

A Drone-based Networked System and Methods for Combating Coronavirus Disease (COVID-19) Pandemic

Adarsh Kumar¹, Kriti Sharma², Harvinder Singh³, Sagar Gupta Naugriya⁴, Sukhpal Singh Gill⁵, and Rajkumar Buyya⁶

Department of Systemics, School of Computer Science, University of Petroleum and Energy Studies, Dehradun, India^{1},²*

Department of Virtualization, School of Computer Science, University of Petroleum and Energy Studies, Dehradun, India³

Indian Robotics Solution Pvt. Ltd. (IRS), New Delhi, India⁴

School of Electronic Engineering and Computer Science, Queen Mary University of London, UK⁵

Cloud Computing and Distributed Systems (CLOUDS), Laboratory, School of Computing and Information Systems, The University of Melbourne, Australia⁶

Abstract

Coronavirus disease (COVID-19) is an infectious disease caused by a newly discovered coronavirus. It is similar to influenza viruses and raises concerns through alarming levels of spread and severity resulting in an ongoing pandemic world-wide. Within five months (by May 2020), it infected 5.89 million persons world-wide and over 357 thousand have died. Drones or Unmanned Aerial Vehicles (UAVs) are very helpful in handling the COVID-19 pandemic. This work investigates the drone-based systems, COVID-19 pandemic situations, and proposes architecture for handling pandemic situations in different scenarios using real-time and simulation-based case studies. The proposed architecture uses wearable sensors to record the observations in Body Area Networks (BANs) in a push-pull data fetching mechanism. The proposed architecture is found to be useful in remote and highly congested pandemic areas where either the wireless or Internet connectivity is a major issue or chances of COVID-19 spreading are high. It collects and stores the substantial amount of data in a stipulated period and helps to take appropriate action as and when required. In real-time drone-based healthcare system implementation for COVID-19 operations, it is observed that a large area can be covered for sanitization, thermal image collection, patient identification etc. within a short period (2 KMs within 10 minutes approx.) through aerial route. In the simulation, the same statistics are observed with an addition of collision-resistant strategies working successfully for indoor and outdoor healthcare operations.

Keywords: Artificial Intelligence, Collision Avoidance, COVID-19, Drones, Internet of Things, Pandemic.

1. Introduction

Coronavirus disease (COVID-19) is a transferable illness that is recently identified [1]. This infection was unfamiliar before the occurrence of the Wuhan chain in December 2019 and within five months (by May 2020), over 5.89 million persons are infected and over 357 thousand have died. COVID-19's most commonly recognized symptoms are fever, tiredness, and dry cough and some of the people suffered from throbbing pain, nasal clog, runny nose, sore throat, or diarrhea [2]. The old people with medical conditions such as hypertension, heart issues, or diabetes are enduring with illness; individuals with fever, cough, and trouble breathing should seek immediate medical care. This virus spreads between people during close contact, i.e. at a minimum distance of one meter (3 feet), through small beads during hacking, sniffing, or talking [2]. These beads are delivered during exhalation, usually falling to the ground or to the surface instead of being contaminations over long distances [3]. The virus can survive upto 72 hours on most surfaces. Recommended protective measures include hand washing, closing the mouth while hacking, keeping away from others, observing, and self-isolating of persons associated with being infected [2]. This led to usage of transportation restrictions, isolations, lockdowns, stay at occupational risk assessments and closures of facilities. Coronavirus (CoVs) has evolved as a significant global virus since 2002 in different forms affected thousands of people in multiple countries [3].

Drone-based COVID-19 health and respiratory monitoring platforms ceation is being explored by the Australian Department of Defence for health monitoring and detection of infectious and respiratory conditions including monitoring temperatures, heart and respiratory rates, amongst crowds, workforces, airlines, cruise ships,

¹ Corresponding author at: Department of Systemics, School of Computer Science, University of Petroleum and Energy Studies, Dehradun, India. E-mail addresses: adarsh.kumar@ddn.upes.ac.in (A. Kumar), meetkritisharmahere@gmail.com (Kriti Sharma), hsingh@ddn.upes.ac.in (H. Singh), sagar@irs.org.in (Sagar Gupta Naugriya), s.s.gill@qmul.ac.uk (S.S. Gill), rbuyya@unimelb.edu.au (R. Buyya).

potential at-risk groups, i.e., seniors in care facilities, convention centers, border crossings or critical infrastructure facilities. [4]. ‘Drone’ a term usually used for an air vehicle that flies like other aviation craft (airplane/pilot) but with a difference of pilot. Traditional aircraft are timely operated by pilots (Auto-pilot mode is no distinct), this is what makes drone different. Under condition when an unmanned aerial vehicle is in aerospace it is termed as “Platform”. When external hardware or embedded systems are implemented to it is termed as “Payload”. Attaching payload to platform results in a drone that can be used in various applications with increased efficiency and accuracy. In [4][5], it is found that drones are widely used in the present COVID-19 pandemic. It is used for monitoring, vigilance, thermal scanning, medication, food supply, alter system etc. In their use, data collection centralization and analysis is a major challenge. The features of present drone-based systems can further be enhanced by integrating the features of measuring social distancing, COVID-19 monitoring, and data collection using artificial intelligence (AI), thermal imaging, sanitization with data analytics, record keeping etc. Understanding the necessity and requirements of drone-based system enhancements for the smart healthcare system, *the main objectives of this work are:*

- To propose collision-free zone-based single and multi-layered drones movement strategies.
- To propose an artificial intelligence based system that collects the data through drones, analyze and provides the necessary security measures.
- To propose a multi-layered architecture that collects the information from drones and exchanges with edge, fog and cloud servers for necessary computing, data sharing, and analytics.
- To simulate the drone-based system for COVID-19 operations such as monitoring, control, thermal imaging, sanitization, social-distancing, medication, data analytics, and statistics generation for the control room.
- To implement a real-time drone-based system for sanitization, monitoring, vigilance, face recognition, thermal scanning etc. in COVID-19 hotspots.
- To design and display the statistics of the drone-based smart healthcare system in a control room.

This work starts with reviewing the necessity to design, develop, simulate, and implement a drone-based healthcare system for COVID-19 scenario. In consideration of existing drone-based systems and their features, a drone-based system suitable for COVID-19 or other influenza viruses pandemic situation is proposed. The proposed approach integrates artificial intelligence processes for data collection, analysis, statistical visualization, sharing, and decision making. In this work, both simulation and real-time implementation are carried out for COVID-19 operations (sanitization, medication, monitoring, thermal imaging, etc.). In the real-time drone-based implementation, a drone is designed, developed and tested for COVID-19 operations in the Delhi/NCR, India with the approval of government authorities. In the simulation, multiple drone scenarios are considered for COVID-19 operations. Further, multiple drones collision-resistant strategies and their COVID-19 operation in outdoor and indoor activities are proposed and experimented for evaluations. We observed that the drone-based approach can cover a wide area in a short duration and it is an effective approach in pandemic situations and indoor patient statistics.

The rest of the paper is organized as follows. Section 2 presents the start-of-the-art over drone-based systems, COVID-19, drone-based movement tracking systems, and usage of drone-based systems in healthcare. Section 3 presents the proposed drone-based architecture for the smart healthcare system using artificial intelligence processes, fog, edge, and cloud computing services. Section 4 presents the collision avoidance algorithms used in drones’ network. Section 5 presents the real-time drone-based case study and case study considered for simulating the proposed drone-based system for various COVID-19 operations. Finally, conclusions and future scope are presented in Section 6.

2. Related Work

Extending the use of a drone from mission-centric, science, or defense sector to social health is of critical importance especially for dealing with COVID-19 epidemic facing the world. This work supports the argument that drones have impacted health quality and relief measures in real life at a significant level. People are living in unprecedented times where almost whole world has been affected by COVID-19. Worldwide, doctors and medical professionals are working hard to help diagnose patients, nation leaders are suggesting to maintain social distancing, police and health caring units are inspecting areas trying to sensitize the public along with many other measures being taken at all levels [35]. Drones are proving to be of great assistance in all these areas at varying levels. Countries are considering drones to be of great use through various measures[4]-[6]. Few scenarios where drones have effectively escorted society with health supplements are briefly explained as follows.

- In Australia, a drone flight across cities detects if someone has a “doubtful” respiratory pattern or not [4]. Sensors fitted in the drones record body-temperature, heart pulse rate, respiratory rate, and other abnormalities. These measurements are taken in different areas, especially in overcrowded areas. Here, a network of the camera is

used for monitoring and medication, and it is found to be effective and useful as well. The designed technology for epidemic and disaster control is saving lives, helping people working in critical infrastructure, and deployment of this technology over a large domain is in progress.

- China is practicing surveillance with more than 100 drones (The MicroMultiCopter company) over many cities [7]. This measure is considered to be useful to prevent viral transmission by alarming people if the inter-personal distance between individuals becomes less than a “specific” value or if people are walking on public places without a mask (similar practices were also followed in Spain, Kuwait, and UAE) [7]. The majority of the countries are supporting the drone-based approach for sanitization, monitoring, thermal scanning, governance, vigilance etc. because it provides a safe way to help mankind.
- Sanitization is regulated in China by spraying disinfectant over mass (Terra drone) [5]. In this experimentation, medicine delivery in fixed areas, sanitization, monitoring, and analysis is performed. This approach is tested with at least 1000 patients and effective in a real-time environment. The proposed approach is found to be more effective in rural areas where resources are scarce especially medical supplies. Further, the drone-based system helps in teaching the people how to wear mass and stop spreading the virus. Lastly, the potential patients are identified, counted, and analyzed using thermal images and measuring the body temperatures. Thus, the proposed approach is found to be very effective in smart healthcare systems.
- In the United States, a personal medical kit for COVID-19 is being delivered by UAVs to remote locations [7]. Like other drone-based systems, this system is found to be effective in delivering medical and other necessary supplies. In the US, it is found to be effective in rural areas where corona symptoms are found in patients. Likewise, it is recommended that the use of this technology should be increased to a large scale to overcome the situations and help mankind in every aspect that we can do for saving the lives, providing them with their necessities, and establishing healthy communication with everyone in all aspects.
- In India, states like Delhi, Kerala, and Assam are making announcements during surveillance across cities via drones. Maharashtra is a step ahead as it has generated data analysis reports of the area being covered via drones [8] [9]. In overall observations, government authorities in India have given special permissions to their bureaucrats and police officials to use drone-based technology for vigilance, monitoring, medication, sanitization, data analysis, reporting, and future decision makings. Here, top officials in the government and senior ranked officials are monitoring and taking control over COVID-19 hotspot positions through various means. Drone-based systems are made an advance to handle individual patients or thermal scanning a large area in short as well. Further, they are used for delivering medicines, food supplies, and other necessary equipment weighing a few kilograms. Thousands of drones are deployed in each state of India for similar actions with government permissions and it is observed that the success rate these drone-based systems and networks is very high.

Table 1 shows the comparative analysis of various existing drone-based approaches used in a pandemic or other disasters. Table 2 shows the comparative analysis of state-of-the-art drone-based approaches used in various applications (including healthcare systems).

Table 1: Comparative analysis of the proposed approach with an existing drone-based system for pandemic or disaster analysis.

Authors	Year	System Type	Features						
			A	B	C	D	E	F	G
Lum et al. [10]	2007	Drones / UAVs deployed for a surgical robot	×	✓	✓	×	✓	×	×
Câmara [11]	2014	Drone-based Rescuers and disasters scenario system	✓	✓	×	×	×	✓	×
Kimet al. [12]	2017	Drone-based healthcare services for patients with chronic disease	×	✓	✓	×	✓	×	×
Robert et al. [13]	2018	Drone-based system for medical services	✓	✓	✓	×	✓	×	×
Peng et al. [14]	2018	Drone-based vacant parking system	✓	✓	×	×	×	✓	×
Pirbhulal et al. [15]	2019	Time-domain feature-based medical system using wearable sensor devices	✓	✓	×	×	✓	×	×
Ullah et al. [16]	2019	Drone-based multi-layered architecture with healthcare use-cases	×	✓	✓	×	✓	×	×
Jones et al. [17]	2019	Drone-based system in medical drug supply	×	×	✓	×	✓	×	×
Islam and Shin [18]	2020	Drone-based system integrated with IoT and blockchain-technology	×	✓	×	×	×	✓	×
Sethuraman et al. [19]	2020	Drone-based healthcare system experimented and tested for cyber-attacks.	✓	×	×	✓	✓	×	×
Proposed Approach	2020	Drone-based system for COVID-19 operations with AI processes	✓	✓	✓	✓	✓	×	✓

Features: A: Monitoring, B: Data Collection, C: Medication, D: Thermal Imaging, E: Healthcare, F: Other Application, G: AI Trends,

Table 2: Comparative analysis of existing drone-based systems for various applications.

Authors	Year	Pros	Cons
Surveys conducted over drone-based systems			
Lee and Park [20]	2017	Conducted drone-based medical services surveys[13][21].	Challenges and solutions to congested drone networks are not proposed. All-weather drones and their usage is missing. Surveys over drone-based networks and their implementation issues are not conducted. Discussions over types of laws, procedure, process, and governance is missing.
Robert et al. [13]	2018	Discussed the drone-based system benefits in rural areas [13][16][21].	
Ullah et al. [16]	2019	Discussed drone-based medical and non-medical systems' use-cases [13][16][21].	
Ullah et al. [21]	2019	Discussed drone-based medical and non-medical systems' use-cases [13][16][21].	
Skorup and Haaland [22]	2020	The pros and cons of drone-based healthcare systems over pandemics (e.g. COVID-19) and disasters are widely discussed [13][21][22].	

Drone and robot-based system for surgical operations			
Harnett et al. [23]	2008	Conducted robot and drone-based operations remotely [10][12][23].	Congested drone-networks construction and operations are not discussed.
Lum et al. [10]	2007		
Lee and Park [20]	2017	Measured performances over drone, robot, and control room integration and networks [10][16].	Drone-collision strategies and unanimous decision making are not planned.
Kimet al. [12]	2017		
Ullah et al. [16]	2019	Created medical facilities with drone-based operations [10][16][20]. Healthcare services for chronic disease in one-to-one connectivity and medical facility is a unique approach for data exchange [12].	One-to-one connectivity can increase the number of drones presence in a small region. Thus, it would be very difficult to avoid collisions. Surgical operations with high success rates are yet to be practiced.
Drone-based system for monitoring and data collection			
Todd et al. [24]	2015	Data collection features and related use cases with 5G networks are discussed [16].	Drone-networks interoperations, data format standardization, data pre-processing, and redundancy removal techniques are not discussed in detail.
Thiels et al. [25]	2015		
Ullah et al. [16]	2019	An IoT and blockchain integration and interoperation are proposed for providing data security, speed, and QoS in medical data collection [18].	The IoT and AI lack in measuring the drone-network performances and QoS performances.
Islam and Shin [18]	2020		
Sethuraman et al. [19]	2020	Indoor drone-based systems are designed for patient monitoring and medications [24]. These drones are very useful for patients affected with influenza, COVID-19 or airborne viruses.	Indoor patient monitoring drones are restricted to monitoring, data collection, or intimating for medications only.
Drone-based system for data analysis and decision making			
Harnett et al. [23]	2008	The integration of IoT and blockchain technologies helps in decision making for healthcare scenarios at edge computing levels [10][16].	The IoT, edge computing and blockchain technology integration could be enhanced with AI processes and practices.
Ullah et al. [16]	2019		
Islam and Shin [18]	2020		
Sethuraman et al. [19]	2020	A network of drones helps in collecting the data from remote drone locations. Thus, it is found to be helpful in drone network monitoring as well [19].	The scarcity of resources over drone devices does not help to process large data and fast decision making. Thus, federated learning should be adopted for quick and reliable decisions.
Drone-based system for data and product sharing			
Kimet al. [12]	2017	Time-domain feature-based drone-systems are proposed [15][16].	Time-domain feature-based systems do not experiment in real-scenarios.
Pirbhulal et al. [15]	2019		
Ullah et al. [16]	2019	Medical drug supply and order confirmation is proposed [17].	The drone and its network performance analysis are required for optimizing the services while in data or product sharing scenarios.
Jones et al. [17]	2019	Body-area sensor values helped in medical decision-making [18].	
Islam and Shin [18]	2020		
Sethuraman et al. [19]	2020	A network of drones is constituted for cyber-attack detection [19]. The low load-carrying drones can cover a large area within a short time (upto 4 kilometers in 20 minutes) [18][26].	The importance of indoor drone-experimentation is realized in COVID-19 pandemics.

Critical Analysis: In the existing literature [27]-[30], various drone-based approaches are proposed for smart healthcare systems. This approach can be realized from COVID-19 pandemic situations as well. Various challenges and requirements in establishing drone-based smart healthcare design, simulation, implementation, or analysis include: (i) the construction, designing, and analysis of drone-networks for healthcare or other applications are least practiced, (ii) performance and QoS improvement in a resource constraint drone device collecting medical data from heterogeneous sensor, (iii) collision-free drones based network and routing, (iv) multi-layered drone flying, collision detection and resistance strategies, (v) solar-based environment-friendly in-air drone-charging system, (vi) testing of the drone-based system in pandemic situations (such as COVID-19) can be performed for various operations like monitoring, vigilance, sanitization, medication, thermal imaging etc., (vii) applying artificial intelligence in drone-operations, and (viii) integration of drone-level federated learning for self-governed processes and analyzing changing COVID-19 viruses, symptoms and strategies.

3. A Drone-based Architecture for Smart Healthcare System

This section proposes a drone-based architecture for the smart healthcare system. In this architecture, Artificial Intelligence trends are integrated as shown in Fig. 1. This integration includes machine learning, and deep learning for data analysis, Internet of Things (IoT) [36], Industrial IoT (IIoT), Internet of Medical Things (IoMT), and Internet of Drones (IoD) for data collection or instruction-based services. AI is applied to design, develop, and make internal processes more efficient. Thereafter, cloud, fog, and edge computing approaches are applied for efficient data storage and processing starting from nearby locations to a distant secure position. Likewise, other technological aspects including commuter movement, profiling, monitoring etc. are recovered, observed, and analyzed for pandemic spreading.

Fig. 1 shows the proposed architecture for drone-based COVID-19 monitoring, control, and analytics in a smart healthcare system. In this architecture, there are six systems, which are discussed below:

- **Thermal Imaging System:** An alternative to sensor deployment-based test data collection, drone-based cameras can capture the person images and can be useful in social distancing measurements and density-based thermal imaging. Using this system, the camera scanner detects the object and signal for the thermal image display. If the image is not clear for thermal display then it is made clear through detection and unit system.

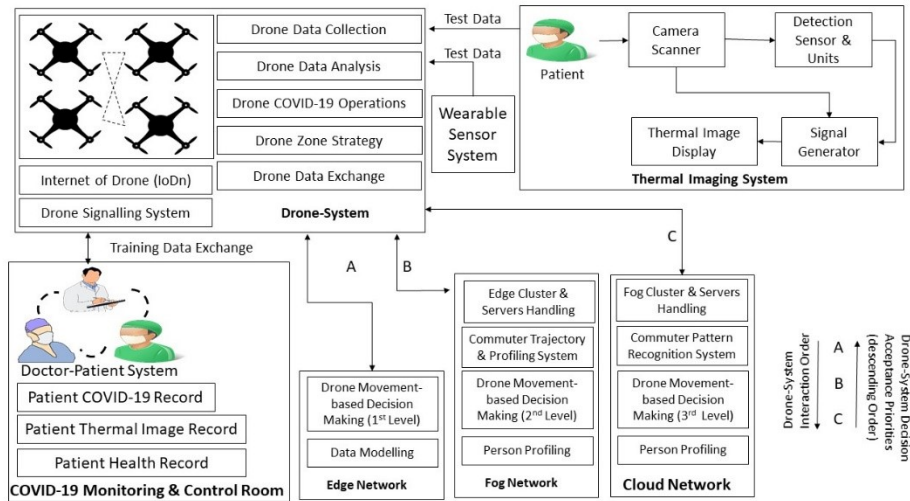


Figure 1: Architecture for Drone-based COVID-19 Monitoring, Control, and Analytics in Smart Healthcare System

- Wearable Sensor System:** In this architecture, it is assumed that sensors are deployed in the observational area. The deployment of the sensor includes wearable sensors, or movement detection sensors at the ground near to target monitoring/serving areas. This helps construct an IoT network using sensors, increase the scale of interconnection and construct IIoT, or IoMT. All these deployments help in collecting the required data, data analysis, and generating statistics. The wearable sensors, movement detection sensors, image processing etc. can be used to monitor the COVID-19 pandemics. Fig. 2 shows a drone-based person monitoring system using wearable sensors. A person under observation is monitored continuously through wearable sensors. Drones placed closer to the population for collecting the patient's data from wearable sensors or thermal imaging receive and store data in drone memory. The stored data is forwarded to big data storage through multiple servers. These servers use edge, fog, and cloud computing for processing, modeling, profiling, and analyze the data. The analyzed and refined data is exchanged with hospitals with proper policies and procedures, controlled and governed by the medical board and federal government. This way, it would be much convenient for both the federal government and hospital to pre-plan the resources in emergency cases. Patient data is securely transferred to the doctor/hospital as and when required. This proposal is found to be very handy to tackle pandemic situations such as COVID-19. In pandemic situations, when data such as time and location of collecting data, population size, person's profiling, methods of collecting data etc. is available then it would be much convenient for everyone to govern the activities and events. This way, it would be much convenient to identify the zero COVID-19 patient and chain of the pandemic. The integration of wearable sensors and drones are considered in IoT. An IIoT is formulated when multiple stakeholders (e.g. hospital, drug, and equipment supplier, government, medical board etc.) are involved. Further, IoMT is considered to interconnect the medical equipment, drug, patient, and doctor system for clinical trial data fetching and storage. Similar or different clinical trials data is helpful for analysis and advancements.

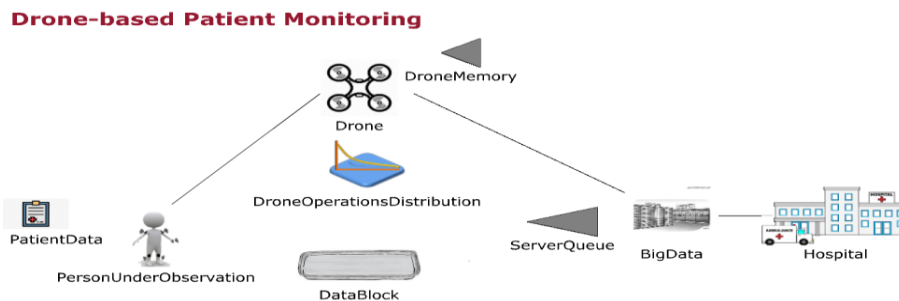


Figure 2: Drone-based Person Monitoring System using Wearable-Sensor Data

- Edge Network and Computing System:** This system applies edge computing for data modeling and initial decision making. Edge computing does not fetch all drone data. The drone does self-processing and keeps the data discrete. Edge computing saves time and resources while maintaining the data collection, pre-processing, and

analysis in real-time. Thus, edge computing is helpful to drones in making quick real-time decisions. Those initial level decision is helpful for drones that need instructions and operate within a stipulated time. Here, the major challenge for edge computing is to balance the performance in handling drone-system and fog computing tasks. In the proposed system edge computing system sometimes need to make the decision locally and other times, it has to send the data to fog servers for further detailed processing. The cost of transferring data to fog servers increases with an increase in the scalability of sensors, IoT, and drone networks. Large data would require resources and intelligence. Here, edge computing shreds its load by performing data aggregation at the initial level and transfer the necessary data to fog or cloud networks as and when required.

- **Fog Network and Computing System:** This system adds fog computing services in the architecture for commuter profiling, monitoring, and decision-making processes executed in the initial phase. Thereafter, data analytics helps in smart and intelligent commuter trajectory profiling, monitoring, and decision making. In the system, when the same person's different information is collected from different drones then it would be much convenient to make a person's profile. Likewise, a COVID person's profile helps in tracking the COVID-19 cases' chain.
- **Cloud Network and Computing System:** This system applies application-level services for activities such as pattern recognition, monitoring, decision making, and large scale sanitization are created. High-end cloud computing resources offer capabilities for comprehensive analytics and decision making compared to other layers.
- **Drone-System:** In this system, one or more drones move-around and push/pull the required information/instructions from sensors as and when required. The data is processed initially at the drone for initial instructions. Thereafter, it is shared with other systems for further detailed processing. The internet of drones is constituted for longer data transfer and analysis. This internet of drones avoids collisions either through Radar/LiDAR systems or collision avoidance strategies. Apart from Radar/optical systems, collision avoidance strategies are required if a large number of drones are used for different services. Each of these services governs their strategy for drone movement. Using collision avoidance strategies, a pre-planned drone movement strategies could be implemented and short-distance based collisions could further be avoided with Radar/Optical systems.
- **COVID-19 Monitoring & Control Room System:** In this system, drones and area under observations, and their associated statistics are observed. This system helps in monitoring COVID-19 hotspots remotely and plan for necessary actions. Further, individual drone's performance and movement can also be measured and controlled.

4. Algorithms and Operational Strategies

AI-based drones captured raw data from IoT networks and can turn them into useful and actionable outcomes. Our approach helps in multiple-drones to collaborate, share, and process the data and trace the pandemic. AI-powered drones are useful in gathering pandemic ground intelligence, assess the COVID-19 virus spreading, thermal imaging for pinpoint, and diagnose issues. All these COVID-19 operation statistics can be efficiently computed if data is collected systemically. Thus, a geographical area is divided into multiple zones for drone-based COVID-19 operations as shown in Fig. 3. Here, square zones of τ distance are formed and each zone is planned to have an area that can be covered by a single drone. Algorithm 1 shows the drone's federated learning process before sharing its training data with an edge, fog, or cloud network computing. Thus, each drone can monitor its zone based on individual experiences. However, an average value of observations from all zones is collected at the edge computing side for collective decision.

Algorithm 1 proposed applying the patient monitoring, thermal scanning, and image identification followed by the patient's body temperature measurement. The scalability of applying a unique solution to drones increases as the decision process moves from edge computing towards cloud computing. In the drone-system (shown in Fig. 1), sensor and IoT-enabled infrastructure can be monitored by drones, and the movements of drones are important to observe for collision avoidance. Thus, the zone-based approach does not allow any collision. In every zone, there is a collision feasibility area. If any drones move to the collision feasibility area then it will send a signal (through LiDAR/RADAR/beam systems) to all neighboring drones for collision avoidance. Now, if any drone wants to transfer its zones due to various reasons such as high-battery drone requirement, longer operation time drone requirement, malfunctioning of certain drones, specialized drones requirement, rotation of drone shifts etc. then zone transfer algorithms with artificial intelligence components based experiences can be applied. The zone-transfer strategies are divided into single or multi-layered algorithms. These algorithms are explained in the following sections.

Algorithm 1: Federated learning for drone-based zone operations (monitoring, sanitization, vigilance etc.)

Goal: To integrate an individual drone's zone-based self-learning for COVID-19 experiences and securely exchange with an edge, fog, and cloud servers.

Premises: Let N_l represents the l^{th} drone-network, Z_i represents the i^{th} zone in the area, D_j^i shows the j^{th} drone in i^{th} zone and P_k^i represents the k^{th} patient in i^{th} zone. τ presents the length and width of a single zone. δ is a time interval of the drone' zone scanning process. $Q_{Z_i}^{N_l}$ shows the QoS measurements for Z_i in N_l . $C_{Z_i}^{N_l}$ is the COVID-19 experiences for D_j^i in Z_i of N_l . E^{N_l} represents the edge server used for computing N_l statistics. Here, $Z_{i+n+1} = Z_i$.

1. **For each** N_l :
2. **For each** Z_i :
3. Associate D_j^i with each P_k^i
4. **For each** δ duration:
5. Collect COVID-19 scanning, thermal image collection, temperature, and other wearable sensor-based measurements
6. **If** (P_k^i 's body temperature increases with time) **then**
7. Start sanitization and medication
8. **End If**
9. $\delta = \delta + \delta$
10. **End For**
11. **Measure** $Q_{Z_i}^{N_l}$ and $C_{Z_i}^{N_l}$
12. **End For**
13. **Share** $Q_{Z_i}^{N_l}$ and $C_{Z_i}^{N_l}$ with E^{N_l}
14. **End For**

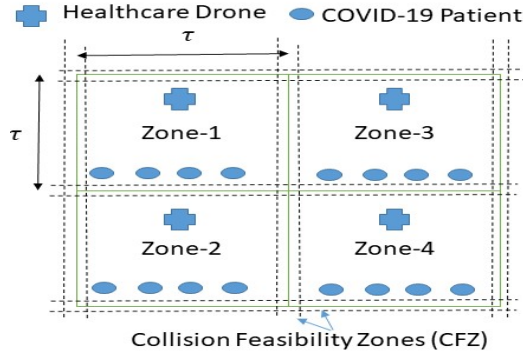


Figure 3: Proposed collision avoidance strategy for a drone network.

4.1 Single Layer Zone-Transfer Algorithms

This section presents three zone-transfer algorithms: fixed-area transfer, zig-zag transfer, and parallel movements and zone-transfer. Fig. 4 proposes a single-layered fixed-zone transfer strategy. In this proposed approach, drones are allowed to change or exchange their zones using a zone transfer area. This area is pre-planned to have a storage of at least one drone. The exchange is allowed if both the transfer zones (left to right and right to left) linking each other is empty. The details of the proposed single-layered zone transfer strategy are explained in algorithm 2. Fig. 5 shows the simulation of the single-layered zone transfer strategy (in execution). For example, if one drone is present in each zone-1 and zone-3, and they want to exchange their positions then zones transfer areas marked with arrows help them to swap the position without collision.

Algorithm 2: Single-layer fixed-area drone's zone transfer strategy

Goal: To transfer or exchange the drones from one zone to another zone without any collision with a fixed transfer/exchange area.

Premises: Same as algorithm 1. Additionally, T_o^{LR} and T_o^{RL} represents o^{th} zone transfer area from left to right zone and from right to left zone respectively.

1. Allocate one D_j^i in each Z_i
2. **For each** COVID-19 drone-based operation:
3. **If** (D_j^i in Z_i and D_j^{i+1} in Z_{i+1} want to swap the location) then
4. **If** (T_o^{LR} and T_o^{RL} are empty) then:
5. **Move** D_j^i in Z_i to Z_{i+1}
6. **Move** D_j^{i+1} in Z_{i+1} to Z_i
7. **End If**
8. **Else If** (T_o^{LR} is not empty) then:
9. **Move** D_j^i in Z_i to T_o^{RL}
10. **While** (T_o^{LR} is not empty):
11. **Wait** D_j^i in T_o^{RL}
12. **End While**
13. **Move** D_j^i in T_o^{RL} to Z_{i+1}
14. **Move** D_j^{i+1} in Z_{i+1} to Z_i
15. **End If**
16. **Else If** (T_o^{RL} is not empty) then:
17. **Move** D_j^{i+1} in Z_{i+1} to T_o^{RL}
18. **While** (T_o^{RL} is not empty):
19. **Wait** D_j^{i+1} in T_o^{RL}
20. **End While**
21. **Move** D_j^{i+1} in T_o^{RL} to Z_i
22. **Move** D_j^i in Z_i to Z_{i+1}
23. **End If**
24. **End If**
25. **Else**
26. Start thermal scanning, social distancing, COVID-19 hotspot detection, sanitization and data analytics after every δ intervals.
27. **End If**

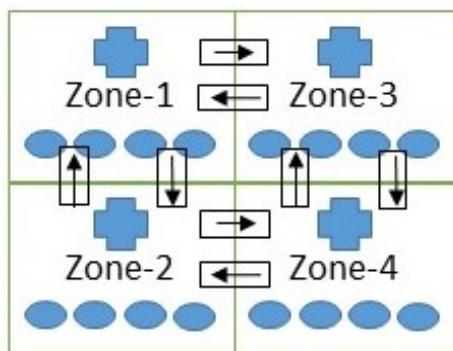


Figure 4: Single layer fixed-area zone transfer strategy

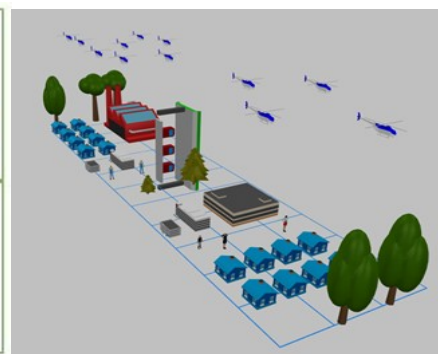


Figure 5: Proposed Single-layered Drone-based system for COVID-19 (3D View)

Fig. 6 shows the zig-zag movement and zone-transfer strategy. Here, drones enter the area through an entry zone and follow a zig-zag strategy for transferring the zone. Algorithm 3 explains this strategy in detail. Additionally,

algorithm 4 helps in identifying any drone's current zone by passing the index value. This index value could be mapped to (latitude, longitude) value as well. Further, the collision feasibility zone (as shown in figure 3) in each zone will avoid small distance collisions. Fig. 7 shows a single-layer drone movement strategy where multiple drones can enter the area through multiple and parallel zone's entry points. Algorithm 5 explains this strategy in detail.

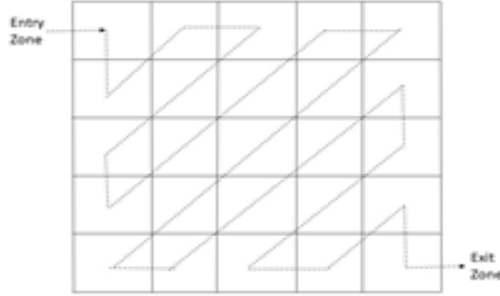


Figure 6: Single-layer zig-zag strategy

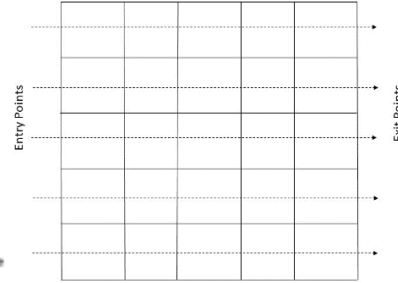


Figure 7: Single-layer parallel movements strategy

Algorithm 3: Zig-zag zone transfer strategy

Goal: To transfer or exchange the drones from one zone to another zone in a zig-zag strategy

Premises: Same as algorithm 2. Additionally, (a, b) represents the index value in $n \times n$ zone matrix and δ is an interval between two drone's movement.

Assumptions: The given area is divided into $n \times n$ -zone matrix and each zone has an area τ^2 .

1. Set Index = []
 2. **For** $k = 0$ to $n^2 - 1$:
 3. **If** $k \geq n * (n + 1)/2$:
 4. $(a, b) = \text{Upper_Zone_Matrix_Index}(k, n)$
 5. **Else**
 6. $(a, b) = \text{Lower_Zone_Matrix_Index}(k, n)$
 7. **End If**
 8. Append (a, b) to Index
 9. **End For**
 10. **Set** $j = 0$
 11. **For each** δ interval:
 12. **For** (a, b) in Index:
 13. **If** (a, b) is empty:
 14. Move D_j^i to (a, b)
 15. **End If**
 16. **End For**
 17. $j = j + 1$
 18. **End For each**
- Function Upper_Zone_Matrix_Index(k, n)**
1. $a, b = \text{Upper_Zone_Matrix_Index}(n * n - 1 - k, n)$
 2. **return** $(n - 1 - a, n - 1 - b)$
- Function Lower_Zone_Matrix_Index(k, n)**
1. $a = (\sqrt{1 + 8 * k} - 1) / 2$
 2. $b = k - a * (a + 1) / 2$
 3. **If** $a \neq 0$:
 4. **return** $(b, a - b)$
 5. **Else**
 6. **return** $(a - b, b)$
 7. **End If**

Algorithm 4: Identify drone's current location in a zig-zag zone transfer strategy

Goal: To identify the drone's current zone for operational control

Premises: Same as algorithm 3.

1. **For each** D_j^i
2. $Z_i = \text{Drone_Zone_Value}(a, b, n)$
3. **End For each**

Function $\text{Drone_Zone_Value}(a, b, n)$

1. **If** $a + b \geq n$:
2. **return** $n - (n-1) - \text{Drone_Zone_Value}(n-1-i, n-1-j, n)$
3. **Else**
4. $k = (a+b) * (a+b+1) / 2$
5. **If** $(a+b) \neq 0$:
6. **return** $k+a$
7. **Else**
8. **return** $k+b$
9. **End If**
10. **End If**

Algorithm 5: Single layer parallel movement strategy

Goal: To transfer or exchange the drones from one zone to another zone in a parallel drone movement strategy.

1. **Set** $l = 0$
2. **Set** $a = 0$:
3. **While** (True):
4. **For** $b = 0$ to n :
5. Move D_{j+l}^i to (a, b)
6. Move D_{j+l+1}^i to $(a+1, b)$
7. Move D_{j+l+2}^i to $(a+2, b)$
8.
9. Move D_{j+l+n}^i to $(a+n, b)$
10. **End For**
11. **If** δ interval spent:
12. $l = l+1$
13. **End If**
14. **End While**

4.2 Multi-Layer Zone-Transfer Algorithms

This section presents two multi-layered zone-transfer algorithms: two-layer zone transfer and hybrid zone-transfer. Fig. 8 shows a two-layered drone transfer strategy. Here, two-layers are proposed to have different drone-based COVID-19 activities (at different layers). The top-layer is considered as a zone-transfer layer and the bottom layer is considered as the COVID-19 operation layer. Now, transfer from one layer to another layer for collision avoidance happens through movements from the operation layer (layer-2) to the zone-transfer layer (layer-1). For example, drones present in zone-2 and zone-4 want to swap their positions. Thus, zone-2 and zone 4 drones will move from layer-2 to layer-1. Thereafter, zone-3 drone from layer-1 will move to zone-2 of layer-2, and zone-1 drone from layer-1 will move to zone-4 of layer-2. This approach can be extended for multiple layers for different COVID-19 or other services' operations/activities and/or working in uneven building structures. Every second layer in the multi-layered architecture is considered as zone-transfer layer. Algorithm 6 explains the multi-layer drone transfer strategy in detail. Fig. 9 and Fig. 10 show the simulation of the two-layered drone-based approach in 2D and 3D views respectively (in execution).

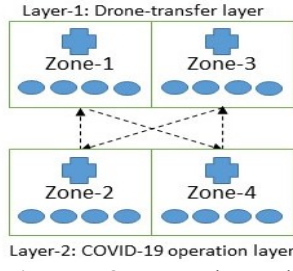


Figure 8: Two-layered zone transfer strategy

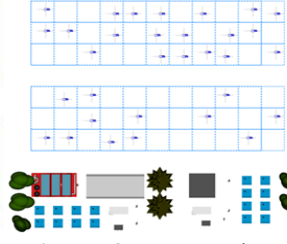


Figure 9: Proposed Two-layered drone-based system for COVID-19 (2D View)

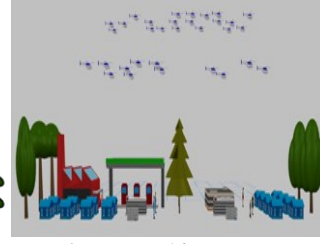


Figure 10: Proposed Multi-layered Drone-based system for COVID-19 (3D View)

Algorithm 6: Multi-layered zone transfer strategy

Goal: To transfer or exchange the drones from one zone to another zone without any collision with the usage of multi-layered air zones

Premises: Same s algorithm 1. Additionally, L_m represents m^{th} layer.

1. **For each** COVID-19 drone-based operation:
2. **If** (D_j^i in Z_i and D_j^{i+1} in Z_{i+1} at m^{th} layer want to swap the location) then
3. **Move** D_j^i in Z_i at m^{th} layer to Z_i at $(m-1)^{\text{th}}$ layer
4. **Move** D_j^{i+1} in Z_{i+1} at m^{th} layer to Z_{i+1} at $(m-1)^{\text{th}}$ layer
5. **Move** D_j^i in Z_i at $(m-1)^{\text{th}}$ layer to Z_{i+1} at m^{th} layer
6. **Move** D_j^{i+1} in Z_{i+1} at $(m-1)^{\text{th}}$ layer to Z_i at m^{th} layer
7. **End If**
8. **Else If** (D_j^i in Z_i at m^{th} layer want to move to an empty drone zone Z_{i+1}) then
9. **Move** D_j^i in Z_i at m^{th} layer to Z_i at $(m-1)^{\text{th}}$ layer
10. **If** (no other neighboring zone's drone want to moveto this zone) **then**
11. **Move** D_j^i in Z_i at $(m-1)^{\text{th}}$ layer to Z_{i+1} at m^{th} layer
12. **Else**
13. **Move** first request drone to Z_{i+1} at m^{th} layer
14. **End If**
15. **If** (D_j^i in Z_i and D_j^n in Z_n at m^{th} layer want to swap the location) then
16. **Move** D_j^i in Z_i at m^{th} layer to Z_i at $(m-1)^{\text{th}}$ layer
17. **Move** D_j^n in Z_n at m^{th} layer to Z_i at $(m-1)^{\text{th}}$ layer
18. Apply single layer drone's zone transfer strategy proposed in algorithm 2 and find the route from Z_i to Z_n for transfer
19. **End If**
20. **End for**

Fig. 11 shows the multi-layer hybrid movements strategy. In this strategy, the drones' movement area is divided into multiple layers as per the existing infrastructure and possibilities of divisions. Thereafter, different zone movement and transfer strategies could be applied for different operations. For example, four levels with four areas are shown in fig. 11. Area-2 at level-2 and area-4 at level 4 can use two-layered drone-movement and zone transfer strategy for COVID-19 operations. Whereas, area 3 at level-3 can use a parallel drone movement strategy for passing by drones. Similarly, area-1 at level-1 can use zig-zag drones' movement strategy for product delivery.

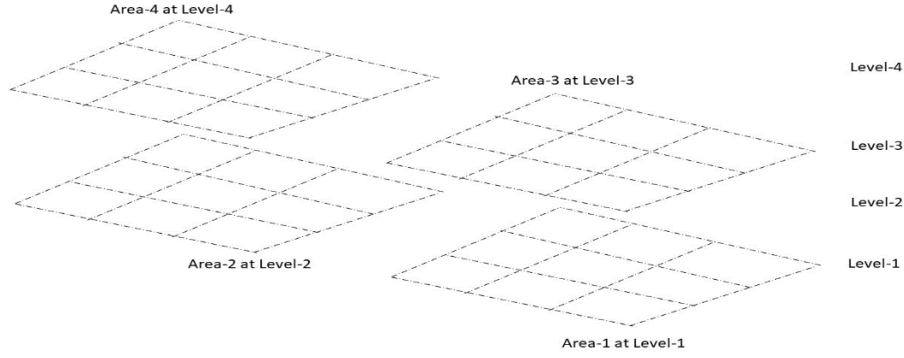


Figure 11: Multi-Layer Hybrid Movements Strategies

4.3 Social-Distancing Algorithms

This section shows two different approaches to maintain social distancing in COVID-19 operation. This system helps in generating alerts/alarms through drones when social-distance is not maintained in an observational area. Algorithm 7 proposed an approach that ensures the symmetric distance between any two persons standing in a queue. Algorithm 8 proposed an approach that ensures the symmetric distance between any two persons when the population is randomly distributed in a geographical region. Algorithm 7 and Algorithm 8 uses the following four functions for COVID-19 social distancing.

- *Max_Person_Calculation()*: This function measures the number of people allowed in a geographical area. If the number of people is greater than a certain threshold then it intimates the people through a wearable sensor or speaker based alert generation system for spreading out.
- *Distance_Mesurement()*: This function calculates the distance between two persons using various distance measurement formulas. Initially, the distance is recommended to be measured using acoustic, acoustic, laser, radio, infra-red or mono/stereo distance sensors but if none of these choices are available then it measures the distance from longitude and latitude measurements. For example, tunnel-based distance measurements are preferred only for those cases when the distance between two persons is very long. In COVID-19 cases, tunnel-based distance formula can be used for data analytics of two different places and then comparing the results.
- *Person_Intimation()*: This function uses the intimation system to people through wearable sensors or alert generation based system.
- *Control_Room_Notification()*: this function is used to measure the functionalities of an individual drone as well as the drone-based network. Further, this function measures the COVID-19 social distancing and hotspot identification as well.

Algorithm 7: Symmetric distance between any two persons standing in a queue.

Goal: To measure the distance between two persons standing consecutively in a queue, ensure minimum distance and intimate through a wearable device, if necessary.

Premises: Let P_i^j represents i^{th} person standing in j^{th} queue. Where $i \in \{1, 2, \dots, n\}$ and $j \in \{1, 2, \dots, m\}$ i.e. there is a maximum of n -persons and m -queues. $D_{i,k}^j$ is the distance between i^{th} person and k^{th} person when standing in j^{th} queue. Here, $k=i+1$ or $i-1$. Let $\phi_{P_i^j}$ and $\phi_{P_k^j}$ represents the latitude, and $\lambda_{P_i^j}$ and $\lambda_{P_k^j}$ represents the longitude of i^{th} person and k^{th} person respectively. R represents the radius of the earth, $e(D_{i,k}^j)$ is the maximum error in computing $D_{i,k}^j$. F is the footpoint width of the camera image taken over the earth, d is the ground sample distance and it is used to measure the distance between two adjacent pixels values, ϑ and μ_w represents the pixel width in image and image width respectively, $P_i^j(r)$ is the distance between the camera and person/object, $P_i^j(L)$ represents the length of i^{th} person standing in j^{th} queue. C_i^j represents i^{th} control room for j^{th} queue. δ is drone utralization measurement.

1. **For** $j=1$ to m :
2. Max_Person_Calculation()
3. Distance_Mesurement()

4. Person_Intimation()
5. Control_Room_Notification()
6. End For

Max_person_calculation()

1. Set count=0
2. **If** (acoustic, laser, radio, infra-red, mono/stereo distance sensors are available) **then**
3. Measure $P_i^j(r)$
4. **For each** $P_i^j(r)$:
5. $Count=count+1$
6. **End For**
7. **End If**
8. **Else**
9. **For** each object in camera image:
10. **Measure** $P_i^j(L) = \emptyset * P_i^j(r)$
11. **If** $P_i^j(L) > \text{threshold}$ **then**
12. $Count=count+1$
13. **End If**
14. **End For**

Distance_Mesurement()

1. **If** (distance measurement is based on latitude-longitude and tunnel formula) **then**
2. **If** (distance formula is based on spherical surface having very long distance) **then**
3. $\Delta X = \cos(\emptyset_{P_k^j}) \cdot \cos(\lambda_{P_k^j}) - \cos(\emptyset_{P_i^j}) \cdot \cos(\lambda_{P_i^j})$
4. $\Delta Y = \cos(\emptyset_{P_k^j}) \cdot \sin(\lambda_{P_k^j}) - \cos(\emptyset_{P_i^j}) \cdot \sin(\lambda_{P_i^j})$
5. $\Delta Z = \sin(\emptyset_{P_k^j}) - \sin(\emptyset_{P_i^j})$
6. Tunnel Distance (T_D) = $\sqrt{(\Delta X)^2 + (\Delta Y)^2 + (\Delta Z)^2}$
7. $D_{i,k}^j = T_D \cdot R$
8. **If** ($D_{i,k}^j \ll R$) **then**
9. $e(D_{i,k}^j) = D_{i,k}^j (D_{i,k}^j / R)^2 / 24$
10. **End If**
11. **End If**
12. **If** (distance measurement is based on latitude-longitude only) **then**
13. $D_{i,k}^j = 111.32 * \sqrt{(\emptyset_{P_k^j} - \emptyset_{P_i^j})^2 + (\lambda_{P_k^j} - \lambda_{P_i^j})^2}$
14. **End If**
15. **If** (distance measurement is based on image processing and ground sample distance (GSD)) **then**
16. $d = (g * a * 100) / (f * \theta)$
17. $w = d * \mu_w$
18. Apply linear discriminant analysis for feature-based person detection in an image with width w and compute $D_{i,k}^j$.
19. **End If**
20. **If** (distance measurement is based on image processing) **then**
21. $P_i^j(r) = P_i^j(L) / \emptyset$
22. $D_{i,k}^j = P_i^j(r) - P_k^j(r)$
23. **End If**

Person_Intimation()

1. **For each** $D_{i,k}^j$:
2. **If** $D_{i,k}^j < \text{threshold}$ **then**
3. Send signal to $P_i^j(r)$ and $P_k^j(r)$
4. **Call** Distance_Mesurement()
5. **End If**

6. **End For**

Control_Room_Notification()

1. **For each** drone:
2. **Measure** δ
3. **If** $\delta \geq$ upper_threshold **then**
4. **Call** drone back
5. **Else If** $\delta <$ lower_threshold **then**
6. **Instruct** to start COVID-19 process
7. **End If**
8. **End For**
9. **For each** C_i^j :
10. **For each** j in C_i^j :
11. **If** $D_{i,k}^j <$ threshold **then**
12. Send signal to $P_i^j(r)$ and $P_k^j(r)$
13. **Call** Distance_Mesurement()
14. **End If**
15. **End For**
16. **End For**

Algorithm 8: Symmetric distance between any two persons when the population is randomly distributed in a geographical region.

Goal: To measure the distance between two persons standing consecutively when people are randomly distributed over a geographical region and intimate through wearable devices, if necessary.

Premises: same as algorithm 1

1. **For** $j=1$ to m :
2. Max_person_Calculation()
3. Distance_Mesurement() //Same as in algorithm 1
4. Person_Intimation() //Same as in algorithm 1
5. Control_Room_Notification() //Same as in algorithm 1
6. **End For**

Max_person_Calculation()

1. Set $count=0$
2. **For each** direction (north, south, west, east) in a circle:
3. **Rotate** sensors in all directions
4. **If** (acoustic, laser, radio, infra-red, mono/stereo distance sensors are available and detect the person) **then**
5. $count=count+1$
7. **Else**
8. **Call** Distance_Mesurement() and Measure $P_i^j(r)$
9. **End If**
10. **End For**
11. **For each** $P_i^j(r)$:
6. $Count=count+1$
7. **End For**
8. **For each** object in camera image:
9. **Measure** $P_i^j(L) = \emptyset * P_i^j(r)$
10. **If** $P_i^j(L) >$ threshold **then**
11. $Count=count+1$
12. **End If**
13. **End For**

5. Case Studies and Performance Evaluation

This section discusses real-time and simulation-based realisation of proposed system architecture incorporating algorithms. It presents case studies adopted for COVID-19 scanning, sanitization, monitoring, analysis, and statistics for the control room. These case studies along with performance evaluation results are presented below.

5.1 Case Study-1: Drone-based Real-Time System for COVID-19

We present a real-time drone system for COVID-19 developed by **the Indian Robotics Solution (IRS)**. It is used for sanitizing, monitoring, and controlling COVID-19 pandemic in Delhi and the National Capital Region (NCR) of India.

• **Thermal Corona Combat Drone (TCCD):** This system is deployed in-practice for object identification and thermal scanning over many areas in Delhi and NCR, and found it as a suitable help to fight against COVID-19. Table 3 shows the complete specifications and features of the build and used a TCCD system [6].

Table 3. Thermal Corona Combat Drone (TCCD)

Parameters	Value
Type of drone	Multi-Rotor Drone
No. of Rotor	Six rotors (Hexa-copter)
Frame Material	Carbon fiber Sheet and tube
Camera	Thermal camera and RGB camera with Spot Light for Night Operation
Remote Control Working frequency	2.4Ghz and 5.8Ghz
Circuit designing	In-house
Flight Mode	Autonomous mode suing waypoint, Manual Mode, Hovering
Coding skills and Technology	Thermal imaging, Geothermal sensing, GPS tracking, Compaction and Photography
Model	Thermal Corona Combat Drone (TCCD)
Machinery Used	Waterjet, CNC, 3D printer, Metal molding, and R & D tools
Spraying System	Brushless Pump + 4 nozzle
Gimbal	3 Axis Gimbal for camera movement
Battery Type	Lithium Polymer batteries (1 battery set)
Battery cycle	200 cycle/each
Charger	Lipo Balance charger (20A)
Payload	10 kg payload
Attachment	Medicine box 2 kg, 5L sanitizing tank, 2 cameras, Loud Speaker
Weight of drone	15 Kg. (Empty tank) and 20 Kg. (full tank)
Satellites for GPS	A cluster of 60 satellites
Flight time	35- 40 minutes (if only thermal imaging) 12-15 minutes (if spray and thermal imaging)
Success rate	95%

• **Working of TCCD:** TCCD takes off vertically from the ground and no explicit launching pad is required. First, the team finalizes the area to be surveyed (densely populated areas usually) and takes clearances from relevant government authorities. When the drone is at a suitable height inside a society (suburban area), it makes announcements requesting the residents to come out on their balconies. Once the people are standing in their balconies then thermal scanning begins for one person at a time where the body temperature is recorded. Thermal scanning can be done of a person within 20 feet range. If the recorded temperature of any person is greater by at least 2°C than normal body temperature, an alarm beeps and an announcement is made over the loudspeaker fitted on the drone. To further take an action either the person having higher temperature may come down or an official from the outreach team may go up for more check-ups. This multipurpose UAV facilitates society by sanitizing the entire area via built-in spray functionality and providing medical supplies (if required). Two cameras help in thermal image sensing and video recording of the survey site even in the night using night vision mode. Thermal image sensor recording and video of live scanning are visible on a connected portable digital assistant like a mobile phone or phablet.

• **Outcomes:** Testing of TCCD has been completed in more than 15 densely populated areas (mostly slum areas) where the roads are not good and reachability is an issue for the officials. Around 1 million people live in these Delhi areas which include Keshav Puram, Narela, Sadar Bazaar, Slum areas of Civil Lines, Majnu ka Tila, Paschim Vihar, Dwarka. A sample of the scanned images which can be seen on the PDA device is shown in Fig. 12. Fig. 12(a) and Fig. 12(b) show the temperature reading measurement over a PDA device from a long and short

distance respectively. Fig. 12(c) shows the drone designed and used for COVID-19 operations. Fig. 12(d) shows the thermal image-based surface scanning. Scanning and sanitization of these areas were done in just 7 days. It is observed that an area of 2 KMs radius can be sanitized within 10 minutes. Authors (mainly IRS-founders) explained how their vision to scale it up by using proposed artificial intelligence for faster image processing and to use electrostatic spray. The electrostatic spray helps droplets of sanitizer to be more centric and overlapping thus making it more effective and avoids wastage.

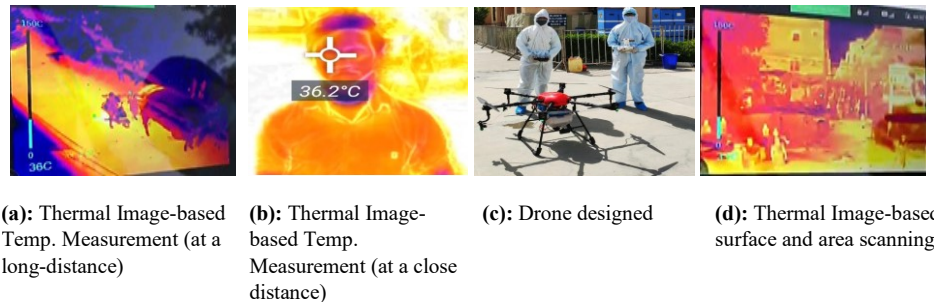


Figure 12: Real-Time Drone-based COVID-19 Temperature Reading, Thermal Scanning and Medication System

5.2 Case Study-2: Drone-based Simulation for COVID-19 Operations (Monitoring, Sanitising, and Thermal Imaging) in Outdoor Slum or Overused Areas

Authors have developed and present a simulation-based drone system for COVID-19 using AnyLogic [31] and JaamSim Simulators [32]. In this simulation, multimedia modelling, agent-based modelling, discrete event modelling and system dynamics are applied over an area variations of 250m² to 1000m². Fig. 13 shows the drone-based simulation when people are living or moving in close locations like in slum areas. The chances of sharing toilets, bathrooms, water supply, and other public resources are very high. Thus, this increases the chances of COVID-19 pandemic as well. To avoid spreading of COVID-19 cases, regular monitoring and sanitization are required. Fig. 13 shows the side view of the area where drones are used for sanitizing the space. Here, two drones are shown that can move freely and sanitize the area with instructions. Fig. 14 shows the drone-based thermal image of people's movement monitoring and image processing. Here, people's movements are monitored and density-based analysis is performed with the help of proposed multi-layered architecture. Fig. 14 shows the single-day observations and severity of experimentation increases with the darkness of the red color. This indicates that sanitization is required at those places. Fig. 15 shows the circuit used for simulating drone-based COVID-19 operations. Various components of this circuit are briefly explained as follows.

- pedSource: ensures (i) significant passengers travel, and (ii) passengers increase with services and type of services.
- pedGoTo: ensures randomness and free-pedestrian movements.
- pedWait: ensures (i) significant and random stay-time, and (ii) social-distancing.
- pedSink: ensures smooth pedestrian removal.

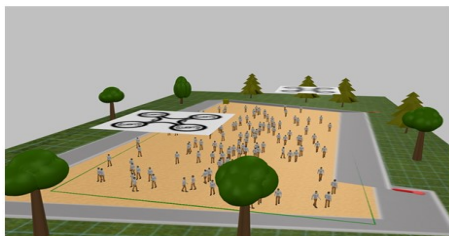


Figure 13: Drone-based pandemic areas considered for monitoring (side-view).

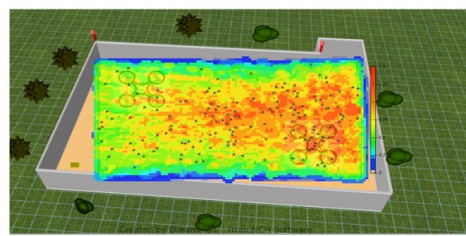


Figure 14: Drone-based thermal image for people movement monitoring and sanitizing in COVID-19 hotspots. (single-day observations)



Figure 15 Anylogic Simulation Model for COVID-19 Operation

Fig. 16 shows the comparative analysis of the time required to sanitize 100 to 1200 kilometers of the area with variations in the number of drones. Results show that 18900, 9390, 3680, and 2293 minutes are required to cover 1200 kilometers of the area with 3, 10, 20, and 30 drones respectively. The drone-recharging and sanitizer filling time are additional.

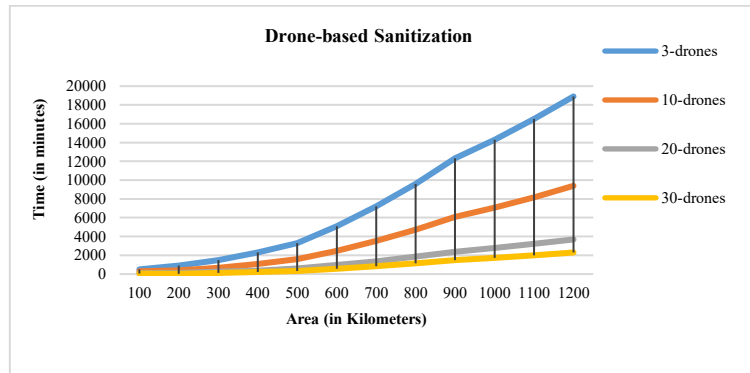


Figure 16: Comparative analysis of the time required to sanitize 100 to 1200 kilometers of the area with variations in the number of drones.

5.3 Case Study-3: Drone-based Simulation for COVID-19 Operations in Indoor Monitoring

Fig. 17 shows the experimentation for drone-based simulation for inspecting indoor COVID-19 patients. In an indoor activity, nano or low altitude drones are preferred because of their various advantages [29] [30]. Fig. 17 shows the hospital's internal building and multiple patient wards for admission. This drone's camera is programmed for inspecting the patients based on their movements and density. It is assumed that irrespective of drone-based special sanitization service, the wards are sanitized (manually) after regular intervals or after patient discharge. Thus, drone-based sanitization is made mandatory in those areas where the movement of people/patients is higher.

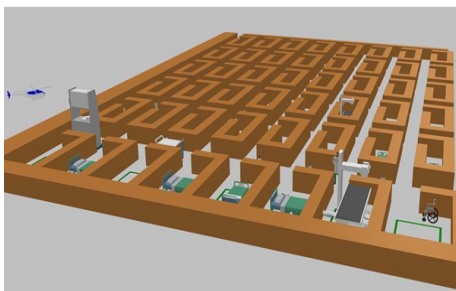


Figure 17: Hospital building for inspection (3D view)



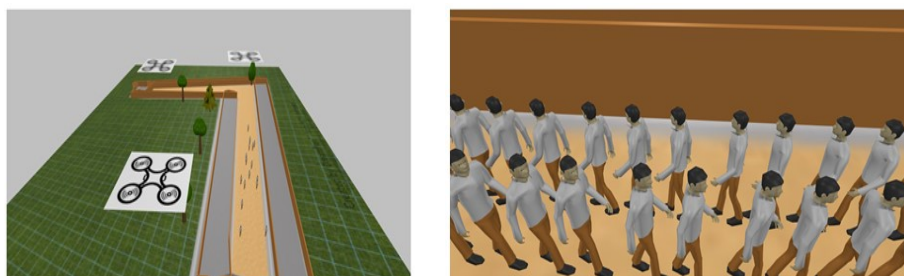
Figure 18: AnyLogic Model for inspecting COVID-19 patients and sanitization

The drone camera-enabled hospital room gives real-statistics to proposed architecture for data analysis and instructions are given back to the drone for the operation of sanitization and medication in the predefined area. Drone's camera used for COVID-19 operations shows that the accuracy of the proposed simulation is higher (93% approx.). Fig. 18 shows the simulation's thermal image of density-based areas that need sanitization. An increase in darkness of red color indicates urgent sanitization.

5.4 Case Study-4: Drone-based Simulation for Social Distancing

This section presents the drone-based simulation for social distancing experiments. In the experiments, algorithm 7 is used for ensuring symmetric distance between two persons. Algorithm 7 compute the number of persons standing in a geographical area in its initial calculations. If the number of people standing in an area is more than the acceptable limit then an alert is generated to reduce the count or stop the services. Thereafter, a distance measurement process starts. Now, distance can be measured in multiple ways and through different formulas. Figure 11 shows the application of the proposed approach in simulation. Fig. 19 (a) shows a road where people are free to move through the front-view camera. In this view, three drones are shown to monitor the movement of people. Fig. 19(b) shows social distancing in practice and the queue formation process. Here, people have made a queue and they are served for their necessity as well. This queue ensures that if certain people are not following the social distance rules then they will not be served and they have to go back to the queue-end for their turns. Fig. 19(c) is the circuit diagram designed and programmed for social distancing simulations. Various components of this diagram are explained as follows.

- *pedSource*: This generates the number of pedestrians for experimentation from a pre-defined and fixed-line. The pedestrians are free to move randomly and in any direction in the pre-defined area. However, everyone has to follow the queue and social distancing otherwise they have to go back at the start of the queue and follows the current position.
- *atFareGates*: As the number of pedestrians increases with time but space does not allow to move above a fixed number of passengers. Thus, a crowd is generated at the entry gates. To avoid the pandemics, all people are alerted to go back or follow the social distancing here as well.
- *pedGoTo*: specifies the number of pedestrians that are moving from entry gate to service point. This component does not allow multiple people to serve at a time. However, the services resumed only if all are following the social distancing experiment.
- *pedService*: This component ensures that each person following the social distancing experiment is served through a queue. The serving and time duration is fixed and pre-defined.
- *pedSink*: This component removes the pedestrians from observational space after they are served and at the position of exit gates.



(a) Drone-based Monitoring and (b) Drone-based social distancing queue Simulation (front-view)



(c) Drone-based AnyLogic Model for Social Distancing

Figure 19. Drone/UAV-based Simulation Model for Social Distancing in hospitals, banks, supermarket etc.

Fig. 20 shows the comparative analysis of the number of persons checked for social distancing with variations in the number of drones. In this experimentation 3, 10, 20 and 30 drones are taken for checking the social distancing. Results show that the number of persons checked with drones over simulation time variations increases exponentially. Results show that around 3389 persons can be checked in 55 minutes with 3 drones. Similarly, 13398, 16298, and 19697 persons can be checked in 55 minutes with 10, 20 and 30 drones respectively. Further, fig. 21 shows a comparative analysis of the number of persons served with medicine supply after a social

distancing check. It is observed that 1612, 10073, 13129, and 16166 persons can be served along with social distance checking when the maximum number of working parallel medicine supply units=20, and the maximum time taken to supply a medicine= 120 seconds.

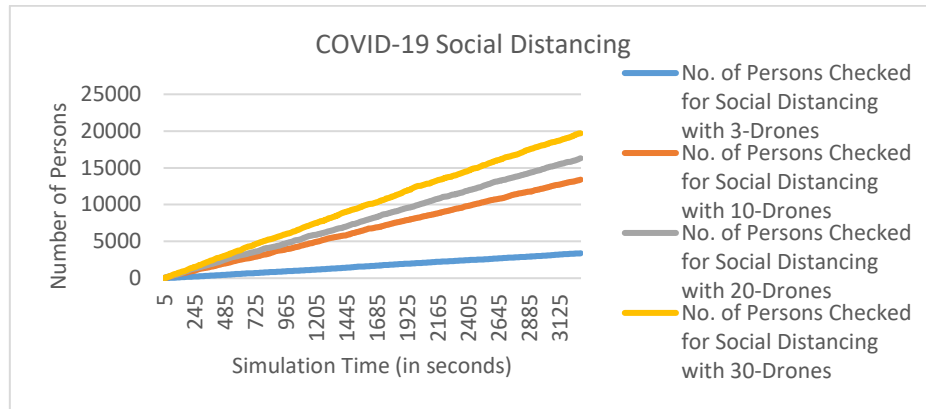


Figure 20: Comparative analysis of the number of persons checked for social distancing with variations in the number of drones

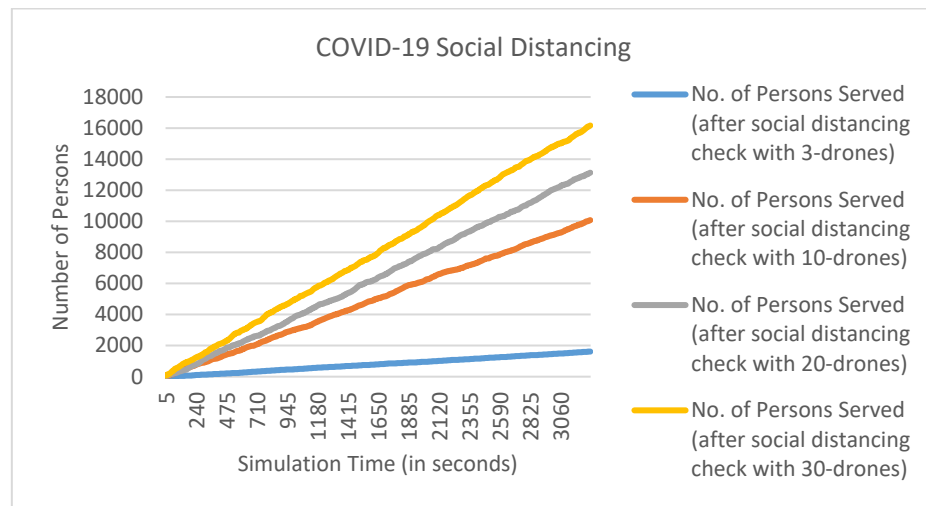


Figure 21: Comparative analysis of the number of persons served with medicine supply after social distancing check (the maximum number of parallel medicine supply units=10, the maximum time taken to supply a medicine= 120 seconds)

5.5 Case-Study-5: Drone-based System and Simulation for Police Monitoring and COVID Control Room

Fig. 22 and fig. 23 show the results that can be displayed in the control room in addition to statistics shown in other case-studies. Fig. 22 shows the variations in drones used over the number of simulation days in the sanitization process. This statistic is variable and it varies with simulation. However, fig. 22 shows a static view of statistics between 250 to 400 days. Here, it is observed that 170 to 230 drones are used for the sanitization process. This number is cumulative and reusability of the drone is considered as well. Fig. 23 shows the percentage of drone utilization. Results show that the percentage of drone utilization varies from 0% to 80% approximately. These statistics are variable as well and it varies with simulation. Fig. 23 shows the results for 30-drones. These statistics can be helpful to control room officials for analyzing the drone situation and instructions could be passed accordingly. If the utilization is higher then the chance of drone to deplete its battery, at a much fast rate, is higher as well. Thus, minimum utilized drones can be used for subsequent operations.

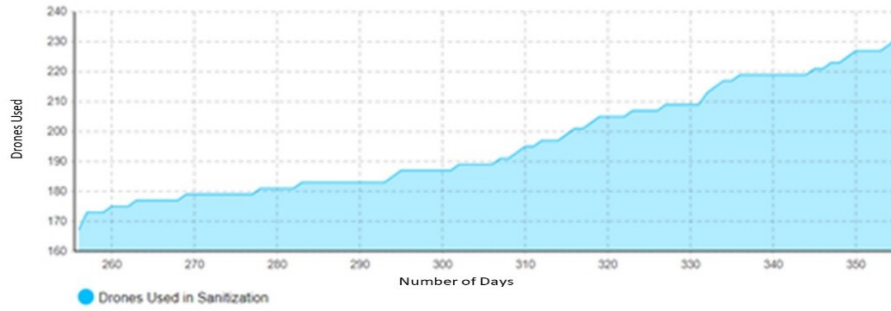


Figure 22: Drone utilization over the simulation time

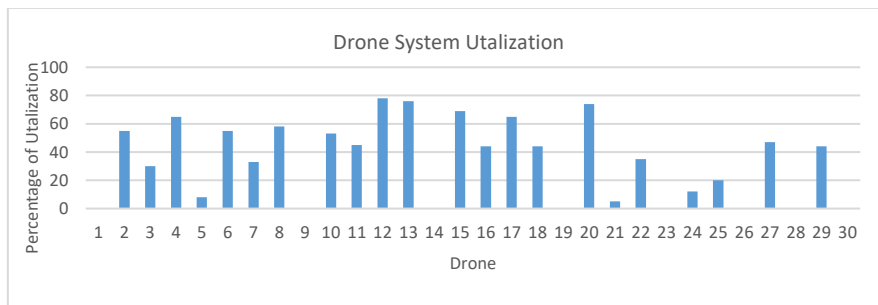


Figure 23: Percentage of drone-system utilization

5.6 Case Study-6: Drone-based Simulation for Performance Analysis in COVID-19 Scenario

Simulation Model: Fig. 24 shows the drone-based sanitization system designed and programmed for simulating the sanitization process in the COVID-19 system with a sequential drone-movement strategy.

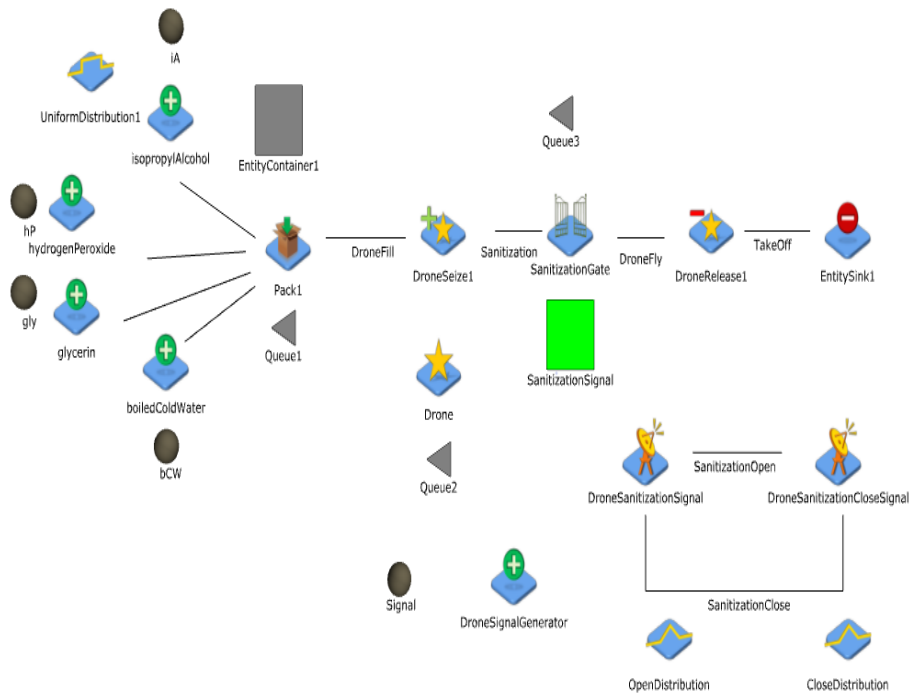


Figure 24: Drone-based Sanitization System with sequential drones' movement

Assumptions: It is assumed that the maximum time taken to send a signal to the drone is 10 seconds. Here, triangular distribution (compared to a normal distribution) is used for setting the signal time variation in the simulation model because distribution is expected to be skewed with completion of the area under observation at the minimum, maximum and modal values.

Outcomes & Discussions: This sub-section explains the various parameters used for performance measurement. These are explained as follows.

Ground to Drones Signal Transmission Time Analysis: Fig 25. shows the variations in signal transmission time from a ground transmitter to the drone’s receiver. This variation is observed for an infinite period. Fig. 25 shows the variations for the past one hour (0 to 3600 seconds). Here, “-“ sign is an indication of past time only. Results show that signal duration varies from 0 (minimum) to 9 seconds (maximum). Mean and standard deviation values of time variation are found to be 4.1 seconds and 3.7 seconds for 10 hours.

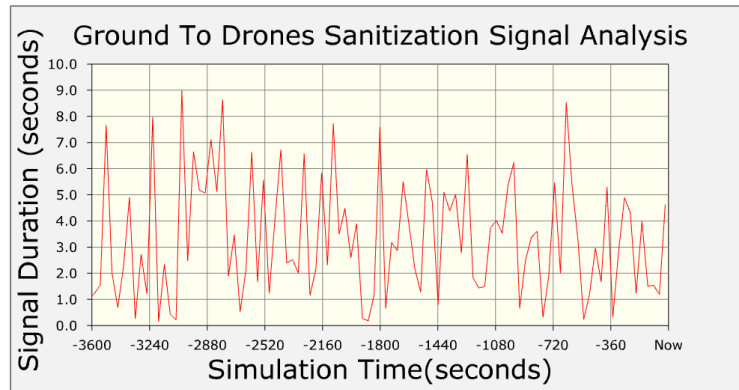


Figure 25: Ground to Drones Signal Transmission Time Analysis

Number of Drones Used: Fig. 26 shows the number of drones used over simulation time. In the proposed simulation model, it is observed that a minimum of 25 and a maximum of 55 drones are used at a time. This usage includes drones while operating inside the zone, filling the sanitizer, flying with no operation, and landing operations.

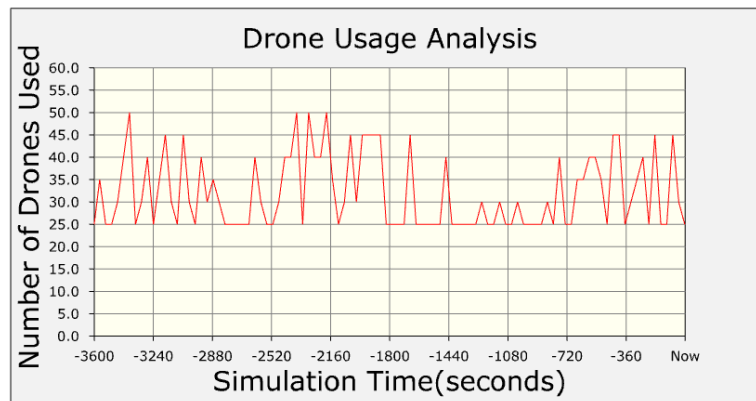


Figure 26: Drone Usage Analysis

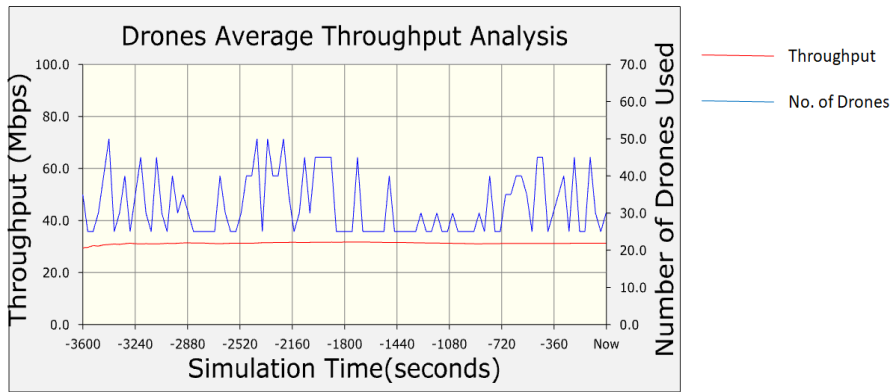


Figure 27: Drone Average Throughput Analysis with Variations in Number of Drones

Fig. 27 shows the average throughput variation analysis. Equation (i) is used to compute the throughput [33]. Here, Bit Error Ratio (BER) is the ratio of the number of bits errors by the total number of transmitted bits during the total transmission time. With an average number of drones usage around 22, average throughput varies from 35 Mbps (minimum) to 70 Mbps (maximum).

$$Throughput = \frac{256 * 8 * N_{success} * (1 - BER)}{Total\ Packet\ Transmission\ Time} \quad (i)$$

Fig. 28 shows a drone-based sanitization system with parallel drone movements. In this experimentation, it is realized that the average throughput lies between 35 Mbps to 80 Mbps with an average number of drones usage around 17.

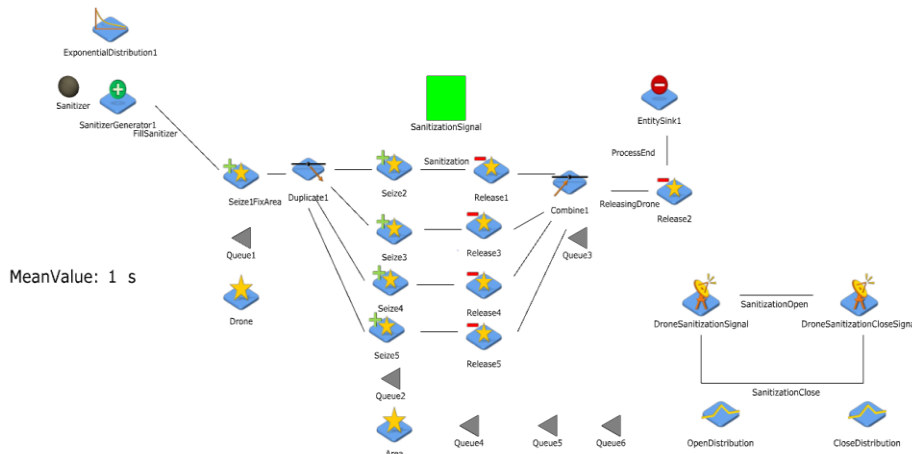


Figure 28: Drone-based sanitization system with parallel drones movement

Fig. 29 shows the comparative analysis of drone movement and zone transfer strategy with the existing approach [34] with simulation time variation. Nageli et al. [34] use video graphing-based multi drone movement and collision avoidance algorithms. Results show that Nageli et al. algorithm takes more time in execution as compared to proposed single-layer algorithms such as fixed-area (algorithm 2), zig-zag (algorithm 3), and parallel (algorithm 5) in the majority of the cases. The two-layered zone transfer approach (algorithm 6) is expensive in some cases.

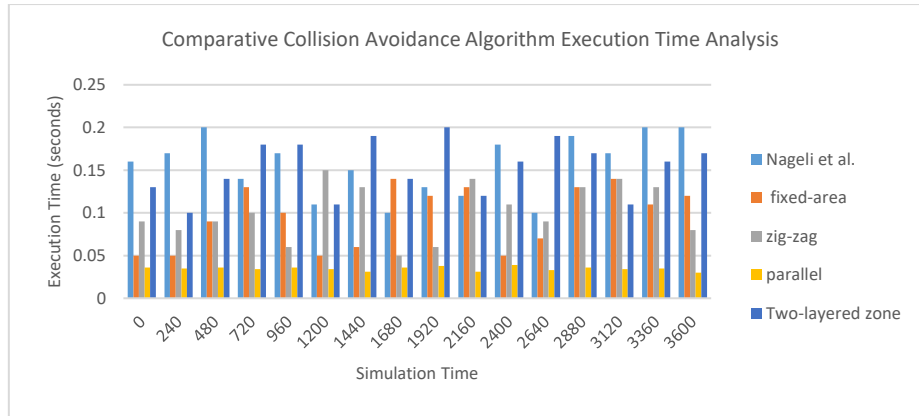


Figure 29: Comparative Collision Avoidance Algorithm Execution Time Analysis

6. Conclusions and Future Work

This paper proposed a UAV-based smart healthcare system for COVID-19 monitoring, sanitization, social distancing, data analysis, and control room. Our framework gathers data by either through wearable sensors, movement sensors deployed in the targeted areas, or through thermal image processing. The data is processed through multi-layered architecture for analysis and decision making. In multilayered architecture, edge computing controls the proposed drones' collision-resistant strategies. Whereas, fog and cloud computing approaches build commuters and patient profiles before making decisions. The proposed approach demonstrated with implementation and simulation. In an implementation, it is observed that a large distance can be covered within a short period and the proposed drone-based healthcare system is effective for COVID-19 operations in Delhi/NCR regions. In the simulation, the proposed approach is tested for indoor and outdoor activities. Results show that a distance of 1200 kilometers can be covered in 2293 to 18900 minutes with a variation of 3 to 30 drones. In an indoor activity, thermal image-based patient identification is found to be very effective for COVID-19 pandemics. In the future, the feasibility of large scale medicine delivery with different collision-resistant strategies will be explored keeping infrastructure constraints in consideration.

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Author's Biography



Adarsh Kumar is an Associate Professor in the School of Computer Science with University of Petroleum & Energy Studies, Dehradun, India . He received his Master degree (M. Tech) in Software Engineering from Thapar University, Patiala, Punjab, India, in 2005 and earned his PhD degree from Jaypee Institute of Information Technology University, Noida, India in 2016 followed by Post-Doc from Software Research Institute, Athlone Institute of Technology, Ireland during 2016-2018. From 2005 to 2016, he has been associated with the Department of Computer Science Engineering & Information Technology, Jaypee Institute of Information Technology, Noida, Uttar-Pardesh, India, where he worked as Assistant Professor. His main research interests are cybersecurity, cryptography, network security, and ad-hoc networks. He has published 60+ research papers in reputed journals, conferences and workshops. He participated in one European Union H2020 sponsored research project and he is currently executing two research projects sponsored from UPES SEED division.



Kriti Sharma is an Assistant Professor in Department of Engineering and Technology at K R Mangalam University, Gurgaon for over 4 years. Presently, pursuing Ph.D. degree from School of Computer Science, University of Petroleum and Energy Studies (UPES), Dehradun, India. Her keen interest in teaching made her joined education sector after finishing her M.Tech from Northcap University, Gurgaon in 2014. She completed her B.Tech from Government Women Engineering College, Ajmer in 2011. She is inclined towards latest and futuristic technology like Machine learning, Artificial Intelligence and Blockchain. Most of her research work revolves around how to use recommendation techniques in multiple domains.



Harvinder Singh is an Assistant Professor in Department of Virtualization, School of Computer Science, University of Petroleum and Energy Studies, Dehradun, India. He received his M.Tech degree in 2009 and B.Tech degree in 2005 from Kurukshetra University, Kurukshetra. He has also served as Assistant Professor in Department of Computer Science & Engineering, HCTM Technical Campus, Kaithal, Haryana, India. His research interest lies in Cloud Computing, Resource Management, Software Project Management, Internet of Things, Healthcare Informatics and Artificial Intelligence. He has published 10 research papers in Referred Journals and International Conferences. He has also served as TPC member of International Conferences.



Sagar Gupta Naugriya is the founder and CEO of Indian Robo Store and Indian Robotics Solution Pvt Ltd., New Delhi, India. He has done his Bachelors in Engineering from ITM University, Gwalior, Madhya Pradesh, India in Electronics and communications engineering in the year 2015 . His interests lies in Robotics and Electronic gadgets.



Sukhpal Singh Gill is a Lecturer (Assistant Professor) in Cloud Computing at School of Electronic Engineering and Computer Science , Queen Mary University of London, UK. Prior to this, Dr. Gill has held positions as a Research Associate at the School of Computing and Communications, Lancaster University, UK and also as a Postdoctoral Research Fellow at CLOUDS Laboratory, The University of Melbourne, Australia. His research interests include Cloud Computing, Fog Computing, Software Engineering, Internet of Things and Healthcare. For further information, please visit <http://www.ssgill.me>



Rajkumar Buyya is a Redmond Barry Distinguished Professor and Director of the Cloud Computing and Distributed Systems (CLOUDS) Laboratory at the University of Melbourne, Australia. He is also serving as the founding CEO of Manjrasoft, a spin-off company of the University, commercializing its innovations in Cloud Computing. He has authored over 725 publications and seven textbooks including "Mastering Cloud Computing" published by McGraw Hill, China Machine Press, and Morgan Kaufmann for Indian, Chinese and international markets respectively. He is one of the highly cited authors in computer science and software engineering worldwide (h-index=136, g-index=300, 97,900+ citations). He is a Fellow of the IEEE.