Cloud-based drone management system in smart cities

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Abstract: Recently, unmanned aerial vehicles (UAVs), or drones, can be used to complete a wide range of different tasks from the military to the industry with numerous studies available in the literature. With the rapid development of technologies, especially computing, sensing, the Internet of things (IoT), and Information and Communication Technologies (ICT), the demand for using drones has been increased in real-world applications. However, the larger the number of operating drones, the more accidents in the sky. Therefore, it is essential to manage drones in traffic flows. This study proposes an approach, called a cloud-based approach for managing drones in a smart city. This approach is based on the cloud devices and services such as computation, storage, and web services. A ground control station is used to control and monitor drones, which allows users to define path planning and to achieve the drone sensor's data. Users, or remoted pilots, can create paths or missions for drones, which can be saved and sent to a connected drone. This approach allows users to control and monitor drones as connected objects in a real-time environment. The experience results demonstrate the effectiveness and promotion of the proposed method.

Keywords: transport managing system, air traffic managing system, drones, internet of things, internet of drones.

1. Introduction

Drones, commonly term of unmanned aerial vehicles (UAVs), are remotely piloted aircraft that have significant roles in defense as well as commercial sectors. The drones can navigate autonomously without the involvement of human control. A drone can equip with several IoT smart devices, such as sensors and payloads, to do several specific tasks [1]. Recently, drones are used in a wide range of applications such as monitoring, surveillance and mapping, cargo delivery, etc.

Drones can be equipped with sensors for obtaining data and getting orders like an actuator [2]. These drones can be used to deliver packages, patrol areas, monitor infrastructure, search, and secure. In these platforms, drones were used as teleoperated vehicles through the Internet, which is based on low-level services directly related to the basic drone movements. However, controlling and managing drones through the Internet poses new challenges, which means that a large number of drone applications in particular airspace raises the need for drone traffic management or, in general, unmanned aircraft vehicle traffic management (UTM). Many studies have been proposed potential methods and technologies as well as system architecture for the UTM [3-7].

The investigations [8, 9] into the development of UTM for the drones' urban operation and analysis of the possible solutions have resulted in the identification of several significant problems, including

- difficulties in using passive surveillance systems (due to the low flight altitudes and large buildings),
- the complexity of conflict /obstacle detection and resolution (due to high traffic intensity and a lot of built obstacles such as houses), and
- need for a cost-effective solution (low-cost UTM, due to the very low operational cost of drones).

The solutions for these problems require full integration of UTM into the urban transport management systems and the development of unique methods for managing a large number of drones in formation flight. Such approaches include the management of dynamically variable groups of drones [10, 11], swarm optimization [12, 13] and drone-following models for individual vehicles [18, 19] moving with similar trajectories; being in the same "trajectory tunnels".

For outdoor environments, managing connective drones through the Internet was conducted in several research projects as well as commercial applications [14-16]. Besides, a novel IoT platform for managing connected drones in indoor environments was proposed in the study [17], where indoor flight plans were used to control multiple connected drones.

This study proposes an approach called a cloud-based method for managing drones in a smart city, which is based on cloud devices and services such as computation, storage, and web services. In section 2, some related works will be presented. The cloud-based connected drone management system is demonstrated in section 3. Section 4 will show elements of a drone, including software, hardware, and communication units. The experimental study and evaluation process are illustrated in section 5. This paper is ended by concluding section 6.

2. Related works

In this section, several studies regarding the management of drones in smart cities are presented.

In [18, 19], the authors presented the regulations of the use of drones and proposed the drone-following models to manage drones in traffic flows. These models describe the one-by-one following the process of drones in the traffic flow. This approach based on determining the drone acceleration that depends on the differences in velocities and distances between the given drone and its leading one. Although the simulation results show that these models can be applied to develop the significant simulation technologies or a new type of controls, the equations of motion of drones must be integrated into these models to improve the proposed method.

In an IoT environment, many proposal platforms are proposed to use drones as connected objects, which are based on the system communication of low-level services. The authors in [17] proposed a novel IoT platform for controlling and monitoring connected drones in indoor environments. This platform consists of three significant parts, as follows:

- the web application used to define flight plans, and it is allowed for sending and accomplishing these trajectories by continuous communication with the drones,
- a local Wi-Fi network where the server and the drones are connected,
- one or more connected drones that send and get data from the server.

In this study, users in a web application used indoor flight plans to control and monitor connected drones. This method can allow controlling multiple drones because flight plans do not have to be designed and taken at the same time. Also, with sensors equipped on drones, data can be shown in monitoring tasks by automatic communication flow between the server and the selected drone. The proposed platform is validated based on use cases and the evaluation process. However, this platform is not designed for high-level services.

For high-level services, a net-drone using connected drones can be managed and monitored by IoT systems [16]. Such a system can operate many drones at the same time. A fleet of net-drones will be deployed on-demand network service in an emergency network infrastructure, such as a sudden increase in population or disasters. Moreover, net-drones are used by a service provider to enhance the network quality of experience. Because net-drones were used to collect data about links, traffic, and neighboring drones, that collected information can be exploited to provide enhanced network access to users nearby. In this study, net-drones are managed by controlling their height as well as the distance between drones. Several platforms based on IoT were presented in the literature [20-23].

After performing its mission, a drone needs to find the optimum station to be recharged. It could be harder in smart cities where plenty of drones can be operated. To overcome this problem, the authors in [24] proposed an innovative and optimized concept for networking and assigning the stations for drones, which is based on a Kuhn-Munkres (Hungarian) algorithm that used to optimum power for the drones to find the defined stations in smart cities.

Regarding a group of drones, the authors in [25] presented a novel and feasible path planning technique based on particle swarm optimization algorithm that used to generate the desired trajectory that is sent to an individual track for each drone based on its defined position. This method is not only simple implemented for the group of drones but also generated the optimum paths for each drone in the formation.

Because drones can fly near people and property, safety regulations play an essential role in the drone managing system. All drones, then, must be managed and controlled as aircraft according to the Federal Aviation Administration (FAA) regulations [26]. Several cases of studies regarding the legal use of drones are presented. For example, in the use case of drones in the Slovak Republic [27], the use of drones in transportation must guarantee safety and energy efficiency [28, 29].

The authors in [30] highlighted the importance, impact, and diversity of UAV regulations. Most studies did not mention specific rules, even the legal provisions, which applied to their data collection flights. Some articles presented national and international regulatory and its short introductions, which provide only brief overviews and remain highly generalized. However, regarding societal aspects, privacy, data protection, and public safety are concerned, investigated, and presented by lawyers and social scientists. Such researchers also determined the gap between current regulatory frameworks. This study also provided three key aspects, on which current UAV regulations focused, including *(i)* goal of the law is to regulate the use of airspace by UAVs; *(ii)* setting operational limitations to assure appropriate flights; *(iii)* tackling administrative procedures of flight permissions, pilot licenses, and data collection authorization.

Based on the literature review above, it can be noted that the management of drones is a significant issue not only in the transportation system but also in the air traffic management system in smart cities.

3. Cloud-based drone management system

The Cloud-based drone managing system (CbDMS) motivated by IoT and the Internet of Drones (IoD) technologies have demonstrated a useful performance in dealing with complex and dynamic traffic flows. This platform has three main layers: (i) physical layer, including connected drones, and fundamental infrastructure; (ii) cloud layer, including storage, computation and interfaces, is based on the wireless system, using the Internet, and (iii) control layer is a hierarchically organized software set, which used for controlling and managing drones in the traffic flows (Fig. 1).

Because of the increasing number of drones in smart cities, the opportunity of employing CbDMS in the air transport in smart cities cannot be denied. In the following subsections, each layer of the CbDMS is shed light.

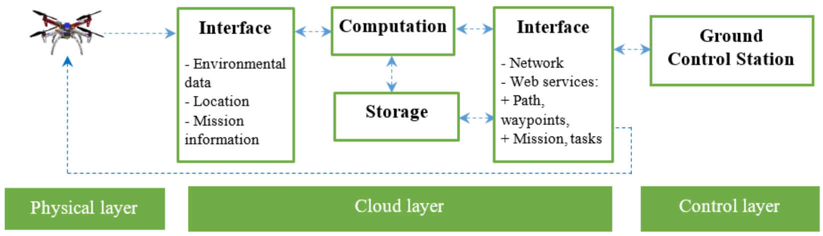

Fig. 1. The Cloud-based drone managing system

3.1. Physical layer

The physical layer is referred to as drones. Drones can take their missions, such as monitoring, crowd controlling, wireless coverage provision, surveillance, delivery [31, 32].

This layer connects various network elements and services such as drone-to-drone (D2D) or drone-to-target (D2T). The physical layer is connected with the IoT cloud by wireless technologies, including two categories: short and long-range [33]. The drones receive control signals and information about traffic situations from the cloud layer to control their behaviors according to the requirements of the ground control station (GCS) in the control layer. In the drone era, this transition is simple due to the integration of drones with the IoT world.

3.2. Cloud layer

The cloud layer has three main components, including storage, computation, and interface components. Providing storage can be used for streams of data about the environment, location, and mission information from drones and captured by this layer. Depending on the application's requirements, this data is stored in a regular Structured Query Language (SQL) database or in a distributed file system, which helps to perform large-scale batch processing on stored data. Data process on the cloud has two types as follows: (i) real-time stream processing, using to detect critical events or possible threats; (ii) batch processing, used to look for particular events into the log file by storing incoming data. Several computation algorithms, such as image processing, Map/Reduce jobs, and data analytics, are executed in the cloud, which may reduce the processing time and improve performance. Interface components include network and web services interfaces, which used to communicate between the physical layer and the control layer.

The cloud layer is also considered as the heart of the CbDMS, which is the central management unit of network operations. The layer aims to transfer the data between the physical layer and control layer and handle network management and resource allocation. The control layer, initially, specifies the required policy to the central controller in the cloud layer, and the controller passes those requirements to the drones in the physical layer. This operation will be done with the help of the interface components based on Internet protocols [34, 35]. Furthermore, communication plays an important role in transferring data from drones to the control layer, which provides higher efficiencies in comparison with conventional communication such as telemetry wireless communication. Besides, the cloud layer can be equipped with advanced sensors or controllers that can handle time sensitivity and data heterogeneity, which provides higher efficiencies.

Interfaces in this layer can use a variety of different communication protocols such as wireless local area network (WLAN), wireless personal area network (WPAN), low-power wide-area network (LPWAN), and cellular [36]. Depending on each drone application, goal, and overall need, more than one communication system can be used for better data integrity and quality. A Wi-Fi transmission system is used to commercial drone operation, where drones communicate directly with the base station without the need for an access point. Besides, long-range wide area networks (LoRaWAN) and long-term evolution (LTE) provide better reliability and low latency communication systems compared to Wi-Fi [37].

3.3. Control layer

The control layer, referred to as the GCS, uses to control and manage drones in the traffic flows. This layer consists of application software that can be used to send the control signal to drones and receive data from drones. Based on such software, the users can register drones, define and modify mission parameters thorough data analysis provided by the cloud. Also, this application allows remoted pilot monitoring and controlling the drones and their missions remotely by connecting/disconnecting available drones.

4. Components of drone

The drones are a complex piece of technology, a mix of mechanics, hardware, and software that ensures a safe and smooth flight. Today, the autonomous control system, such as self-driving vehicles, is possible because of the integration of new generations of computational and physical systems. The IoT devices play the most important role in transferring from offline space (physical, including hardware) to online cyberspace (software).

4.1. Software

The software component is considered as the mind of the system, while the brain of the drone is the flight controller unit (FCU). This component is needed to ensure a straightforward and smooth operation of the drone and the user, which includes multiple layers such as firmware, middleware, and operating system. These layers connect users to the drone hardware, also called flight controllers.

Nowadays, several flight controllers can be used in a variety of drones because of their open-sourced packages, including Ardupilot [38], Pixhawk 4 [39], iNav [40], Paparazzi [41], and LibrePilot [42].

Generally, the performance of the software is linked to the hardware system. The software components are more important because stronger hardware cannot mask out the inefficiencies in the software component.

4.2. Hardware

The hardware has several components, which are demonstrated in Fig. 2. A drone can connect to the cyber world through this hardware. Two essential components of a drone are sensors and electronic speed controllers (working as an actuator). Sensors can be classified into [43]: (i) proprioceptive sensors, measuring information internal for self-monitoring; (ii) exteroceptive sensors, measuring information external such as distance and altitude. (iii) exproprioceptive sensors, correlating the internal and external state of the drone.

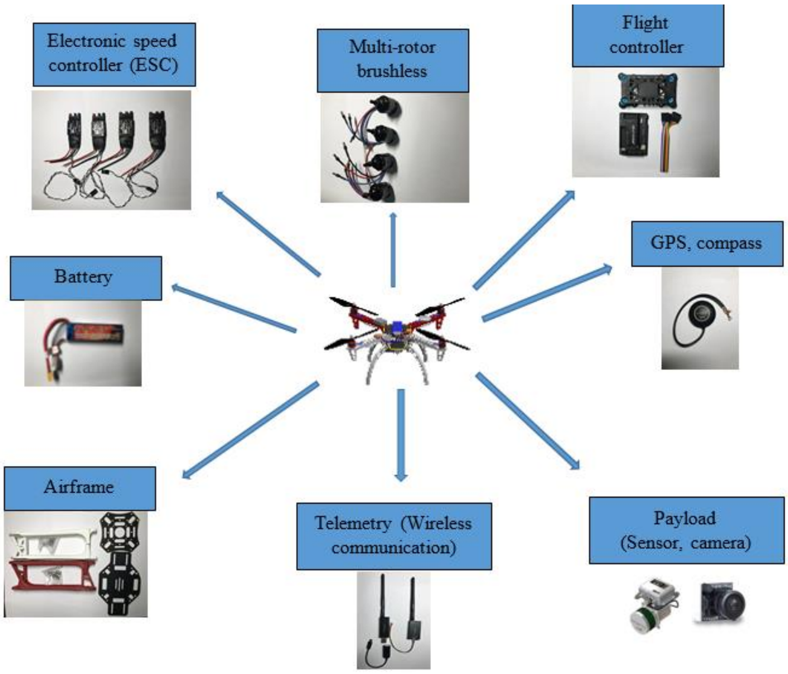

Fig. 2. Components of a drone

Such sensors will constantly collect data about monitoring, movements, and senses. Based on that data, the actuators will decide to react accordingly to the changes in the environment. Flight controllers (FC) can equip with sensors like accelerometers, gyroscope, and magnetometer that repeatedly receive information for a drone such as an altitude, angle, and speed correction. It could be impossible to control and manage the flying drone without FC. A certain position of the drone can be navigated and hovered by the FC decision that is made with the help of the Inertial Navigation System (INS) and Electronic Speed Controller (ESC). The health state of the drone and the flying movements are monitored through the exchange of data between the drone and the GCS. This exchange of information is taken via telemetry information flow, which could cause challenges for the long-range flights. To overcome this problem, satellites and Internet devices are the options for a case of a constant, uninterrupted telemetry information flow. Several payloads such as sensors or cameras can be equipped on the drone due to its tasks. In commercial drones, a First Person View (FPV) camera is mounted to record video during flights.

Another essential component of a drone is a battery that causes the weight of the drone, making it harder to fly. Due to the limitation of the battery, drone tasks must be analyzed and carefully understood. An accident of the drone will occur if there any small error of battery, which leads to failure in wireless communication, data processing, and many other important parts in the drone. The size and the recharging time are the two essential criteria in drone batteries. Before and after performing their missions, drones need to find the charging stations to recharge their battery. Kuhn-Munkres algorithm is carried out to get an optimum power for the drones to land in the suitable stations in smart cities [24].

4.3. Communication unit

Controlling and managing drones in smart cities are performed through communication systems. The exchange of information between drones and the GCS is solved by several solutions, including wireless communication, Internet of drone (IoD) solutions. However, the wireless connection must be a reliable, robust, scalable, and fast system for drone applications.

Besides, the communication of multiple drones will become more challenging at the same time. Although the multi-drone, sometimes referred to as cooperative drones, drone formation, or groups of drones, has significant advantages compared with single-drone. Still, it can cause considerable challenges regarding the broken link, bandwidth limitation, and power. While frequencies of 2.4 GHz to 5.8 GHz are dedicated to remote controlling of the civilian drones, satellites are used in large scale and military applications of drones. Several existing wireless technologies, such as IEEE 802, 3G/4G/LTE, can be deployed for multi-drone applications [44].

In drone communication, several issues should be considered and evaluated, including the speed of the drone, energy limitation, limited onboard storage, and antennas angle. For instant, the antenna's characteristics may cause a lower data rate and reduced radio range.

5. Experimental study and evaluation

In this section, we present an experimental study of monitoring and controlling drone via the Internet (4G D-com Viettel). This exploratory study aims to evaluate the real-time performance of monitoring and controlling drones. This framework is built on hardware on the drone (Pixhawk PX4) and software on the ground (Mission planner).

Besides, this testbed platform is to validate the proposed CbDMS, which provides the management and control of drone applications for delivery, surveys, security, ambulance, and emergency response.

5.1. Experimental setup

We conducted experiments with a real drone to validate the proposed approach and evaluate its performance - the experimental scenario of tracking a set of waypoints with a real drone in a particular area.

The materials to setup hardware are demonstrated as the following:

- Flight controller: Pixhawk PX4
- Companion computers: Raspberry Pi 3B
- Micro SD card: 16GB
- Camera: Raspberry camera V1
- D-Com: Viettel
- UBEC: HobbyKing^{TM} HKU5 5V/3A UBEC
- Direct Cable for connecting companion computer to the flight controller.

The diagram of this testbed platform is illustrated in Fig. 3.

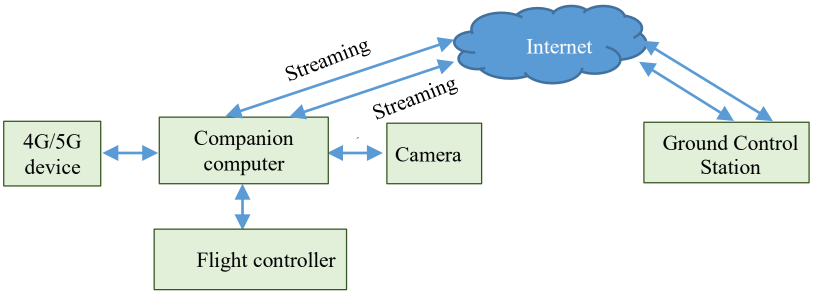

Fig. 3. The diagram of the testbed platform

The connection between hardware components is shown in Fig. 4.

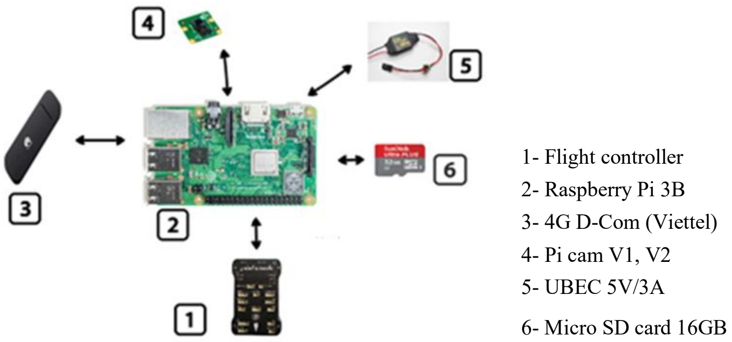

Fig. 4. The connection between hardware components

Using a direct cable to connect the Pixhawk's TELEM2 port to the RPi's Ground, TX and RX pins as shown in Fig. 5.

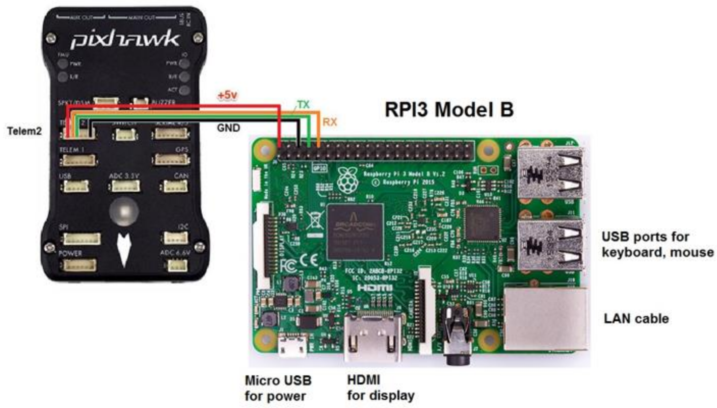

Fig. 5. The connection between companion computer and flight controller

Ground control station (Mission planner) connects to drone through 4G Wi-Fi router (D-com Viettel), which allows monitoring and controlling the drone. Besides, the drone will receive mission and command through MAVLink messages.

5.2. Experimental results

The experimental result is demonstrated in Fig. 6. Initially, the drone was located at a home location. When it received the command from the GCS, it take-off and do mission, visiting the created waypoints. It is seen that the desired trajectory and actual trajectory are correlated. The gap between the two trajectories represents GPS location because the drone receives the GPS location.

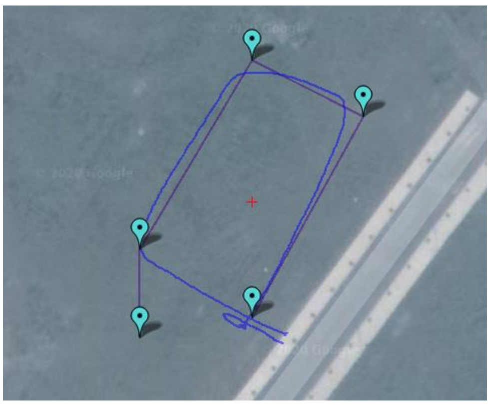

Fig. 6. The difference between desired and real trajectories (pink line – desired trajectory, blue line - real trajectory)

The attitude information, including roll, pitch and yaw angles are shown in Fig. 7-10.

Fig. 7. The pilot's desired roll angle in degrees – red line, the drone's actual roll in degrees – green line

Fig. 8. The pilot's desired pitch angle in degrees – red line, the drone's actual pitch in degrees – green line

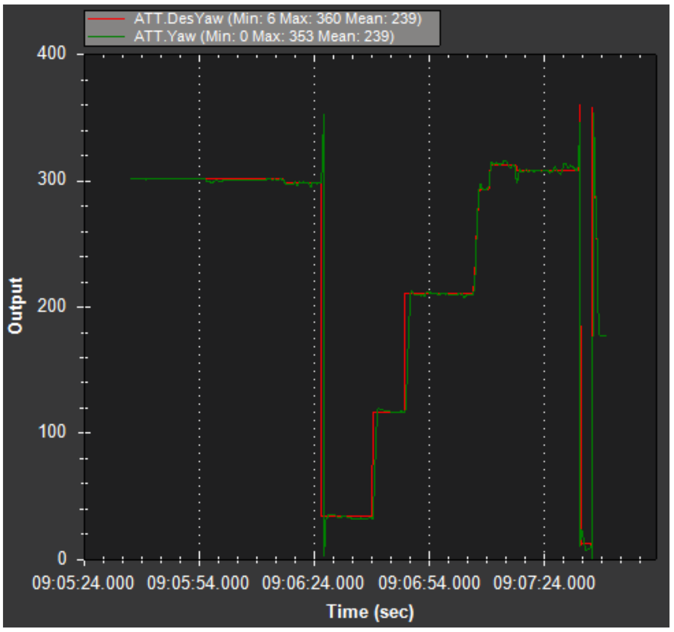

Fig. 9. The pilot's desired yaw angle in degrees – red line, the drone's actual yaw in degrees – green line

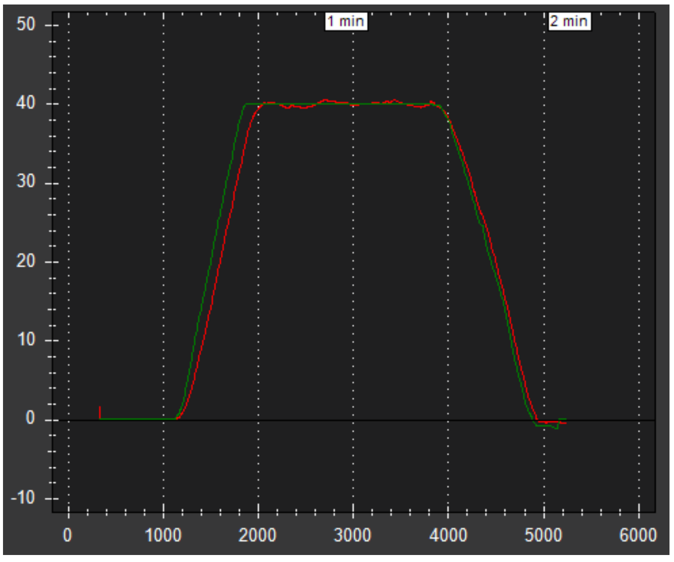

Fig. 10. The difference between desired and actual altitude of drone, green line – desired altitude, red line – actual altitude

The results demonstrate that proposed CbDMS is a cloud solution that enables to manage and control drones in a real-time environment. The monitoring accuracy can be improved by increasing the frequency of updating GPS coordinates or adding filtering techniques (Kalman filters), which can reduce noise.

5.3. Discussion and future research directions

It can be noted that the performance of controlling and managing real-time drones over the network is highly dependent on a reliable quality of service. Controlling drones over the Internet has two typical constraints, including hard real-time control and soft real-time control, which impose the use of safe and high quality of service network. For instance, controlling a drone through the Internet may cause harm or crash to drone because of a missing command, or have a command with delay. To overcome this problem, a smart onboard system is the best solution to avoid crashes in case that a command is not received.

In our experimental study, a drone autonomously followed a list of waypoints, which was sent to drone through the Internet. This constraint is a soft real-time, which means that the Internet is used to deliver offline commands to the drone.

However, drones can detect obstacles and plan their paths by using onboard sensors that receive information in real-time. It means that drones can survey and gather environmental information. Keeping this information up to date enables online managing and controlling drones, which is one of the most advantages of drone applications. However, one drawback may occur in online path designing and obstacle avoidance, such as less accurate due to low input data. Regarding trajectory and path planning, several criteria, including total travel distance, completion time, coverage area, and maneuvers, are used to evaluate the performance of drone applications.

We plan to extend this experiment with a group of drones that one can be a leader and others as followers. Other improvements can be carried out in future research that developing the proposed method to manage and control drones more accurately in a real-time environment. Furthermore, several possible extensions of this method are countless. We are planning to design and test applications based on the Leader-Follower formation of drones.

6. Conclusion

The proposed approach, cloud-based drone managing system, in this work, illustrates a drone managing system consisting of a physical layer, cloud layer, and control layer to ensure safe and efficient of drone operation. Because of the increasing number of drones in smart cities, the opportunity of employing CbDMS in the smart city cannot be denied.

The experimental study demonstrates that proposed CbDMS enables to manage and control drones in a real-time environment. The performance accuracy can be improved by increasing the frequency of updating GPS coordinates or adding filtering techniques such as Kalman filters. Besides, controlling a drone through the Internet may cause harm or crash to drone because of a missing command, or have a command with delay. A smart onboard system is the best solution to solve this problem, which can avoid crashes in case that a command is not received

Several extensions of this study can be conducted in future research, including improvement of the proposed method to ensure more accuracy operation, and experiment with a group of drones that one can be a leader and others as followers.

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