Chapter 1
Dynamic Models and Control Techniques for Drone Delivery of Medications and Other Healthcare Items in COVID-19 Hotspots

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Abstract Drone-based dynamic model and control techniques vary from classical linear proportional integral derivative (CPID) to complex nonlinear multi-constrained and multi-objective schemes such as backstepping, sliding window mode, size-based models, and operation-based models, among others. These approaches can be classified as per their usage. Thus, some will be efficient for indoor operations, and others will be useful for outdoor operations. The performance of both types of drone-based smart healthcare systems can be measured in terms of stabilizing the...
attitude for both indoor and outdoor operations as per requirements. Further, gain-based drone scheduling is commonly used in flight controllers. In COVID-19 pandemic situations, the gains can be measured using an alternative way. Here, different parameters like medication advantage to COVID-19 pandemic areas, identifying the COVID-19 hotspots, sanitizing requirements and potentials, finding the COVID-19 chain, etc., could be considered in gain measurement for the deployment of drone-based COVID-19’s smart healthcare. This work proposes a multi-constraint and multi-objective gain-based simulation-optimization approach for scheduling the linear and nonlinear dynamic and controllable drone movement models. The proposed model considered the identity-based lower and upper limits of control interface. Further, this interface is having the provision to include some human factors in its execution. The performance of the overall system is measured using performance and security metrics. In performance, drone-based smart healthcare systems’ efficiency, accuracy, and effectiveness are measured. The measurements are analyzed by varying optimization parameters. In the security, lightweight cryptography primitives and protocols are analyzed for performance measurements. These lightweight cryptography primitives and protocols ensure secure data storage, transmission, and processing at any device. Further, the scope of centralized and distributed systems of drone cooperations for COVID-19 monitoring, sanitization, cleaning, and control room will be explored to have time-saving and autonomous drone-based smart healthcare systems.

Keywords COVID-19 · Dynamic models · Industry 4.0 · Simulation · Healthcare 4.0 · Pandemic

1.1 Introduction

This section explains the drone-based systems, its features, and applications (specifically in the healthcare section). Details are given as follows.
1.1.1 **What Is Smart Healthcare System and COVID-19 Pandemics**

The latest technology like big data, IoT, data analytics, cloud computing, and many others has revolutionized the traditional healthcare system into a smart healthcare system. In a smart healthcare system, a patient’s biological and psychological data (in form of signals) is collected, recorded, analyzed, stored (as a “history” for future consultation), and transmitted to doctors and healthcare units [1]. This enables continuous, prompt, and regular checkup of blood pressure, diabetes, and heart rate of patients. ICT is one of the components of a successful smart healthcare system as being connected to smart devices, there are regular and immediate follow-ups between patient and doctors. Features like self-monitoring and auto-reporting have encouraged players to foresee the APAC and EMEA sector to reach new heights of USD 251 billion by 2022 [2].

Reasons for such expanding popularity of smart healthcare system are as follows:

- Digitizing and central storage of patients’ records, known as electronic health records (EHR), have reduced intermediate paper mess at patient’s and hospital’s end. No matter even if the patient forgets to give some health-related input to the medical practitioner, it will be visible at the time of examination because of EHR.
- Alarming abnormality about patient’s condition to doctor or hospital treating him through telemedicine gives a sense of personal touch and care.
- In remote areas where medical facilities are not up to the mark, smart healthcare is boon to such a section of society by providing remote diagnosis and prescribing ad delivering medicines.
- Improvement in computational power concerning lesser time lag and accurate result with low power consumption and well connected to the Internet network.
- The patient can view their reports on supporting portable digital assistant in 2D or 3D result set.
- Wait time between patients and doctor’s interaction is reduced to quite an extent.
- Quick response time of diagnosis and prescription increases adoption of this changing trend in the healthcare sector.
- Remote facilities related to health have shown a downfall in footfall of patients to hospitals and clinics.
- Hospitals with smart healthcare facilities may include radio-frequency identification technology (through sensors) responding to inventory or live location of medical equipment and resources [3].
- Follow-up between insurance policyholder and the insurance company will be transparent for patient’s personal and medical data collection, health updates, risk analysis, claim processing, and fraud detection.

High-end technology in smart healthcare systems has shown an effective result in various ways:
• It reduces efforts and expenditures. For example, costs of health clinic visits can be reduced by wearing a portable medical equipment when patient is under observation of a doctor or any family member.
• Usually, it is normal practice that a patient visits a doctor after an abnormality has occurred (maybe unaware or careless); thus, smart healthcare helps to predict an epidemic by seeing sprouting symptoms at the initial stage.
• Immediate response action has improved and saved many lives by providing immediate first aid or similar assistance to patients.

The smart healthcare system is scalable, cost-effective, efficient, and hard real-time responsive, making it adoptable by an aging population, disabled individuals, population at remote sites, and people living alone. Although smart healthcare has all features to fit in society, on other side, few challenges as mentioned below exist:

• Electronic health records (EHRs) are centrally stored and thus very helpful for data sharing, while it is vulnerable to hacking at a point if security is compromised at any point.
• The IoT environment is a costly affair, and the camera needs funds in implementing and maintenance of sensors, monitors, and detectors.
• Technological drift from traditional work style often leads to a lack of coordination (communication gap and technology knowledge are few to mention) from either of the participating entity.
• High-speed data transformation from analog to digital signals for processing should not be compromised with data loss or inaccurate results. High precision needs to be maintained by analytics to generate instant results (most of the times).
• Sudden power cutoff may lead to incomplete and dangerous consequences to the patient.

Despite the abovementioned challenges, smart healthcare systems have explosively shown its capability to serve the society since late 2019. The World Health Organization (WHO) announced an infectious disease caused by acute respiratory syndrome virus (in Wuhan (China) in December 2019) called coronavirus disease 2019 or COVID-19 (survival span is 72 h) [4]. A person suffering fever, lethargy, dry cough with a runny nose, sore throat, and ache may be suspected to be infected with coronavirus. It is considered to be pandemic because of its spreading pattern in chain reaction format with no demographic boundary limits. The spread of coronavirus is vital as no vaccine against it is yet announced by any nation across the world [4]. Thus, the WHO has shared guidelines as preventive measures to be taken across the nations, like social awareness, sanitizing, enhancing emergency response mechanisms, contact tracing, treating the infected patient, and encouraging social distancing. The smart healthcare system has shown its superlative ability during the outbreak of pandemic ranging from recording human health status to sanitization, telemedicine, and diagnosis of the infected patient from the mass of the population.
1.1.2 Importance of Drone-Based Systems in Smart Healthcare System

Unmanned aerial vehicles (UAV) or drones are innovations of technology which are operated by a remotely located pilot (under guidelines framed by the Ministry of Civil Aviation) to fly in airspace. Drones are facilitators to the smart healthcare sector as they are not restricted by traffic, site connectivity, a span of the day, weather, and demographic boundaries. There was a shift from prolonged admission of aged people in hospitals to nursing care at home. In this model, nurses were assigned to take care of patients as and when they needed it. This may lead to many long hours in a day where nurses have nothing critical to attend regarding patients. This refers to a situation where a resource from the hospital (nurse) is occupied for extra time and also increases the cost of the patient’s treatment. Also, in war sites and areas affected by flood and drought, where basic amenities for survival are not available, drones have proven quite helpful by delivering essential medical and food supplies. In such situations, due to its aerial view capability, global positioning system, and high transmission speed, drones are in huge demand to deliver vaccines, drugs, blood, and food packets and to collect samples for testing [5–7]. Drones are used from surveillance to first aid transmission as the need arises. In situations where delay in supply of lifesaving drugs, medical aid, or support is not acceptable and the area is inaccessible (because of natural disaster, remote areas, or poor access to road connectivity), drones have come to the rescue. The major loss was avoided by providing timely assistance of survey and relief measures to the site hit by Typhoon Haiyan in the Philippines [8]. The photogrammetry feature of drones has made detection of an increasing level of particular constituent possible (e.g., tumor detection in the human body) leading to timely treatment or taking precautionary measures [9, 10]. In Rwanda, blood and vaccines were delivered to its citizens via drones [11]. It is estimated that delivering drugs and samples and other support via drones are efficient and taking one-fourth of the time taken by road commuters [12]. Drones not only save lives by transmitting aids and lifesaving supplements like vaccines or blood but also reduce the chances of collision and thus save lives on the road. Vehicles carrying such assistance over road run at high speed and thus may be dangerous for the life of the driver or the people on road.

1.1.3 Indoor and Outdoor Drone-Based Systems for Medication and Monitoring in Smart Healthcare

UAVs were built to carry out those tasks and operations where humans had certain limitations like environmental challenges or to automate and make existing operations more efficient. UAV is a significant result of the Internet of Things that builds up an application for remote regulation and viewing using sensors and transceivers.
As per application and usability, drones can be used in a closed environment (indoor drones) or under the open sky (outdoor). UAVs used outdoor are more common, and they serve several purposes like surveillance for defense organizations, rescue and emergency response operations, monitoring wildlife conservation, agriculture purposes, weather forecasting, and many more. In most of the use cases mentioned above, there are regulatory clearances that are required for a drone manufacturer and drone customer that they need to obtain from the concerned authorities before they can start using drones commercially. Such drones play a very critical role in the healthcare domain when they are used for delivering life care medications and supplies in battlefields or disaster-struck areas. Outdoor drones are usually bigger having higher payload capacities of up to 8–10 kg and higher flight time as they may need to fly several kilometers in remote areas for surveillance or relief measures. Outdoor drones need a Global Positioning System (GPS) for navigation and tracking purposes, and they are controlled by a control circuit box. Due to higher specifications and high-grade sensors being used, the overall cost of outdoor drones is higher as compared to that of indoor drones.

The applicability of a UAV is not limited to only outdoor applications, but it can also be used in indoor environments such as in the manufacturing and services industries. In situations where a bounded premise (hospitals, production, home, warehouse, and many others) needs to be under supervision, an indoor drone-based system is a good option. Such a UAV needs no clearance pass from aviation centers during a flight in most of the cases. The patients could get aid or medicines inside their homes without stepping out of their homes [7, 11]. This is very beneficial for bedridden patients or in a lockdown situation. Indoor drones can also be used for inspection of machines inside an industrial facility with predetermined flight paths avoiding collisions. As outdoor drones use GPS for navigation, indoor drones use indoor positioning system (IPS) or Bluetooth technology for safe navigation and to avoid collision [4, 5, 14–25]. Indoor drones are controlled by an intelligent flight control system (IFCS), and flight of indoor drone is marked safe by protecting propeller using guards and avoiding curtains in their path of flight. While using drone inside closed premises, a drone’s flight path, orientation, and ground clearance level of flight should be well programmed over an integrated circuit. Although payload attached to such drones is not bulky but lighter commands like carrying laundry to the washing area, calling for a medicine from a room and others is a big help to the aged population or persons in need (like a person with plastered leg). Indoor drones are small in size, and the battery life is comparatively fit for local movement between points visible through the naked eyes over line of sight (LOS). In contrast to outdoor drones, indoor drones are agile, compact, and lightweight, and sensors like GPS (add-on to the cost of a drone) are not required which lowers down the cost.
1.1.4 Research Challenges in Designing and Developing Drone-Based Smart Healthcare Systems

All the applications and case studies discussed in this research and many other similar researches tell us that usability of drones in healthcare has effectively reduced response time and surpassed natural restrictions. Still while designing and creating a drone-based smart healthcare system, it is important to think holistically about the problem to be solved, the users—patients, medical professionals, record keepers, and drone manufacturers. Research challenges also include setting up parameters to evaluate the performance of the drones. The performance should be measured in terms of technical performance, usability, acceptance of the system by the user, and efficacy of the system. Overall acceptance for general everyday use even in healthcare is still very low. There are several challenges to overcome, and they are not just limited to technology but also regulatory aspects.

While transmitting health-related aid or services via an aerial channel through drones, a highly accurate navigation system is required. UAV should in hard real-time synchronization with ground control unit be operated by a pilot who is monitoring the movement of the drone to the target for the intended purpose by integrating ground controls with aerospace allocated for drone flights. As drones carry medicines or samples to-and-fro between target site to ground site, APM control board should be capable enough to hold payload during flight [15]. In usual case, if payload overshoots threshold of APM, it won’t allow the drone to fly. After attending remote target site, the drones are pre-commanded to return to the base location. This concept of the drone is called a return to home (RTH) feature. Drones have home GPS location with exact longitude and latitude, and this helps RTH feature to be active and well addressed for safe and on-site landing. Communicating medium between the pilot and receiver (similar to IoT-enabled unit) should be error- and disturbance-free during signal transmission [16]. Any disturbance in signal transmission during the telemedicine process may result in fatal consequences. Thus, to counter such an unaffordable situation, highly efficient and dedicated air to ground channel is required to work against a blockage, elevation, and weather conditions also. In the healthcare system, using aerial technology like drones needs multiple participating technologies to synchronize on a common platform to achieve a common objective. Drone in healthcare uses multiple technology coordinates to accomplish accurate results by securing functionalities of sensors and networks along with data of patients [13]. Drones fly to unseen remote sites by path drawn by the pilot. A specific predesigned algorithm may not work all the time or in all situations. An algorithm to select optimal flight paths among all possible navigation paths is complicated and critical as it overall reflects the functionality of drone in rescue or assisting action. Drones are fully or partially automated with reflexes in case of an unexpected situation or conditions like low power mode or encountering an obstacle. Such sensitivity of drones increases designing complexity and needs highly sensitive sensors along with add-ons related to guarding dedicated components of drones under such conditions.
Details of people being attended by drones are recorded and used by medical authorities for treatment and cure in the form of electronic health records (EHRs). These EHRs need to be uniform at the patient’s end and to the hospital/doctor in charge, and also data should transmit between intended end users. Data should not get compromised with its confidentiality or integrity aspect. Attackers will make every possible attempt of spoofing, traffic analysis, masquerading, phishing, or non-repudiation using IPsec to extract data from IoT-embedded devices (patient or payload) or the network. Healthcare services provide two-way authentication and added encryption of data which is time-consuming and disturbing phase for many non-technical users especially at the time of emergency. Multilevel authentication and encryption phase result in a time-consuming and disturbing phase at the time of emergency [4]. Firewall and intrusion detection and prevention system (IDPS) counter routing attack at the network layer of the OSI reference model. This enables us to keep a check on incoming or outgoing data, and in return authentication is maintained. A challenge was recorded as data authentication was disturbed by denial of service attack. Attackers fly self-governed own drones in shared airspace and send multiple signals to the targeted genuine drone. The targeted genuine drone mixes up with the original signal and loses real informative signals because of modified or overflooded incoming signals to the genuine drone in the communication network [5].

### 1.1.5 Organization of Work

This work is organized in a systematic manner where Sect. 1.1 introduces the smart healthcare system and its significance in the COVID-19 pandemic. It includes functionalities of smart healthcare like remote examination of patients and assistance by indoor and outdoor drones and challenges faced while designing and developing the systems. COVID-19 hotspots are discussed in Sect. 1.2, which further explains adopted preventive and alert methods along with its impact on social and economic sectors. Further, rules, regulations, policies, and procedures of COVID-19 monitoring and control rooms are discussed. In Sect. 1.3, a literature survey of recently developed drone-based systems (agriculture, mining sites, defense, and healthcare are few to mention), COVID-19 hotspots, and drone movement for monitoring and data analysis over such areas along with drone-based systems for smart healthcare systems in other pandemic situations is discussed. Drone-based frameworks for smart healthcare systems using Industry 4.0 trends in COVID-19 hotspots are discussed in Sect. 1.3. Section 1.4 deals with a real-time drone-based system for COVID-19 along with its benefits and limitations. Section 1.5 is about drone-based simulation done for COVID-19 hotspot tracking (monitoring, analysis, control room positioning). In Sect. 1.6, outdoor COVID-19 hotspot tracking, monitoring, analysis, and control room positioning are discussed. Conclusion and future scope of work constitute Sect. 1.7.
1.2 COVID-19 Hotpots

This section introduces COVID-19 hotspot, positions and statistics, prevention and alert methods, effects over social and economic sectors, and rules and regulations.

1.2.1 What Is COVID-19 Hotspot

On 11 March 2020, after spreading to more than 100 countries and report of thousands of cases within a few months, the World Health Organization declared the outbreak as “pandemic” resulting in a socioeconomic crisis of an unprecedented scale. Most of the nations focusing on identifying critical regions and strategies to avoid the spread of the virus. A hotspot is a region where a comparatively higher number of confirmed COVID-19 cases are reported [17]. The confirmed cases may not be from the same family, thereby increasing the chances of community transmission of the virus in such regions. To avoid spreading it further, governing bodies sealed off such regions to stop people from coming out of their home. These regions can vary in the geographical area from a small society of people to a city or a district in some countries.

1.2.2 Worldwide COVID-19 Hotspot Positions and Statistics

On 31 December 2019, the first case of pneumonia of unknown cause was detected in Wuhan City, China [18]. From the data provided by the World Health Organization [19], Fig. 1.1 shows a timeline of how rapidly it spread to the majority of the countries worldwide starting from the first case reported outside of China in Thailand (8 January 2020) followed by Japan (14 January 2020) and the Republic of Korea (19 January 2020). On 20 January 2020, the USA reported its first case and was the

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Fig. 1.1 Number of countries and first reported COVID-19 case day
most affected country with more than 38,000 deaths as of 22 April 2020 [20]. On 10 April 2020, the latest country to report COVID-19 case was Yemen.

Figure 1.1 shows timeline of several countries reporting their first confirmed case from six regions divided by the World Health Organization: Africa (AFRO), America (AMRO), Eastern Mediterranean (EMRO), Europe (EURO), Southeast Asia (SEARO), and Western Pacific (WPRO) [21].

As of 22 April 2020, the totally confirmed cases of COVID-19 are 2,471,136, and 169,006 deaths have been reported by the WHO [19, 20]. As shown in Fig. 1.2, the European region and the region of America are the most affected regions with more than 90% of the worldwide cases. To understand the worldwide position, Fig. 1.3 shows the number of COVID-19 confirmed cases in the top 20 affected countries. Figure 1.4 shows several deaths due to COVID-19 in the top 20 affected countries.

1.2.3 COVID-19 Pandemic Prevention and Alert Methods

To reduce the spread of the virus, the following preventive measures are suggested by the WHO and other concerned agencies:

- Clean your hands with alcohol-based hand sanitizer or wash it regularly with soap and water to kill viruses.
- Avoid touching the face as the virus can enter your body through the nose, mouth, and eyes.
• Maintain good respiratory hygiene. Use tissue paper or bent elbow to cover your mouth and nose and then dispose of used tissue immediately. Droplet is one of the carriers of the virus, and this will ensure fewer droplets in the environment.

• If you are feeling unwell, then you need to stay at home. If symptoms are cough, fever, and breathing issues, then immediately consult the doctor. This will ensure timely treatment.

• Maintain a minimum of 3 ft. distance between yourself and another person. Avoid handshakes or other physical contacts.

• Keep yourself up to date with the latest hotspots and avoid traveling to such hotspots.

In case of any pandemic situation like COVID-19, the government must alert the following:

• Airports for screening passengers who have travel history from affected areas.

• Educational institutes need to follow preventive measures.
• Health organizations to keep the preparation for handing the patients. Health organizations should give proper training to all health workers to deal with the situation.
• Law enforcement agencies for strict implementation of lockdown.
• All essential service providers.

1.2.4 COVID-19 Pandemic Effects in Social and Economic Sectors

The COVID-19 pandemic has already affected the lives of many people by restricting their movements. On 18 March 2020, the WHO issued a report to address mental health and psychosocial issues of the general public, healthcare workers, team leaders or managers in health facilities, guardians of children, old people, and people with underlying health conditions [24]. Many people are now hesitating to keep their pets as they may pass on the coronavirus to them [25]. Millions of people may lose jobs worldwide, thereby increasing unemployment and poverty. The effect of a pandemic situation can be seen in these sectors:

• **Education sector**: Most of the educational institutes worldwide are temporarily closed to control the spread of the virus. According to data released by UNESCO on 18 Apr 2020, 91.3% (1,575,270,054) of the total enrolled learners from 191 nations are affected [14]. Children from poor sections may drop out of school permanently [15].
• **Religious sector**: Temples, churches, mosques, and other religious places have started offering services online for the devotees [16].
• **Sports sector**: The majority of international sports events are either called off or rescheduled [26].
• **Entertainment industry**: Most of the media events are now canceled or delayed [27]. The demand of online digital media platforms like Netflix, Amazon Prime, etc., has increased.
• **Aviation industry**: Due to the cancellation of flights, few airlines have sent their employees on leave without salary on a rotational basis [24].
• **Tourism industry**: Countries with high earnings from tourism are greatly affected. Hotels and restaurants are closed temporarily.
• **Transportation sector**: All local transportations are closed or have restricted access.
• **Science and technology sector**: Various organizations have asked their employees to work from home. Leading space agencies like NASA have halted their space and technology projects.

Worldwide border seal has affected international trade of various goods and commodities. Various industries have stopped their production. Financial markets have collapsed. Manufacturing industries are seeing a large drop in the demand.
1.2.5 Rules, Regulations, Policies, and Procedures for COVID-19 Monitoring and Control Room

To deal with the pandemic situation, strong measures are required for effective containment of COVID-19. The worldwide focus has been to upgrade health infrastructure by providing COVID-19-dedicated hospitals and other medical equipment. The public is advised to follow social distancing, and, in some places, the government has forced complete lockdown to reduce further spread of COVID-19.

On 25 March 2020, the WHO has released guidelines: “operational guidance for maintaining essential health services during an outbreak” [28]. The report focuses on building coordination mechanisms to help response teams, determining essential services and optimization of delivery platforms, setting up the efficient flow of patients, managing health workers, and identifying mechanisms to keep track of essential medications, equipment, and supplies.

Some of the important containment policies and procedures are as follows [17, 22]:

• Social distancing while interacting in public places.
• Quarantine people if found any contact history or travel record from the affected area.
• Active surveillance in all possible hotspot zones.
• Testing maximum possible suspected cases.
• Isolation of all COVID-19-positive cases and providing suitable medical care.
• Mass awareness of preventive public health measures through all possible channels.
• In the hotspot regions special teams to be formed to search for new cases and do contact tracing.
• Expanding laboratory capacity for testing a higher number of cases.
• The government should review the existing legal instruments that provide legal support to implement the containment plan.

For information management, the control room has to be set up at state and district levels. A control room for the team at hotspot zones can also be set up depending on the number of cases. Data managers at the state level will compile data from various districts and update the total number of suspects, confirmed, critical, deaths, and contacts under surveillance with a centralized control room [22].

1.3 Literature Survey

This section presents the literature survey over drone-based systems in various applications. Further, drone-based usage in COVID-19 pandemic, hotspot identification, monitoring, sanitization, etc., are explored. The details are presented as follows.
1.3.1 Literature over Recently Developed Drone-Based Systems

In recent past years, drone technology has been used by government organizations, defense organizations, and private companies for both humanitarian causes and commercial purposes. The technology and types of drones have also evolved, and still a lot of research is being done to improve the performance and save time and costs by using drones in the areas where humans or other machines either take more time or cannot reach easily. Table 1.1 shows the areas where drone manufacturers are harnessing the technology for both social and commercial purposes.

Drones in Healthcare Conventional healthcare ecosystem requires a lot of human intervention starting from examining the patients to the distributing and transporting of medical supplies. Timely delivery of medicines, blood, and other supplies is very important in healthcare. The location of distribution can be difficult to access via vehicles due to poor infrastructure, remote areas, accidents, or traffic congestion. In metro cities, traffic can cause huge problems in delivery at peak hours. Since a drone can fly over the roads and inaccessible routes or areas, the healthcare organizations have started using drones to provide healthcare facilities.

Delivery of Medical Supplies, Blood, Lifesaving Equipment, and Sample Transportation Drones have been used in many social and humanitarian causes to deliver emergency aid medical supplies and other aid packages in different countries during natural disasters. Drones are also helping elderly people who need regular checkups and medical facilities, but due to the lack of transportation, they miss appointments as they might be living in rural areas or areas which are not easily accessible. In such situations, drone-based systems help deliver routine test kits and refills of medicines and pick up test reports from the home location of elderly people, thereby reducing the workload of medical teams (doctors and nurses) and reducing travel time for the patients. An interesting application of drones can be in the delivery of AEDs (automated external defibrillators). In case of heart attacks, the survival rate is low, and the patient needs to be given a shock with a defibrillator within minutes of the attack. Survival chance reduces as the time expires to use a defibrillator (74% chances of survival in the first 3 min and 50% after 5 min). Conventionally, AEDs are carried via ambulance, and in a study done in Stockholm, it takes around 13 min on average for an ambulance to reach a patient. If drones are to be used, then AEDs might reach faster than ambulance (>80% of the times) in seven out of ten places researched [45, 46].

Tracking and Monitoring Adversely Affected Areas Drones have proved very useful in tracking, monitoring, and gathering data from areas that get affected by a natural disaster or by a pandemic (a recent example being COVID-19). When there is a natural calamity or a pandemic situation, the affected areas could become inaccessible using UAVs that can be remotely controlled and can fly over such areas hit by disasters like the earthquake in Haiti (2010), Hurricane Sandy (the USA, Canada, and the Caribbean, 2012), Typhoon Haiyan in the Philippines (2013), and the


| Area                      | Usage                      | Consumer(s)                                                                 | Manufacturer(s)                                                                 | Type of UAV |
|---------------------------|----------------------------|----------------------------------------------------------------------------|--------------------------------------------------------------------------------|-------------|
| Defense                   | Surveillance               | US Marines [26], British Army [27], Australian Army [24], the Netherland’s Army [25], Indian National Security Guard [29] | Prox Dynamics (acquired by FLIR Systems)                                     | Micro (The Black Hornet Nano) |
|                           |                            |                                                                             |                                                                                |             |
| Rescue and emergency      | Affected areas and victim identification | Fire Department of Los Angeles [30], European Emergency Number Association (EENA) [31] | DJI, USA                                                                | Hybrid (Matrice 200 series, Matrice 600 series, Phantom 4 Pro) |
| Emergency response        |                            |                                                                             |                                                                                |             |
| Wildlife conservation     | Track animals and mammals and collect samples | The Ocean Alliance [32]                                                   | DJI, USA                                                                | Hybrid      |
| Healthcare                | Delivery of medical supplies, collection of samples and reports | Government of Rwanda [33], Government of Malawi [34]                       | Zipline, USA, Matternet, USA                                               | Hybrid      |
|                           |                            |                                                                            |                                                                                |             |
| Agriculture               | Analytics, seed planting, plant health monitoring [35] | Deveron UAS Corp [36], state governments, the USA [37]                     | Raptor Maps, USA, DroneSeed, USA                                           | Large drones (up to 57 kg payload) |
|                           |                            |                                                                            |                                                                                |             |
| Weather forecasting       | Data collection, imagery   | Australian Government [38]                                                 | Saildrone                                                                | Drone: 7 m in length and 4 m in height |
|                           |                            |                                                                            |                                                                                |             |
| Mining                    | 3D mine mapping, site planning | Mining companies in the USA, Israel, Australia [39]                         | Airobotics, USA, Terra Drone, Japan                                        | Multi-rotor drones |
|                           |                            |                                                                            |                                                                                |             |
| Infrastructure and         | Site survey, goods         | Microsoft [40]                                                             | Skycatch, USA                                                            | Unknown     |
| construction              | transportation, aerial     |                                                                            |                                                                                |             |
|                           | photography                |                                                                            |                                                                                |             |
| Retail and logistics      | Last mile delivery, Warehouse operations | Amazon [41]                                                               | Amazon, USA                                                             | Hybrid (fly range 15 miles, payload up to 5 lb) |
|                           |                            |                                                                            |                                                                                |             |
| Sports                    | Live broadcasting, video recording | Fox Sports [42], ESPN                                                       |                                                                                |             |
| Entertainment             | Cinematography, aerial live shows | Hollywood, Universal Studios [43]                                        |                                                                                |             |
| Telecommunication         | Radio tower inspection    | AT&T, Verizon [44]                                                        | Skyward, USA                                                            |             |
earthquake in Nepal (2015) [47]. During the recent COVID-19 pandemic situation, different countries have used drones to track people’s movements so that they maintain social distancing, to monitor the health and record temperatures from a distance in highly populated and remote areas, and also to carry samples and test reports between healthcare centers and affected areas [48, 49].

Medical Evacuation The unique design and ability of a UAV to fly in inaccessible terrain have been used to locate and rescue a lot of victims. In a recent case of a mishap during rappelling, it was reported how a person was located using a UAV [50]. Another study conducted by researchers in Turkey highlights the usage of drones in searching for injured or missing skiers on mountain slopes [51]. Table 1.2 shows the other applications of drones in the healthcare system.

1.3.2 Literature over COVID-19 Hotpots

Coronavirus (CoV) is a single-stranded RNA virus that affects the respiratory and intestinal system of human beings and animals. Out of seven human coronaviruses (HCoVs) having varying degrees of impact over respiration pattern, severe acute respiratory syndrome CoV (SARS-CoV), Middle East respiratory syndrome CoV (MERS-CoV), and SARS-CoV-2 (COVID-19) result in more deaths as compared to the other four. High transmission rate makes COVID-19 as highly contagious which has resulted in 1,133,758 reported cases globally, out of which 3374 confirmed cases are in India, while the count of death is 62,784 (globally) and 77 (India) according to the report generated on 5 April 2020 by the World Health Organization [57]. During the initial phase of COVID-19 when it started spreading from China, people with cough and cold were asked to quarantine themselves or were quarantined forcefully. As it started spreading to other countries like Thailand, South Korea, Vietnam, Italy, Iran, and the USA, the travel history of people was being checked, and anyone who traveled to these countries in the last 14 days was also examined for the symptoms. As symptoms are visible after a time gap of 10–14 days, unknowingly patients or carriers infected numerous other people by providing hosts to the novel virus. It led to a chain reaction, and the virus grew exponentially, creating some areas in a particular city where more people got affected in a very short period. Areas where a relatively higher number of positive COVID-19 cases are reported come under the category of “hotspot.” In Delhi and Uttar Pradesh, areas with more than six positive confirmed cases (irrespective of the area of the site) were declared as hotspots or “Red Zones” [58].

In areas where transmission happened rapidly and virus carriers were difficult to control, extra precautionary measures were taken to monitor the movement of people, and quarantine zones were created where no entry or exit was allowed. As the virus spread to most of the countries, on 11 March 2020, the WHO declared it a pandemic. By that time many countries have enforced nationwide lockdown already, and the concept of social distancing was being promoted aggressively in the media.
Table 1.2  Application of drone in the healthcare system

| Year  | Country     | Manufacturer          | Type of UAV                  | Applications/purpose                                                                                       | Supporter(s)                                                                                       |
|-------|-------------|-----------------------|------------------------------|-----------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| 2007  | South Africa| Custom-built (e-Juba or electronic pigeon project) | Hybrid                        | Facilitate transportation of microbiological test samples up to 500 g of payload [52]                     | NHLS and Denel Dynamics (UAV Division)                                                              |
| 2014  | Bhutan      | Matternet, USA        | Hybrid (fixed wing and quadcopter) | Delivering medical supplies via drones to remote hospitals [53]                                           | The WHO and Bhutan’s Ministry of Health                                                              |
| 2016  | Ghana       | Unknown               | Unknown                       | Delivering contraceptives and other medical supplies to remote villages; delivery times reduced from 2 days to 30 min at a reasonable price of $15/flight [54] | The United Nations Population Fund and the Dutch government                                           |
| 2017  | Malawi      | Matternet, USA        | Hybrid (fixed wing and quadcopter) | Collection of medical samples (TB and HIV diagnosis) and delivery of medication [55]                     | Government of Malawi and UNICEF                                                                     |
| 2018  | Tanzania    | Wingcopter, Germany   | Hybrid (fixed wing and quadcopter) | Delivery of medicines to a remote island in Lake Victoria; reduced delivery time from 6 h (road/ferry) to 40 min [56] | DHL and Deutsche GIZ                                                                                 |
| 2016–2018 | Madagascar | Technology Delta Quad | Hybrid (fixed wing and quadcopter) | Sputum and medication transport for diagnosis and treatment of tuberculosis [55]                         | Government of Madagascar                                                                            |
| 2017  | Senegal     | Vayu                  | Hybrid (fixed wing and quadcopter) | Delivering urgent medicines and collection of samples [55]                                               | BMGF, Senegal Government                                                                            |

to spread awareness. India announced its first nationwide lockdown on 24 March 2020, of 21 days, and issued the guidelines for the citizens and different organizations to be followed. COVID-19 tests started to happen, and a list of hotspots was released which used to be updated every day as more and more tests were conducted all over the country. No movement is allowed in hotspots, and people cannot step out of their homes even for groceries or medicines. The government ensures door-step deliveries of limited essential items including groceries and medicines. Strict monitoring is done by the police force inside and on the perimeter of all hotspots. Testing of the population inside hotspots is intensified, and state governments start “pool testing.” It is carried out by collecting several samples in a tube and testing them together for COVID-19. If the result is negative, then all people are considered
unaffected, and if the result is positive, then every person is tested individually [59]. Government agencies took measures to spread awareness among people about social distancing and surveillance and requested citizens to help medical professionals in carrying out tests. Regular preventive health measures like sanitization of societies, regular checkups, and surveying to gather information on recent travel history (even house-to-house survey) were taken by healthcare organizations in COVID-19 hotspot zones. Social media and technology played a significant role to help people as in many societies under quarantine, people started using WhatsApp (social networking application) and Google sheets to create and share grocery and medicine needs. The lists were accessed by shop owners, and then required items were ultimately delivered to the doorsteps. Table 1.3 shows the list of COVID-19 hotspots.

1.3.3 Literature over Drone-Based Movement Tracing, Monitoring, and Data Analysis for COVID-19 Hotspots

**UAV/Drones for Commercial Purposes** Near the Mediterranean Sea, it is always more difficult to maintain a golf course. For such kind of difficult terrains, drone technology is used for the maintenance of the golf course. The data collected from the drones gives a lot of agronomical information to increase productivity. A UAV is a device used by the greenkeeper of the golf course for making decisions regarding the maintenance of the golf course. Drones can help with early detection of turf deterioration and illustration of irrigation throw and uniformity. It can help in analyzing turf textures, diseases, and weeds. It can be used for optimal golf course irrigation design. It can help optimize irrigation scheduling to prevent water wastage. Drones can easily detect poor irrigation coverage and uneven turf growth. Their multi-spectral cameras identify a specific compound as nitrates found in fertilizer or type of grass. UAV/drone surveying and mapping operations help in preparing 3D modeling for golf resort development and reconstruction. Drones can create GIS-based tree management plans and generate 3D models showing investors what the resort will look like [35].

**UAV/Drones for Military Purposes** The US Army’s future frontline fighters may have an interesting new use for their grenade launchers. The idea is to shoot tiny camera drones into the sky which can then survey the vicinity for enemy threats. Army Research Lab scientists are developing micro-drones the same size as the Army’s 40 mm grenade, which are meant to be fired by the service’s standard M203 grenade launchers. They have dubbed the new drones Grenade Launched Unmanned Aerial Systems, or GLUAS. This is probably a one-of-a-kind experiment anywhere in the world and holds a lot of promise. Infantrymen often find themselves in a situation where they can see the enemy from their location as they may be behind a natural or man-made barrier. In this situation, it is very useful if they can in some
way get an eye on the enemy and able to observe their movements remotely. Soldiers under attack from an unseen enemy could fire the GLAUS and almost instantly receive a “bird’s eye view” of the battlefield. GLAUS thus provides an autonomy and intelligence platform to help soldiers perform useful missions while having a lookout from hundreds of feet in the air. Since the drones are similar in size, weight, and shape to the US Army’s standard grenades, they would most likely fit into the standard kit combat soldiers carry. Once launched, the drones spread their wings,
and their motor takes over allowing soldiers to control them using a joystick or other handheld device. The camera sends live video feedback to the soldiers on the ground and adds GPS receivers to the drones, allowing soldiers to identify the exact location of objects or persons observed from the air. Information is key in the modern battlefield. Ability to quickly perform a recon and analyze the situation can be the difference between life and death [61].

**UAV/Drones for Animal Tracking** Animal tracking and sensor technology programs for beef sustainability are related to animal health welfare. GPS collars were typically designed with wildlife in mind, and so they put in sensors such as mortality sensors that would notify the researcher when the animal was dead, or they would incorporate a very high-frequency transmitter that tracks and recovers the animal even if the GPS unit failed. There are a couple of sensors that would be common to both wildlife and domestic livestock; they have temperature sensors built in and have activity sensors that will help in monitoring the behavior of the species. Additionally, drones equipped with high-resolution cameras are used for tracking and monitoring every activity of the animal under surveillance.

**UAV/Drones for Personal/Community Surveillance** Nowadays drones are used in various applications. The challenge is how they can be used, where they can be used, and for what purposes. They were used extensively in application areas like assessing damage in a flood or in an insurance-related loss [62]. Surveillance refers to the sneaking in the personal life of an individual for getting private information about him without being caught [17]. New laws are coming down from the authorities that require people flying drones for commercial use to have license [34]. So if you are going to use a drone to conduct an investigation or surveillance, you have to follow the legal parameters of the law, and the evidence and information that you obtain will be admissible and usable.

### 1.3.4 Literature over Drone-Based System for Smart Healthcare Systems and Other Pandemic Situations

In recent times, researchers and scientists are doing their best in the containment of the spread of the COVID-19 virus. A surgeon and his team have developed a drone to use for organ transplant transportation for the patients affected by the COVID-19 virus. Apart from this, it is amazing seeing something as useful as a drone being used for so many different applications. Scientists and researchers are building big-enough drones where they can be attached to fire-retardant stuff. The drones can fly up in the air and shoot the flame with the retardant stuff through the window of a burning 20-story building [15]. Amazon is going to start delivering stuff to customers via drones [30].
For detecting the symptoms of COVID-19 in a patient, nowadays, research scientists have outfitted the drones with coolers and biosensors that can monitor the health of the organ of a probable patient throughout its whole aerial journey. On the drone, a human organ-monitoring apparatus travelling for long distance measures all the biophysical properties like temperature, pressure, vibration, and altitude of the organ of an individual. Further, an android application is developed where a health worker can watch it and suggest preventive and precautionary measures to be taken in this regard [20].

When the number of COVID-19 patients is increasing exponentially, a fast and reliable organ transportation system is required. The drones can be used as a transportation device for short-distance travel like within a city, i.e., between two hospitals that are close to one another [5]. Drones are helping in the organ transportation between hospitals with a huge reduction in transportation time without having to deal with issues of security of the driver and vehicle, traffic on the roads, and police escorts requirements. Before the usage of drones for organ transportation, the organs are transported from hospital to hospital in transportation vans. So whatever type of traffic, the carriers are supposed to get on the road, and they can be stuck in that just like anybody else.

Nowadays, for transportation of organ using a drone, what hospital authorities have to do is just pop this organ onto a drone, send it into the air, and have it fly across the sky to its destination at another hospital. There would be a significant reduction in travel time. As soon as an organ leaves its donor body, that organ is made to reach the recipient’s body. This increases the success rate of the surgeries in the hospitals which is significantly reducing the COVID-19 mortality rates. Drones are started to be considered as the most favorable aerial technology for transportation in the healthcare system.

1.4 Case Study 1: Drone-Based Real-Time System for COVID-19 Hotspots

This section explains the real-time drone system designed and used for the COVID-19 system. The details are presented as follows.

1.4.1 Real-Time Drone-Based System Description, Work, and Results in India

A drone is used in real life and has many applications like environmental study, commercial purposes, military services, and a whole gamut of other areas. There have been many technological advancements in developing UAVs to increase usage and adoption in different areas. Under a situation where the whole world is fighting...
a pandemic caused by a novel virus disease, COVID-19, the World Health Organization has proposed guidelines to be followed as precautionary measures like regular sanitization of hands, usage of face masks, and maintaining social distancing. The WHO is closely working with countries and their respective health organizations to conduct checkups and do tests of people in a phased manner. Since this virus spreads from human contact, the tests have to be conducted in a very controlled and regulated environment. Drones are proving to be of great help under these conditions to keep a regulatory check over health status, assistance to maintain social hygiene, and to spread awareness about government policies and social distancing. Developed countries like China, the USA, Italy, France, Australia, and few others where a large number of cities are under surveillance round the clock to restrict the transmission of the virus in every possible manner are already using drone technology. India has also developed an indigenous drone called Thermal Corona Combat Drone (TCCD), a project developed by the Indian Robotics Solution (IRS), India. IRS used an in-house designed PCB coded for thermal imaging, geothermal sensing, GPS tracking, photo and videography, and compaction.

The team from the Indian Robotics Solution has come up with an all-in-one multirotor drone to fight against COVID-19 spread. This thermal drone includes 6 propellers that help to take off vertically and fly at a height of 20 m using 1 set of lithium polymer batteries (200 cycles) as a source of power. The frame of TCCD is made up of a carbon fiber sheet and tube. TCCD is remotely operated, and it works at frequencies of 2.4 and 5.8 GHz. It supports three flight modes – autonomous mode using waypoint, manual mode, and hovering. High-definition cameras with optical zoom features provide clear images and features of video recording during the day and night span. TCCD is also equipped with an RGB camera with a spotlight feature for night vision. A three-axis gimbal has also been used for camera movement. Some of the tools used to develop this drone are computer numerical control (CNC), waterjet, 3D printer, metal molder, and some other R&D software tools. Different machinery is used for sanitization. It has a built-in brushless pump having four nozzles and a sanitizer tank of 10 L (maximum payload capacity) that consists of a sanitizing solution which is sprayed in the form of droplets over the supervised area.

TCCD is helping medical officers by conducting surveillance in different areas. Surveillance is conducted to record the temperature of the people of those areas after getting approval from the concerned government agencies. People are requested to come to open areas (like rooftops or balconies) of their homes where the drone can conduct the scanning. Thermal scanning and thermal imaging techniques have been used to record human body temperature using two cameras as a part of the payload of the drone. An alarm attached to a drone beeps when the body temperature of an individual is found (using a spotlight feature of the attached camera) to be greater than normal body temperature (37 °C). If the alarm beeps, then either that individual is asked to come out of its premises or an official from the medical team goes inside the home for further checkups. Clusters of 60 satellites help in the global positioning of a person, and thus the exact location can be traced. Thermal image sensors enable a live view of an area over connected digital
assistants like mobile phones, iPad, tablets, or others. Another feature of TCCD is it helps in carrying and delivering medical aid supplies to a location. It can cover an area of up to 1.5 km if the flight path is unidirectional, while for a flight path where the line of motion changes often, then it covers an area of 200 m² (on an average) within 30–45 min (only thermal imaging is used) and 10–12 min (if both thermal imaging and sanitization are used). TCCD successfully surveyed 15 densely populated areas in Delhi with a population strength of 10 lakhs. Figures 1.5 and 1.6 show pictures of TCCD and thermal imaging scanned results of the surveyed areas.

1.4.2 Real-Time Drone-Based System Advantages and Disadvantages

Drone technology is improving continuously as it is being explored day-by-day to greater depths. Humans are trying to overcome the limitations and improve existing processes or system efficiencies using drones. Some of the benefits of using a real-time drone-based system are as follows:

- Provides access to inaccessible areas like poor infrastructure, remote locations, natural calamities near hilly areas, or areas near huge water bodies.
- Faster response time as compared to conventional methods—Drones can reach faster than ambulances in a short period especially when an ambulance is not present nearby or there is an accident on the road or traffic congestion.
- Provides access to areas where human surveillance is not possible—Conducting the medical examination in containment zones during COVID-19 or areas where dangerous gas leakage may occur.
- Provides feasibility to track and monitor small areas—For public safety and security, the government needs to have an aerial view and real-time live recording of some areas of the city.
- Works under adverse environmental conditions—Serves continuously for long hours until the power supply lasts without any limitations of rain, humidity, or temperature variations.
- Highly accurate and precise—In agriculture, planting seeds with a uniform distribution in the field or spraying pesticides has been made possible as drones are pre-programmed to maintain a high degree of accuracy and precision.
- Real-time reporting and responsiveness helps in quick data processing.

Despite having so many benefits, drone-based systems also face challenges and have some disadvantages and concerns that need to be addressed for further advancements. Here are some of the disadvantages of a real-time drone-based system:

- Privacy concerns—People have expressed concerns over the usage and surveillance conducted, and the collected data is used for inappropriate purposes.
• Not so cost-efficient—Developing and deploying drone-based systems is still a costlier affair as compared to other conventional methods (although they may be less effective).
• Regulatory issues—Flight clearance license from authorized agencies need to be issued before each flight, and this often feels like overhead in case of emergency.
• Suboptimal performance when fully automated—Optimal path finding for fully automated pilot drone need high precision and artificial intelligence as obstacles may change anytime during the flight in real time.
1.5 Case Study 2: Drone-Based Simulation for COVID-19 Hotspot Tracking, Monitoring, Analysis, and Control Room Positioning

This section explains the indoor and outdoor drone-based activities. In this work, these activities include COVID-19 hotspot tracking, monitoring, analysis, and statistics for the control room. Both indoor and outdoor operations are explained as follows.
1.5.1 Indoor COVID-19 Hotspot Tracking, Monitoring, Analysis, and Control Room Positioning

This section explains the indoor drone-based hotspot detection, monitoring, analysis, and statistics for the control room. To understand and analyze the indoor drone-based system activities for the smart healthcare system, a hospital design is prepared as shown in Fig. 1.7. Figure 1.8 shows the 2D views of the proposed design and

Fig. 1.7 Proposed drone’s zones strategies and their movements

Fig. 1.8 Indoor hospital activities in execution (2D view)
system execution. Figure 1.9 shows the patient’s intake in the hospital with time. Figure 1.10 shows the number of drones used in hospital function with variations in the number of days. Figure 1.11 shows the percentage of individual drone utilization.
1.6 Outdoor COVID-19 Hotspot Tracking, Monitoring, Analysis, and Control Room Positioning

This section explains the outdoor hotspot tracking, monitoring, analysis, and control room statistics. Figure 1.12 shows the 2D view of the area considered for sanitization. Figure 1.13 shows the 3D view of drone-based outdoor sanitization with drones. Figure 1.14a shows the patient intake variations with time. This is a cumulative number. Figure 1.14b shows the drones used in outdoor sanitization with variations in the number of days. Figure 1.14c shows the percentage of individual drone utilization. Figure 1.14d shows the generation of thermal images for the COVID-19 hotspot. Overall, Fig. 1.14 presents the drone-based outdoor COVID-19 hotspot tracking, monitoring, analysis, and control room positioning.

Fig. 1.12  Outdoor area considered for sanitization (2D view)
1.7 Conclusion and Future Scope

The present COVID-19 pandemic situation forces to propose methods of accurate and timely sharing of disease, its varying effects, causes, and treatment-related information. The pervasive internet connectivity helps to have presence of various types of equipments (such as drones, IoT, thermal imaging, IRS cameras, etc.) for collecting and sharing the required information as and when required. This work started with an overview of COVID-19, hotspots identification, monitoring, and effects over social and economic sectors. Further, drone-based approaches are explored for the COVID-19 pandemic. Here, drone-based indoor and outdoor COVID-19 operations (including sanitization, monitoring, data collection, and sharing) are explored. The real-time drone used for COVID-19 operation in a real scenario is discussed as well. In results and analysis, the number of patient intake, number of drones used, and percentage of individual drone utilization are evaluated and discussed.
Drone-based outdoor COVID-19 hotspot tracking, monitoring, analysis, and control room positioning. (a) Drone-based outdoor area statistics 1 for control room. (b) Drone-based outdoor area statistics 2 for control room. (c) Drone-based outdoor area statistics 3 for control room. (d) Drone-based outdoor COVID-19 hotspot detection
Fig. 1.14  (continued)

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