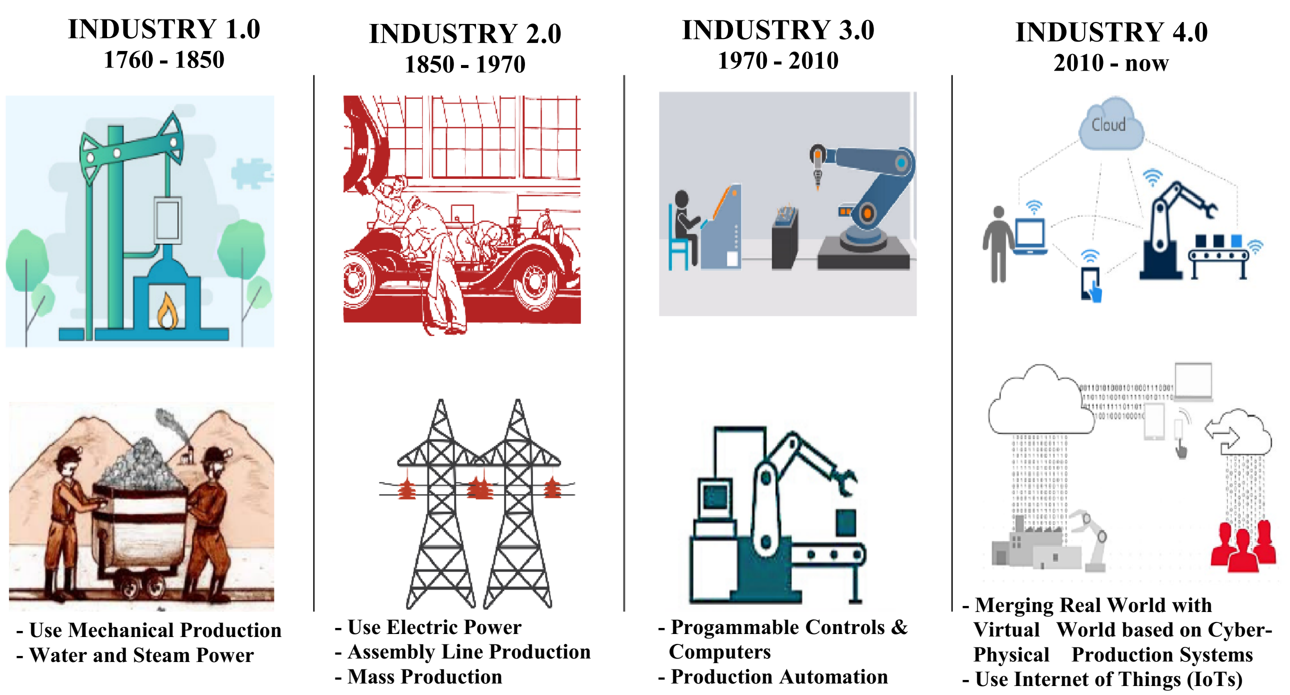


Fig. 2 Major phases of Industrial Revolution, adapted from [3]

the workplace and industry are affecting not only productivity but also education and healthcare delivery. The use of digital technologies/Industry 4.0 techniques can significantly minimise the impact of the COVID-19 pandemic [14]. For example, to prevent the spread of COVID-19, people were isolated to work and study from home. IoT solutions/virtual reality such as Microsoft Teams/ Zoom meetings/ Google Meet/ Tencent (VooV), virtual education platforms (Blackboard, Moodle, Canvas, etc.) are increasingly being used to continue commercial services/ operations, industrial activities, healthcare services delivery, and teaching and learning activities. Figure 3 shows some Digital Technologies and tools that have immense potentials and/or are already for use in COVID-19 impact mitigation.

A detailed review of applications of feasible Digital Technologies and Industry 4.0 tools/ techniques was undertaken that are being used across the world in fighting the COVID-19 pandemic. Figure 3 outlines vital Digital Technologies, and tools selected for review such as a) 3D Printing of medical devices, b) Artificial Intelligence, c) Cloud Repository for infected patients, d) Autonomous Robot, e) Use of Biosensors, f) Telemedicine Services, g) Internet of Things (IoT), h) Augmented Reality/Virtual Reality and Holography for online education, and i) Creating a Work from Home (WFH) environment using Cloud Computing. Each of these technologies and tools is analysed in the following subsections.

2.1 3-D printing technology for medical devices

Three-dimensional (3D) printing is a computer-controlled process that creates three-dimensional objects by depositing materials, usually in layers using computer-aided design. It allows manufacturing complex shapes (e.g., precise geometric shapes), generally harder with the conventional manufacturing process. The technique is commonly known as Additive Manufacturing (AM) and Rapid Prototyping [15]. 3D printing does not require a large and complex industrial setup to manufacture a product and can be operated and controlled remotely using cloud technology requiring a minimal workforce [16]. This computer-aided design (CAD) manufacturing technology is used to manufacture customized medical implants, tools, and devices. During COVID-19, it came as an emerging

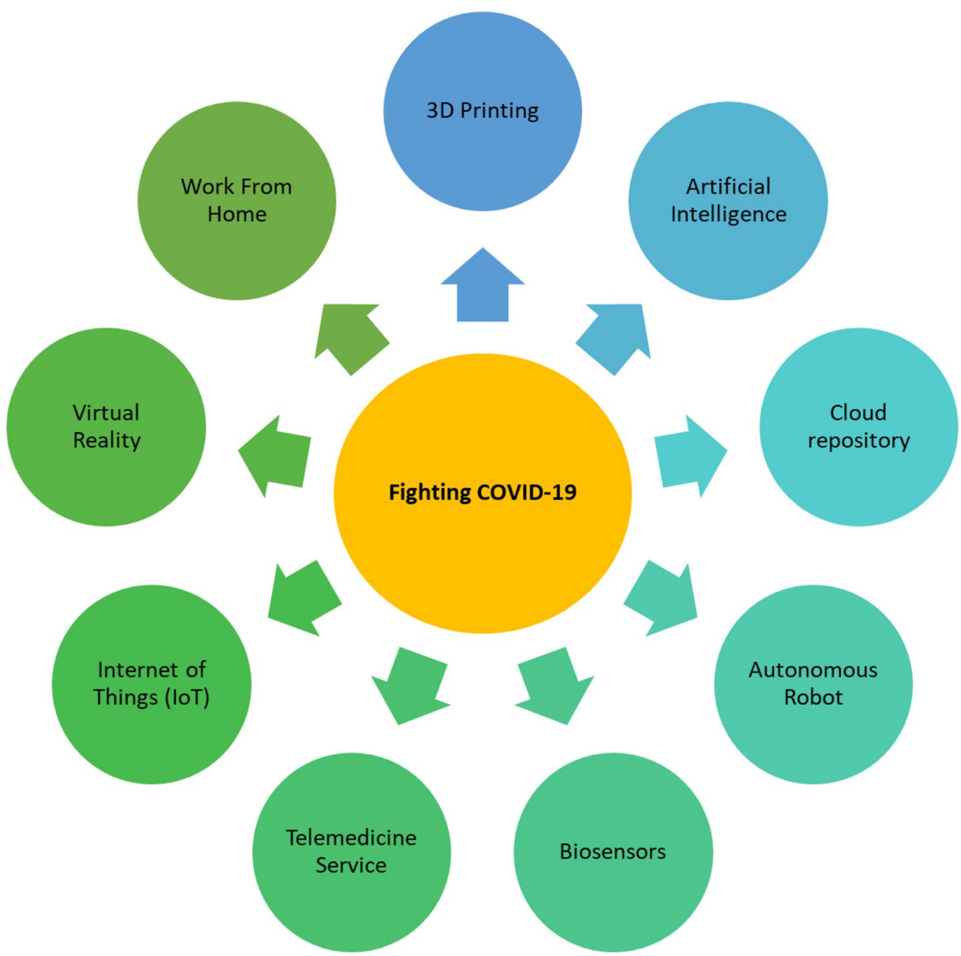


Fig. 3 Digital technologies and Industry 4.0 techniques to fight COVID-19

technology in the medical field for manufacturing medical devices including face masks (e.g., surgical and N95/KN95/P2 Respirator), ventilator respiratory valve, face shield, Personal Protective Equipment (PPE), hand sanitiser holders, door handle attachments, 3D printed quarantine booths, SARS-CoV-2 test swabs, Oxygen valves, etc. [16–18], which are shown in Fig. 4. Additional 3-D printed products developed during this pandemic include 3D printed face shield by Siemens Centre of Excellence of NIT, Tiruchirappalli [20], re-usable face mask by Virtual Frontier Robotics Private Limited, Coimbatore-based start-up in India, helmet systems as PPE [21], KUKA test robot [22], etc.

In response to the COVID-19 emergency in April 2020, the Advanced Manufacturing Precinct (AMP) of RMIT University, Melbourne, Australia has manufactured over 3,000 face shields using 3D Printing technology and supplied various hospitals and healthcare centres (as shown in Table 1) to

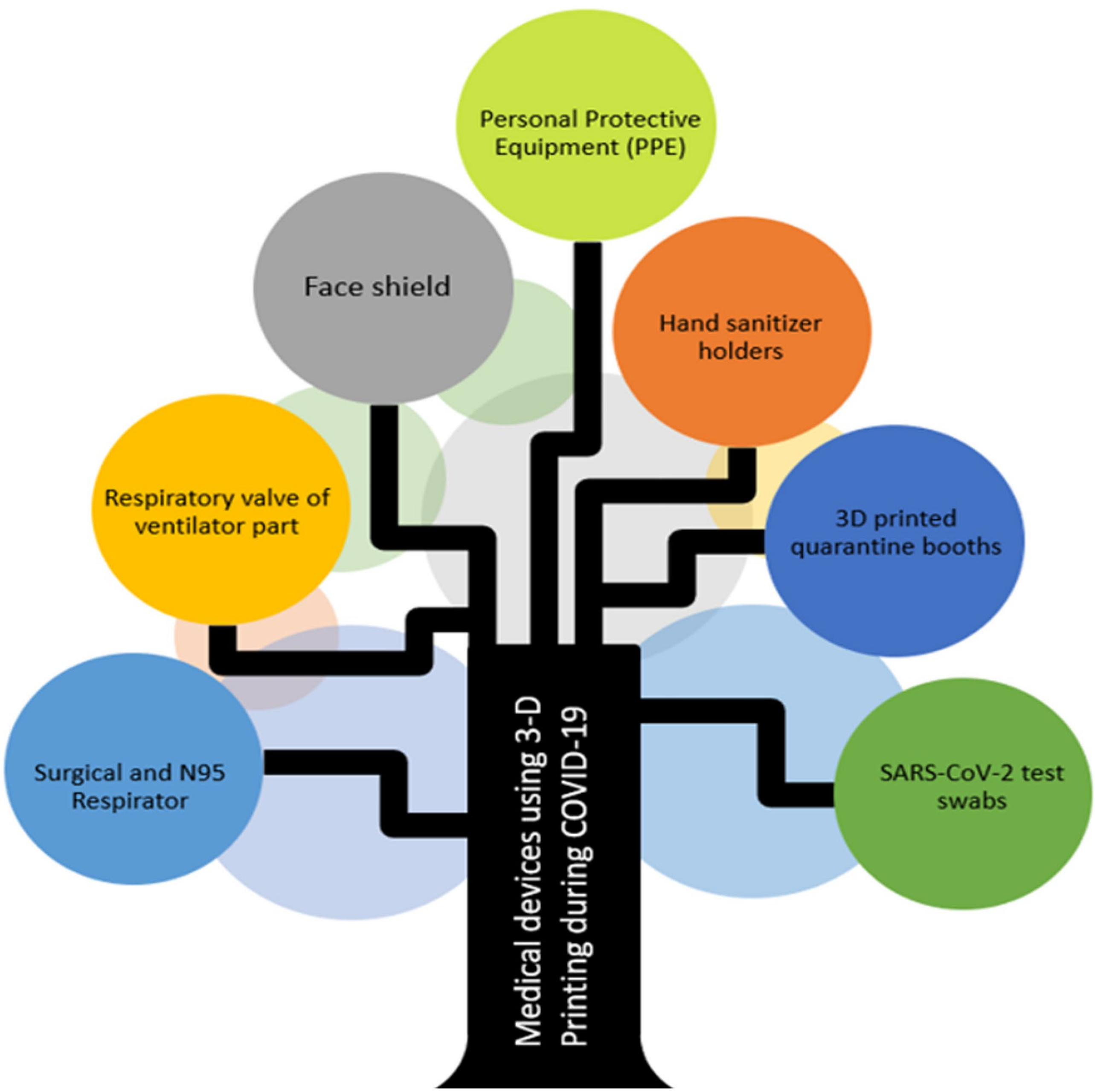


Fig. 4 Medical devices being developed using 3-D Printing during COVID-19

Table 1 RMIT 3D Printed Face Shields donated to Healthcare Services, adapted from [23]

Healthcare Services	
1) Launceston General Hospital, Tasmania	14) St Vincent's Hospital Public/Private
2) Albury Wodonga Health, New South Wales	15) Ear Nose and Throat Victoria
3) Box Hill Hospital, Melbourne, Victoria	16) Royal Victoria Eye and Ear Hospital
4) Austin Health, Melbourne, Victoria	17) Westmead Paediatric ENT
5) Royal Melbourne Hospital, Victoria	18) Warrnambool ENT's, Victoria
6) Biofix 3D	19) Tasmania ENT's
7) Northern Anaesthetics	20) Sunshine ENT's
8) Newcastle Private Hospital, New South Wales	21) Individual ENT's in Victoria
9) Alfred Hospital, Melbourne, Victoria	22) Individual ENT's in New South Wales
10) Peter McCallum Cancer Centre	23) Guy's and St. Morris ENT (London UK)
11) Eastern Health, Victoria	24) Individual ENT's of Southampton, UK
12) Oral & Maxillofacial Surgeon	25) Melton Dentist
13) SVHM Pharmacy	

enhance frontline healthcare personnel's protection against airborne droplets that can carry the COVID-19 virus. This effort by RMIT University was timely to overcome the acute shortage of protective gears in the early stage COVID-19 outbreak in 2020. Examples of RMIT University 3D printed face shields, straps and 3D printers are shown in Fig. 5.

2.2 Artificial intelligence

Humans possess nature gifted intelligence to easily distinguish between objects just by using sensory organs. However, machines work better with numbers and calculation processes. While machines do not tire out and are increasingly more fast, accurate, and precise than humans, they fail to recognize objects. Artificial Intelligence (AI) is the technique/ technology that simulates human-like intelligence in machines. In contrast, a machine without the AI fails to recognise objects due to a lack of technological capability (sensors, imagery, movement, etc.). In short, AI enables a machine to simulate human behaviour while a machine using a subset of AI automatically learn from past data without programming explicitly. The goal of AI is to make a smart computer system like humans to solve complex problems.

The value of the global AI market size in 2020 was US$ 62.4 billion and it is expected to reach US$ 1,033 billion by 2028 [24]. The advancement by research and innovation accelerates the adoption of advanced technologies in healthcare, banking, financial services, and insurance (BFSI), advertising, media, automation, transportation, manufacturing industries, retails, etc. as shown in Fig. 6. Healthcare, advertising, media, Business, Financial Services, and Insurance – BFSI are the leaders in the utilisation of AI. The global AI constitutes by a) Component (hardware, software), b) Technology (machine learning, natural language processing, etc.), c) Application (medical imaging, robotics, smartphones, smart wearables, automobile, security systems, etc.), and d) Vertical (healthcare, advertising and media, business financial services and insurance – BFSI, consumer electronics, information technology & telecommunication, automobile, retail, etc.).

The basic element of AI is shown in Fig. 7. The AI is considered the foundation of the impending digital era. Technology giants such as Amazon, Google, Apple, Facebook; IBM, Microsoft, Intel, Samsung, Huawei, Xilinx, Micron, NVIDIA, Qualcomm, and others are heavily investing to lead the AI sector globally.

The analysis techniques of Big Data with the help of AI can be employed in COVID-19 healthcare data management and tracing the history of COVID-19 infected people [25]. The significant applications of AI in fighting coronavirus disease include detecting infection, monitoring treatment, understanding, and tracking individuals, forecasting cases and mortality rates, developing vaccines and helping in scaling down the workload of healthcare workers [25, 26]. Rajaraman et al. [28] used weekly data of chest X-rays for COVID-19 detection using deep learning at Lister Hill National Center for Biomedical Communications, USA. Yan et al. [29] developed an XGBoost machine learning-based model to predict the mortality rates of COVID-19 patients in advance with 90% accuracy. Cyberbullying materials related to COVID-19 on various social media platforms is detected and removed with the application of AI [30]. Optimization and improvisation against viruses can be undertaken for clinical trials of drugs and vaccines (called drug repurposing) with the use of AI [31]. The AI facilitates reducing steps of the process taken to identify and treat COVID-19 patients. A detailed review of different AI techniques assisting during the COVID-19 pandemic can be found in Alabool et al. [32]. Figure 8 illustrates the potential use of AI in the detection and treatment of COVID-19 patients.

2.3 Cloud repository of infected patients using big data and mask R-CNN

Big Data is an analytic field that extracts desired and detailed information from large and complex data sets [32–

Fig. 5 Face shield and straps manufactured by 3-D Printing at RMIT University in the beginning of COVID-19 pandemic, adapted from [23]

34]. Python with its NumPy libraries is one of the prominent computer languages used in the domain of Big Data. Regional Convolutional Neural Networks (R-CNN) has the capability of recognizing objects by marking out rectangular boundaries around them [35]. Mask Regional Convolutional Neural Networks (Mask R-CNN) is a more advanced form of R-CNN which has the capabilities to mark out exact boundaries of recognized objects with almost a single-pixel image precision [36].

A detailed worldwide repository of positive COVID-19 patients with their symptoms, medical history, reports, X-Rays, and CT (Computer Tomography) scans can be made and stored on the cloud so that they can be accessed by registered and authorised medical institutions /practitioners worldwide. This data set can be used to effectively train R-CNN with very high accuracies (above 99%). A trained model can now predict if a patient is suffering from COVID-19 and for how long. This can speed up the testing procedure for COVID-19 where a patient can know whether he/she is COVID-19 positive simply by providing his/her medical history, symptoms, and X-Ray and/or CT scan reports. Ouyang et al. [37] developed a 3D CNN network to assist the diagnosis of COVID-19 patients. Wang et al. [38] used a CNN based Deep Learning (DL) for screening COVID-19 infected patients with an accuracy of 89.5%, a sensitivity of 87%, and specificity of 88% by using their computed

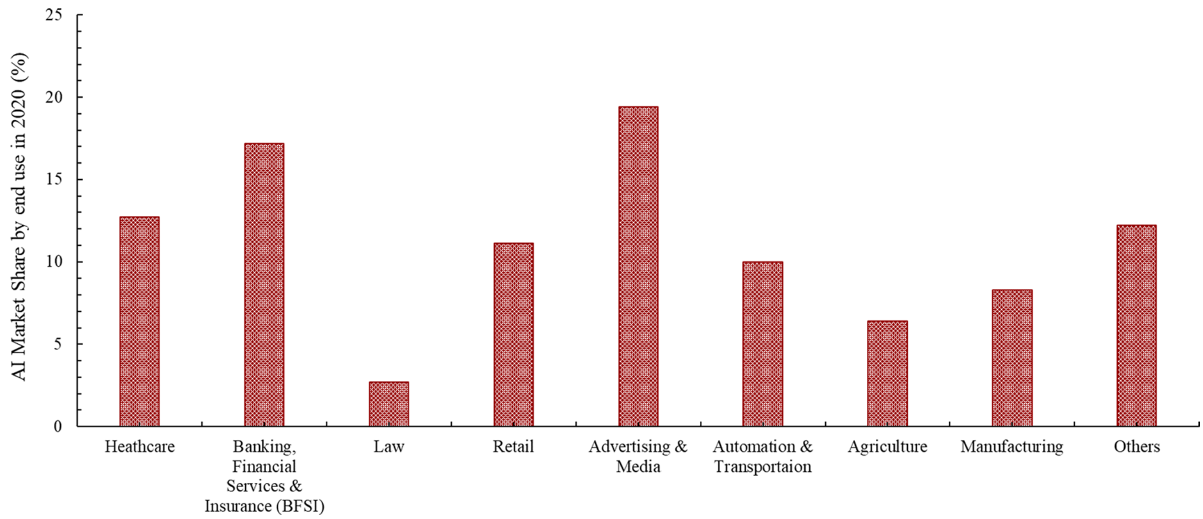


Fig. 6 Global Artificial Intelligence market share, by end-use in 2020, adapted from [24]

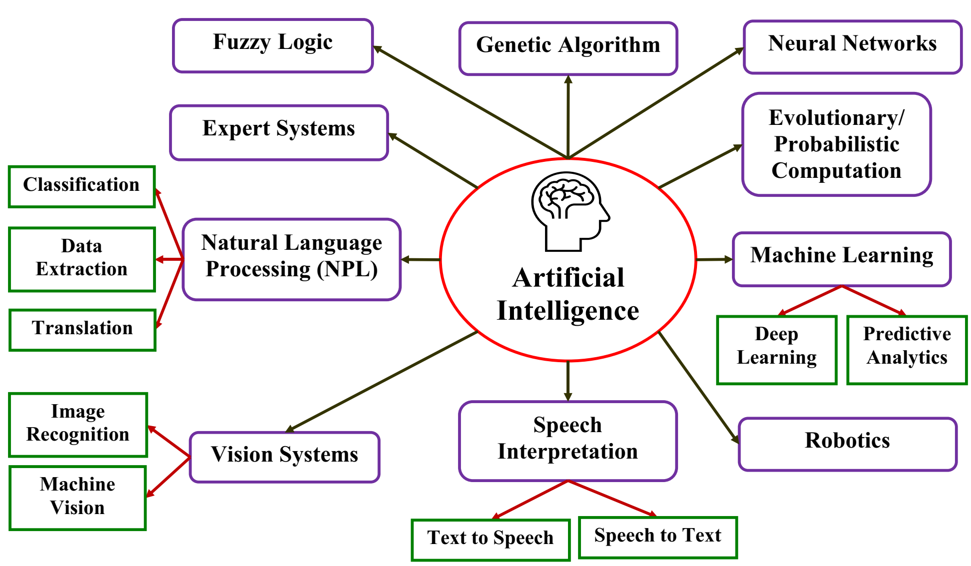
tomography (CT) images. A detailed and systematic review of Deep Learning (DL), Deep Transfer Learning (DTL) and Edge Computing (EC) to mitigate COVID-19 was presented by Sufia et al. [39].

2.4 Autonomous robot

COVID-19 pandemic has created the need for preventing interhuman contagion and stopping the spread SARS-CoV-2 virus. Using an autonomous robot during the COVID-19 pandemic, it is possible to reduce interhuman contagion, manage, monitor, and control human loitering or purposeless movement during lockdown [39, 40]. A robot can be deployed for disinfection and sanitizing large areas of the containment zone with minimal downtime. It can also help the delivery of food items and medicine to COVID-19 positive patients in hospitals without direct human contact [41–43]. Humanoid robots, autonomous vehicles, quadcopters (commonly known as Drone) and other intelligent robots are excellent examples of Autonomous robots. Examples of some robots used for COVID-19 are shown in Fig. 9.

Drones played a major role during lockdown for patrolling and analysing containment zones thereby helping the law enforcement and protective agencies. As drones are equipped with advanced cameras, various sensors, and integrated data management systems, they can check an individual's temperature, heart and breathing rate from a distance and hence, it helped in the rapid testing of COVID-19 cases. Tavakoli et al. [44] examined some other robots including telerobots, collaborative robots, social robots and wearables that can also be used during the COVID-19 situation. Robots

Fig. 7 Major elements of Artificial Intelligence (AI)



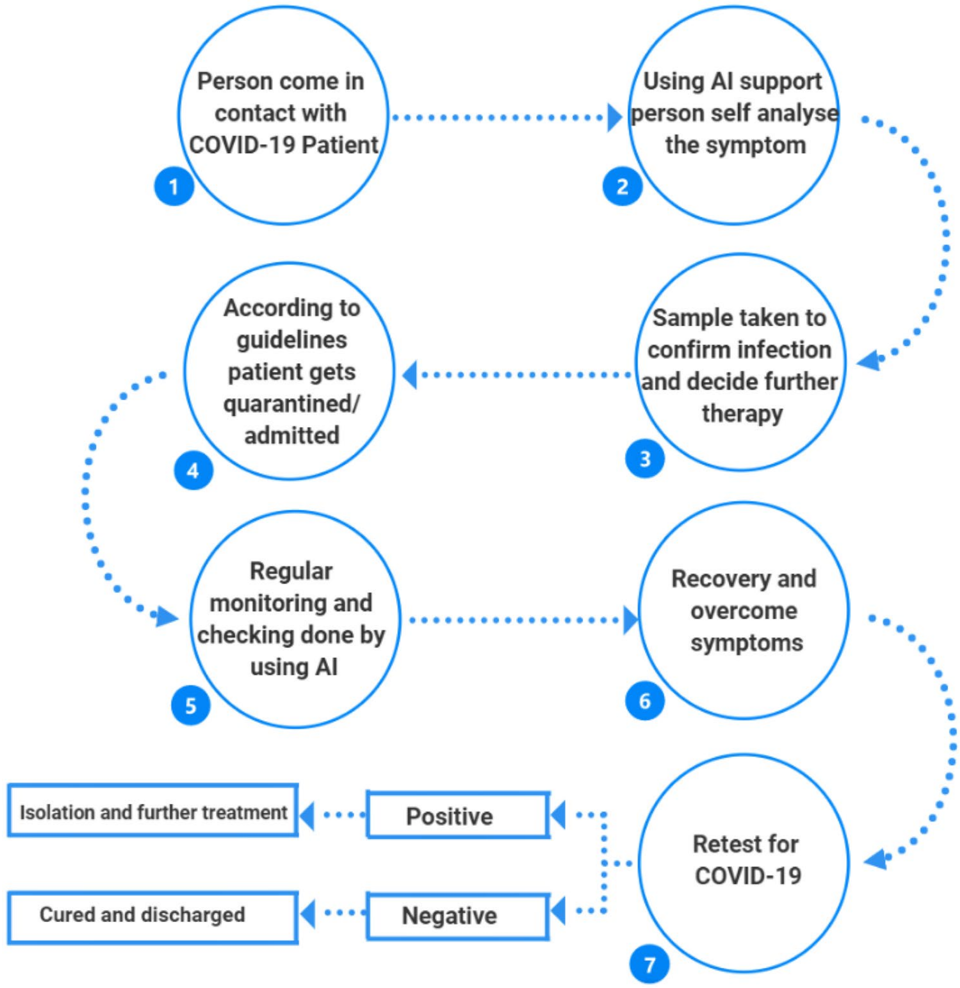


Fig. 8 Typical flow process of AI-enabled detection and treatment of suspected COVID-19 patient

along with their applications in fighting the COVID-19 pandemic across the world are given in Table 2.

2.5 Use of Biosensors

Biosensor devices are used to detect chemical compounds usually by electrical, thermal or optical signals [45]. Biosensors are classified as thermal, optical, electrochemical, and piezoelectric biosensors [45, 46]. Major application area of biosensors includes medical science, food industry, plant biology, agro-food industry, military in biological attacks, etc. [47, 48]. In medical science, biosensors are used for diagnosing diabetes mellitus [49], detection of human interleukin-10 [50], detection and monitoring of glucose, cholesterol, H_2O_2, small biomolecules, etc. Table 3 shows various biosensors, working principles and their major applications.

The working of biosensors have a few phases i.e., sample collection to obtain bioagents, to send biochemical information to the bio-receptor, from bio-receptor to bio-transducer the component in transducer analyses and send the information to the amplifier and then signal data for processing [51]. Figure 10 shows the basic principle of a biosensor. Biosensors in the form of a patch are used for recording human body temperature, respiration rate, Electrocardiogram (ECG) trace, heart rate in real-time, monitoring and detecting COVID-19 symptoms. Seo et al. [52] reported that a field-effect transistor (FET)-based biosensing device detects SARS-CoV-2. The sensor is coated with graphene sheets of the FET with a specific antibody against SARS-CoV-2 spike protein for rapid detection of COVID-19 patients.

2.6 Telemedicine service

According to WHO, telemedicine is defined as the delivery of healthcare service(s) using telecommunication technologies (audio, video, social communication apps, and other media of communications) for the exchange of medical information, diagnosis, consultation, and treatment where physical distance is a critical issue [53]. The COVID-19 pandemic brought telemedicine into the limelight. Patients with acute and chronic ailments, including diabetes, pregnancy, obesity, malnutrition, chronic respiratory diseases, cardiovascular

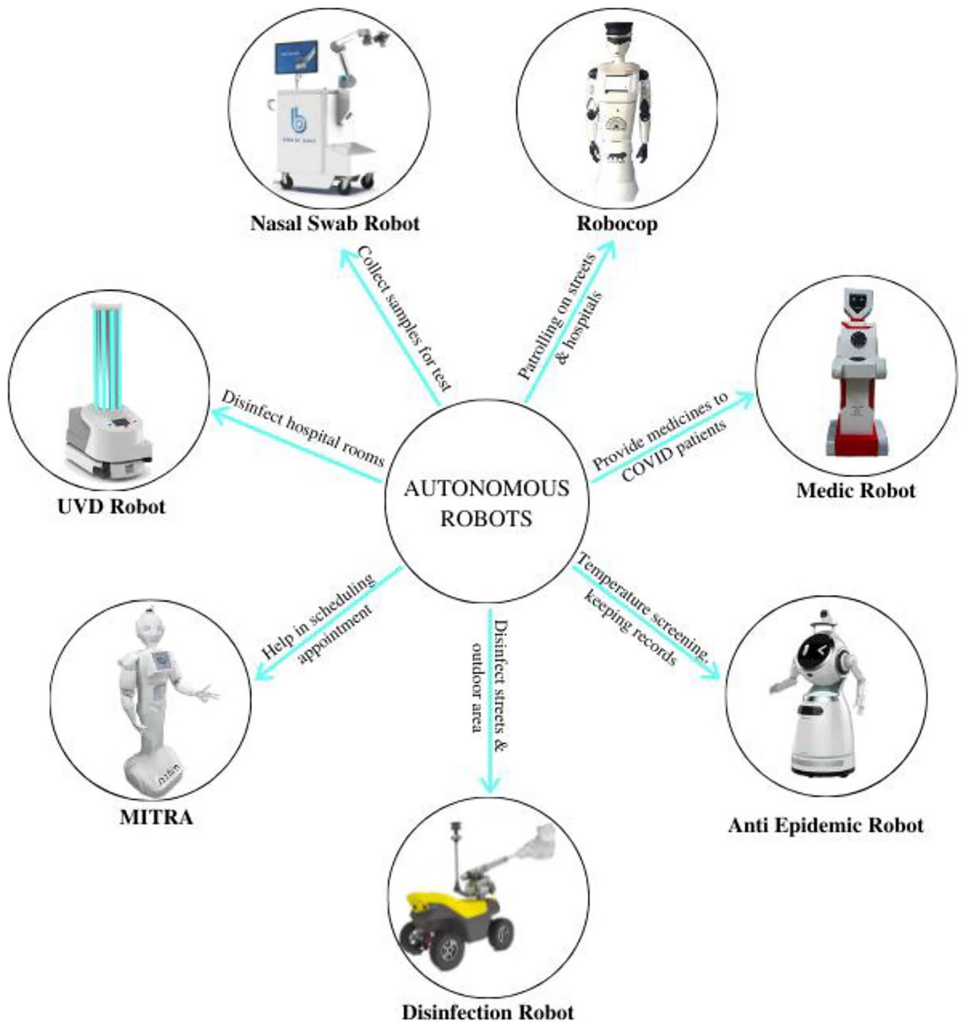


Fig. 9 Autonomous robots used for healthcare service delivery including COVID-19 disinfection

disease, cancer, and mental health conditions need to visit healthcare service delivery facilities and healthcare professionals physically. However, the COVID-19 emergency has created a significant strain on existing healthcare facilities as limited medical resources and healthcare professionals have been diverted to treat COVID-19 infected patients. Overburdened and/or under-resourced healthcare systems, infrastructures, facilities, shortages of trained healthcare professionals (doctors, nurses, and health technologists) make it harder for a non-COVID immunocompromised population to receive

Table 2 Robots and their application in fighting COVID-19 pandemic in different nations

Sl No	Robot	Application	Country
1	UVD Robots by Blue Ocean Robotics	Ensure infection-free environments	Denmark
2	Nasal Swab Robot (NSR) by BNB	COVID-19 Nasal Swab Tests	Taiwan
3	Zafi Medic robots	Deliver food and medicines to Covid-19 patients under quarantine	India
4	Autonomous Sanitation Robot by Fab Lab	Uses ultraviolet germicidal irradiation (UVGI) for disinfection	Bahrain
5	ASTRA-C by Invento Robotics	Disinfect buildings, stores, rooms, and lobbies	India
6	PRITHVI	Help medical workers and COVID-19 patients reduce contact	India
7	Robocop	Patrolling on streets and hospitals	Tunisia
8	MITRA by Invento Robotics	Scans temperatures collect patients details, phone numbers and schedule appointments with a doctor	India
9	Anti-Epidemic Robots donated by United Nations Development Program (UNDP)	Used for mass temperature screening and keeping medical records of COVID-19 victims	Rwanda

Table 3 Types of biosensors, their working principles, and applications in the medical industry

Types of biosensors	Description	Application
a) Resonant biosensor	Acoustic wave transducers are used with receptors	Analysis of therapeutic antibody concentrations
b) Optical detection biosensor	A signal is generated when UV light passes through the silicon wafers	Therapeutic Drug Monitoring
c) Thermal detection biosensor	Temperature detectors are used to monitor changes in temperature	Constantly monitor body temperatures
d) Ion sensitive biosensor	The interaction of ions with a semiconductor changes the electric potential of the semiconductor which is then measured	Drug testing and screening
e) Electrochemical biosensor	It generates ions by a chemical process that changes the electrical properties of the analytic solution	Early detection of gene mutation and cancer

healthcare services and severely restrict the treatment of the COVID-19 infected population. Furthermore, due to insufficient capacity, inaccessibility, shortages of life-saving ventilators, Intensive Care Unit (ICU) beds, trained medical staff, PPE, non-COVID vulnerable populations are deprived of primary healthcare services as many hospitals, clinics, medical centres, doctors, and nurses are reluctant to provide healthcare services, fearing coronavirus exposure. In this dire situation, telemedicine and digital health services offer a viable alternative for ensuring the delivery of primary and emergency healthcare services to the immunocompromised vulnerable population during the COVID-19 pandemic. The terms telemedicine and telehealth are frequently used interchangeably. However, there is a minor difference between these two terms as telemedicine generally signifies remote clinical services whereas telehealth is a broader term than telemedicine denoting both remote non-clinical services (e.g., administrative meetings) and remote clinical services [53, 54].

Telemedicine service becomes vital during COVID-19 lockdown. Telemedicine allows two-way interactive communication between a patient and a healthcare professional through telephone, social communication video apps such as Zoom, Viber, Google Meet, Microsoft Teams, Tencent (VooV), Facebook, etc. using smartphones, laptops, and desktop computers. The most common modalities of telemedicine include real-time technology, store-and-forward technology, remote monitoring, and M-health approaches [55–57]. During the COVID-19 pandemic, healthcare professionals are serving the COVID-19 patients as well as other patients from hospitals to different remote locations without the risk of coronavirus infection exposure [58, 59].

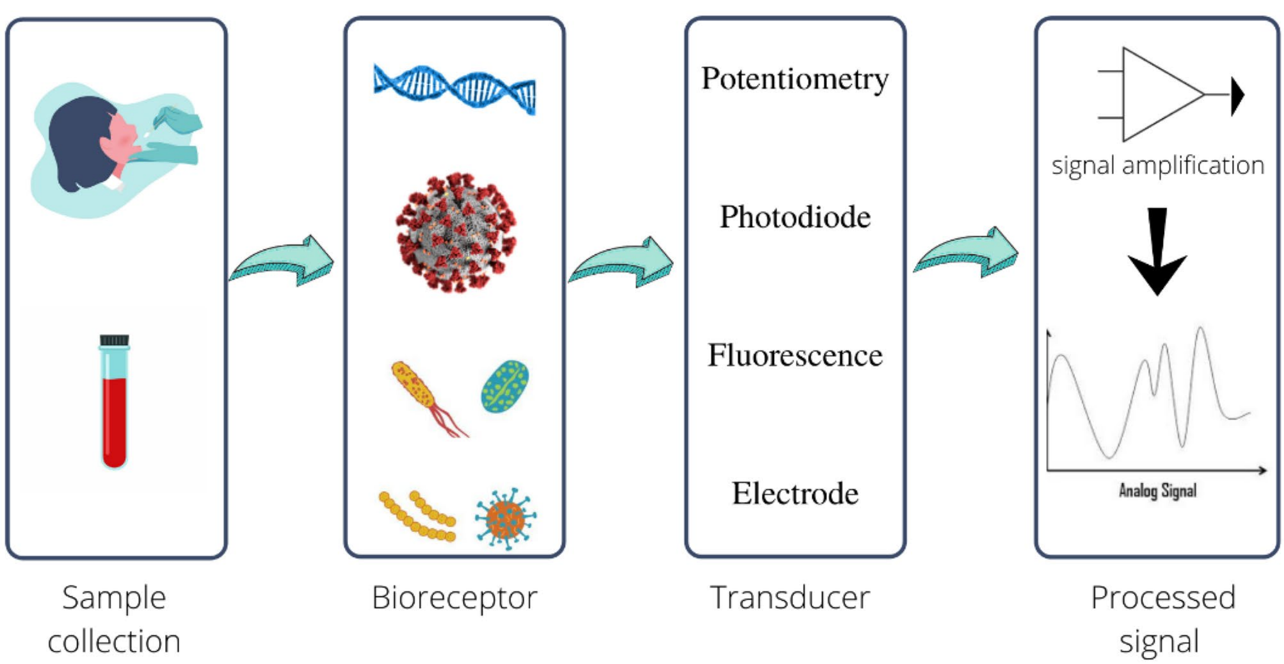


Fig. 10 Basic principle of biosensor

When COVID-19 broke out, the Centre for Disease Control and Prevention (CDC) and WHO advised the healthcare units to use telemedicine to expand access to essential health services for monitoring and treating patients thereby reducing risks of virus-infected patients visiting hospitals and other health and public facilities [60]. A smartphone being a very common and affordable digital device is used for telemedicine services in areas where the network is available [61]. Figure 11 shows the schematic of the Telemedicine concept. Telemedicine is often the last resort in primary healthcare services delivery in remote, hard to access, isolated areas where the vast majority of socio-economically-disadvantaged populations live in the least developing and emerging countries.

By using Telemedicine services for regular, essential medical care/ services, and general check-ups, it is possible to free up medical professionals and equipment required for those who become seriously ill from COVID-19. People are using telemedicine services widely for different types of care for COVID-19, screening, testing recommendations, and guidance on isolation or quarantine, general health care including common issues, prescriptions for medication, nutrition counselling, and mental health counselling which is more important in this tough time. Major benefits of telemedicine include a) patients to talk to their doctor(s) live over video or phone, b) remote monitoring of patients, c) saving travel time/cost and helping to reduce carbon footprint, d) reducing wait-time for services, and e) reducing the number of clinical visits, maintaining social distancing, and lessening close interaction within crowds.

Some examples of telemedicine services in India during COVID-19 includes "*eSanjeevani OPD*", a national teleconsultation service by the Government of India [62], online doctor consultation by "*Practo*", "*E-Doctor Seva*", "*Milo Doctor*", a start-up of BIT Sindri at Dhanbad and "*FOREIGN OPD*", India's only healthcare brand to provide face to face consultations with international medical experts. The main aim of "*eSanjeevani OPD*" is to provide medical counselling to patients in home isolation due to COVID-19 and the patients would receive a free consultation at home via telemedicine, for the feasibility of patients this service can also be accessed via WhatsApp video call and a toll-free helpline. Practo has introduced "*Practo instant*" which provides an appointment booking experience to patients, allowing them to view available slots in real-time calendars and book instant appointments and consultations with specialized doctors. It also introduced a practo search facility that helps patients to find relevant healthcare professionals (doctors, nurses, paramedics. medical technologists, and other relevant professionals). In the USA, over 50 US healthcare companies including Jefferson Health,

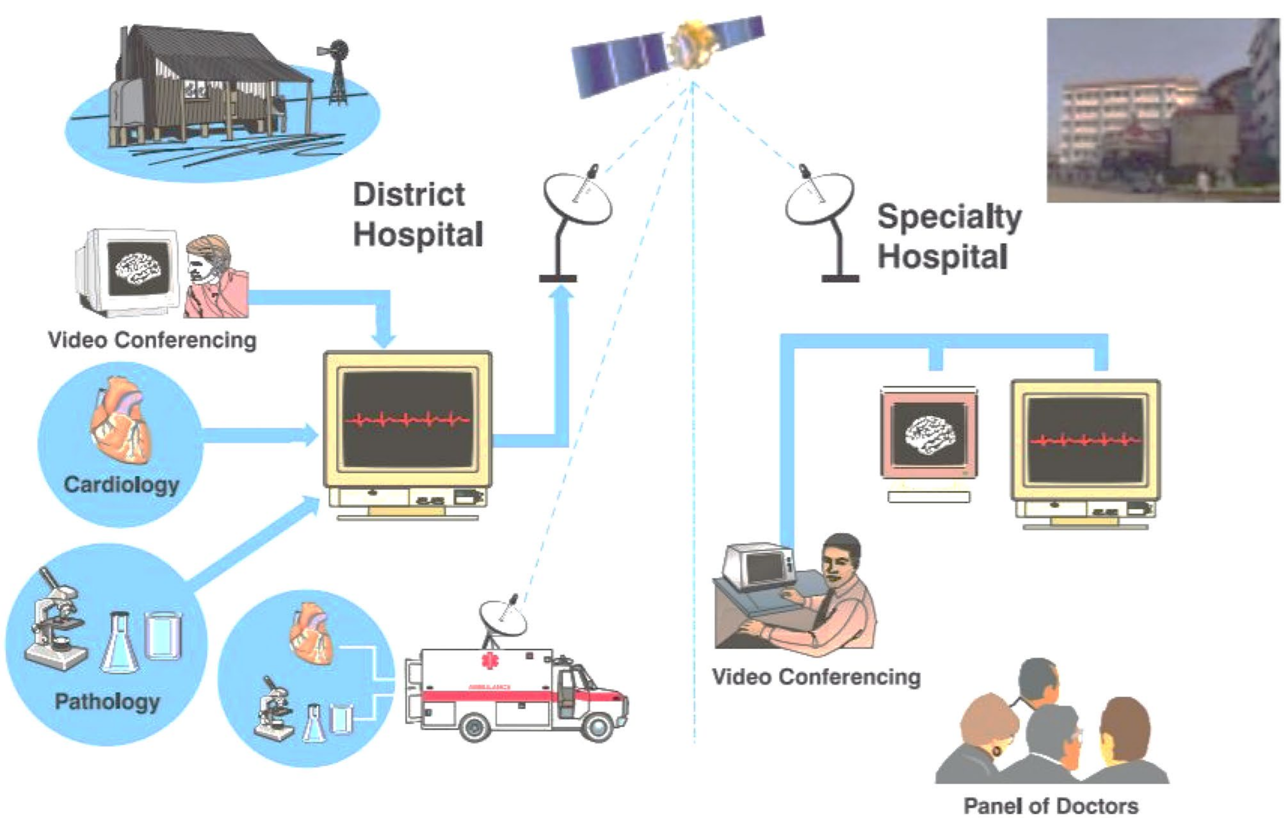


Fig. 11 Understanding the Telemedicine concept, adapted from ISRO, India

Cleveland Clinic, and Providence are providing telemedical services to COVID-19 patients. Figure 12 shows a process flow of a telemedicine service by any healthcare unit.

Global System for Mobile Communications Association (GSMA) conducted a study on six African and Asian least developing and emerging countries' health systems, digital health, and the impact of COVID-19. These countries are Benin, Nigeria, Rwanda, Bangladesh, Myanmar (Burma), and Pakistan. The study focused on digital health as a strengthening tool for health systems, featuring different private sector business models and the role of digital health in managing COVID-19 impact. Data extracted from interviews/ discussions with government health officials, development partners, non-government organisations (NGOs), private sector healthcare investors and health technology start-ups, and mobile operators over 3 months (January to March) in 2020 [63]. The number of the total start-up in thirteen categories of telemedicine/digital health care services in above mentioned six countries was reported (Fig. 13). The highest number of start-ups among all categories was found in Nigeria followed by Bangladesh and Pakistan. These digital/ telemedicine healthcare start-ups deliver services were delivered in partnership with government departments, development partners and NGOs. For example, CMED Health in Bangladesh, an IoT enabled, cloud-based healthcare platform monitors health parameters, predict health risks and provides advice for low-cost healthcare [63]. CMED Health has developed a COVID-19 digital health services module for providing screening, education and awareness, triage for potential cases for sample collection, laboratory tests and patient management services. Over two million people were benefitted from CMED digital healthcare/ telemedicine services in Bangladesh in 2020. Likewise, MyanCare in Myanmar, Sehat Kahani in Pakistan, Rema in Benin, LifeBank in Nigeria, and Babyl in Rwanda provide low-cost digital healthcare services to their populations [63].

Traditionally healthcare service seekers prefer to physically see healthcare professionals at health centres and hospitals instead of digital health service telemedicine. However, this perception of healthcare service seekers is also changing. A multi-centric online survey on preferences of telemedicine modalities by Shiferaw et al. [64] undertaken in Ethiopia showed that 36% of 423 respondents prefer mobile health services (mHealth), 28%—live streaming (real-time

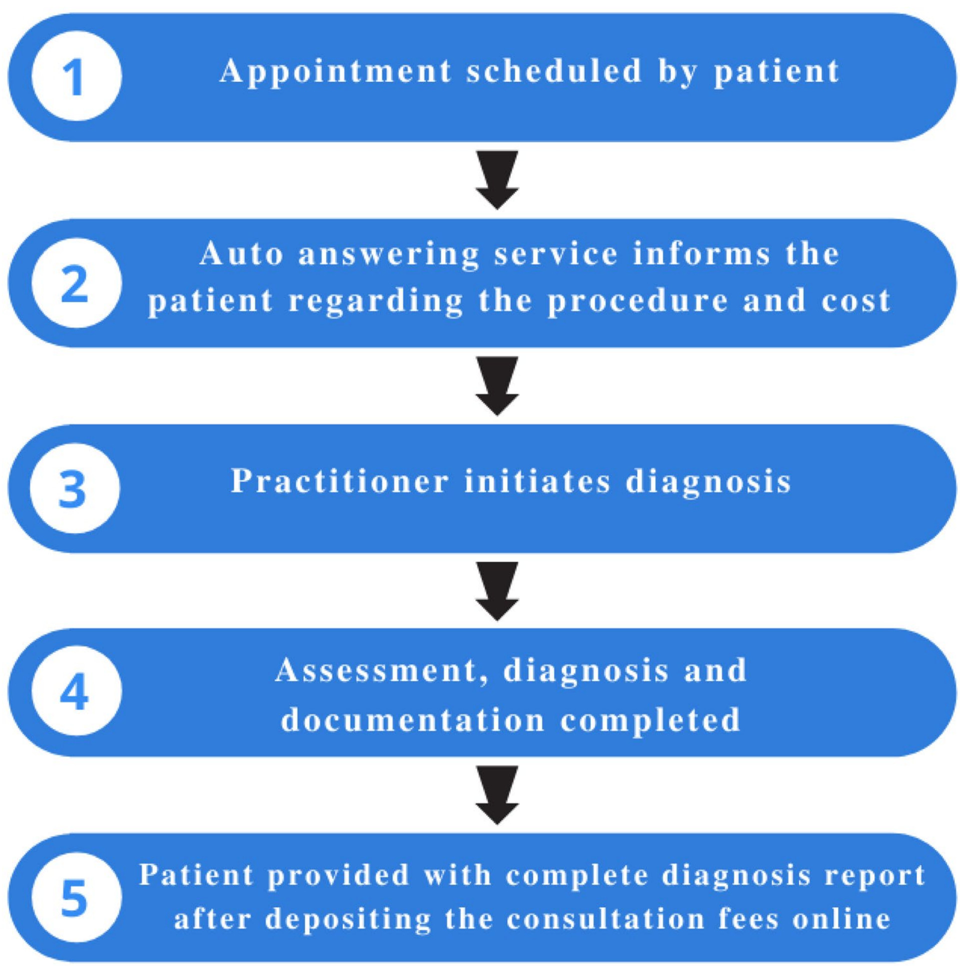


Fig. 12 Flow chart depicting employment of telemedicine services by healthcare units

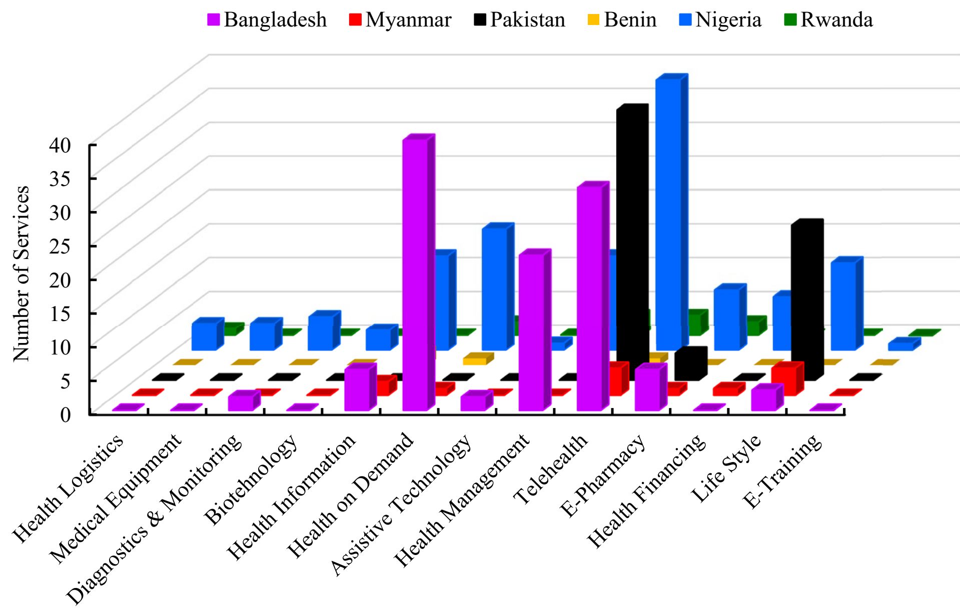


Fig. 13 Digital Health Start-ups, adapted from [63]

communication), 24%—record and send (store and forward, and 12% -remote patient monitoring (RPM). The general acceptance of digital healthcare/ telemedicine is progressively increasing due to COVID-19 mobility restriction and frequent lockdowns.

2.7 Internet of things (IoT)

Internet of Things (IoT) delivers internet-connected hospitals, rapid screening of patients, automated treatment by connecting all medical tools and devices, wireless healthcare network, and telehealthcare consultation during COVID-19 emergencies [65]. A class of Cognitive Internet of Things (CIoT) i.e., Cognitive Internet of Medical Things (CIoMT) can help in smart healthcare in the medical industry [66]. Subsequently, the Internet of Robotic Things (IoRT) integrates robots with sensors and IoTs devices which provides real-time health information, reduces the risk of human mistakes [67]. Detailed application of IoRT can be found in Romeo et al. [68]. Bai et al. [69] used COVID-19 Intelligent Diagnosis and Treatment Assistant Program (nCapp) to diagnose COVID-19 patients in an earlier stage.

Since the outbreak of the COVID-19 pandemic, the use of IoT is gaining momentum especially for preventing the

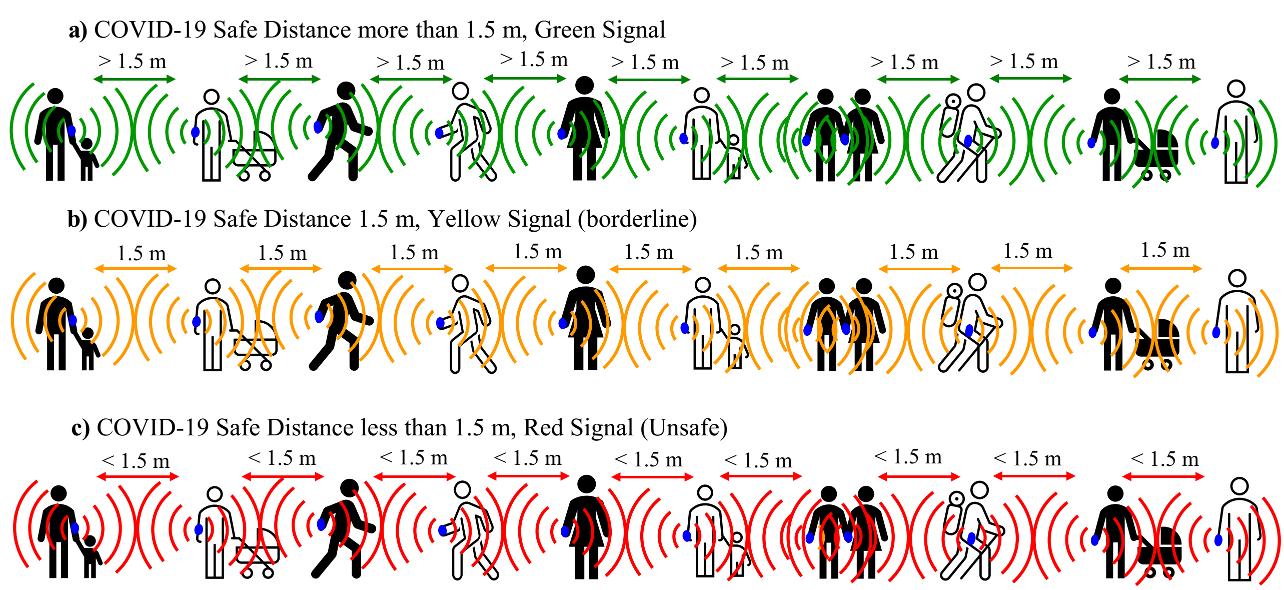


Fig. 14 Application of Wearable EasyBand for COVID-19 Safe Distance Monitoring

spread and/ or lowering the infection of COVID-19. The IoT is used to monitor quarantine compliances, contact tracing, social distancing, diagnosis, monitoring, etc. Some IoT-based solutions combating COVID-19 are a) Wearables, b) Smartphones with apps, c) Drones, and e) IoT Buttons.

Wearable technologies are generally electronic devices that can be worn or attached to the body. They are in a variety of forms such as bands, patches, watches, spectators, helmets, etc. and are used to trace proximity (social distance), movement, contact, body temperature, heartbeat, and many other parameters related to healthcare, fitness, lifestyle, security, and monitoring. Figure 14 shows a typical application of wearable technology (band) for alerting social distances in public places. The wearable bend alerts with red beep if the distance to the nearest person (s) is less than 1.5 m (Fig. 14 (c)), yellow beep if the distance is 1.5 m (Fig. 14(b)) and the green signal without beep if the distance is over 1.5 m (Fig. 14(a)).

Smartphones with purpose-made software (apps) are capable to undertake certain tasks in COVID-19 emergencies. Examples of such apps are nCapp, DetectaChem, Stop Corona, Social Monitoring, Selfie app, Civitas, StayHomeSafe, AarogyaSetu, TraceTogether, Hamagen, Coalition, BeAware Bahrain, eRouska, and many others [68–71]. Smartphones with apps are used in over 50 countries (including Australia, Bangladesh, Canada, China, France, Germany,

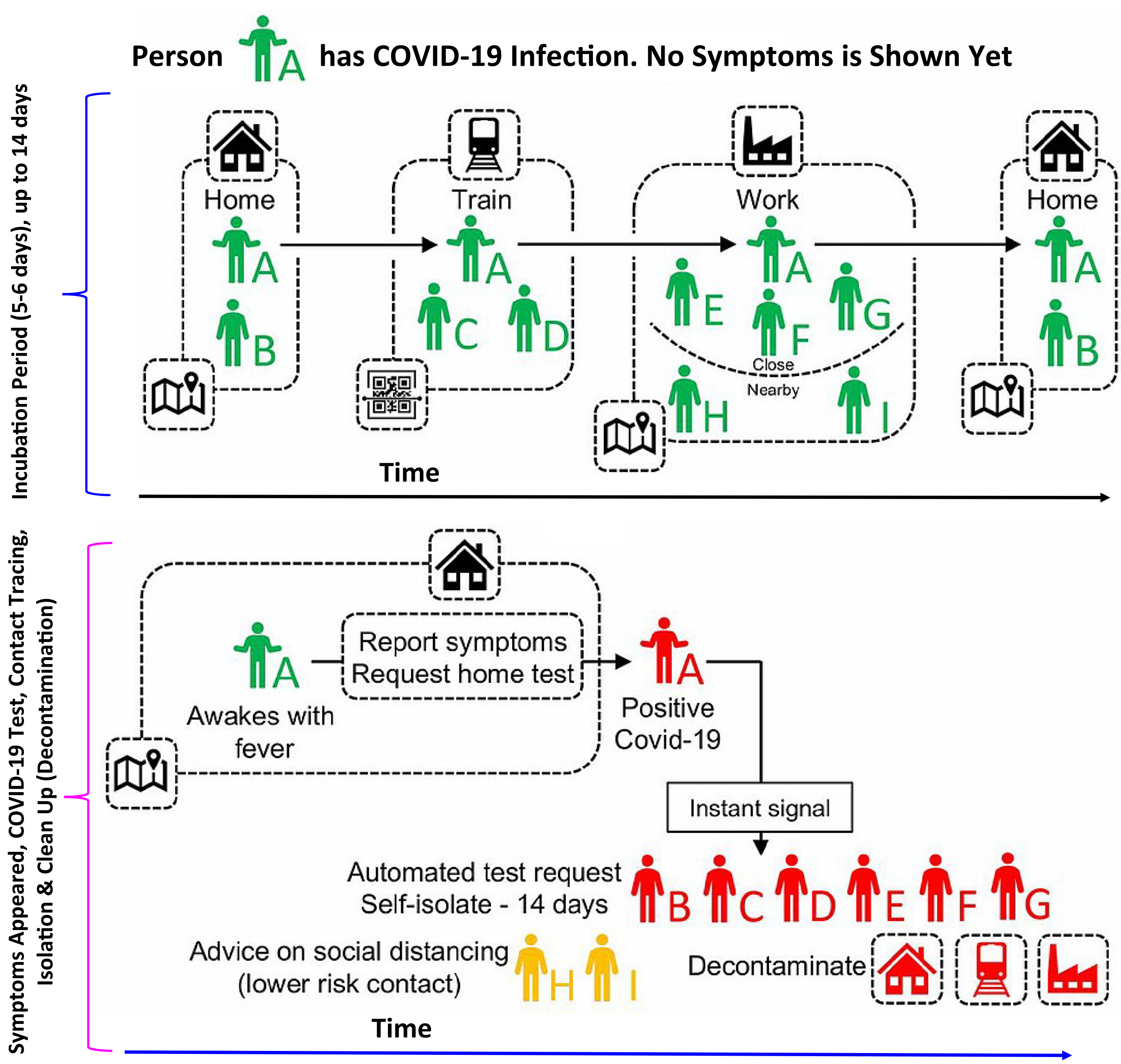


Fig. 15 Typical COVID-19 Infection and Contact Tracing, adapted from [91]

India, Israel, Japan, Malaysia, New Zealand, Russia, Saudi Arabia, Singapore, South Africa, Turkey, Spain, and the United Kingdom) for contact tracing and quarantine monitoring. A schematic of contact tracing is shown in Fig. 15.

Drones are unmanned aerial vehicles (UAVs) aided by sensors, GPS, and communication devices/tools. IoT equipped drones are used for thermal imaging, disinfection, medical supply, surveillance, public announcement, and COVID-19 lockdown monitoring [71–73]. IoT Buttons are tiny programmable devices connected to the cloud through wireless communication. Based on its written code on the cloud, this device can perform different repetitive tasks by pressing any one button. IoT Buttons such as Wanda QuickTouch, Sefucy, etc. are used for alerting the COVID-19 response team(s), communities and/or infected person's family members during the emergency [69, 74–77].

2.8 Augmented reality/virtual reality and holography for online education

Traditional methods of online education are competent in providing only classroom-related teaching and learning [78]. It is difficult to deliver practical experiments and laboratory work online. A simulated environment for experimental/laboratory work can be created by augmented reality or Virtual Reality (VR) and holography using computer technology and head-mounted display for students remotely. VR can provide enhanced interactivity to learners because it allows for synchronous communication and places the learner/student in a spatial dimension [79].

VR finds application in simulation-based training for podiatric medical education [80], Surgical Education [81], learning of dental morphologies [82], conducting virtual laboratory experiments of engineering domain [83], conducting congress meetings [84] and others illustrated in Fig. 16. These VR technologies are helping during the COVID-19 pandemic situation in industries such as retail business, healthcare, and education to continue their business as usual while following COVID-19 guidelines. It is also contributing to manufacturing industries by designing essential medical equipment to meet shortages in very limited timelines. Some other applications of VR in fighting COVID-19 are illustrated by Singh et al. [85].

2.9 Work from home (WFH) environment using cloud computing

National Institute of Standards and Technology (NIST) defines Cloud Computing as a model for enabling ubiquitous and on-demand availability of computer system resources e.g., data storage, applications, servers, networks, and services [86]. Working from home mainly depends on cloud computing (CC) applications that help employees and workers efficiently undertake and complete their specified tasks. Cloud Computing Environment (CCE) is a system consisting of technology like applications, IT infrastructure, and network services. It uses the resources of a data centre (DC), which can be shared through virtualization technology. This use of services is on-demand, elastic, or instant services and rates. For the quality and efficient service, they charged their service fee as a utility bill, schematic visual of CCE is shown in Fig. 17. For example, a user desires to perform a complex simulation using software such as ANSYS, he/she can simply upload the project files to the cloud where it will be solved using high-end CPU (Central Processing Unit) and GPU (Graphical Processing Unit). The cloud platform providers charge a small fee in the form of monthly or yearly subscriptions depending upon the required computing power

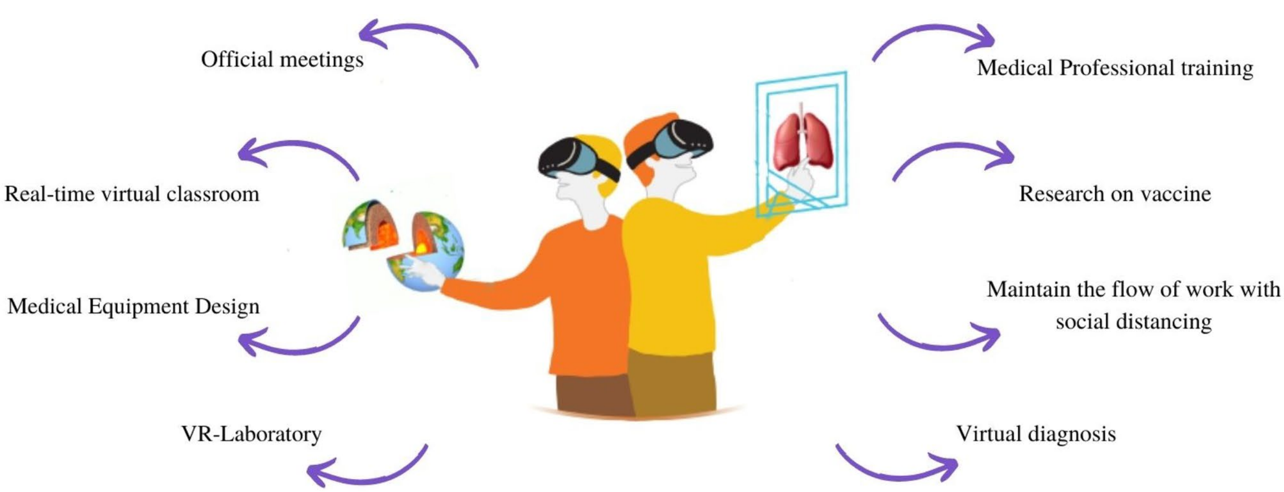


Fig. 16 Application of Virtual Reality in various fields

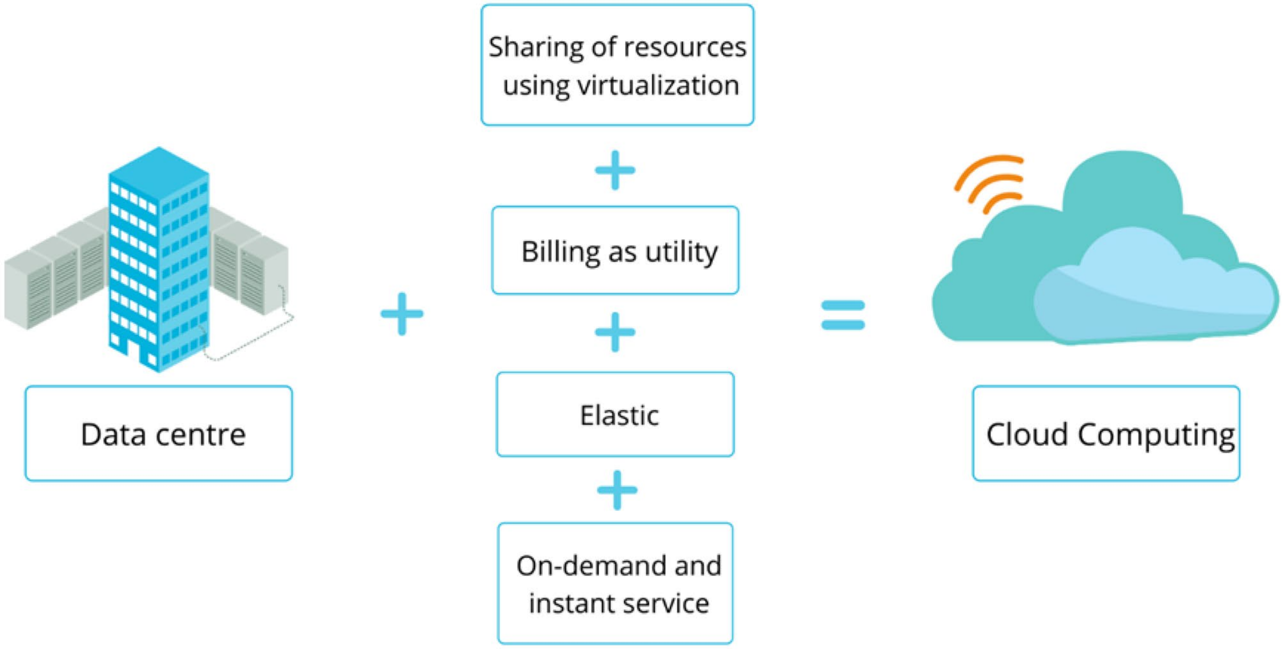


Fig. 17 Characteristic of Cloud Computing Environment (CCE)

of the individual. Amazon Web Services (AWS), Microsoft Azure, Google Cloud are some popular cloud computing platforms currently available. Different types of Cloud Computing services under three categories (SAAS, IaaS, and PaaS) with examples are shown in Fig. 18.

WFH using Cloud Computing can easily be imparted for IT/Service sector organization, customer service/care provider, e-commerce, banking, design labs, manufacturing etc. during this pandemic time. The productivity of an average person working from home increases by up to 42% using Cloud Computing [87]. The global market shut down and supply chain disruption have created a shortage of high-end computing devices (like computers and workstations) [88]. Consequently, a large number of working professionals were offered WFH using cloud computing platforms with their own devices and hence saving the cost for the company. Working on a Cloud Computing platform ensures data security [89] and provide high computing capability and efficiency which minimizes system lags and maintains the productivity of employees from their home.

3 Discussion

Application of Digital Technologies and Industry 4.0 tools is no more a futuristic matter. In every field, Digital Technologies and Industry 4.0 tools/techniques are affecting our lives, environment, flora, and fauna. The use and penetration of Digital Technologies and Industry 4.0 techniques during the COVID-19 pandemic are unprecedented and will continue so. Autonomous robots were used in hospitals and industries in Brazil, France, Italy, UK, USA; Big Data and 3D Printings were widely used in medical applications, hospitals and other areas in many countries including Australia, Denmark, India, Italy, South Korea, Taiwan, UK, and the USA. Telemedicine is getting popularity and wide acceptance in developing and developed countries including India, Bangladesh, Pakistan, Nigeria, Ethiopia, Australia, USA, Canada, and New Zealand. Artificial Intelligence, Virtual Reality, Biosensors and IoT are well received in hospitals, medical applications, industry, residential houses, and other areas in India, the USA, UK, South Korea, Israel, Spain and many more countries. Similarly, other Digital Technologies

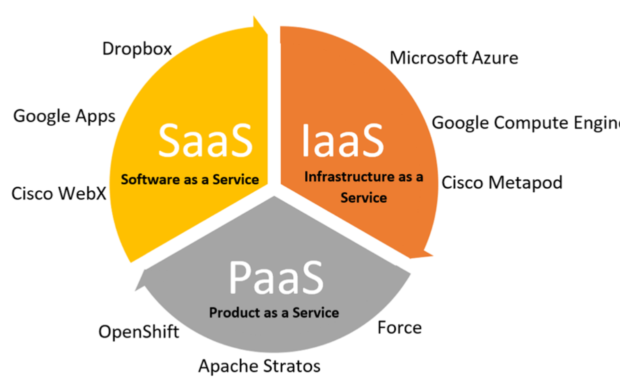


Fig. 18 Types of Cloud Computing Services with examples

Table 4 Digital Technologies and Industry 4.0 technique implemented in fighting COVID-19 across the world since 2020

Digital Technologies	Application during COVID-19	Major Area	Country	Ref
Autonomous Robot	Autonomous Robot has numerous applications in the field of the manufacturing industry, hospitality industry (hotels), aviation, hospital, surveillance, border security and many more. Autonomous Robot 'Tommy' is used to care for COVID-19 patients	Hospitals/ healthcare services	Italy	[90]
Telemedicine	Hospitals/ healthcare centres located in remote areas could be easily accessed from well-equipped hospitals of metro areas and hence a better consulting and treatment can be provided to patients. RP-VITA made by iRobot: allows medical specialists to communicate remotely with patients	Hospitals/ healthcare services	USA, India, Bangladesh, and other countries	[90]
Drone	Police Patrolling	Cities, towns, rural areas	India, USA	[90]
Contact tracing apps	Helps to identify persons who may have been in contact with a COVID infected individual	All possible areas	Australia, Canada, Germany, France, UK, China, Japan, India, Bangladesh, and 50 + countries	[91]
Advanced Robotics	Fast medicine and equipment production and reduce human interaction leads to less virus transmission	Industries	Italy, Brazil, US, France, UK	[40]
Big Data	To store and analyze data	Hospitals/ healthcare services	South Korea, Taiwan	[92]
3D printing	It is used in the manufacturing and fabrication of sophisticated components including aerospace, defence, automobile, home appliance and medical field. 3D Printing is also used to make ventilator parts, masks, respirators, and personal protective equipment (PPE), face shields, masks, nasal swabs, 3D-printed robot help to Perform throat swab testing with zero human contact	All medical fields	Australia, UK, USA, India, Denmark, Italy	[19]
Artificial Intelligence	Al does the task by training machines using BIG Data in areas of banking & finance, healthcare, agriculture, gaming, space Exploration, social media, Cybersecurity. etc. AI-based chest X-ray diagnosis technology is used for Rapid detection of suspected Covid-19	Hospitals/ healthcare services	UK, India, USA	[25–27]
Virtual reality	Virtual reality is used in the study of Engineering, Medical and Architectural sciences. Using holography, the concept makes easier to understand and interestingly it could be carried out online as well as offline education. Virtual reality is used for rendering infected areas, healthcare professional training, real-time education for the student	Home, hospitals/ healthcare services	USA, South Korea	[93]

Table 4 (continued)

Digital Technologies	Application during COVID-19	Major Area	Country	Ref
Biosensor	Biosensor helps extract and monitor different types of data of the human body thereby easy and early detection of various diseases without carrying out an expensive body checkup. Biosensors are used for fast COVID-19 diagnosis. Life signals biosensors wireless patch can help in continuous remote monitoring of COVID-19 patient/suspect	All medical fields	South Korea, Israel, Taiwan, India	[51, 86]
IoT	Tracking, screening, Monitoring data	Homes, public areas, hospitals/ healthcare services	India, Spain, USA, South Korea	[94]
Cloud computing	Cloud computing helps to store medical data on the cloud and give assistance in curing patient infected with various disease easily. During COVID-19, work from home environment could be easily created in various locations of the city as well as the town. Office collaboration within businesses, increase in remote education and training at educational institution levels	Banking and finances, healthcare, manufacturing sectors, etc	India, Singapore, Australia, Hong Kong	[95]
Cybersecurity	Prevention from hacking and cyber-attack in name of COVID-19	Defence, internal agencies, big organization	India, Israel	[89]

and Industry 4.0 tools such as Drone are used in surveillance, non-contact postal delivery, and crowd pictures in many countries including Australia, China, and the USA. Cloud Computing, Contact Tracing and Cybersecurity are used in Australia, Brazil, China, India, Israel, Japan, New Zealand, Saudi Arabia, South Korea, Taiwan, the USA, UK, Europe, and Africa. 3D printing technology was widely used in the manufacturing of PPE, and other devices to safeguard against COVID-19. Popular Digital Technologies and Industry 4.0 tools used during COVID-19 since 2020 are summarized in Table 4. The application and uses of these technologies and tools will certainly continue and play a pivotal role in healthcare services delivery worldwide during and post-COVID-19 period.

4 Conclusions

The impact of COVID-19 on healthcare services delivery is innumerable. Digital Technologies and Industry 4.0 tools/techniques have shown immense capabilities that can be used to change the scenario of the present world during and post COVID-19 pandemic. COVID-19 played a vital role in the improvement and development of medical and healthcare facilities, and service delivery.

Digital Health/Telemedicine plays a crucial role in healthcare service delivery to vulnerable and immunocompromised people globally thereby protecting them from COVID-19 infection and minimising the COVID-19 infection to frontline healthcare professionals by reducing interhuman contagion. This allows diverting resources and facilities for COVID patients' treatment and care.

3D printing as rapid prototype manufacturing shows its immense capabilities in manufacturing of PPE, face shield, mask, nasal swabs, etc. 3D printing allows fast and customised production of COVID-19 protective equipment.

Autonomous Robot allows providing non-contact services to COVID-19 patients. The application of an autonomous robot minimises the direct contact with COVID-19 patients and, also allows undertaking disinfection work; thereby reducing the spread of COVID infection and viruses.

Biosensors offer huge benefits for COVID-19 detection. Once the infection is detected, the cases can be isolated thereby slowing down the virus-spread. Two biosensors (electrochemical and optical) can be used for simple, rapid, and low-cost detection of COVID-19 from saliva.

The data size in the health care industry is massive and growing rapidly that needs to be securely collected, processed, stored, and shared among stakeholders within the national boundary and beyond. Cloud computing serves as a perfect platform to effectively use and share vast healthcare data among stakeholders (healthcare professionals, hospitals, pharmaceutical benefits schemes, medical research centres and national vaccination data centres). Cloud computing with integrated use of IoTs, Artificial Intelligence, and Machine Learning will provide citizens with full control over their health data, security, and misuse prevention.

Digital Technologies and Industry 4.0 tools/techniques implemented for fighting COVID-19 offer an opportunity for developing and developed countries to create a framework for integrated healthcare service delivery during and post-COVID period.

Authors' contributions Mukesh Chandra: Paper conceptualization, Preparation of first draft of manuscript, data collection, and analysis; Kunal Kumar: Data collection, and analysis; Prabhat Thakur; Data collection, and analysis; Somnath Chattopadhyaya: Updating, formatting and reviewing; Firoz Alam: Updating, formatting and reviewing: Satish Kumar: Paper conceptualization.

Funding Not applicable.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Conflicts of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

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