IoMT and DNN-Enabled Drone-Assisted Covid-19 Screening and Detection Framework for Rural Areas

N. Naren, Vinay Chamola, Sainath Baitragunta, Ananthakrishna Chintanpalli, Puneet Mishra, Sujan Yenuganti, and Mohsen Guizani

Abstract

Providing rapid testing and proper treatment has become highly challenging due to the rapid and highly unpredictable spread of the coronavirus disease (COVID-19). In most developing countries, rural areas lack adequate medical facilities and medical staff for effective diagnosis and treatment. Recently, there have been several technological advancements across various engineering disciplines such as the Internet of Things, unmanned aerial vehicles (UAVs) or drones, deep neural networks (DNNs), and intelligent robots. This work proposes a prototype that integrates these technologies to develop a payload deployable in a drone to help in providing rapid testing and healthcare. The proposed UAV prototype combines secure patient authentication, an automated disinfection system, and medical sensors as part of the UAV payload. It uses a DNN model for real-time COVID-19 detection. It uses intelligent flight path planning, operational management, battery recharge planning, disinfectant refilling, and strategic location planning to quickly disseminate testing kits and essential medical services to remote locations without direct human involvement.

Introduction

The novel coronavirus (COVID-19) is rapidly and unpredictably spreading worldwide. Due to its highly infectious nature, healthcare and management are becoming more challenging despite significant medicine, medical facilities, and treatment improvements. We witnessed the phenomenal growth of technologies such as the Internet of Medical Things (IoMT) and unmanned aerial vehicles (UAVs), also called drones. Furthermore, the astonishing developments in artificial intelligence (AI), machine learning, and deep neural networks (DNNs) promise to handle challenging problems, including healthcare. Automated technologies such as intelligent robots and drones having clinic-like payloads are undoubtedly valuable for controlling the rapidly spreading pandemic due to less human contact and intelligent robots. However, the challenge still lies in integrating these technologies to develop an automated drone-centric system to provide innovative healthcare and health management. Such systems can quickly reach any required location to serve people's medical needs. There is also an urgent need for rapid automated testing, accurate diagnosis, and treatment without much human intervention.

The current study proposes a contact-less COVID-19 screening and detection system named Covidrone that consists of biomedical sensors to capture COVID-19-related medical data from users. Covidrone would have a payload consisting of a sensing module, a disinfectant module, testing kits, a DNN model, and a wireless communication subsystem. These drones would land on carefully selected locations and wait for users who requested the drone's services. After authenticating the user and sanitizing the sensing equipment, smart medical sensors on the drone capture the required medical data. For COVID-19 detection and analysis, these medical data are then passed through a DNN-based model. The user will be directed for further medication or preventive measures based on his/her test report. Remote medical staff would be able to access these test reports via cloud services for further analysis. Automation of the whole process prevents human contact, thereby contributing to the combat against COVID-19. This approach can provide essential healthcare and testing facilities to elderly and physically disabled individuals. It is expected that Covidrone can significantly help in flattening COVID-19 curves, especially in rural areas where specialized medical facilities are limited.

We propose a prototype that consists of various features:

- Effective authentication for the user to have secure testing
- The integration of an automatic disinfectant system
- Smart medical sensors in the drone's payload
- An efficient and well-trained DNN model for real-time COVID-19 detection
- Intelligent flight path planning, operational management, and battery recharge planning
- Disinfectant refilling and strategic location planning

These features will be incorporated in Covidrone, making it highly effective in tackling COVID-19 and enabling quick dissemination of testing kits and essential medical services to remote locations without direct human involvement.

Related Works

Integrating various next-generation information and communication technologies will help develop smart healthcare to manage the COVID-19 pandemic. These technologies include drones, IoT (e.g., medical things or sensors), fifth-generation cellular networks, and a DNN model [1]. Traditionally, drones are used in defense-related applications, such as remotely controlled aerial missile deployers. However, in recent decades, drones have been used in a wide range of applications such as climate change monitoring, filming, and photography, and blood delivery. The authors of [2] propose using multiple UAV swarms to tackle different problems of COVID-19, such as social distancing, symptoms tracking, and sanitization. They propose using 6G, blockchain, and software defined networking (SDN) for security and performance. The authors in [3] utilized drones and robots to combat COVID-19 by tracking hotspots and delivering medical aid where needed. Several COVID-19 operations such as sanitization, thermal imaging, crowd monitoring, and control are also supported in their framework. Such systems, when deployed in considerably large regions such as a village, might require immense network resources and coordination, and thus the feasibility of its operations remains a question. In another work [4], the authors proposed a drone-based model to provide medical service to reduce COVID-19 spread. However, only some algorithms were proposed based on a few case studies for combating COVID-19 via approaches such as social distancing. In [5], the authors discuss AI and big-data-analytics-based prediction of COVID-19 cases and economic growth, aimed toward economy boosting.

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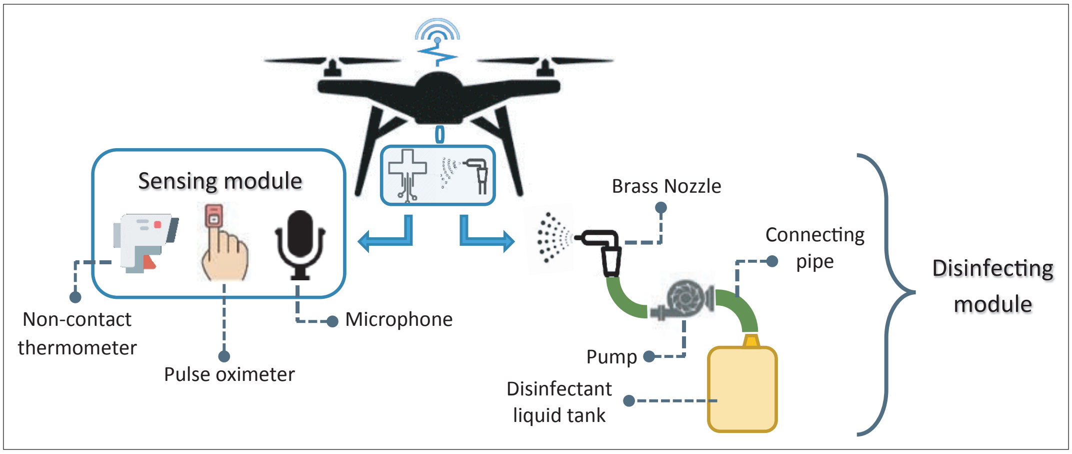

FIGURE 1. Covidrone schematic showing sensing and disinfecting module details.

In the existing literature on COVID-19, different research communities have used various technologies for novel COVID-19 diagnosis and drug discovery. In [6], the authors proposed AI-enabled diagnosis based on cough droplets. More specifically, the authors developed the AI4COVID-19 app, which can diagnose COVID-19 with negligible misdiagnosis probability. Reference [7] discusses a machine-learning-based technique and datasets that can be used for diagnosing COVID-19 and also identifying the stage of infection. In general, the DNN model falls under a big pool of AI techniques. DNN has been used previously for detecting pneumonia and other thorax diseases with chest X-rays [8]. DNN has many other applications in healthcare such as in Parkinson's, breast cancer, electrocardiography, recognition of medical/surgical instruments, and robotic surgery, among others. The authors of [8] also proposed an efficient DNN-based model for COVID-19 detection using x-ray images. Their model achieves 93.9 percent accuracy, 96.8 percent COVID-19 sensitivity, and positivity prediction of 100 percent. The authors showed that the computational requirement of their model is such that it is highly suitable for use in medical equipment or systems on chips (SoCs) such as a smartphone. Therefore, we use the DNN-based approach in the current study. We have this discussion later in the article.

While most existing works are simulation-based analyses, we propose Covidrone, an IoMT and DNN-enabled drone framework, that could be used in real life for contact-less COVID-19 diagnosis and testing.

The major contributions of this work are listed below:

- The integration of sensing, authentication, and disinfectant modules to an IoMT-based drone system for contact-less diagnosis of Covid-19 patients in rural areas
- The development of a DNN to detect COVID-19 using the raw data collected through the drone system and dispensing the COVID-19 test kit when a patient has a high likelihood of having COVID-19
- Design and implementation of drone path planning and operational management while considering parameters like strategic location planning and battery recharging
- Integrating the various subsystems to develop a working prototype and testing the system through a pilot test run

System Development

In this section, we discuss in detail four objectives that are to be achieved as part of the Covidrone framework.

Objective 1

To integrate sensing, authentication, and disinfectant modules to an IoMT-based drone system for contact-less diagnosis of Covid-19 patients in rural areas.

The first step is to procure an indigenous drone and develop the drone system to have the following modules:

- An autonomous sensing module that collects the required data as per the symptoms of the individual
- An authentication module that ensures a proper identification of the individual before data collection
- A disinfectant module which ensures that the complete drone system gets sanitized after every testing

Sensing Module: The sensing module should sense various critical parameters that help the proposed Covidrone system to detect whether a person has COVID-19 or not. This sensing will be carried out on the drone in an autonomous manner. The interface to the sensing module should be carefully designed, considering ease of use for the rural population who may not be familiar with the technology. As the symptoms of COVID-19 infection range from mild to severe, the Covidrone system targets the most common symptoms such as fever, shortness of breath, and dry cough. These symptoms can be measured using the body temperature, oxygen saturation level (SpO_2), and audio input, respectively. These sensing parameters are depicted in Fig. 3.

The medical sensors employed to measure the common symptoms will be a significant part of the payload of Covidrone. The outputs of the sensing module will be inputs to the onboard processing unit (e.g., Raspberry Pi) for further processing and communication of the raw medical data. The salient features of the biomedical sensors of the sensing module are described below.

Body temperature: An infrared temperature sensor can measure the body temperature of an individual without physical contact. It avoids close human contact and thus reduces the chances of viral transmission.

SpO_2: A pulse oximeter sensor measures the percentage of blood hemoglobin carrying oxygen. Normal SpO_2 is usually at least 95 percent, and some patients with chronic lung disease or sleep apnea can have normal levels of around 90 percent. An individual under test can be suspected to have COVID-19 if the SpO_2 level is less than 85 percent. The pulse oximeter is portable and lightweight, and can be mounted on a drone as part of the payload subsystem.

Audio recording: It is used to record the patient's cough patterns through a mic system connected to the onboard processing unit. The recorded information would serve as useful raw medical data that goes as an input to the DNN model for processing. Additionally, other subjective health evaluations (e.g., sore throat, headache, fatigue, muscle pain) will also be recorded.

Authentication module: The onboard processing unit (Raspberry Pi) will authenticate the individual with the drone. This process is carried out without the need for any human intervention (other than the user/patient of concern). The following methodologies are proposed for individual authentication:

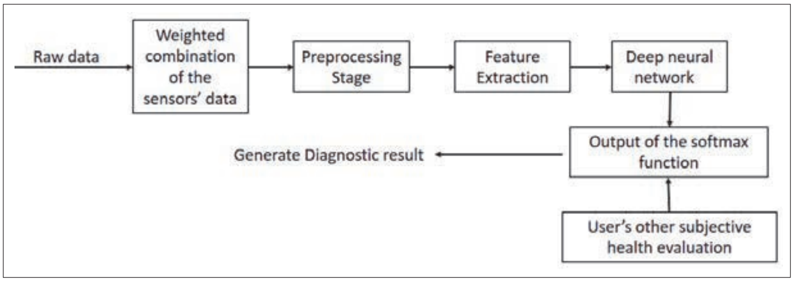

FIGURE 2. Block diagram illustrating the proposed algorithm for detecting COVID-19.

1. A camera will be mounted on the drone, which is connected to the onboard processor.
2. A proximity sensor on the drone will detect that a person is coming near it. Once the user's presence is detected, the onboard processor on the drone will issue a voice command requesting the user to keep their identification card near the camera.
3. The user will put their identification card in front of the camera. The onboard processor will use optical character recognition (OCR) to extract the user's details.
4. Suppose a person does not have their identification card. In that case, the onboard processor unit will use voice commands to seek the user's personal information by asking a set of questions. Finally, the audio input will be converted into text to populate the necessary fields.
5. The user's photograph will also be taken for validation purposes.

Disinfectant module: It is of utmost importance to disinfect the onboard sensors on the drone after each patient is tested to prevent virus spread among different users of the Covidrone.

Currently, there are mainly two methodologies in practice to disinfect exposed surfaces or medical/surgical equipment. The first method uses a suitable chemical, sodium hypochloride (NaOCl), which is sprayed over contaminated surfaces. Its 5 percent w/v strength can help to disinfect the surfaces and other medical equipment from various viruses and bacterial contamination [9]. Additionally, 70 percent alcohol can also be used to wipe down surfaces where the use of bleach is not suitable (e.g., metal) in which case chloroxylenol (4.5–5.5 percent)/benzalkonium chloride may be used [10]. Alternatively, far ultraviolet C (UVC) radiation with sufficient intensity for a suitable time duration can be used to disinfect medical equipment. However, UVC radiation at 254 nm can be a potential health hazard to skin and eyes. In [11], authors showed that 222 nm far UVC radiation can inactivate COVID-19. However, many other sources, including WHO in its advisory, still argue about the safety of UVC radiation on human skin cells and eyes if directly contacted [12]. Hence, a chemical-based disinfectant module is a safe and effective choice. This module will be autonomous and will automatically disinfect the used sensing module after each testing. A pictorial representation of the working of this disinfecting module is shown in Fig. 1. After each testing, the disinfection process will be needed, and hence a suitable sensing mechanism will be developed. Once a single sense cycle is completed, the brass nozzle will spray the disinfectant in the form of small droplets for a pre-defined time period. This complete control will be done by a single master control unit, keeping track of the synchronization of all the tasks to be performed by Covidrone.

Objective 2

To develop a deep neural network to detect COVID-19 using the raw data collected through the drone system, and dispensing the COVID-19 test kit in case the patient is having a high likelihood of having COVID-19.

Following are the various stages of the proposed algorithm for detecting COVID-19 (Fig. 2).

1. The input data to the proposed algorithm will be the weighted combination of the acquired raw data from the biomedical sensors [1].
2. The highest weight value (less than 1) will be assigned to the sensor data coming from the most common symptom of COVID-19, followed by the lower weight values to the less common symptoms. The sum of the proportional weights associated with these symptoms will add up to 1. Furthermore, the exact weight value for each symptom will be decided such that the network meets the performance criteria (see step 7).
3. The input data will then be passed through a pre-processing stage to filter out the unwanted noises acquired during data collection.
4. The signal processing transform (e.g., spectrogram) will be used to extract the important features of the input data.
5, These feature vectors will then be fed to the DNN (e.g., convolutional neural network). The output layer of this network will be passed through a soft-max function to obtain the probabilistic value for each class. There will be three classes: negative (no COVID-19), positive (COVID-19), and test inconclusive. The network will be trained and validated using the dataset collected from Objective I. If required, a clustering algorithm can also be adopted for diagnosis.
6 The output of the soft-max function, along with the other subjective information gathered (e.g., sore throat, headache, fatigue, muscle pain), will be used for decision making.
7 The overall accuracy rate, COVID-19 sensitivity, and positive prediction will be computed to evaluate the performance of the network. Additionally, these quantitative metrics will assist in determining the number of hidden layers and the exact weight values (of step 2) such that these values will be ≥ 90 percent.
8 The network will be tested against the data collected from objective 1 (that were not included in the training and validation stages) and from the pilot test run.
9 The diagnostic result will be generated and stored on the cloud so that the doctor/hospital staff/patient can view or download the report for further action (if required).

COVID-19 testing kit dispensing setup: Our proposed solution, Covidrone, will be equipped to dispense antigen test kits (IgG/IgM) to the user based on his/her likelihood of being infected with COVID-19, as predicted by the DNN model. As the maximum number of kits that the drone can carry could be limited, the kit will only be dispensed to a person who has a high likelihood of infection. Figure 3 shows the process flow diagram for distributing the kit by Covidrone.

The National Institute of Virology, Pune, has successfully developed the first indigenous anti-SARS-CoV-2 human IgG enzyme-linked immunosorbent assay (ELISA) test kit for antibody detection of COVID-19. According to the Indian Council of Medical Research (ICMR), ELISA kits are more reliable and cheaper than rapid antibody testing kits. The ELISA antibody test is a kind of blood test, which is quite similar to rapid antibody tests that detect antibodies in the blood to determine if an individual is infected with COVID-19 or not. Other rapid testing kits, such as Pathocatch COVID-19 by Mylab Discovery Solutions and Standard Q COVID-19 Ag rapid antigen detection test by SD Biosensor, have also been developed to detect the antibodies present in the body. Most of these kits are inexpensive and can be made available under US$7 per kit. A picture of a typical rapid antibody detection kit for COVID-19 is shown in Fig. 4.

Objective 3

To design and implement drone path planning and operational management while considering parameters like strategic location planning and battery recharging.

This objective describes the path planning of the drone to reach the destination village site for testing. The overall flow of the drone hosting, path planning, recharging, and landing

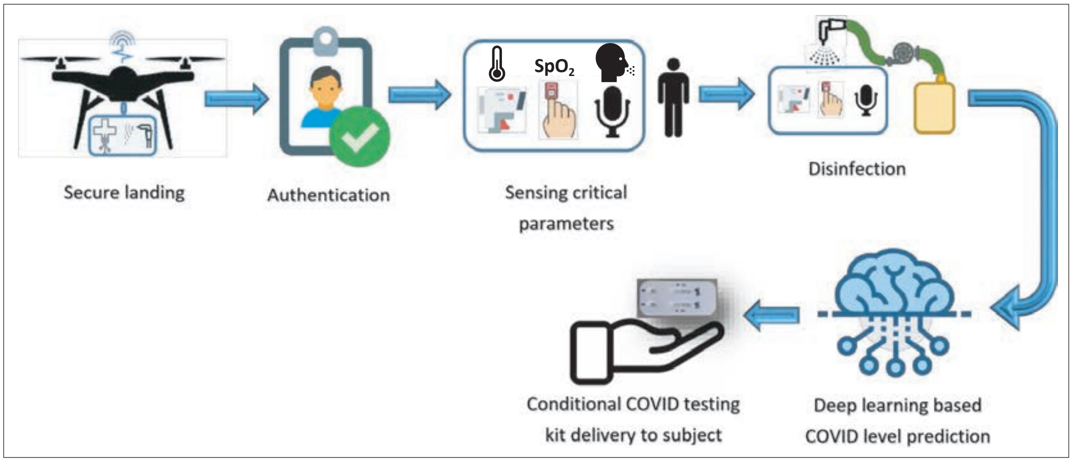

FIGURE 3. Process schematic for dispensing a COVID testing kit to a user.

is shown in Fig. 5. The following are the practical aspects that need to be considered for the implementation of drone battery charging:

1. A single drone will be responsible for medical operations in approximately 8 to 10 villages, with a central facility hosting the setup required for the drone. For example, this central facility could be a major hospital in the given area.
2. The drone visits will be scheduled for testing in a particular village/locality as per the requirement or can take turns visiting various localities. The drone visits will be planned as unmanned visits using mission planner software to choose the drone's trajectory to reach the required site. The Covidrone will be equipped with an onboard GPS module to enable dynamic path planning.
3. The Covidrone architecture can communicate on existing cellular networks (2G/3G/4G/5G). Its communication requirements are very minimal — to send and receive details of the patient and of the next area to visit, or to communicate emergency notifications — which does not require large bandwidth or high data rates. A single drone will be responsible for medical operations in approximately 8 to 10 villages, with a central facility hosting the setup required for the drone. In the absence of network connectivity, the drone will function in a fully autonomous manner (e.g., in the region between two villages where network connectivity may not be available). Within the villages, the drone is expected to be in range of network connectivity (either 2G/3G/4G/5G), and it will exchange the required information with the central facility using the available network. If the drone gathers information in regions where there is no Internet connectivity, it will log this information in its onboard storage for future use.
4. As the drone relies on batteries for its operations, careful battery recharging is crucial to ensure smooth operations and longer battery life cycles. Suppose the battery recharging is not done properly, and the battery has to undergo deep discharge cycles. In that case, it may degrade the battery life and might reduce the drone's flight time. To avoid this problem, every village can have an emergency setup for drone charging to reach the central medical facility. This emergency setup could be the village medical center or the residence of a responsible person.
5. Drone scheduling and charging can be implemented using novel energy trading frameworks as described in [13, 14]. In [13], the authors discussed an energy trading framework containing UAVs and charging stations. It is based on blockchain and allows UAVs to charge at charging stations in exchange for digital tokens. In this work, charge scheduling (deciding which UAV gets access to the charging station at a particular point in time) is implemented using a game-theoretic model. Similarly, in [14], the authors described a peer-to-peer and distributed network comprising UAVs and charging stations.

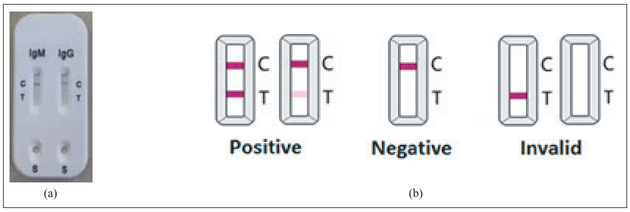

FIGURE 4. a) A typical COVID-19 IgM/IgG rapid test kit; b) indications of the test kit.

Additionally, an optimal scheduling algorithm was proposed that resulted in cost-optimal charging for the UAVs and higher profits for the charging station. Careful and strategic placement of charging stations combined with efficient charge scheduling schemes can result in less frequent recharge requirements for the drones and thus can increase the number of clients who can be served in a particular time duration.

6. There will be a caretaker for the drone in the central facility who will be responsible for scheduling the drone flights. As the drone will be on unmanned missions, the caretaker can set/choose the GPS locations for the testing sites.
7 There can be multiple spots in a village where the drone can be scheduled to land for testing, taking into account the affected areas. Initially, each village will be divided into clusters. There will be a drone landing spot in every cluster, enabling the drone to land in any of the clusters based on the population targeted for testing. The clustering of the village will be achieved based on population density across various regions of the village. Regions of the village with higher population density will have smaller clusters so that more drones can be deployed to these regions to cater to the larger number of people. Population information collected from local authorities will be fed into the system's backend, which would use an efficient clustering algorithm to decide the number of clusters and their boundaries. This will be modeled as an optimization problem in which the number of people catered to in a given amount of time should be maximized for a given number of drones. Parameters such as drone payload capacity, the time required to serve each patient, drone recharging, the closeness of emergency setups, and time of return to the central facility should be taken into account while making these clusters. This would also ensure that older/physically disabled persons in that cluster would not have to travel far distances for testing.
8 The drone can also be used for other healthcare emergencies (e.g., blood delivery). In such healthcare applications, the caretaker for the drone at the central health facility shall have to select the path of the drone on the mission planner to the desired delivery location.

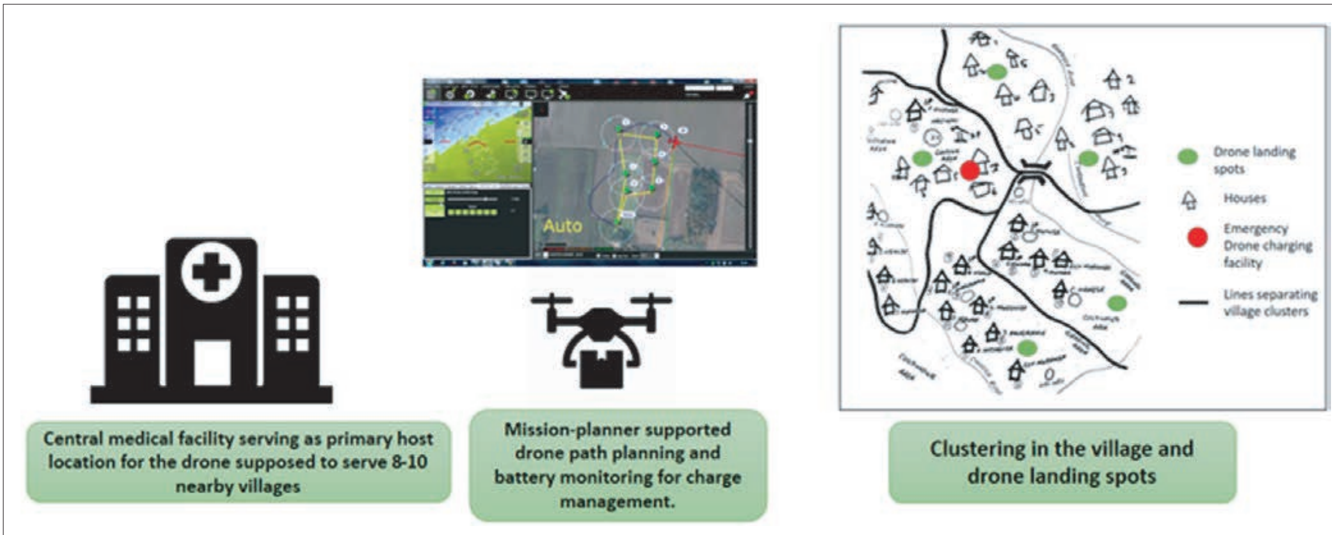

FIGURE 5. Overall flow of drone hosting, path planning, recharging, and landing.

Objective 4

To integrate the various subsystems to develop a working prototype and test the system through a pilot test run.

This objective aims at integrating the various subsystems. Specifically, the biomedical sensing setup, the disinfecting setup, and the onboard signal processing boards will be mounted on the drone. We will choose a central medical setup and carry out an unmanned mission by sending the drone to a test site and conduct a test trial on patients to verify the working status of the system.

End-to-end performance testing can find and eliminate time-consuming bottlenecks and reduce security and operational risks in the entire system. The following are the major factors that need to be considered while testing:

Security and Privacy: During the entire operation, it is critical to ensure security and privacy for the Covidrones and the patients. The communication of the Covidrones with the central medical facility should be secure. Specifically, this communication must satisfy the following features: mutual authentication, data integrity, confidentiality, and identity privacy [15]. Additionally, since the Covidrone would operate mainly in remote areas, there is a risk of being captured physically or taken control of by people/groups with malicious intent. It may be possible that they may try to gain control of the drone's communication with the central facility, such as extracting secret credentials stored on the drone. They may also even try to steal/replace the onboard testing kits or some components of the onboard sensing module, such as the non-contact thermometer or the pulse oximeter, for monetary gains. By using tamper-proof hardware root of trust (e.g., physical unclonable functions), these attempts can be detected and stopped quickly before significant damage occurs to the Covidrone system or the clients.

Sensing functionality and delay: On many occasions, the Covidrone could be responsible for catering to several clients at the same landing location. Hence, it is essential that the authentication, sensing, disinfection, COVID-19 prediction, and conditional kit delivery be conducted quickly. Before the drone departs to a particular location, the patient's basic details (e.g., name, photograph, identification number) can be gathered from government databases, encrypted, and stored locally on the Covidrone for quick authentication. A possible time-consuming bottleneck at this stage could be OCR, which can be eliminated using a suitable camera (with high resolution, fast shutter, and image stabilization features) to capture high-quality images. Hence, a fast and accurate OCR model can significantly decrease the time consumed at this stage. An outer layer of this model can identify the type of ID card (e.g., driver's license, insurance card), following which an OCR model can quickly recognize the text for the specific ID card.

At the sensing stage, it is expected that the major delay would arise while the microphone records the cough patterns of the patient. Suitable modifications to the neural network can reduce both the prediction time and the length of the audio clip required for prediction.

Disinfection Stage: The disinfection of the onboard sensors can happen soon after the patient's inputs are recorded. However, depending on the strength of the chemical disinfectant used, there would be a minimum wait time before a new patient's pulse oximeter data can be obtained. There is no such wait time required for the non-contact thermometer and the microphone.

Test Kit Delivery: The conditional testing kit delivery could take a few seconds (5–10) using suitable actuation.

Final Report Generation: The prediction of the DNN model will be uploaded to the cloud server, which has virtually unlimited resources. Hence, the report will be generated immediately and available to the patient/client and the doctor. However, the entire time for generating the report depends on the available network connectivity to the drone at the testing location. If network connectivity is unavailable at the testing location, the result will be stored on the Covidrone itself and uploaded later.

Open Challenges and Future Work

The following improvements and modifications can be explored in future works on drone-assisted COVID-19 screening and detection frameworks.

Patient Health History: The present work proposes the use of a camera-based setup on the drone to scan the patient's identification card and also take a photograph of the user for authentication purposes. Future works can explore the use of more advanced camera and processing systems onboard the Covidrone that can scan previous health and diagnostic reports of the patient. This can be immediately relayed to authorized healthcare personnel for personalized medical advice.

Reconfigurable Platforms: The use of reconfigurable platforms such as field programmable gate arrays (FPGAs) can add virtually unlimited functionality to the drone. Partial reconfiguration of the FPGA can be performed at any time to add/remove/modify any of the functionalities of the drone with the only constraint being that the necessary medical sensors (heart rate sensor, ECG sensor, etc.) are already mounted on the drone. With optimal resource partitioning and hardware-level parallelization, an FPGA-based drone system can provide the best balance of both performance and flexibility.

Generic Payloads: While the proposed Covidrone system is specifically meant to be used for tackling COVID-19, future works can implement generic payloads containing a wide variety of medical sensors and processing systems, which could be implemented as per situational requirements using partial reconfiguration as mentioned in the previous point. These systems would help healthcare bodies to respond quickly in the case of any future outbreaks of infectious diseases that occur without warning and spread rapidly.

Integration with healthcare databases: Future works can also work on integrating drone-based COVID-19 screening and detecting systems with local/national/international healthcare databases to enable real-time updates and more accurate statistics of total positive cases, active cases, number of deaths, and number of asymptomatic cases along with their demographic distributions. This will help healthcare authorities make better decisions to contain the spread and strategize better healthcare emergency responses.

Drone navigation in challenging environments: In several cases, the drone might be required to navigate within remote regions that have thick forest cover or in densely packed rural areas. Unexpected weather phenomena such as rain, fog, and haze could also add to these challenges. To solve this, future works can focus on including computer-vision-based video-feed enhancement systems, which could result in better and safer autonomous/manual flying of the drones.

Health and Safety Risks: Using drones for healthcare applications where the drones have to interact with patients in very close proximity presents several health and safety risks. The drone's battery has to be properly sealed and secured to prevent harmful chemical leakage. The drone's rotors should be properly guarded to prevent untoward accidents that can harm nearby people. Damage to the rotors may also render the drone unable to return back to its central facility. Hence, future works can include an exclusive focus on these issues and ways to solve them.

Conclusion

COVID-19 has spread rapidly to almost all countries across the globe. It has resulted in millions of human casualties and severely affected economies worldwide. Due to its highly contagious nature, there is an urgent need for technological innovations that can tackle this pandemic with minimal or no human involvement. The proposed Covidrone system utilizes state-of-the-art technologies, including IoMT, drone, and DNN model, for COVID-19 detection. It can authenticate a user, disinfect sensing equipment, and detect COVID-19. Its intelligent and automated path planning, battery recharging, and disinfectant refilling functions will enable secure, reliable, and affordable COVID-19 diagnosis. Thus, it would help disseminate testing kits and essential medical services quickly to remote locations without direct human involvement (fostering contact-less diagnosis and rapid testing). The proposed approach has great importance for combating COVID-19, especially in rural areas where specialized medical facilities are limited.

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Biographies

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