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Full length article

Smart delivery and retrieval of swab collection kit for COVID-19 test using autonomous Unmanned Aerial Vehicles

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1. Background

Drones were only restricted to military use in the early days as the case usually is with all new inventions and discoveries. But with the passage of time, they became popular in civilians operations [1]. In recent years, there has been an exponential increase in the production and the development of unmanned aerial vehicles, which led to increased difficulty in their classification [2]. Although drones have made good progress in many of their aspects and will do so in the coming years, their main characteristics will remain the same [3]. More than ninety countries in the world are in the business of operating drones out of which at least ten countries own armed drones while more than twenty countries are in the process of developing them [4].

With the advent of GPS, light composite materials, and advancement in lithium batteries, drone flight efficiency has increased significantly. Mobile phone- and tablet-based apps can be used along with the drone software for the purpose of navigation and tracking [5].

Besides other applications, drones are particularly useful in healthcare where there is an urgent need for items to be delivered to locations where road access is difficult. Especially when these items are related to healthcare emergencies such as blood, vaccine, emergency kits and other medication [5]. Drone ambulance also plays a vital role in emergency because it can avoid the issues...
such as traffic jam, congestion in cities and difficult routes [6] (see Fig. 1).

2. Introduction

UAVs and aircraft have almost the same history. The idea of UAVs came even earlier than the human-crewed aircraft as there was a risk of someone losing life by flying an aircraft for the first time. Nowadays, unmanned aircraft are so much developed that they can almost function like a proper manned aircraft. These machines have been called upon by myriad names over the years such as unmanned aerial vehicles, unmanned aircraft systems, flying machines, aerial torpedoes, remotely controlled vehicles, autonomous and pilot-less vehicles [5,8].

Drones are equipped with sophisticated technologies such as high definition cameras, sensors and GPS devices. With cameras, drones can take aerial photos and record high definition videos, whereas with the GPS device, a drone can easily identify the specified location and do the programmed task autonomously. Many drones provide a programming interface so that the researchers and developers can experiment with their own ideas of flying drones. For example, AR drone provides a Linux-, Android- and iOS-based software development kit (SDK) [9–11]. Also, most of the drones such as Parrot’s AR drone, DJI Phantom and Iris can be operated easily because of their compatibility with the Android and iOS smartphones. As most of the world’s smartphones’ market is dominated by Apple and Samsung, the drone users can now control their machines through their smartphones instead of carrying a cumbersome joystick all the time [9,12]. In the present day, a drone or a UAV can be as small as an insect or it can be as large as a commercial aeroplane, depending on its application. Some drones are launched from runways, while others need special launchers and launch pads and some just take off vertically without the need of any launcher [5,13,14].

Severe Acute Respiratory Syndrome (SARS) causes the novel Coronavirus Disease-2019 [15,16]. In December 2019, The COVID-19 was discovered in Wuhan province of China [17,18] and its isolation and sequencing was done by Zhou et al. [19]. Coronavirus infections have existed in the past. In 2002–2003, the SARS-Cov caused an outbreak in China and the Middle Eastern Respiratory Syndrome MERS-Cov affected the Middle East back in 2013 [20,21]. Common symptoms of Coronavirus disease include but are not limited to fever and/or cold and/or fatigue and bilateral opacity in posterior or peripheral lungs [22,23].

In the rest of the paper, Section 3 provides detail of existing studies conducted in emergency medicine and healthcare delivery using drones. Section 4 elaborates the tools and our scheme of study. Section 5 illustrates how we have implemented our proposed scheme. Section 6 shows the results of our study and finally Section 7 concludes our findings.

2.1. Problem statement

With the advent of the COVID-19 pandemic, the rapid increase in the confirmed cases, the uncertain situation and excessive flow of information on social media has caused panic as well as confusion among the general public. As a result, everyone wants to test themselves for the infection. However, due to shortage of staff, equipment and ongoing conditions, it is not possible for everyone to go to healthcare centre and undergo tests. Therefore, a mechanism needs to be developed so that the people can get tested safely and the swab samples can be collected at home.

2.2. Our contribution

With the advent of the COVID-19 pandemic, the rapid increase in the confirmed cases, the uncertain situation, and excessive flow of information on social media have caused panic and confusion among the general public. The drone retrieves the GPS coordinates from the alert signal and locates the spot where the swab collection kit is to be delivered. The Android application is further divided into two parts. One application is installed on the user’s smartphone while the second application is installed on the smartphone deployed at the healthcare emergency control centre. The patient sends an alert signal from his/her smartphone application. This alert signal is received by the application deployed on the control centre smartphone. These coordinates are forwarded to the drone from the control centre’s Android application and the drone then delivers the swab collection kit to the patient’s spot. The patient collects the kit and provides a swab sample. The kit is then attached back to the drone and another request is sent to the control centre via android application from the user’s smartphone. The control centre issues the Return-to-home call to the drone and the drone heads back to the control centre.

This study can serve as a basis for the paradigm shift in handling medical emergencies. Technology inspired approach could be proven as a game changer in the field of health and medical emergencies. Introducing drones to tackle emergencies can serve a great benefit to mankind. Until now, we are using ground vehicles and routes to attend to a medical emergency. However, with this approach, we can use aerial vehicles for the cases where there is need to deliver emergency kits or collect test samples which do not only save both time and money but also precious human lives.

3. Literature review

Drones are pilot-less autonomous flying machines that are used for several civil and military applications. In order to elaborate on “autonomous”, we must differentiate automatic and autonomous first. An automatic machine is a pre-programmed system that is able to perform a pre-programmed task on its own. Autonomous systems, on the other hand, use a set of pre-programmed rules to deal with any unexpected situation on the go. In UAVs, there is always some level of autonomy [3].
3.1. Applications of drones

Despite the safety and privacy concerns, drone has applications in several fields. Due to its small size, a UAV can be flown in narrow areas such as in a forest or in urban areas among large buildings. Non-military applications of drones exist in the fields of agriculture, wildlife monitoring, entertainment, sports, medicine and healthcare and many more [5,29,30].

In law enforcement and security: In situations like public protests or sit-ins, it is often very difficult to guarantee full security. Secondly, there is a threat of collision or obstruction of flight pathway due to other aerial vehicles. Therefore, monitoring of airspace is also important which can be done by police drones [31–33].

In disaster response: Using drones to assess the environment and locate the victims not only ensures the safety of the volunteers but also carries out the job efficiently [34].

In search and rescue: In comparison with aeroplanes or helicopters, the deployment of a drone can perform the actions such as rapid overview of an area quicker [35]. People often lose their way during hiking, trekking or snow mountaineering. Drones can be extremely helpful in these situations [36].

In journalism: Journalists have been the civilian pioneers of adapting this technology because they can fly it with camera and sensors on-board in order to gather data to perform reporting [37,38].

In agriculture: Drones can be used for monitoring pests and identifying the tree gap to control deforestation [39]. Drones are particularly useful in situations where there are tall and dense crops in the field. A drone can easily traverse through the field providing aerial imagery for easy inspection of the crop [40].

In sports: Sports events often involve filming of multiple moving targets which can be captured by a drone in the form of stable and non-cluttered imagery [41]. Also if an injury is caused to an athlete on the field, the drone can provide an emergency first aid kit quickly [25].

In forensics: With the help of drones, a crime scene can be investigated more thoroughly without losing any traces of evidence. Drones can also inspect areas where human reach may not be possible [3].

In medicine and healthcare: The advent of drone technology has brought a revolution in the field of medicine and healthcare [42]. Bhatt et al. [42] divided the applications of drones in medicine and healthcare into three categories:

### Table 1

| No. | Study | Proposed scheme | Architecture/Tools | Pros | Cons | Results |
|-----|-------|----------------|--------------------|------|------|---------|
| 1   | Scott et al. [5] | Drone healthcare delivery network. | Studied existing work and proposed two models for delivery. | Time is calculated keeping the budget constraint in the view | The routes are calculated empirically. It would be better if actual routes were used | Timely responses even in budget constraints. |
| 2   | Kumar et al. [25] | Basic first aid delivery to an athlete on field via drone and fire extinguishing with drone. | UAV, GSM, GPS module, camera, ground control station, elide fire-extinguishing balls. | Instant delivery of first aid and immediate assistance in fire incident. | Payload issue. Limited to sports however, can be extended to other fields. | Easy, affordable and timely solution for handling sports emergencies. |
| 3   | Momont et al. [26] | Making a drone equipped with defibrillator for handling out of hospital cardiac arrest patients. | Specially designed tri-copter, defibrillator and supporting equipment. | Significant improvement in mortality rate and reduction in delivery time of defibrillator. | No solution is given for patients in rural areas or those living at long distances | Significant improvement survival rate and is increased from 8 percent to 80 percent. |
| 4   | Kim et al. [27] | Models for improving the quality of healthcare delivery service in rural areas via drone. | Mathematical models, pre-processing algorithm, cost–benefit analysis. | Reduction in expenses of patients’ routine visits. Eased up the burden of caregivers | The scheme still needs humans (Caregivers) to operate. The samples cannot be collected if the caregivers are not present on the spot. | Improved quality of healthcare in rural areas and lower the burden of caregivers. |
| 5   | Dhivya et al. [6] | Drone ambulance for emergency healthcare. | PIC micro-controller, temperature, heartbeat, respiration and ECG sensors. A quad copter. | Early delivery of patient’s details which makes the doctors able to be ready for the patient even when the patient has not arrived yet. | There is no elaboration on how the drone will use GPS to track the patient’s location. | The proposed system can alert the doctors and the ambulance staff about the patient’s condition prior to the arrival of the patient to the hospital. |
| 6   | Claesson et al. [28] | Feasibility study of delivering a defibrillator through a drone in Stockholm city. | A drone, defibrillator and supporting equipment. | Significant improvement in the delivery time of defibrillator | The study is conducted using statistics from the past. The results may vary if it is practically conducted | The defibrillator was delivered early in 32% of the cases in urban area and 93% of the cases in rural area. |
| 7   | Our scheme | Delivering emergency swab collection kit to the public at home. | DJI Phantom 4, GPS Module and Open Source App for drone as well as smartphone. | A mathematical model is proposed. Use of open-source application. Autonomous operation. Solution proposed for a chronic disease. | The drone selected can carry a small amount of payload. The flight of drone is limited due to power constraints. | Delivery of COVID-19 testing kit for patients using novel technique. Quick and efficient response in rural as well as urban areas. |
1. Pre-hospital emergency care: Out of Hospital Cardiac Arrest (OHCA) patients use drones which have significantly reduced the response time thereby improving the survival rate.
2. Expediting laboratory diagnostic testing: People living in rural communities often do not have access to proper healthcare. This may be due to a lack of road infrastructure and unavailability of transportation. In such cases, drones can prove as productive and inexpensive to deliver vaccines or collect samples from patients.
3. Surveillance in healthcare and law enforcement: Nowadays, drones are equipped with hi-tech cameras which can be used for monitoring by law enforcement agencies and also by lifeguards on the beaches to identify any drowning victim.

As the role of healthcare is vital to human beings so the research in this field is given great importance as it can save lives of many people. We are also working on the idea of using drones in healthcare. We have developed an Android application for smartphone of a patient who want to test for COVID-19. The patient can directly call a drone using that mobile application and the drone will deliver the swab collection kit to the patient using the smartphone’s GPS coordinates.

Table 1 summarizes the prominent studies conducted on the delivery drones in the field of medicine and healthcare. Lastly, our scheme of study has been stated briefly.

4. Methodology

Our research proposes a reliable and efficient way for a testing kit to be delivered to the patients who wants to test for COVID-19. The patient can summon a drone (having a swab collection kit attached to it) for himself by using his/her smartphone.

We have developed an Android application for the patient’s smartphone as well as an application for the drone control centre with the help of which the patient is able to initiate a request to drone control centre and the drone delivers the sample collection kit to the patient. The patient takes the kit and collects swab with it. Once the sample is taken it is put back in the kit and attached to the drone. The RETURN call is initiated and the drone flies back to its home position with the sample and the kit. A mathematical model is also developed to serve as a base for future studies of this kind.

4.1. Assumptions

- The smartphone and the drone both are connected to a network.
- The developed software is compatible with both the smartphone and the drone.
- The weather conditions for drone flight are favourable and conducive i.e., wind speed, humidity and air pressure.
- The flight range of the drone is limited and is, therefore, not operational in longer distances.

4.2. Selection of the delivery vehicle

In order to pick up or drop off something, an aerial vehicle must be able to hover, navigate and land easily at the pick up or delivery spot. Also the delivery vehicle must be capable of a vertical take-off mitigating the need of a runway. The vehicle should be capable of manoeuvring and hovering in tighter spaces for delivery, especially in dense and hilly areas [43].

Considering the mentioned requirements, it can be deduced that we must choose a quadcopter as a delivery vehicle for our study because it is capable of vertical take-off and landing and it can have a stable flight with some weight attached to it. For this purpose, we have selected the DJI Phantom 4 quadcopter.

The Phantom 4’s ability to detect and avoid obstacles is quite efficient making its flight more time saving and accurate. Because of the double downward cameras and powerful Inertial Measurement Unit (IMU), the stability of Phantom 4 is about 5 times higher than Phantom 3 and other drones of comparable size. The average time of flight for Phantom 4 is approximately to be 26 min and it can fly at 35 Miles per hour approximately in the normal mode. These capabilities along with the stronger frame, powerful motors and robust shape makes Phantom 4 able to carry a payload of 1 kg and still fly for about 13 min on average. Therefore, Phantom 4 is an ideal choice for an emergency delivery.

4.3. Tools

We have used DJI Phantom 4 drone which already has an embedded GPS module for tracking the location information. The open source SDKs of Phantom 4 are available online on the DJI website. We have hacked the open source mobile SDK of Phantom 4 for our application. The application for smartphone is developed in Android using Android Studio. The source SDKs of the drone is manipulated in such a way that the GPS coordinates of the patients smartphone are fed to the drone via the Android application at control centre. To summarize, we used the following tools.

1. Hardware

- Drone: DJI Phantom 4 quadcopter drone is used to carry the swab collection kit, to identify the patient’s location, to deliver the kit to the spot and return back with the swab sample of the patient.
- Swab Collection Kit: The kit comprises a pair of disposable gloves, a mask, a hand sanitizer and a swab collection package.
- Smartphones: One Android smartphone is used by the user for placing the request for the kit using the Android application and another smartphone is used at the control centre for communication with the drone.
2. Software

- OS on the drone: The drone SDK libraries are moulded in such a way that they can trace the location given to the drone by the control centre. The block diagram of DJI Phantom 4 SDK is given in Fig. 2.
- Kit Delivery Android application: A Kit Delivery Android application is developed which is used by the patient to request for the swab collection kit and another Android application is developed which is used by the person in control centre who feeds the location coordinates of the patient which is received from Android application of the patients smartphone.

4.4. Limitations

DJI Phantom 4 can carry a limited amount of payload which is appropriate for our case study but in situations where the payload is high, the performance may get affected. Also this research only considers testing for patients of COVID-19. However, it may be customized for other studies in the future. The applications are newly developed and enhancements may be made with the passage of time.

4.5. Our scheme

With the advent of COVID-19, there is uncertainty and chaos everywhere due to which a lot of people wants to test themselves for COVID-19. However, handling so many people at the same time can be difficult and at times exhausting. Therefore, we have proposed a mechanism which helps both the people and the staff in these difficult times. Our proposed system works in three phases.

- Phase I: Whenever a patient wants to take a test for CoVID-19, he/she takes out a smartphone and opens the Kit Delivery Android application. In the application, there is a button labelled Request Kit. When the patient presses that button, a confirmation dialogue appears and after confirmation, a request for the kit is initiated. As soon as the Request Kit button is pressed, the location coordinates of the patient’s smartphone is sent to the firebase database running at the back end of Android application as well as via text message to the smartphone deployed at the control centre.
- Phase II: In the control centre, one person is deputed to monitor and control the request and delivery operations. After the request is received at the centre, the person on duty opens the drone’s Android application (DJIMyWay) on the smartphone and feeds the coordinates received from the patient’s smartphone. In future, the Android application of control centre’s smartphone is intended to retrieve the location coordinates itself from the firebase database of the Kit Delivery Application of the patient’s smartphone.
- Phase III: The drone makes waypoints for flight and the person on duty feeds the flight parameters at the control centre. Further, the drone picks its flight path and takes off along with the swab collection kit. Next, the drone arrives at the destination and delivers the kit to the patient. After collecting swab, the patient attaches the kit back to the drone and presses the RETURN button on the Kit Delivery Application screen. This initiates the Return to Home call for the drone and the drone safely returns to the control centre.

Fig. 3 summarizes our idea.

The study is further supported by a flow diagram that explains how the scheme proceeds step by step during the three phases. The flow diagram of our study is shown in Fig. 4.
4.6. Mathematical model

An optimization factor is needed to be introduced in order to check the efficiency of our work and as a base for future studies. This factor takes the following parameters into account:

- Power consumption
- Weight of the drone
- Weight of the Payload
- Distance to be covered
- Total flight time

According to D’Andrea [44], the power consumption for a UAV can be approximated in kW using Eq. (1)

$$\frac{(u_x + u_p)v}{370\eta r} + p$$  \hspace{1cm} (1)

where,
- $u_x =$ Weight of the vehicle
- $u_p =$ Weight of the payload
- $v =$ Speed of the vehicle
- $p =$ Power consumption
- $r =$ Lift to drag ratio
- $\eta =$ Power-transfer-efficiency

However in order to validate our research, we propose a maximization function which considers the correlation of above mentioned parameters. The optimization factor $\tau$ is given by Eq. (2).

$$\tau = \max \left[ \frac{(w_x + w_p)v + d_s}{t + p} \right]$$  \hspace{1cm} (2)

where,
- $w_x =$ Weight of the drone without payload (in kg)
- $w_p =$ Weight of the payload (in kg)
- $v =$ Speed of the drone (in metre/seconds)
- $d_s =$ Distance (in metres) covered by the drone from control centre to the destination (delivery point) and back
- $t =$ Time (in seconds) taken by the drone from control centre to the destination (delivery point) and back
- $p =$ Power consumption of the drone

In order to justify our scheme and results, we have compared the timings to that of the ground vehicle.

5. Implementation

The implementation of this study is done using a step-by-step approach. We have divided the study into different modules and then implemented each of them individually.

5.1. Module 1: User end

At the user-end, we have developed an Android application which enables the user to call for a drone in case of taking a COVID-19 test. The Kit Delivery Android Application is comprised of the following activities.

5.1.1. Main activity

The main activity or home activity is the first activity that appears when user taps on the application icon on the smartphone. This activity is basically on checking the credentials of the user. If the user is already registered, he/she may enter the credentials and can also check the option Remember Account to avoid entering data every time he/she uses the application. Further the user presses the LOG IN button to proceed to the next activity. If the user is not registered, he/she may click on the REGISTER button and go to the registration activity. Screenshot of the activity is shown in Fig. 5a.

5.1.2. Registration activity

This activity appears when new user clicks on the REGISTER button from the main activity. This activity is designed to get the new user’s credentials and forward them to the real time Firebase database. The user enters email address and password and then clicks on the REGISTER button to proceed. After successful registration, a pop-up appears to confirm successful registration and the Logged in activity appears. A screenshot of the activity is shown in Fig. 5b.

5.1.3. Logged-in activity

This activity appears when either the credentials of the existing user have been verified or the registration of new user is
successful. In this activity, there is one large red coloured Request Kit button in the centre of the smartphone screen. When the button is pressed, a dialogue appears for confirmation? When the user confirms an emergency, the application proceeds to new activity. A screenshot of the activity are shown in Figs. 5c and 5d.

5.1.4. Location information activity

When the user confirms the request on the confirmation dialogue from the Logged-In Activity, this activity appears. In this activity, a message is displayed to the user that Your CoVID testing Kit will be here shortly. The location of the user is also displayed in the form of latitude and longitude. There is a RETURN button at the bottom of this activity which is pressed when the patient
attaches the kit to the drone and wants to send it back to the control centre. Screenshot of the activity is shown in Fig. 5e. The working of this application is summarized in Algorithm 1.

Algorithm 1 Kit Delivery Android Application

1: Display Main Activity
2: if User Registered then
3:  Go to Logged-in Activity
4:  On Request Kit Button-Click, Show Confirmation Dialogue
5:  if Request Confirmed then
6:   Go to Location Info Activity and send SMS to Control Centre
7:  else
8:   Stay on Logged-in Activity
9: end if
10: else
11:  if New User then
12:   Go to Registration Activity
13:  On Request Kit Button-Click, Show Confirmation Dialogue
14:  if Request Confirmed then
15:   Go to Location Info Activity and send SMS to Control Centre
16:   else
17:   Stay on Logged-in Activity
18: end if
19: end if
20: end if
21: end if

5.2. Module 2: Back end

5.2.1. Firebase

Firebase is a tool from Google Inc. which can help develop applications quickly and easily. Fig. 6 shows the interface of Firebase console. The Firebase offers a lot of exciting features but we have just used the Authentication and Database features.

5.2.2. Authentication

Firebase Authentication feature provides support to authenticate users signing in using any of the platforms from Google, Facebook, Twitter, Email/Password, GitHub or anonymous sign-in. For this project, we have implemented the Email/Password platform from the Authentication Sign-in providers menu.

In order to add our project to Firebase console, we logged-in to the Firebase online. The Authentication page offers Sign-in providers menu in which several platforms are given. We have selected the Email/Password option. The rest of the platforms are disabled. Fig. 7 shows the Platforms selection window.

5.2.3. How authentication works?

When the user taps on the Kit Delivery application on Android phone, the main activity appears where the user is asked for Email/Password credentials. If the user is not registered before, he/she can go to the Registration activity to get registered. In the Registration Activity, the user is asked to enter email and password in the provided fields. As soon as the user provides the credentials and taps on the REGISTER button, the Firebase stores his/her credentials in its Authentication database and the application proceeds to next activity. If the user is already registered then he/she enters the credentials in the given fields and then taps on the LOG IN button. As soon as the user taps on the button, the Firebase checks the credentials with its database. If the credentials are authentic, the application proceeds to next activity. Otherwise, it displays a toast with the error message.

In Fig. 8, there are some users shown in Firebase database who are registered in our application.
5.3. Module 3: Control centre-end

The control centre is a place where the drones are available and a person on duty will be monitoring the Firebase database as well as the cell phone at the control centre. When a request for swab collection kit is received, the person on duty will start the DJI drone’s Android application and feed the destination coordinates to the drone. The Android application at the control centre is called “DJI MyWay” and it has been developed by the Pakzarzameen team. DJI MyWay is already available on Google Playstore [45].

After the coordinates are fed to DJI MyWay, the drone will mathematically calculate the distance to the destination using its current coordinates and the provided coordinates. If it is able to fly successfully, it will accept the task and set the waypoints to the destination and back. The person on duty at the control centre will configure the flight parameters such as altitude, speed and heading values and the drone will set out to perform the delivery and collect sample for tests [46].

5.3.1. DJI Phantom 4 drone

DJI’s 4th generation drone Phantom 4 is a high performance, simple and technologically advanced aircraft. Phantom 4 is a quadcopter that is about 2 ft in size including the wings. Its weight is about 3 lbs or 1.4 km. It is equipped with a 12+ MP camera which is non-detachable. The 5350 mAh intelligent flight battery of Phantom 4 provides power to the aircraft’s four rotors, it is camera and the chip on board [47]. The total flight time of Phantom 4 without payload is about 27 min under normal conditions [48].

5.3.2. Android Application for smartphone at control centre end (DJI MyWay)

The DJI MyWay is comprised of two major activities.

1. Location activity: this activity displays the way points on the map after the application fetches the location coordinates from the Firebase database of the Kit Delivery application and the drone decides to deliver the swab collection kit.
2. Waypoint configuration: in this activity, the configuration options are displayed and the user is asked to enter the flight parameters such as speed, altitude and return to home options.

The screenshots of these activities are shown in Fig. 9. The activities of the control centre’s smartphone application are summarized in Algorithm 2. Fig. 10 shows the flight path after waypoints are configured. Algorithm 2 illustrates the algorithm for Control Centre’s smartphone application.

6. Results and discussion

In order to validate the hypothesis of “efficient delivery of a testing kit using quadcopter UAV”, we acquired the equipment and conducted some test deliveries. The location for tests was chosen to be the College of Electrical and Mechanical Engineering (EME), National University of Science and Technology (NUST), Islamabad.

This centre was selected for two main reasons. First, we already have collaboration with them for this project and second, they have permit for flying a drone in the premises of EME NUST. The centre point of EME playground was considered to be the control centre (Home Position). We chose 5 points for kit delivery and swab collection at various displacements and in different directions from the control centre. Volunteers for swab collection were present at all the selected points. The details of the delivery points are given in Table 2.

The following satellite images (Figs. 11 to 15) show the location and distance of each delivery point relative to the control centre (Home position of Drone).
Fig. 10. Flight path overview.

Fig. 11. Delivery Point 1: Incubation centre lawn.

Table 2
Details of the delivery points.

| S. No | Delivery point       | Displacement from control centre (in Metres) | Location coordinates (Latitude, Longitude) |
|-------|----------------------|---------------------------------------------|--------------------------------------------|
| 1     | Incubation centre lawn | 327.11                                      | 33.623119, 72.958811                       |
| 2     | Golf course EME NUST  | 485.23                                      | 33.617532, 72.957139                       |
| 3     | APS ground           | 394.05                                      | 33.621200, 72.959902                       |
| 4     | Hostel bank          | 363.5                                       | 33.624031, 72.958497                       |
| 5     | Iqbal hostel         | 285.84                                      | 33.619416, 72.957020                       |

Table 3
Parameters used in the experiments.

| S. No | Parameter name                                | Value            |
|-------|----------------------------------------------|------------------|
| 1     | Weight of the test payload                   | 0.25 kg          |
| 2     | Maximum altitude of flight                   | 40 m             |
| 3     | Ascent speed of Phantom 4 with payload       | 5 m/s approx     |
| 4     | Descent speed of Phantom 4 with payload      | 4.5 m/s approx   |

6.1. Experiments

The experiments were conducted in the form of three scenarios and parameters used in the tests are shown in Table 3.

6.1.1. Scenario 1

In the first scenario, the flight of DJI Phantom 4 was tested without payload in order to estimate the time of flight to these destinations. The test run without payload was conducted to each destination and the duration of flight was noted as shown in Table 4.
Table 4
Time taken by DJI Phantom 4 (without Payload) to reach destinations and arrive back.

| S. No | Destination         | Distance from control centre (in Metres) | Time taken by DJI phantom 4 without payload (in seconds) |
|-------|---------------------|------------------------------------------|----------------------------------------------------------|
| 1     | Incubation centre lawn | 327.11                                   | 94                                                       |
| 2     | Golf course EME NUST  | 485.23                                   | 150                                                      |
| 3     | APS ground           | 394.05                                   | 118                                                      |
| 4     | Hostel bank          | 363.5                                    | 109                                                      |
| 5     | Iqbal hostel         | 285.84                                   | 93                                                       |
| Total |                     | 1855.73                                  | 564                                                      |

The graph in Fig. 19 further illustrates the data of Table 4.

6.1.2. Scenario 2
In the scenario 2, we tested the drone with swab collection kit attached to it so that we may perform actual experiment of swab collection and note the total flight time of DJI Phantom 4 and cumulative time of the swab collection phenomenon. We conducted deliveries to the above mentioned 5 destinations. The total flight times of DJI Phantom 4 (with 0.25 kg payload attached) taken in order to go to the destination, collect the sample and arrive back to the control centre are given in Table 5.

The cumulative times of the swab collection phenomenon at different points are shown in Fig. 20.

6.1.3. Scenario 3
In scenario 3, we have used a car for patient to go to the health care centre and have swab collected for tests. The destinations of
Fig. 14. Delivery Point 4: Hostel bank.

Fig. 15. Delivery Point 5: Iqbal hostel ground.

| S.# | Destination         | Total flight time of DJI Phantom4 with payload (in seconds) | Time taken on the ground while collecting swab (in seconds) | Cumulative time of the phenomenon (in seconds) |
|-----|---------------------|-------------------------------------------------------------|-------------------------------------------------------------|------------------------------------------------|
| 1   | Incubation centre lawn | 100                                                          | 510                                                         | 610                                           |
| 2   | Golf course EME NUST  | 156                                                          | 360                                                         | 516                                           |
| 3   | APS ground           | 125                                                          | 560                                                         | 685                                           |
| 4   | Hostel bank          | 115                                                          | 435                                                         | 550                                           |
| 5   | Iqbal hostel         | 98                                                           | 630                                                         | 728                                           |
|     | **Total**            | **594**                                                      | **2495**                                                    | **3089**                                      |

Table 5
Total flight time of DJI Phantom 4 with swab collection kit attached.

The previous scenario were supposed to be the homes of patients and the healthcare centre was supposed to be the middle of the ground (which was the control centre for the drone in previous scenarios). The cumulative time taken by a patient starting from home and going to the healthcare centre, having swab collected...
Looking at the findings in Tables 5 and 6, we can easily see the difference in cumulative times of ground vehicle and the drone. Fig. 21 shows these differences on a bar graph. It can be observed that there is a clearly large difference in the cumulative times of both scenarios. It may also be noted that we have used shorter distances due to limited flight permissions for drone. This difference will increase as the distances grow longer.

The optimization factor $\tau$ for these destinations is given in Table 7. The average value of optimization factor $\tau$ for our study is 0.5. If we take $d_x$ as the average displacement of these 5 destinations which is 371.15 m and $t_{av}$ as the average cumulative time taken for tests and then reaching back home are recorded in Table 6 along with the distances covered.
Table 6
Cumulative time taken by a patient using a ground vehicle.

| S. No | Delivery point          | Distance from control centre (in Metres) | Cumulative time taken by the ground vehicle (in seconds) |
|-------|-------------------------|------------------------------------------|---------------------------------------------------------|
| 1     | Incubation centre lawn  | 439.62                                   | 978                                                     |
| 2     | Golf course EME NUST    | 609.19                                   | 1206                                                   |
| 3     | APS ground              | 629.31                                   | 1218                                                   |
| 4     | Hostel bank             | 569.81                                   | 1260                                                   |
| 5     | Iqbal hostel            | 384.1                                    | 1038                                                   |
| Total |                         | 2632.03                                  | 5700                                                   |

Table 7
Optimization factor $\tau$ of the time taken for swab collection via drone.

| S. No | Delivery point          | Displacement from control centre (in Metres) | Optimization factor $\tau$ |
|-------|-------------------------|----------------------------------------------|-----------------------------|
| 1     | Incubation centre lawn  | 327.11                                       | 0.44                        |
| 2     | Golf course EME NUST    | 485.23                                       | 0.73                        |
| 3     | APS ground              | 394.05                                       | 0.48                        |
| 4     | Hostel bank             | 363.5                                        | 0.53                        |
| 5     | Iqbal hostel            | 285.84                                       | 0.34                        |
| Average|                        | 371.15                                       | 0.5                         |

The value of the $z$ factor for our study is 0.6. The lesser the $z$ factor, the better the results.

7. Conclusion and future work

The advent of unmanned aerial vehicles has resulted in a huge technological advancement of the twenty-first century. It has so many advantages in almost every field of life. However, these UAVs can also be used to save time and precious lives by playing their role in the delivery of emergency medicine and healthcare kits. We have conducted a similar study with the objective of delivering a CoVID-19 swab collection kit to the patient at home via a drone efficiently. We have studied the existing models of delivery with drones in medicine and healthcare to learn how these UAVs can be used to benefit mankind. We have developed an Android application for patients through which the patient can send a request to the control centre whenever the patient needs to test for CoVID-19. As soon as the request reaches the control centre it is forwarded to the drone through Android application and the drone makes a flight path to the patient. The drone flies to the patient’s location and delivers the kit. The patient takes out the apparatus and collects swab. When the swab is collected, the patient initiates a return call via the android application and the drone takes the collected swab back to the lab. We have proposed a maximization function that is represented by optimization factor $\tau$ and a $z$ factor. These factors serve as a base case for future research. The results in the previous section show that drones can easily be used for delivery of items as we have seen in the experiments conducted. It is concluded from the results of the preceding section that drones can be a feasible and efficient alternative in the field of medicine and healthcare delivery. The experiments were conducted in the centre where we had permission radius of about 500 m. The results could be more accurate if the tests are conducted over a longer range as we are planning to extend the range in our future studies. The above study shows that using drones in the field of emergency healthcare delivery can bring a lot of ease in the process of collecting samples and it can be of great advantage considering the time factor as well. It is evident from the results that as the range of operation grows longer, the results tend to be better. As a future work, we are going to introduce a detaching mechanism of the kit from the drone so that the emergency kit can be dropped by the drone at the patient’s location. The algorithm for obstacle avoidance also needs to be developed and included in the system. Our proposed scheme is semi-autonomous as it needs one person at the control centre to monitor and control the drone and feed coordinates to the drone. Our future target is to achieve full autonomy by synchronizing the patient’s smartphone application to that of the control centre’s Android application so that the drone can receive and pick up the target locations by itself and collect the swab sample from a patient.

CRediT authorship contribution statement

Fahad Saeed: Conception and design of study, Acquisition of data. Amjad Mehmood: Acquisition of data, Analysis and/or interpretation of data, Drafting the manuscript. Muhammad Faran Majeed: Analysis and/or interpretation of data, Revising the manuscript critically for important intellectual content. Carsten Maple: Acquisition of data, Analysis and/or interpretation of data, Drafting the manuscript. Khalid Saeed: Conception and design of study. Muhammad Kashif Khattak: Conception and design of study. Huihui Wang: Revising the manuscript critically for important intellectual content. Gregory Epiphaniou: Analysis and/or interpretation of data, Drafting the manuscript.
Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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