Journal of Modern Technology and Engineering
Vol.7, No.1, 2022, pp.51-73

A PORTABLE HEALTH CLINIC (PHC) APPROACH USING SELF-ORGANIZING MULTI-UAV NETWORK TO COMBAT COVID-19 PANDEMIC SITUATION IN HOTSPOT AREAS

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Abstract. With the spread of the COVID-19 pandemic, medical staff nowadays is being posed to a real risk of infection from patients when combating coronavirus on a daily basis and many are affected by the virus worldwide. As a consequence of the disease spread along with the growing number of infections, so many governments have already declared prolonged curfews in COVID-19 hotspot areas that could last for days or even weeks for the virus containment. During lockdowns, people are not allowed to leave their houses even for getting tested for COVID-19 to prevent gathering and passing the infection to others. One solution for minimizing the risk of transmitting COVID-19 is the Remote Healthcare Systems (RHS). This study applied the World Health Organization (WHO) guidelines to redesign the Portable Health Clinic (PHC), an RHS, for the spread of COVID-19 containment. Additionally, a COVID-19 triage process (CT-process) for the main symptoms of COVID-19 is being suggested based on the analysis of measurement readings taken from patients, where Unmanned Aerial Vehicles (UAVs) are used as a PHC platform and are equipped with the required sensors and essential COVID-19 medications for testing and treating people at their doorstep autonomously during a full curfew.

Keywords: COVID-19, drones, remote healthcare system, portable health clinic, full curfew.
AMS Subject Classification: 68M10.
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Received: 22 February 2022; Revised: 19 March 2022; Accepted: 27 March 2022; Published: 29 April 2022.

1 Introduction

COVID-19, an abbreviation to Coronavirus disease, is an infectious illness that has been discovered recently (Li et al., 2020). This virus was unknown before the Wuhan chain occurrence in December 2019, and by August 2021 over 200 million people globally are infected and over 4 million have died (Organization, 2021). COVID-19's most like to appear symptoms are fever, fatigue, and dry cough. Furthermore, several patients also experienced runny noses, nasal clog, sore throat, throbbing pain, or diarrhea (Rocke et al., 2020). The elderly with health conditions like diabetes, hypertension, or heart troubles suffer more from the virus; people suffering from fever, cough, and having breathing issues should look for immediate medical assistance. Individuals get infected by this virus through tiny beads when coughing, sniffling, or talking during close contact, e.g. at a minimum gap of 3 feet or one meter (Hopkins & Kumar, 2020). These small beads are dispensed while exhalation and usually fall to a surface or ground making contaminations over long distances (Wu et al., 2020). Unfortunately, the survival time for the virus on most surfaces can be up to 72 hours (Hopkins & Kumar, 2020). As the spread of the virus has reached most countries, on 11 March 2020, the WHO announced it a pandemic. At that point, numerous countries have imposed nationwide lockdown especially in COVID-19 hotspots with an aggressive promotion of the social distancing concept in the media to raise awareness (Sharma et al., 2021). Moreover, recommended measures of protection, such as hand washing, keeping distance from others, closing the mouth while hacking, and self-isolating of infected people, are encouraged (Hopkins & Kumar, 2020). In general, the impact of COVID-19 led to isolations, transportation restrictions, curfews, closures of facilities (Wu et al., 2020).

Usually, COVID-19 hotspot areas are placed under curfew. A hotspot is a district where reports indicate a relatively larger number of confirmed COVID-19 infections. The confirmed cases do not necessarily belong to the same family, therefore increasing the likelihood of virus transmission among society in such regions (Sharma et al., 2021). This motivates the idea of this paper, where populations under a curfew are being tested for COVID-19 symptoms at their doorsteps with minimal human intervention by using a portable health platform comprised of UAVs.

1.1 Telehealth System Evaluation During Emergency

In general, tremendous research efforts are mostly focused on hospital information systems to develop hospital management information system that handles contagious diseases by studying the risk factors, emergence rules, and control means for infectious disease management (Huang et al., 2007; Zhong et al., 2005; Farias et al., 2010). Nonetheless, one challenge during the ongoing pandemic is identifying the key factors that define the spatial and temporal patterns of COVID-19 which allow decision-makers to work out and apply precautionary strategies (Timpka et al., 2008). Many recent articles are well-focused on the major beneficial impact of telemedicine for healthcare systems in handling coronavirus disease, particularly on monitoring, detection, surveillance, medical supplies delivery, sanitization, and the possibility of machine learning and artificial intelligence involvements. However, patients' opinion towards such approaches is not well reported yet, even though the importance of patients' engagement with such solutions for COVID-19 containment (Hollander & Carr, 2020; Pappot et al., 2020; Ting et al., 2020).

At the time of public health emergencies, similar to the COVID-19 pandemic, the digital infrastructures stay intact while health practitioners can still keep in contact with patients. Nevertheless, no wide-scale telehealth services for monitoring the health status of acute and chronic patients and for enabling continuous care provision have been considered in the greatly affected countries such as Italy (Omboni, 2020). As the significance of e-health is being formally acknowledged, many governments are updating regulations permitting remote medical services by licensed professionals. Healthcare budgets are supplemented by many governments to lessen the impact of coronavirus disease, for instance, the Medicare Benefits Schedule (Online, 2021) and Medicare services are made available in the United States, extending the coverage range for better containment of COVID-19 by testing and treatment of people with their least spending possible. This additional budget allocation can improve e-health services during the coronavirus pandemic allowing more citizens to take healthcare at a considerably lower cost as against hospital-centric services, e.g. telemedicine consultations with general doctors and specialists over video communication (Sampa et al., 2020). Generally, the rapid adaptation of healthcare systems to the quickly evolving situation is made mainly for three reasons: firstly, the need for a significant number of patients with respiratory issues to be triaged and treated early and carefully Zhang et al. (2020); secondly, healthcare workers need to be protected to facilitate treating infected people (Schwartz et al., 2020; Chang et al., 2020); and thirdly, the elderly and highly vulnerable patients should be mostly shielded against infection (Andreas et al., 2020).

1.2 The Drone Technology

The term drone is usually used to describe an air vehicle that can fly similar to other aviation craft apart from the absence of a pilot onboard. When a drone is in aerospace, it is called a platform, and the equipped external hardware or embedded systems to it is named payload. Attaching payload to platform gives a UAV the capability to perform different tasks in various applications with enhanced efficiency and accuracy (Kumar et al., 2021). Since 2013 the expenditure on UAVs worldwide has been increased greatly. The annual global expenditure across the whole sector is estimated by the Teal Group to be $5.2 billion in 2013, and by 2023 it is anticipated to reach $11.6 billion (Newswire, 2012). The International Data Corporation (IDC) in 2018 predicted a rise in the annual predicted spending anticipated by Teal Group to reach $12.3 billion in 2019 together with a Compound Annual Growth Rate (CAGR) prediction of 30.6% in 2022 (Harrington, 2019). In the last few years, government bodies, defense organizations, and private enterprises have adopted drone technology for both humanitarian and commercial causes. For instance, in areas like telecommunication, agriculture, Search and Rescue (SAR) and emergency response, delivery, healthcare, weather forecasting, sports, entertainment, retail and logistics, and wildlife conservation, to name a few (Sharma et al., 2021).

The WHO is working collaboratively with health organizations in different countries to carry out checkups and conduct tests of residents progressively. Since COVID-19 is transmitted in human contact, the tests must be done in an extremely controlled and regulated environment (Sharma et al., 2021). On the earliest days of discovering coronavirus, it has been noted that drone technology is already available to provide a mass service to assist in virus containment (Skorup & Haaland, 2020). UAVs show great assistance under these conditions to maintain a periodic check over one's health status, help to keep social hygiene and to educate people about public policies and social distancing. Developed countries such as the United States, China, Australia, France, Italy, and several others, which have many of their cities monitored and watched throughout the day to limit the spread of coronavirus are already utilizing drones technology (Sharma et al., 2021). for example, In Australia, drones are used to detect whether anyone has a suspicious respiratory pattern (News, 2021) where special sensors are mounted on a UAV for registering body temperature, respiratory and heartbeat rates, and other abnormalities Kumar et al. (2021). Furthermore, China employs more than 100 drones (The MicroMultiCopter company) over some cities to monitor and prevent COVID-19 transmission through measuring the inter-personal distance between individuals and alarming people if the distance is found less than a certain value, people are notified as well if they are in public places without wearing a mask (Meszaros). Also, Terra drones are used in China for regulated sanitization spraying disinfectant over mass Kumar et al. (2021). Another example, the delivery of personal medical kits for coronavirus by drones to remote locations in the United States (Meszaros), while UAVs are used for making public announcements during surveillance in some states in India like Delhi, Kerala, and Assam. Typically, the vast majority of the countries adopt the drone-based technique for governance, surveillance, thermal scanning, sanitization, etc. as it offers a safe manner to help humanity (Kumar et al., 2021).

1.2.1 Multi-drone Network Concept

The main reason behind the ability of quadcopter drones to participate in surveillance, SAR, and aerial photography missions is their hovering capability (Ding et al., 2018; Ye et al., 2018; Yavuz et al., 2016). The efficient accomplishment of similar missions is largely hindered as the drone is unable to stay in the air for longer periods (Bernardini et al., 2014; Lee et al., 2015). Therefore, just keeping itself airborne requires consideration of energy. Existing battery technology claims that the maximum drone's flight time is limited to thirty minutes (Dronethusiast, 2021). This weakness of employing one drone was the primary cause for the development of multiple drone systems. Drone swarm members connect and communicate over a network allowing wider area coverage with an equal flight time when compared to a single drone (Yanmaz et al., 2018). Although the performance of the multi drone network is better in comparison to a single drone, many technological challenges arise that need addressing to guarantee efficient completion of the specified mission Gupta et al. (2015).

Drones forming a swarm can be either controlled from a ground Base Station (BS) or they can operate autonomously, taking, communicating, and applying decisions as the mission progresses

Yanmaz et al. (2011). Despite the multi UAV network type, sensing capability, and other features that are mission-dependent, the following fundamental interconnected building blocks are required by all drone networks (Yanmaz et al., 2018; Gupta et al., 2015; Shakhatreh et al., 2019):

- Communication and Networking: Handles data flow over the network, e.g. data obtained from onboard sensors as well as the flight commands communication. Also assures that Quality of Service (QoS) requirements are fulfilled, manages routing and scheduling, and maintains the whole network connectivity.

- Coordination: Employs drone's onboard sensor data along with the information collected from other drones on the network to make decisions about flight path planning.

- Sensing: Essential data are provided by sensors to complete the required mission. Thus, the onboard sensor type is predetermined and depends on the mission itself. For example, knowing the UAV position in the swarm is important to avoid obstacles and drone collisions, and one way to achieve this is through Global Positioning System (GPS).

In general, the multi-UAV technology has a broad spectrum of application scenarios including but not limited to; assisting in unreached, unknown, and dangerous environments such as SAR missions (Alsamhi et al., 2018, 2019), surveillance, underwater exploration, humanitarian demining (Strobel et al., 2018), and quarantine area (Otiede et al., 2017).

1.2.2 Self-organizing in Drone Networks

Traditionally, the configuration of a multi-UAV network shows certain major issues including flight cost, pilot skills, mission duration, and pilot safety in hazardous missions (De Benedetti et al., 2017). Furthermore, performance degradation could happen due to nodes' mobility, interference, or bandwidth limitations, and can be effectively handled when the network is reconfigurable (Sharnya & Raj, 2013), here comes Self-organizing Network (SON) as a solution (Giyenko & Im Cho, 2016). SON can be defined as a set of functions that are used in wireless communication networks to automate the configuration, optimization, and maintenance of these networks. This novel technique is urgently required in future communication systems because of the increased cost burden (Kim et al., 2011). SON functions start to operate once Network Elements (NEs) are switched on and started the basic setup procedure. The SON functions can be classified according to the operational phases into Yan et al. (2020); Kumar et al. (2014); Giannini et al. (2016):

1. Self-configuration functions: The self-configuration technique, also named self-deployment (Giannini et al., 2016; Albino et al., 2015), is an operation that involves the immediate configuration of newly deployed NEs to obtain basic information and download necessary operating software; automatic installation procedure helps in performing this operation.

2. Self-optimization functions: A self-optimization mechanism is an approach of network auto-tuning by utilizing NEs and performance measurements, i.e. Key Performance Indicators (KPIs), during the operational phase that begins when the RF interface is powered on (Yan et al., 2020). The goal is to figure out the best-performing network parameters at any given moment, thus system parameters must be reconfigured dynamically responding to the variations of network environment over time (Zanella et al., 2014), where agreement among multi-UAVs is important to improve real-time decision-making (Zheng et al., 2011).

3. Self-healing functions: Self-healing functionality, also termed self-planning to take healing decisions (Albino et al., 2015), monitors the alarms and captures correlated data, e.g. measurements, testing results, etc. to carry out deep analysis that results in triggering appropriate recovery actions as a means of addressing the occurred problem. It then oversees the recovery actions execution and decides the next action accordingly (Yan et al., 2020).

2 COVID-19 Data Collection: Traditional vs. Drone-based Methods

In Kunovjanek & Wankmüller (2021), the authors mention a traditional COVID-19 data collection approach named Vehicle-Based Testing (VBT) used by the state Red Cross Organization, where a mobile testing team, composed of two health care professionals, uses a customized minivan for COVID-19 data collection at patient sites. When arriving, both health workers should wear personal protective equipment which includes a respiratory mask, gloves, and safety glasses. After dressing, the patient is being approached by one healthcare worker and informed about the coronavirus testing process then required data is gathered. Meanwhile, the other health worker stays outside at the minivan and fills out patient-related documentation. Thereafter, both health workers get their potentially contaminated personal protective equipment undressed following a standard procedure to avoid any contact. Subsequently, all equipment items are thrown away after a single use, as they are disposable products, except safety glasses which can be reused after disinfection. After undertaking a complete tour, the final step involves the minivan disinfection, the equipment preparation for the coming testing tour, and taking hygienic measures for the staff.

However, the traditional healthcare system has been revolutionized into a smart healthcare system through the utilization of the latest technology such as the Internet of Things (IoT), cloud computing, big data, data analytics, and many others. Where patient data, both biological and psychological, is remotely collected, registered, stored, analyzed, and transmitted to related healthcare units. Broadly speaking, the smart healthcare system has proven its superiority throughout the outbreak of the COVID-19 pandemic in telemedicine, sanitization, detection of the infected person in the mass population, and recording people's health status (Sharma et al., 2021).

When comparing the abovementioned traditional approach to the drone-based approach, as a smart healthcare system application, the latter is of a better choice when it comes to an infectious disease environment like COVID-19 hotspots, where it reduces the human intervention and thus preventing to some extent the spread of the virus, besides it can reach hard-to-access locations. Furthermore, there is no need to use personal protective equipment during testing operation as there is no direct-contact human involvement in collecting required data from individuals, and hence the cost of the equipment is preserved. Finally, a drone swarm can spread and work in parallel to collect and share the required data with the BS.

3 Related Work

After the development of Information and Communication Technology (ICT), IoT-based systems received great acknowledgment from healthcare application developers (Soltanisehat et al., 2020) as a highly feasible alternative for COVID-19 control. IoT technologies offer a variety of services in such a contagious environment, e.g. telemedicine services, diagnosing coronavirus patients, tracking the coronavirus contamination pattern, and combining the aforementioned services to wearable devices like smart bands, smartwatches, etc. (Abir et al., 2020). Drones, as carrying platforms of IoT payload sensors, are used for fighting against COVID-19 by various means such as vigilance, monitoring, thermal scan, sanitization, medicine delivery, food delivery, ensuring social distance, and alert system (News, 2021; Dukowitz, 2020), where most developed countries support the drone-based approach because it offers a safe way to help humanity (Kumar et al., 2021).

Drones can be used for providing communication coverage as the authors in (Patchou et al., 2021) suggest, where their proposed approach offers several services like reliable communication links establishment and maintaining between certain ground vehicles, assigning and distributing last-mile COVID-19 supplies delivery jobs, and mobility control and path planning. Similarly in Elbir et al. (2020), the authors integrate UAVs into the vehicle-to-vehicle communication architecture, in a COVID-19 lockdown situation, so the health status of passengers inside ground vehicles, e.g. cars, can be delivered steadily to the health workforce, where drones operate as message relays for the communication link between ground vehicle, and in the event of an accident, they arrive nearby and gather information from close vehicles. Furthermore, a hybrid vehicle delivery system is proposed in Soni & Gangwar (2021) that uses both ground vehicles and UAVs for delivery during the COVID-19 pandemic, and the collaboration between vehicles is achieved by organizing and maintaining stable communication links and also mobility control.

For surveillance and public statements, the authors in Elbir et al. (2020) proposed the fly of UAVs over a congested area for social distance monitoring. Additionally, in Soni & Gangwar (2021) drones with equipped surveillance cameras and loudspeakers are used to inform people about the guidelines in case of emergency. Moreover in India, the authors of Kumar et al. (2021) used a drone-based system for monitoring social distancing and telling individuals the right way to wear a mask, similar to Dronethusiast (2021), where a preprogrammed flight routes UAV is utilized for mass monitoring and quarantine zones reinforcement, and the operator is notified if social distancing regulations are not followed.

Showering of disinfectants is another area where UAVs can participate similar to sprinkling pesticides in agriculture (Soni & Gangwar, 2021). The authors in Joshi et al. (2020) show that South Delhi Municipal Corporation (SMDC) in India deployed drones to sanitize COVID-19 hotspots by spraying a disinfectant containing 1% sodium hypochlorite solution. A simulation study by the authors of Sharma et al. (2021) considers statistics about drones for outdoor sanitization with variations in the number of drones, periods, and the percentage of individual drone utilization, unlike the authors in Manigandan et al. (2020) who utilized a real drone with a disinfect tank for sanitizing indoor and outdoor environments as needed.

For delivery missions, authors in Kunovjanek & Wankmüller (2021) investigate the capability of drones for distributing viral tests to possibly infected patients using existing drone infrastructure where UAVs owned and operated by multiple public and private bodies are modified for delivering basic necessities in the case of emergency. Another study is made for automated drone-based food and parcels delivery for residents during long curfews regardless of their infection status (Kellermann et al., 2020). Delivering life-saving medicines in faraway hospitals using drones is investigated in Mesar et al. (2018). The authors in Khan & Javaid (2020) proposed an automatic coronavirus emergency response system to deliver primary supplies at minimal transportation cost based on a combination of blockchain and a multi-UAV network.

UAVs can take part in data gathering and temperature screening during the current outbreak of COVID-19, wherein Mohammed et al. (2020) an Arduino-based drone with mounted optical and thermal cameras is built to collect people's temperature and face information while in operation. Meanwhile, the cameras transmit live video to a smartphone located inside Virtual Reality (VR) glasses worn by the pilot. Another study investigates what so-called pandemic drones, which are remotely steered aircraft systems created by a Canadian aircraft manufacturing company named Dragonfly, that are used in combating COVID-19 to further assist in improving emergency response time, health status monitoring, and infectious and respiratory issues detection, e.g. measuring body temperature, and heart and respiratory rates (Joshi et al., 2020). Also, the authors of Kumar et al. (2021) discussed the drone's real-time data gathering process from wearable sensors, movement sensors, cameras, thermal scanners, where UAV is considered as an edge intelligent to process data and avoid collisions.

Drone-based systems can provide a mixture of services that facilitate the fight against COVID-19 spread, as in Singh et al. (2020) where the authors study the possibility of creating a UAV-based method that can offer multiple services like testing, contact tracing, sanitization, protocol enforcements, and spread analysis. Also, the authors in Kumar et al. (2021) analyze coronavirus conditions along with drone-based methods and came up with a UAV-based healthcare system architecture that suits several COVID-19 handling situations, and is applied in both real-time and simulation-based scenarios providing surveillance, announcement, live video communication, sanitization, thermal image capturing and patient identification for large areas. Table 1 shows a comparative study.

All the COVID-19 combating drone-based system applications and case studies reviewed in this paper and several other similar papers highlight the fact that the possibility of using UAVs in the healthcare sector could reduce response time effectively and overcome natural restrictions. Still, when it comes to a UAV-based smart healthcare system design and creation, it is important to holistically consider the problem to be solved, medical professionals, patients, database, way of communication, and drone manufacturers. In the proposed work, we assume a drone swarm is launched and autonomously fly and reach a nearby neighborhood to detect COVID-19 suspicious cases and send related data, including health measured data, GPS coordinates, person's identification (ID), etc., to the BS for further investigation.

Table 1: A comparative analysis of the proposed approach with existing drone-based systems for COVID—19 response

Authors	**Year**	**System type**	**Features**								
			A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Mohammed et al. (2020)	2020	IoT-based drone system for COVID-19 detection	✓				✓		✓		
Manigandan et al. (2020)	2020	Drone detection of COVID-19 with no human interventions	✓					✓			
Soni & Gangwar (2021)	2020	UAS for consumer utilities in COVID-19 pandemic								✓	✓
Elbir et al. (2020)	2020	Vehicular Network for combating the spread of COVID-19							✓		✓
Sharma et al. (2021)	2021	Drone delivery dynamic models in COVID-19 hotspots	✓					✓		✓	
Patchou et al. (2021)	2021	Drone-based efficient parcel delivery during COVID-19								✓	✓
Alsamhi et al. (2021)	2021	Blockchain for multi-drone to combat COVID-19	✓					✓	✓	✓	
Kumar et al. (2021)	2021	Drone-based network for COVID-19 operations	✓		✓	✓	✓	✓	✓		
Proposed Work	2021	Drone swarm as a PHC in COVID-19 hotspots	✓	✓	✓	✓	✓	✓		✓	

Features: A: Covid-19-related Data Collection, B: Multi-level Classification, C: Announcement, D: Person Identification, E: Real-time Video Communication, F: Sanitization, G: Surveillance, H: Delivery, I: Communication Relay.

4 Design Methodology

WHO guidelines for combating COVID-19 disease are followed in this study as a theoretical basis of the designed multi-drone system to meet the general requirements in the service. Following the WHO guidelines Organization (2020a,b), the main elements of the required healthcare services for the fight against the COVID-19 pandemic are:

1- Primary screening and triage: Screening and isolation of all suspected COVID-19 once in contact with the healthcare system to allow for proper prevention and control actions.

2- Prevention and control: Isolation prevents viral transmission from a person susceptible to exposure to an infectious disease. Quarantine may be at home rather than a hospital for a suspected COVID-19 person who is not in urgent need of medical attention.

3- Traceability and privacy: The virus could be transmitted via direct or indirect physical contacts, so contact tracing is essential to identify people who may have had exposure to a confirmed COVID-19 patient and trace all possible contacts. Also, the patient's privacy should be maintained to avoid any discrimination against the patient or his/her family.

4.1 The Proposed Platform Specifications

Many researchers have adopted a commercial multi-rotor UAV as a platform, which is the DJI Phantom Pro v2, for different applications (Heincke et al., 2019; Vasuki et al., 2014; Kirsch et al., 2018; Honarmand and Shahriari, 2021) and hence it is selected as the drone of choice in this research. A network of autonomous commercially available DJI Phantom Pro v2 quadcopter drones creates aswarm consisting of one Leader Drone (LD) and many Slave Drones (SDs), specifications are illustrated in table 2 (DJI Company, 2022), also it is assumed that each drone to be fitted with two IoT Wi-Fi modules to control the drone flight and enable network capability as explained in Harrington (2019), and SDs can communicate with the LD as well as transmitting, receiving and reacting to flight control codes to implement any required flight plan. Additionally, the fifth Generation of cellular networks (5G) is used by the LD as in Abir et al. (2020) for long communications i.e. the base station. Therefore, the LD needs to be more powerful and durable than other SDs so it is assumed to have a double battery capacity, which can be done by soldering another battrey in parallel to the existing one.

Table 2: Specification of the DJI Phantom Pro v2 drone

Aircraft and Camera	Weight: 1375 g, Diagonal Size (Propellers Excluded): 350 mm, Max Ascent Speed: S-mode: 6 m/s, P-mode: 5 m/s, Max Descent Speed: S-mode: 4 m/s, P-mode: 3 m/s, Max Speed: S-mode: 45 mph (72 kph), A-mode: 36 mph (58 kph), P-mode: 31 mph (50 kph), Max Wind Speed Resistance: 10 m/s, Max Flight Time: Approx. 30 minutes, Satellite Positioning Systems: GPS/GLONASS, Hover Accuracy Range (with GPS Positioning): Vertical: $B \pm 0.5m$, Horizontal: $B \pm 1.5m$, Camera Sensor: 1-inch CMOS, Effective pixels: 20M, Max Video Bitrate: 100Mbps, Supported SD Card: microSD, Capacity: 128GB.
Infrared Sensing System	Obstacle Sensory Range: 0.6-23 feet (0.2-7 m), FOV: $70B°$ (Horizontal), $B \pm 10B°$ (Vertical), Measuring Frequency: 10 Hz, Operating Environment: Surface with diffuse reflection material, and reflectivity ¿8 percent (such as wall, trees, humans, etc.)
Intelligent Flight Battery	Capacity: 5870 mAh, Voltage: 15.2 V, Battery Type: LiPo 4S, Energy: 89.2 Wh, Net Weight: 468 g, Charging Temperature Range: $41B°$ to $104B_{\circ}F$ ($5B°$ to $40B°C$), Max Charging Power: 160. W

Furthermore, each drone is equipped with a Raspberry Pi 4 that has its own battery and is connected to sensors like a body thermometer; oximeter, motion detection, ID scanner, and a microphone and a loudspeaker for human interaction, and also solar energy panel for recharging the battreries while in mission.

4.2 Drones Network Architecture

The gathered data is initially processed at the drone level then shared with upper-level systems for further detailed processing and/or database storing. In our approach, we assume to have three operational levels; drone level, local clinic level, and general hospital level. Firstly, drones collect COVID-19 related data from people and determine individual status then act accordingly. They also obtain one's ID for identification and include it in the status report along with GPS coordinates and housekeeping data, e.g. battery status. After testing, a triage algorithm classifies the given data into classes; if a person is healthy or showing insignificant COVID-19 symptoms then it is considered as a safe case and given protection instructions. However, if the test results indicate that the individual is highly suspected to be infected then the local health center will be alarmed and will check the local medical records of that patient and take proper action, such as having a live video call with the patient for getting more information, and if it needs further help, i.e. an emergency case, it will consider informing the general hospital about the case for further investigation. The general hospital, in turn, has specialist doctors who have access to the general medical record database and study the patient's case to take the best possible action, e.g. holding a video conference, prescribing a medication available on the drone, or sending an ambulance, figure 1 shows an overview of the proposed system architecture.

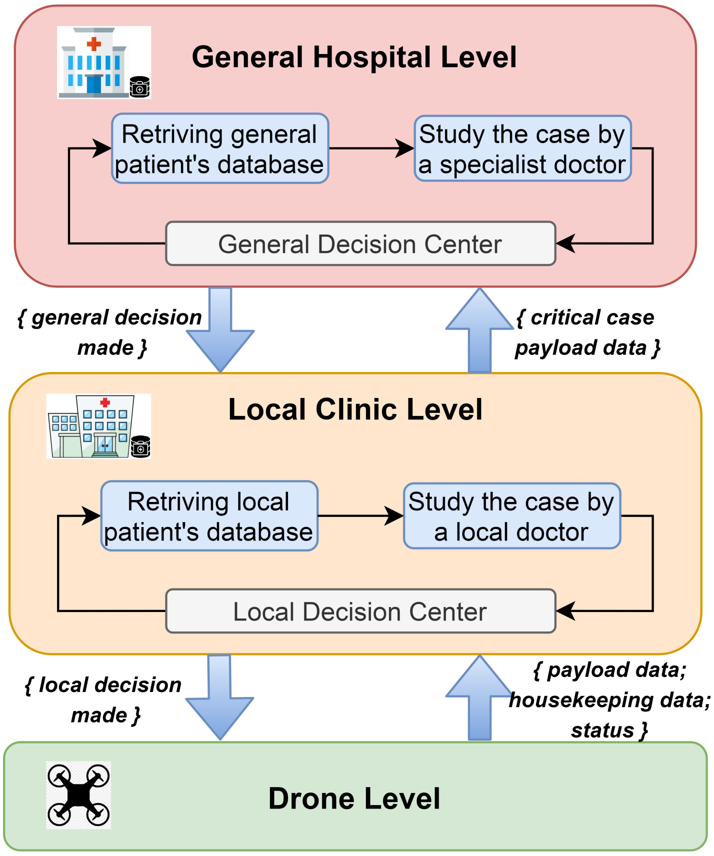

Figure 1: Overview of system architecture

The proposed approach has several architectural levels, or layers, which makes it scalable in a hierarchical and controlled manner as shown in figure 2. Starting with the drone level which is comprised of slave drones (SDs) and the leader drone (LD). SDs collect COVID-19 related data and identify persons using onboard sensors then a case status report is created and forwarded to the LD, which acts as a swarm sink node and is connected to the local clinic level where the BS and drone operators are located.

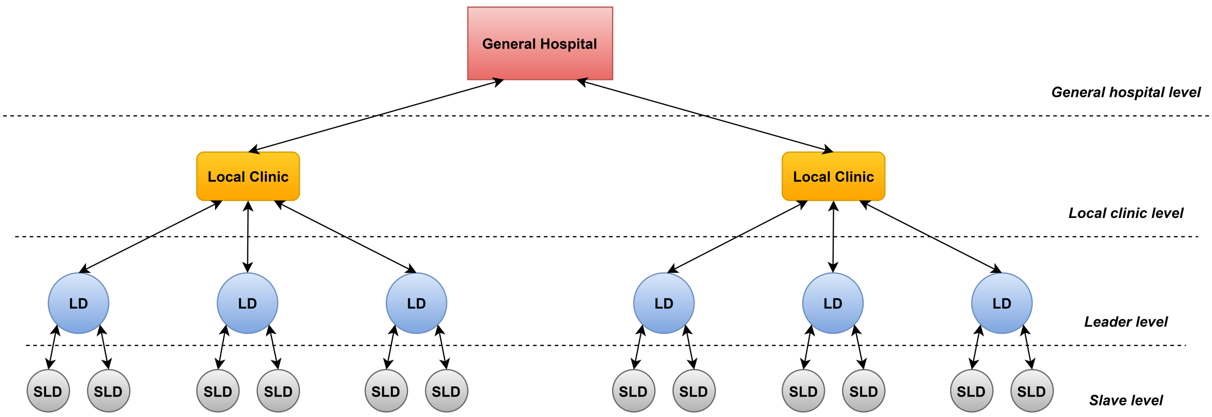

Figure 2: System layered architecture

At the local clinic level, a local clinic can run and manage multiple scanning operations in nearby areas simultaneously by deploying several drone swarms each for a specific neighborhood, and if any critical case is found to be beyond the local clinic's capability to handle, then it can call the general hospital for help. Therefore, a local clinic acts as a sink node for the drone swarms as it is connected to a higher level, which is the general hospital level.

The general hospital level is the highest level in the proposed architecture. The general hospital, which is specialized in COVID-19 infection control, treatment, and quarantine, has the best available services for COVID-19 containment in town including specialist doctors, medical equipment and supplies, and a united database for all patients in the city. The general hospital, as a central management unit, supervises local clinics' operations and can intervene to diagnose emergency cases reported by local clinics upon their request.

4.3 Key SON Functions

In general, improving multi-UAV network performance could be realized by implementing SON functions, where the more SON functions being used the better performance is gained at the expense of complexity and cost Jorguseski et al. (2014). However, the decision on which SON functions to include in this paper was based on the design simplicity and low cost. Therefore, only essential and most relevant SON functions to the suggested PHC platform scenario are selected. These SON functions are classified based on the phase of operation including:

4.3.1 Self-configuration SON Functions

•**Automatic generation of default parameters for newly inserted NE:** For introducing a new NE, several different types of parameters need to be assigned such as (Scully et al., 2008):

- Network and security parameters: including Internet Protocol (IP) address, server addresses, certificates.
- Software parameters: such as software version.
- Hardware-specific parameters: as firmware and required drivers.
- Radio network-specific parameters: such as node parameters, neighbor relationships, transmission power, etc.

•**Network authentication:** Mutual authentication of node and network is needed during the self-configuration phase especially when deploying new network elements, e.g. to assure the node is connected to the right network, and to prevent the misusing of home BS for network intrusion (Scully et al., 2008).

4.3.2 Self-optimization SON Functions

•**Congestion control parameter optimization:** The congestion control technique monitors network load, detects overload cases, measures the urgency degree of the overload conditions, and makes appropriate responses for bringing the system back quickly to a feasible load situation in a controlled manner (Scully et al., 2008).

•**Packet scheduling parameter optimization:** It manages the access to shared channel resources to optimize resource efficiency while meeting QoS requirements. Distinctive network traffic features and QoS requirements fulfilling interactive, streaming, and background services highly complicate this (Scully et al., 2008).

•**Reduction of energy consumption:** Previously, wireless networks design's main goal was to improve spectral efficiency maximizing data rates with a given spectrum. However, lately, energy cost is one of high interest in the public, especially when it comes to drones' hardware limitations. Therefore, energy efficiency must be considered, e.g. minimizing the energy consumed by UAVs as much as possible (Scully et al., 2008).

4.3.3 Self-healing SON Functions

•**Cell outage prediction:** It estimates which node is a candidate for outage based on different measurements and provides information about the outage expected time, likelihood, scope, and type, then it reports the estimation to the cell outage detection function for further processing of the possible causes (Scully et al., 2008).

•**Cell outage detection:** An outage should be detected within an adequately short time, e.g. minutes, to respond effectively. The outage detection report may include (Scully et al., 2008):

- The node ID for the malfunctioned node.
- The scope of the outage, e.g. the whole node or only certain functionality.
- The type of the outage, e.g. hardware or software failure, sensor or radio part, etc.

•**Cell outage compensation:** Network performance degradation reduction in the case of the failed node is achieved by autonomously adjusting network parameters to maximize performance and coverage as well as fulfill mission requirements to the largest possible extent (Scully et al., 2008).

4.4 Security Concerns

The proposed drone-based smart healthcare system aims to obtain individuals' coronavirus-related information using drones then transmit it to upper-level health units remotely. However, data processing, security, and privacy concerns need to be taken into account for successful considerations/implementation. Therefore, a secure tunnel, that uses end-to-end data encryption, can be utilized in data collection and transmission as only authenticated nodes can receive the data. UAV's data collector applies cryptographic primitives and protocols to secure data transmission and storage. In the proposed scenario, status reports are sent from drone level to local clinic level automatically; while a manual transmission of data is done between the general hospital and local clinics. All data is transmitted using an end-to-end secure data sharing tunnel.

5 Results

5.1 Redesigned PHC System for Combating COVID-19

A Portable Health Clinic (PHC) system, shown in figure 3, has been developed as a Remote Healthcare System (RHS) for the COVID-19 basic test during a full lockdown. The control strategy of large-scale and prolonged lockdowns is bound to complicate the management of the COVID-19 testing process, where people are not allowed to visit local clinics or hospitals for testing, and thus there might be suspected or already confirmed COVID-19 patients that are not aware of carrying the virus and might be spreading it to family members unintentionally. Therefore, there should be a mechanism to test these individuals during the imposition of a full curfew, especially prolonged ones. However, to the best of the authors' knowledge, to this day, still no scholar study the possibility of providing an automated COVID-19 testing service to the mass at their doorsteps during curfew situations with reduced human intervention, i.e. employing a multi-UAV network as a PHC platform for COVID-19 testing, and report critical conditions to local/general hospitals for further investigation/reaction.

Hence, the uniqueness of the proposed approach is that the PHC platform is fully automated and delivers the COVID-19 testing service to one's doorstep during a full curfew. Furthermore, it suggests an algorithm to categorize patients' conditions to a multi-level of seriousness, as well as the whole system is designed to be scalable with a hierarchy distribution of roles. The main five elements of the suggested approach are:

1. The PHC payload, which consists of the required sensors and instructions for the testing process as well as essential COVID-19 medicine to be delivered as used when needed.

2. The multi-UAV network, which acts as a portable platform and transmits the needed information to the local clinic, or BS.

3. The person/patient at home during a full curfew to be tested.

4. The local clinic with general practitioners/doctors and local medical database, also it is considered to be the BS for the drone swarm with a drones operator.

5. The general hospital in the city is the best-equipped place with human and medical equipment resources for COVID-19 containment, i.e. specialist doctors, medicine, infection control, treatment, and quarantine.

As shown in figure 3, it is assumed that the UAV-based PHC system starts with equipping the drone swarm with required testing sensors at the Base Station (BS), or local clinic. Then self-configuration including coordinate processing is conducted during a startup phase. After take-off, the drones perform a vertical ascent up to a given maximum altitude, fly horizontally to the destination area, and then descend vertically before landing at the designated spot. Afterward, one approaches a particular drone and conducts the required steps for self-testing under the instructions provided by the UAV then leaves the drone-landing zone.

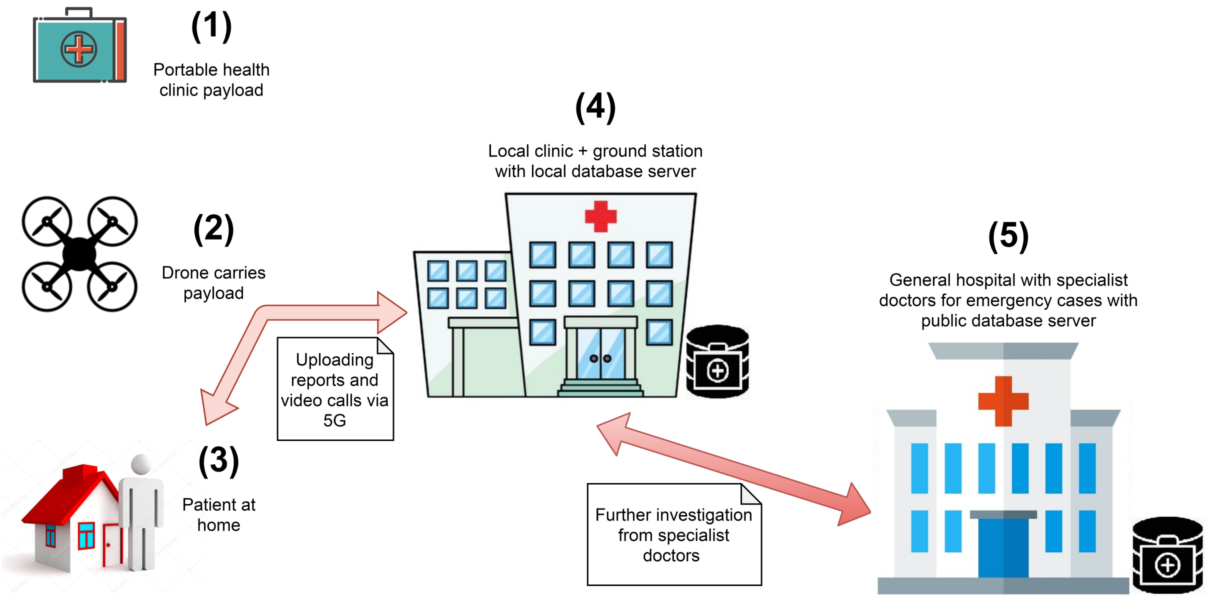

Figure 3: Portable Health Clinic (PHC) system operational procedure.

The PHC system introduces a triage system to classify the subjects in four categories, so the obtained test information is being analyzed and if the case is infected then the local health center is being informed for further investigation where the general hospital assistance might be needed, and the patient may be advised to take some medicine off the drone. When a drone is done with one house, it moves to another and the same procedure is repeated till all the specified area is scanned then the swarm of drones flies back safely to the BS.

5.2 The Roles and Responsibilities of the proposed PHC System Units

In the suggested scenario, the roles and responsibilities of PHC system units are distributed hierarchically for the ease of management and scalability and are described below:

5.2.1 The Local Clinic (or BS) Roles

The BS is located within the local health center, nearby the neighborhood to be scanned, and has the drone swarm(s) as a PHC platform fully equipped with the required payload, i.e. sensors and drugs for basic COVID-19 testing and mitigation. Also, there is a drone network operator that initiates the drones with essential mission data such as GPS coordinates, flying speed and altitude, swarm size in terms of the number of involved drones, etc. through a server dedicated to swam initialization phase. The drone operator should always have the ability to intervene in the autonomous UAV system and manually give orders to drones as if required.

Additionally, the local clinic itself has medical staff members, general doctors, and practitioners, as well as local patients' records in the local database. When the swarm is flown, the BS keeps getting periodic information of the swarm status through the leader drone and if it receives a report of an infected patient, the health worker retrieves the patient's database and study the case and either make a video call with the patient or escalate the case to the general hospital if it is an urgent one and beyond the local clinic capabilities. He also carries a contact tracing and identifies potentially infected contacts. Once the mission is ended, the BS waits for the drone swarm to come back where the drones are being disinfected and prepared again for future tours. In case of failure and one drone is gone missing, the BS will be reported with drone ID, last GPS coordinates, time of loss, etc. to respond accordingly.

5.2.2 The Slave Drone Roles

Slave drones in a drone swarm generally have identical payloads, e.g. sensors and drugs, and mission procedures. When a slave drone is chosen to be in the team, it is notified to update certain parameters through the self-configuration phase including, for example, the required network configuration, authentication with the leader drone, obtaining swarm flying parameters such as speed, altitude, swarm member ID that can be used for positioning in the formation and future communications, and destination GPS coordinates.

When the swarm is ready to fly, a slave drone performs a vertical ascent up to a given maximum altitude in a formation taking the leader drone as a reference and positions itself within the swarm according to its ID to avoid colliding with other drones. When reaching the destination area it lands according to the assigned coordinates then it enters the power-saving mode by switching off unneeded functions, e.g. turning off propellers. A slave drone provides the leader drone with mission status periodically.

The slave drone is now ready to deliver the testing service to residents so after reaching the intended house it makes a certain sound to inform the householder of its presence, and senses the person's approach through a mounted motion detection sensor. Then it gives guidance instructions on how to get required measures, such as the body temperature, heart rate, and the oxygen saturation of the blood, a detailed primary screening process is shown in figure 4. After testing, the slave drone sanitizes the oximeter for the next test. Then the ID of the tested person should be scanned, i.e. passport or national ID. After the test completion of one person, a test results report is sent to the leader drone. If the case requires more attention, a video call is placed between the patient and a remote doctor and is handled through the slave and leader drones. Then the same procedure is repeated for other family members and when all are tested, the slave drone flies back near the leader drone and puts itself in idle mode, waiting for further instructions from the leader drone.

During the mission, all implemented SON functions are in operation as part of the system. For example, in case of a slave drone failure expectation, e.g. battery is being noticed to run down soon, the self-healing SON procedure will take place by reporting status to the leader drone, aborting current task, then flying and landing nearby the leader drone and going into idle mode. In the meantime, the mounted solar panel keeps charging the drone's battery.

5.2.3 The Leader Drone Roles

The leader drone first gets the required network configuration and mission information from a dedicated server in the BS during the self-configuration process, then it authenticates the slave drones to create a swarm. Also, it obtains a full map of GPS coordinates of the destination area, which is divided into strips or sub-areas where each street is considered as a sub-task of the mission. Then the leader drone starts taking off leaving the BS followed by the slave drones. After that, it chooses the coordinates of the center of the first street as a destination and assigns relevant GPS coordinates for each slave drone to land at; technically each slave drone is responsible for testing individuals of one house for a given street.

When the leader drone reaches the destination GPS coordinates, it lands vertically on the required spot of that street in the middle of the line formation of the swarm by having five slave drones on each side creating the least distance between itself and the furthest slave drone for better communication. After landing, the leader drone enters the power-saving mode by turning off unnecessary functions, i.e. turning off propellers. The leader drone collects the status of slave drones periodically and sends a periodic report of the mission to the BS, it receives each completed test report and applies a COVID-19 triage process (CT-process) on the measured data to classify the seriousness of the case into four categories, as mentioned in table 3, which are; healthy or green, suspected or yellow, confirmed or orange, and emergent or red. If the case is marked with green or yellow, then only precaution instructions are given automatically by the slave drone through the loudspeaker. However, if the subject is labeled with orange or red then it might need a doctor's consultation, so the leader drone sends an urgent report, high priority is given by SON packet scheduling function, of the infected case to the BS including test data, patients ID, and patient GPS coordinates. Then if needed, a live video call is established between a local clinic doctor and patient through the leader and slave drones.

After all slave drones are returned nearby the leader drone, the latter takes off to the next street to be scanned using pre-given GPS information followed by slave drones and the same process of deploying and testing starts again. Later, when all the area of the mission is being scanned, the leader returns to the BS (drone homing) in a formation with other slave drones. The leader drone may receive a cell outage prediction report which may involve a slave drone aborting its current task, or even figure out a cell outage through periodic mission status reports, in both cases it needs to compensate the loss by re-scheduling the tasks among remaining slave drones, along with reporting the situation to the BS.

5.2.4 The Person Being Tested Roles

During a full curfew, the people of the area to be scanned are already being informed by media for the drone swarm visit for COVID-19 testing, so residents are expecting such a visit. When a person hears a drone certain sound, he/she goes out on the street and tries to approach the slave drone. Then the drone shows how to follow a certain procedure to get the measured data, i.e. having a person's palm in front of the body temperature sensor and finger on the oximeter scanner. Afterward, the person should scan a document proving his/her identity, like a passport or national ID. Then the person leaves the drone area back home and calls for another family member for testing if any. If the given test data is classified as infected or emergent (orange or red labels) then a live video call from a remote doctor is expected with the infected person.

5.2.5 The General Hospital Roles

The general hospital is considered the top-level in this approach and can supervise multiple local clinics at once. As the last resort of this scenario, it should have the best available specialist doctors and medical equipment for COVID-19 treatment and containment. When an infected case cannot be handled by a local clinic; due to a shortage of specialist doctors, databases, or medical equipment, the case is transferred to the general hospital for further verification. The decision is made by specialist doctors based on the patient's database, current case, and available solutions to handle the case, e.g. advising the patient to be quarantined at home via a video call or send an ambulance in case of real emergency for the treatment and quarantine at the hospital. The general hospital also performs contact tracing with keeping the privacy of the patient.

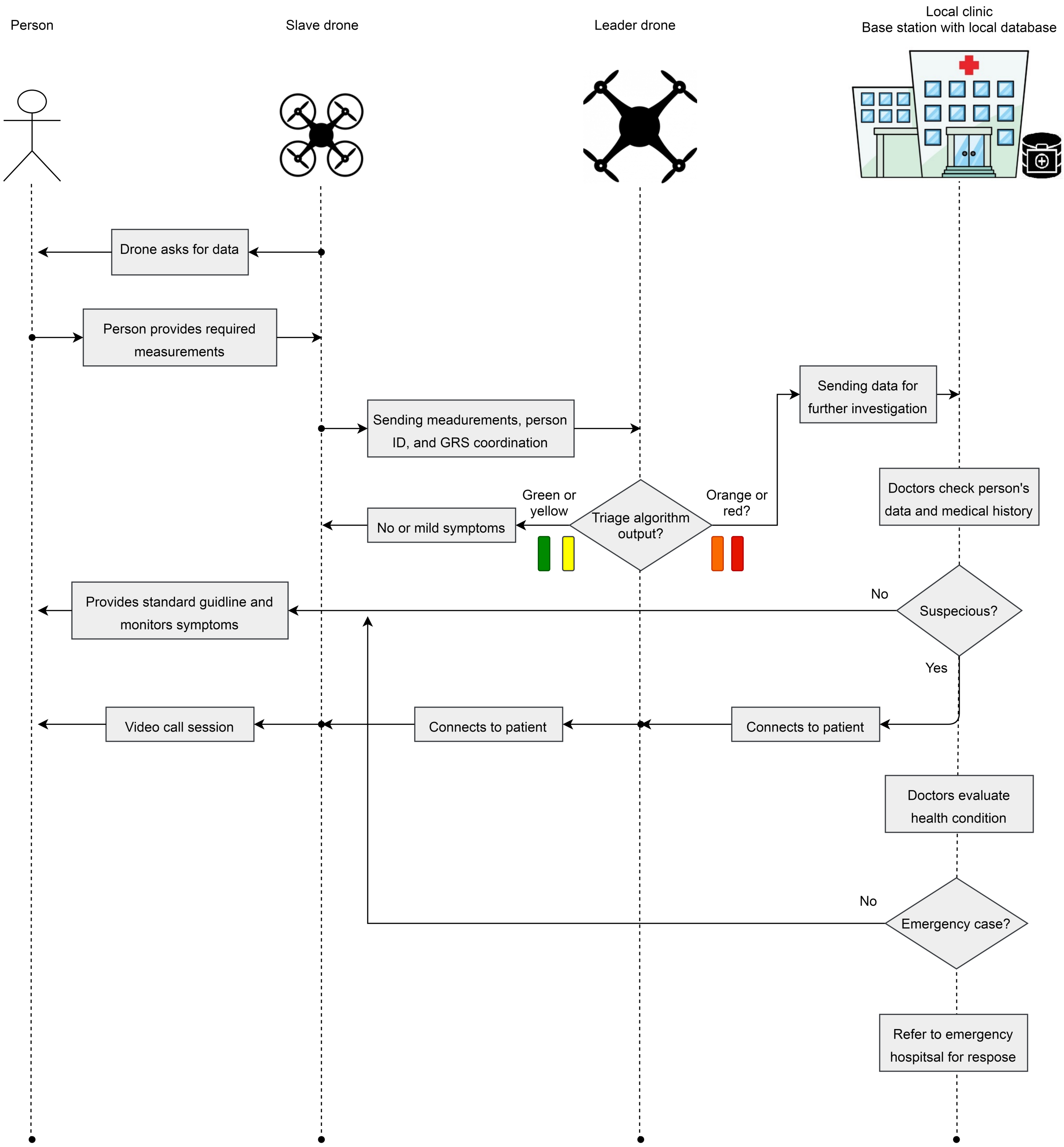

Figure 4: Primary screening and triaging process for COVID-19.

From the aforementioned roles and responsibilities, two operational modes can be concluded for the drone swarm, namely; the dynamic (flying) mode and static (fixed) mode. Where the dynamic mode is when there is high network mobility during flying. On the contrary, the static mode is when the drones are landed with no mobility and entered the power-saving mode.

Table 3: COVID-19 triage process (CT-process) designed for the proposed PHC system

No.	Symptoms	Healthy /Green	Suspicious /Yellow	Infected/Orange (consultation)	Emergent/Red (emergency)
1	Fever	< 37.5	≥ 37.5	≥ 37.5	≥ 37.5
2	SpO2 (%)	$\geq 96\%$	$\leq 95\%$	$\leq 95\%$	$\leq 95\%$
3	Heart Rate	≤ 76	> 76 & < 84	≥ 85& < 90	≥ 90

6 Case Study

The proposed UAV-based PHC platform is applicable for COVID-19 hotspot areas, like the one in the suggested scenario.

6.1 The Suggested Scenario

As COVID-19 is being spread worldwide, the suggested scenario is not limited to a certain area or country. The proposed scenario considers a nearby neighborhood, which is a housing complex called Ashti City, shown in figure 5, and it is located in Erbil – Iraq with GPS coordinates latitude $N\,36B°10'31.4693''$ and longitude $E\,44B°7'27.73828''$, with an altitude of 528 m a.s.l as a case study and it assumes that this area is a COVID-19 hotspot and a full lockdown has been imposed by authorities to avoid spreading the virus, which actually was the case in May-June 2020. The neighborhood area dimensions are about 840 meters in width and 1100 meters in length making a rectangular shape with an area of around 0.924 km2 that is divided into 4 sections and includes 1520 houses in total with an average area of 250 m2 per house, the width is about 12 meters and length is around 21 meters (ESKAN, 2021). The nearest local health center is located about 1 km away from the neighborhood and is assumed to be the local clinic and the Base Station (BS) for drones and contains a database server as well.

6.2 The Proposed PHC Platform in Operation

As a consequence of being under a full curfew, house landlords with their families are staying at home. Meanwhile, it is required to scan all the people in the district for COVID-19 and find suspected and infected cases in the area with minimal, optimally zero, human intervention to avoid the risk of infection. Therefore, a drone swarm consisting of one leader drone and ten slave drones is being activated and it autonomously gets the required initializations, i.e. destination GPS coordinates, network configurations, and swarm flying parameters such as speed (assumed 30 km/h or 8.3 m/s), altitude (assumed 10 meters above ground level) and launched from the nearby local health center heading to the destination area to perform the needed COVID-19 scanning on people there.

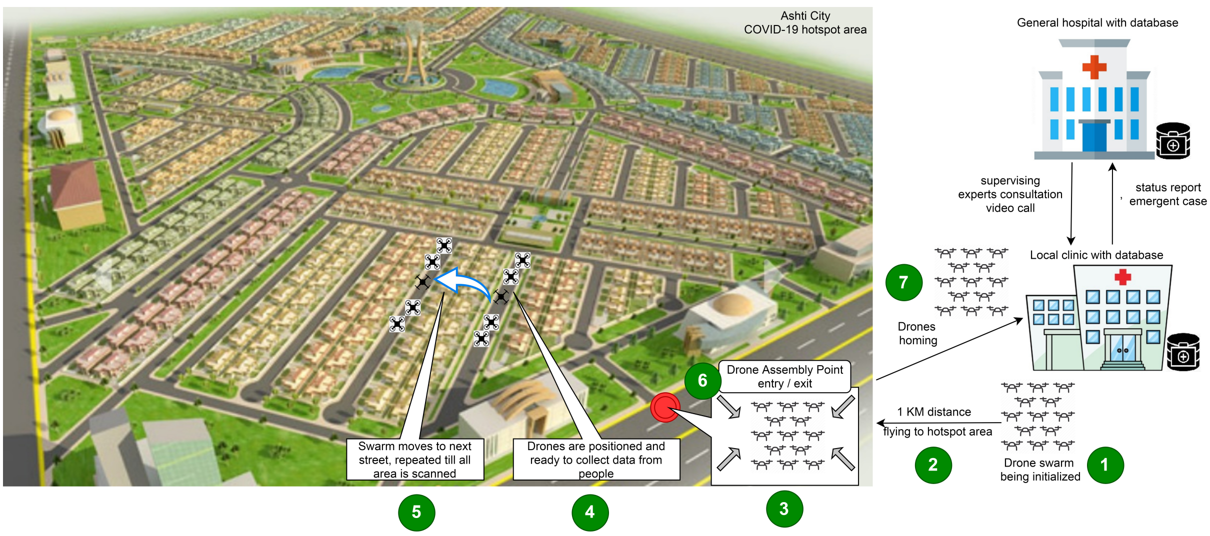

Figure 5: A simulated housing complex map for Ashti City showing the drone swarm in operation.

Figure 5 illustrates the steps of the swarm moving on the area map. During the flight mode, where the mobility is high, the drones use their IDs for the formation and not to collide with other drones (the distance assumed between drones is 1 meter during flight). The neighborhood is divided into many sections or strips, technically streets, for organizing the scanning process. Once the drones land on a street (technically the swarm is 12 meters apart when landing on street in front of houses' front doors as each house has 12 meters of width), they are in the fixed mode with no mobility so they enter the power-saving mode. During the mission, periodic status reports are created and sent from the slave drones to the leader drone and from the leader drone to the BS (assumed every 10 seconds). After all slave drones complete testing, they move nearby the leader drone, and then the next street is scanned. When all area is scanned, the swarm moves to the assembly point and fly back to the BS, where drones get disinfected and prepared for the next flight. Health professionals from the local clinic and general hospital may be needed depending on the case urgency that is classified by the COVID-19 triage process (CT-process).

7 Discussion

During public health emergencies like the COVID-19 pandemic, deploying the PHC and other related RHS technologies in regions under curfew is helpful in terms of minimizing the risk of the virus transmission to frontline healthcare professionals. Furthermore, the stress on frontline medical staff will be reduced with employing such RHS as there will be no direct contact with COVID-19 patients, where the effective physical separation between health workers and patients is achieved affecting care quality or response reliability. Also, avoid crowded places where there is no need for people to come in person to clinics/hospitals which supports preventing to an extent the speared of coronavirus.

8 Limitations and Future Work

Despite having so many advantages, UAV-based RHS also poses challenges and have some shortcomings and concerns that need to be overcome for further enhancements. Some of the real-time drone-based RHS limitations include (Sharma et al., 2021; Kumar et al., 2021; UNICEF, 2020):

1. Privacy concerns: People may feel worried about the surveillance conducted, and the gathered data might be used for improper purposes.

2. Regulatory issues: Authorized bodies are needed to issue flight clearance licenses before making each flight, and this often appears as overhead in case of emergency.

3. Suboptimal performance when fully automated: Such as multi-UAV network should manage to find the optimal path as obstacles may change during the flight.

4. Meeting performance and QoS requirements: Especially for UAVs, where many resource constraints are found when capturing medical data from onboard sensors.

5. Limited energy supply: Solar-based charging system is needed to alleviate this issue.

6. Appropriate financial and human resources: To carry out a drone-based PHC mission, there is a need to have drone technology available when required either by service contracts or through permitting local organizations to launch drone operations.

7. Local sensitization of communities and stakeholders: This is needed before and during the UAV-based PHC implementation for informing the public and increasing awareness about this technology, ending up with ensuring local social and political acceptance.

8. Drone integration into the health supply chain: Should consider the problem that UAVs are solving and their purpose of use, and also figuring out whether drones are the cost-efficient alternative to be incorporated with current healthcare system modalities.

Research challenges are also presented when evaluating the drone network performance, which should be measured concerning usability, technical performance, the efficacy of the system, and system acceptance by the user. In general, full acceptance for common daily use even in the healthcare sector is still very low (Sharma et al., 2021). Even though the proposed UAV-based

PHC system assists in the fight against the COVID-19 pandemic, it can be further improved considering the following aspects:

1. Large scale medicine delivery: The possibility of wide medicine delivery with various collision-resistant strategies can be studied considering infrastructure constraints.

2. Citizens' records and scanning: To ensure that resident in an area is scanned. Even though resident records are kept by the resident welfare association, many individuals may reside outside resident societies as well.

3. Large mini-drones deployment for indoor operations: The suggested approach has drones performing scanning people on streets in a residential area. However, multiple mini-drones are needed to conduct indoor scanning operations, e.g. in the case of elderly and disabled residents.

4. Large scale integration of medical infrastructure: To create fast monitoring and data collecting systems which is capable of gathering long distant patient data and offering large scale services, with the consideration of environmental issues and other limits in flying UAVs, capturing data, and maintaining the data security according to government policies.

9 Conclusion

PHC systems offer an inexpensive, usable set of portable sensors to transfer clinical data to a remote doctor to make an accurate decision. This paper touched upon relevant existing and future public health implications arising from the coronavirus spread. It presented an overview of how some drone-based initiatives have been developed to handle the situation. Our proposed PHC platform and its related methods is a leading contributor to public health responses particularly for residents in prolonged curfews and suggest a strong possibility of positive impact. In this paper, we redesigned the current PHC platform as a means to contain COVID-19 spread, as well as suggested a COVID-19 triage process (CT-process), that classifies the patients on whether they need to be connected on a video call to a doctor and moved to a clinic for further inspection and treatment, by considering and analyzing the main symptoms of COVID-19, such as fever, fast heartbeat, and saturation of oxygen in the blood. Additionally, the proposed approach allows for the delivery of essential coronavirus mitigation drugs. As mentioned in the previous sections, the suggested method minimizes the COVID-19 transmission risk and reduces psychological stress on frontline medical personnel, and maximizes the availability of healthcare resources to be used by patients who are most in desperate need of them.

References

Abir, S., Islam, S.N., Anwar, A., Mahmood, A.N., & Oo, A. M.T. (2020). Building resilience against covid-19 pandemic using artificial intelligence, machine learning, and iot: A survey of recent progress. *IoT*, *1*(2), 506–528.

Albino, V., Berardi, U., & Dangelico, R.M. (2015). Smart cities: Definitions, dimensions, performance, and initiatives. *Journal of urban technology*, *22*(1), 3–21.

Alsamhi, S., Lee, B., Guizani, M., Kumar, N., Qiao, Y., & Liu, X. (2021). Blockchain for decentralized multi-drone to combat covid-19. *arXiv preprint arXiv:2102.00969.*

Alsamhi, S.H., Almalki, F.A., Ma, O., Ansari, M.S., & Angelides, M.C. (2019). Performance optimization of tethered balloon technology for public safety and emergency communications. *Telecommunication Systems*, 1–10.

Alsamhi, S.H., Ansari, M.S., & Rajput, N.S. (2018). Disaster coverage predication for the emerging tethered balloon technology: capability for preparedness, detection, mitigation, and response. *Disaster medicine and public health preparedness*, *12*(2), 222–231.

Andreas, H., Joel, M., Yang, G., & Isaac, C.-H.F. (2020). If long-term suppression is not possible, how do we minimize mortality for covid-19 and other emerging infectious disease outbreaks. *medRxiv*.

Bernardini, S., Fox, M., & Long, D. (2014). Planning the behaviour of low-cost quadcopters for surveillance missions. In *Twenty-Fourth International Conference on Automated Planning and Scheduling*.

Chang, D., Xu, H., Rebaza, A., Sharma, L., & Cruz, C. S.D. (2020). Protecting health-care workers from subclinical coronavirus infection. *The Lancet Respiratory Medicine*, *8*(3), e13.

De Benedetti, M., D'Urso, F., Fortino, G., Messina, F., Pappalardo, G., & Santoro, C. (2017). A fault-tolerant self-organizing flocking approach for uav aerial survey. *Journal of Network and Computer Applications*, 96, 14–30.

Ding, G., Wu, Q., Zhang, L., Lin, Y., Tsiftsis, T.A., & Yao, Y.-D. (2018). An amateur drone surveillance system based on the cognitive internet of things. *IEEE Communications Magazine*, *56*(1), 29–35.

DJI Website (2022). Phantom 4 Pro V2.0 Specs. *Online:*, `https://www.dji.com/phantom-4-pro-v2/specs`

Dronethusiast (2021). Best drones with longest flight times. `https://www.dronethusiast.com/best-drones-with-longest-flight-times/` Accessed: 22 July 2021.

Dukowitz, Z. (2020). Drones and the coronavirus: The many ways drones are supporting containment efforts in China.

Elbir, A.M., Gurbilek, G., Soner, B., & Coleri, S. (2020). Vehicular networks for combating a worldwide pandemic: Preventing the spread of covid-19. *arXiv preprint arXiv:2010.07602*.

ESKAN (2021). Ashti city 1. `https://eskan.iq/en/project/6` Accessed: 29 June 2021.

Farias, D.R., Raffo, L., Bacigalupo, S., Cremaschi, M., Vence, L., Ramos, S., Salguero, A., Claudio, M., Meites, E., & Cubito, A. (2010). Data for decision making: strategic information tools for hospital management during a pandemic. *Disaster medicine and public health preparedness*, *4*(3), 207–212.

Giannini, C., Shaaban, A.A., Buratti, C., & Verdone, R. (2016). Delay tolerant networking for smart city through drones. In *2016 International Symposium on Wireless Communication Systems (ISWCS)*, 603–607. IEEE.

Giyenko, A. & Im Cho, Y. (2016). Intelligent uav in smart cities using iot. In *2016 16th International Conference on Control, Automation and Systems (ICCAS)*, 207–210. IEEE.

Gupta, L., Jain, R., & Vaszkun, G. (2015). Survey of important issues in uav communication networks. *IEEE Communications Surveys & Tutorials*, *18*(2), 1123–1152.

Harrington, P. (2019). *Autonomous Drone Network: Non-Intrusive Control and Indoor Formation Positioning.* University of Northumbria at Newcastle (United Kingdom).

Heincke, B., Jackisch, R., Saartenoja, A., Salmirinne, H., Rapp, S., Zimmermann, R., Pirttijärvi, M., Sörensen, E. V., Gloaguen, R., Ek, L., et al. (2019). Developing multi-sensor drones for geological mapping and mineral exploration: Setup and first results from the mulsedro project. *GEUS Bulletin*, 43.

Hollander, J.E., Carr, B.G. (2020). Virtually perfect? telemedicine for covid-19. *New England Journal of Medicine*, *382*(18), 1679–1681.

Honarmand, M., Shahriari, H. (2021). Geological mapping using drone-based photogrammetry: An application for exploration of vein-type cu mineralization. *Minerals*, *11*(6), 585.

Hopkins, C., Kumar, N. (2020). Loss of sense of smell as marker of Covid-19 infection. ent uk, 2020. *Date accessed*, *26*(03).

Huang, S.-D., Zhang, D.-R., & Zhang, X.-Y. (2007). Integrative administration system of preventive and health care information in hospital based on his. *J. Prev. Med. Inf.* Available online: `http://en.cnki.com.cn/Article_en/CJFDTOTAL-YFYX200704020.htm`

Jorguseski, L., Pais, A., Gunnarsson, F., Centonza, A., and Willcock, C. (2014). Self-organizing networks in 3gpp: standardization and future trends. *IEEE Communications Magazine*, *52*(12), 28–34.

Joshi, A., Dey, N., & Santosh, K. (2020). *Intelligent Systems and Methods to Combat Covid-19*. Springer.

Kellermann, R., Biehle, T., & Fischer, L. (2020). Drones for parcel and passenger transportation: A literature review. *Transportation Research Interdisciplinary Perspectives*, 4, 100088.

Khan, I.H., Javaid, M. (2020). Automated covid-19 emergency response using modern technologies. *Apollo medicine*, *17*(5), 58.

Kim, K.-I., Hyeon, S., Yang, S., & Yi, J. (2011). Development of simulator for aircraft ad hoc networks. In *2011 IEEE/AIAA 30th Digital Avionics Systems Conference*, 5B1–1–5B1–8. IEEE.

Kirsch, M., Lorenz, S., Zimmermann, R., Tusa, L., Möckel, R., Hödl, P., Booysen, R., Khodadadzadeh, M., & Gloaguen, R. (2018). Integration of terrestrial and drone-borne hyperspectral and photogrammetric sensing methods for exploration mapping and mining monitoring. *Remote Sensing*, *10*(9), 1366.

Kumar, A., Sharma, K., Singh, H., Naugriya, S.G., Gill, S.S., & Buyya, R. (2021). A drone-based networked system and methods for combating coronavirus disease (covid-19) pandemic. *Future Generation Computer Systems*, 115, 1–19.

Kumar, V., Rana, A., & Kumar, S. (2014). Aircraft ad-hoc network (aanet). *International Journal of Advanced Research in Computer and Communication Engineering*, *3*(5).

Kunovjanek, M., Wankmüller, C. (2021). Containing the covid-19 pandemic with drones-feasibility of a drone enabled back-up transport system. *Transport Policy*, 106, 141–152.

Lee, D., Zhou, J., & Lin, W. T. (2015). Autonomous battery swapping system for quadcopter. In *2015 international conference on unmanned aircraft systems (ICUAS)*, 118–124. IEEE.

Li, L., Zhang, Q., Wang, X., Zhang, J., Wang, T., Gao, T.-L., Duan, W., Tsoi, K. K.F., & Wang, F.-Y. (2020). Characterizing the propagation of situational information in social media during covid-19 epidemic: A case study on weibo. *IEEE Transactions on Computational Social Systems*, 7(2):556–562.

M. Online (2021). Coronavirus (covid-19) information.
`http://www.mbsonline.gov.au/internet/mbsonline/publishing.nsf/Content/Home`
Accessed: 20 July 2021.

Manigandan, S., Ramesh, P.K.T., Chi, N. T.L., & Brindhadevi, K. (2020). Early detection of sars-cov-2 without human intervention to combat covid-19 using drone technology. *Aircraft Engineering and Aerospace Technology.*

Mesar, T., Lessig, A., & King, D.R. (2018). Use of drone technology for delivery of medical supplies during prolonged field care. *Journal of Special Operations Medicine*, *18*(4), 34–35.

Meszaros, L. Drone technology: A new ally in the fight against covid-19. `https://www.mdlinx.com/article/drone-technology-a-new-ally-in-the-fight-against-covid-19/61gQW7xmBCg6LyGy43925Z` Accessed: 15 July 2021.

Mohammed, M., Hazairin, N.A., Al-Zubaidi, S., AK, S., Mustapha, S., & Yusuf, E. (2020). Toward a novel design for coronavirus detection and diagnosis system using iot based drone technology. *International Journal of Psychosocial Rehabilitation*, 24(7):2287–2295.

News, A. (2021). Draganfly selected to globally integrate breakthrough health diagnosis technology immediately onto autonomous camera's and specialized drones to combat coronavirus (covid-19) and future health emergencies. `https://apnews.com/press-release/pr-globenewswire/dc01344350423d7d64c99ebbe8fb7548` Accessed: 29 June 2021.

Newswire, P. (2012). Teal group predicts worldwide uav market will total $89 billion in its 2012 uav market profile and forecast. *PR Newswire*, 11.

Omboni, S. (2020). Telemedicine during the covid-19 in italy: a missed opportunity? *Telemedicine and e-Health*, *26*(8), 973–975.

Organization, W.H. (2020a). *Clinical management of severe acute respiratory infection when novel coronavirus (2019-nCoV) infection is suspected: interim guidance*, 21–21.

Organization, W.H. (2020b). Considerations in the investigation of cases and clusters of covid-19: interim guidance, 22 october 2020. Report, World Health Organization.

Organization, W.H. (2021). Who coronavirus (covid-19) dashboard. `https://covid19.who.int/` Accessed: 5 August 2021.

Otiede, E., Odeyemi, M., Nwaguru, I., Onuoha, C., Awal, S., Ajibola, O., Adebayo, V., Itoro, E., Ejejigbe, T., & Ejofodomi, O. (2017). Delivering medical products to quarantined regions using unmanned aerial vehicles. *Journal of Applied Mechanics Engineering*, *6*(1), 244.

Pappot, N., Taarnhøj, G.A., & Pappot, H. (2020). Telemedicine and e-health solutions for covid-19: patients' perspective. *Telemedicine and e-Health*, *26*(7), 847–849.

Patchou, M., Sliwa, B., & Wietfeld, C. (2021). Flying robots for safe and efficient parcel delivery within the covid-19 pandemic. In *2021 IEEE International Systems Conference (SysCon)*, 1–7. IEEE.

Rocke, J., Hopkins, C., Philpott, C., & Kumar, N. (2020). Is loss of sense of smell a diagnostic marker in covid-19: a systematic review and meta-analysis. *Clinical Otolaryngology*, *45*(6), 914–922.

Sampa, M.B., Hoque, M., Islam, R., Nishikitani, M., Nakashima, N., Yokota, F., Kikuchi, K., Rahman, M. M., Shah, F., & Ahmed, A. (2020). Redesigning portable health clinic platform as a remote healthcare system to tackle covid-19 pandemic situation in unreached communities. *International Journal of Environmental Research and Public Health*, *17*(13), 4709.

Schwartz, J., King, C.-C., & Yen, M.-Y. (2020). Protecting healthcare workers during the coronavirus disease 2019 (covid-19) outbreak: Lessons from taiwan's severe acute respiratory syndrome response. *Clinical Infectious Diseases*, *71*(15), 858–860.

Scully, N., Thiel, S., Litjens, R., Jorgueski, L., Nascimento, R., Linnell, O., Zetterberg, K., Amirijoo, M., Blondia, C., & Spaey, K. (2008). D2. 1 use cases for self-organising networks. `http://www.fp7-socrates.eu`.

Shakhatreh, H., Sawalmeh, A.H., Al-Fuqaha, A., Dou, Z., Almaita, E., Khalil, I., Othman, N.S., Khreishah, A., & Guizani, M. (2019). Unmanned aerial vehicles (UAVS): A survey on civil applications and key research challenges. *IEEE Access*, 7, 48572–48634.

Sharma, K., Singh, H., Sharma, D.K., Kumar, A., Nayyar, A., & Krishnamurthi, R. (2021). Dynamic models and control techniques for drone delivery of medications and other healthcare items in covid-19 hotspots. *Emerging Technologies for Battling Covid-19: Applications and Innovations*, 1–34.

Sharnya, P., Raj, J.S. (2013). Self organizing wireless mesh network. *International Journal of Innovation and Applied Studies*, *3*(2), 486–492.

Singh, P.K., Nandi, S., Ghafoor, K.Z., Ghosh, U., & Rawat, D.B. (2020). Preventing covid-19 spread using information and communication technology. *IEEE Consumer Electronics Magazine*, *10*(4), 18–27.

Skorup, B., Haaland, C. (2020). How drones can help fight the coronavirus. *Mercatus Center Research Paper Series, Special Edition Policy Brief (2020).*

Soltanisehat, L., Alizadeh, R., Hao, H., & Choo, K.-K.R. (2020). Technical, temporal, and spatial research challenges and opportunities in blockchain-based healthcare: A systematic literature review. *IEEE Transactions on Engineering Management.*

Soni, K., Gangwar, R. (2021). Future scope of unmanned aerial system for consumer utilities in covid-19 pandemic. *Zeichen Journal*, *7*(5), 208-216.

Strobel, V., Castelló Ferrer, E., & Dorigo, M. (2018). Managing byzantine robots via blockchain technology in a swarm robotics collective decision making scenario. In *Proc. of the 17th International Conference on Autonomous Agents and Multiagent Systems* (AAMAS 2018), Stockholm, Sweden, July 10-15, 2018, IFAAMAS, 9 pages.

Timpka, T., Ölvander, C., & Hallberg, N. (2008). Information system needs in health promotion: a case study of the safe community programme using requirements engineering methods. *Health Informatics Journal*, *14*(3), 183–193.

Ting, D.S.W., Carin, L., Dzau, V., & Wong, T.Y. (2020). Digital technology and covid-19. *Nature Medicine*, *26*(4), 459–461.

UNICEF (2020). How drones can be used to combat Covid-19.

Vasuki, Y., Holden, E.-J., Kovesi, P., & Micklethwaite, S. (2014). Semi-automatic mapping of geological structures using uav-based photogrammetric data: An image analysis approach. *Computers & Geosciences*, 69, 22–32.

Wu, J.T., Leung, K., & Leung, G.M. (2020). Nowcasting and forecasting the potential domestic and international spread of the 2019-ncov outbreak originating in wuhan, china: a modelling study. *The Lancet*, *395*(10225), 689–697.

Yan, J., Liu, J., & Tseng, F.-M. (2020). An evaluation system based on the self-organizing system framework of smart cities: A case study of smart transportation systems in china. *Technological Forecasting and Social Change*, 153, 119371.

Yanmaz, E., Kuschnig, R., Quaritsch, M., Bettstetter, C., & Rinner, B. (2011). On path planning strategies for networked unmanned aerial vehicles. In *2011 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)*, 212–216. IEEE.

Yanmaz, E., Yahyanejad, S., Rinner, B., Hellwagner, H., & Bettstetter, C. (2018). Drone networks: Communications, coordination, and sensing. *Ad Hoc Networks*, 68, 1–15.

Yavuz, D., Akbıyık, H., & Bostancı, E. (2016). Intelligent drone navigation for search and rescue operations. In *2016 24th Signal Processing and Communication Application Conference (SIU)*, 565–568. IEEE.

Ye, J.G., Chen, H.T., & Tsai, W.J. (2018). Panorama generation based on aerial images. In *2018 IEEE International Conference on Multimedia & Expo Workshops (ICMEW)*, 1–6. IEEE.

Zanella, A., Bui, N., Castellani, A., Vangelista, L., & Zorzi, M. (2014). Internet of things for smart cities. *IEEE Internet of Things journal*, *1*(1), 22–32.

Zhang, J., Zhou, L., Yang, Y., Peng, W., Wang, W., & Chen, X. (2020). Therapeutic and triage strategies for 2019 novel coronavirus disease in fever clinics. *The Lancet Respiratory Medicine*, *8*(3), e11–e12.

Zheng, Y., Zhu, Y., & Wang, L. (2011). Consensus of heterogeneous multi-agent systems. *IET Control Theory & Applications*, *5*(16), 1881–1888.

Zhong, C.L., Tao, Y., & Zhang, Z.B. (2005). Administrative information system for epidemic situation report of infectious diseases. *Chinese Journal of Nosoconmiology*, 12.

Table 4: Table of Abbreviations

Abbreviation	**Meaning**
5G	The Fifth Generation of Cellular Networks
BS	Base Station
CAGR	Compound Annual Growth Rate
COVID-19	Coronavirus Disease of 2019
CT-process	COVID-19 Triage process
GPS	Global Positioning System
ICT	Information and Communication Technology
ID	Identification
IDC	International Data Corporation
IoT	Internet of Things
IP	Internet Protocol
KPI	Key Performance Indicator
LD	Leader Drone
NE	Network Element
PHC	Portable Health Clinic
QoS	Quality of Service
RHS	Remote Healthcare System
SAR	Search and Rescue
SLD	Slave Drone
SMDC	South Delhi Municipal Corporation
SON	Self-organizing Network
UAV	Unmanned Aerial Vehicle
VBT	Vehicle-Based Testing
VR	Virtual Reality
Wi-Fi	Wireless Fidelity
WHO	World Health Organization