Beyond Visual and Radio Line of Sight UAVs Monitoring System Through Open Software in a Simulated Environment

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Abstract. The problem of loss of line of sight when operating drones has become a reality with adverse effects for professional and amateur drone operators, since it brings technical problems such as loss of data collected by the device in one or more instants of time during the flight and even misunderstandings of legal nature when the drone flies over prohibited or private places. This paper describes the implementation of a drone monitoring system using the Internet as a long-range communication network in order to avoid the problem of loss of communication between the ground station and the device. For this, a simulated environment is used through an appropriate open software tool. The operation of the system is based on a client that makes requests to a server, the latter in turn communicates with several servers, each of which has a drone connected to it. In the proposed system when a drone is ready to start a flight, its server informs the main server of the system, which in turn gives feedback to the client informing it that the device is ready to carry out the flight; this way customers can send a mission to the device and keep track of its progress in real time on the screen of their web application.

Keywords: Drone · Open source · Internet · Web application · Web server · SITL · Line of sight · UAV

1 Introduction

Drones or unmanned aerial vehicles (UAV) are a technology in continuous evolution, they have different fields of application today in diverse areas such as precision agriculture [1, 2], livestock [3], fishing industry [4], among others. However, its use has been affected by different situations, such as the overflight of prohibited places, the overcoming of height limits already established in different legal frameworks, limitation of flights during the day, among others. Another potential problem consists of the loss of control of the UAV. Currently, telemetry is used to control the communication of most commercial drones with the ground station, which is a communication system that allows the transmission of data from one device to another. During these transmissions, interference may occur causing loss of control over the device and making it impossible for the user to know its status during those moments, which could cause accidents and even the possible destruction of the device.

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1.1 The Problem of Loss of Line of Sight

Visual line of sight (VLOS) and radio line of sight (RLOS) establish areas where it is possible to directly visualize and control drones, respectively. While using a drone, its RLOS can be lost due to various factors. For example, the drone could be located behind a large obstacle at a certain moment or there could be a partial or total loss of the data transmitted to the user caused by interference present in the electromagnetic waves that are used in wireless communication [5]. These situations do not allow the operation of long-range flights, consequently generating limitations in the applications that can be given to drones. To this is added the legal issue, since the flight of these devices over prohibited areas is not allowed, a situation that when violated could cause legal problems for the owner of the UAV.

Here are some points that must be considered in order to provide a viable and acceptable solution to the problem described above, which generates many adverse situations for drone users:

- Being able to use a drone through direct control and / or telemetry without losing line of sight.
- Have a stable direct connection alternative on the drone to avoid the problem of loss of line of sight.
- Have access to a web application that allows user-drone interaction to be handled comfortably.

1.2 Some Useful Tools for Testing Drones

The tools that allow the connection with the drones are several, one of the best known is Mission Planner (MP) [6], which provides the user with different functionalities such as creating a route by setting different appropriate parameters, to later load it into the drone and perform the mission. The different measurements of the device (height, speed, current position, current direction during the flight performed, among others) are nicely displayed on a map within MP.

MP also provides the option of simulating the flight of different UAVs with the use of an open source simulation tool known as Software In The Loop (SITL) [7]. The latter, being an open source tool, has functionalities that are not linked to MP, allowing developers to have all the benefits that it entails, such as access to the source code, the use of different libraries that allow handling the simulation data and the control of UAVs during the flight.

The use of the Internet is expanding every day, promoting technology to interconnect different devices thanks to the Internet of Things (IoT), this provides varied functionalities that help users to perform multiple tasks; such as the control of household items (appliances, security cameras, among others). Added to this are the options for data analysis offered by these devices, which give the user the possibility of making timely decisions, some examples of this are the self-adjustment of a luminaire or the temperature control of an air conditioning. This great evolution of the internet has led engineers to seek solutions that facilitate the use of different types of devices, generating interest in the technology community and expanding its use.

2 Technologies Associated with Increased Line of Sight

Laws restrictions regarding flying drones vary from country to country. However, there are many similar limitations. For example, US and many European countries, such as Spain, allow amateur drone operations only within the VLOS of the operator, which is usually define as up to 500 m horizontally and 120 m vertically [8, 9].

Extending the line of sight of drones is a very representative problem that rise many solutions such as Extended Visual Line of Sight (EVLOS), which consists of maintaining permanent contact between the drone pilot and one or more observers through radio. In Europe, one solution for extending the line of sight is VLOS fusion, that consists of positioning a pilot in a central point giving a flight radius of 500 m to the drone while another pilot stands in another central point that has an equal range radius for the same drone (the pilots' trajectories must intersect); thus widening the line of sight and allowing both to have a greater range of travel. This solution however, adds a new negative situation in a collateral way; since requires the use of more personnel to carry out a task that could be controlled by a single person through a control station that allows to maintain control of the unmanned aerial vehicle at all time.

The technologies for location awareness of drones can be classified into two main groups [10]: Direct broadcast and network publishing.

Direct broadcast applies different communication technologies using direct transmission between drones and ground stations. There are technologies that are considered relevant when managing communication between an unmanned aerial vehicle and a ground control station, such as telemetry through the use of 2.4 GHz and 5.8 GHz industrial, scientific and medical (ISM) radio communication bands; as long as the criteria analysis (communication ranges, energy consumption, costs, robustness, security, latency, interoperability between standards, among others), use cases and appropriate scenarios (applications) are carried out. This science is highly useful for one of the most common drone applications, precision agriculture (PA); both for VLOS, EVLOS and Beyond Line of Sight (BVLOS). The use of these bands in PA generates quite satisfactory results compared to other technologies, such as WI-FI, whose main problem is high energy consumption, communication range and security. Despite these statements, it is essential to emphasize the fact that this success has been proven only in this application of UAVs, there are surely many more of them [1].

In areas where BVLOS and RLOS occur, data can be sent to and received from the drone by wireless communication technologies, despite the operator cannot visualize the drone. For example, in [11] a system that realizes long-distance communication for drones using the 400 MHz frequency band and data transmission was developed where the location information is broadcasted at a constant period using a simplified protocol based on peer aware communications defined by the IEEE802.15.8 Working Group enabling location sharing in real time.

On the other hand, network publishing uses existing network infrastructure though cellular or satellite networks [12], allowing BVLOS and beyond RLOS (BRLOS) to control the drones [13, 14].

The use of mobile networks has grown even more in recent years with the birth of 5G, which allows a range of new options in different fields in the use of drones, analysis have already been carried out of the possible benefits that will be obtained thanks to its use, being one of them wide, safe and reliable connectivity. These factors favor the use of this technology in different industries since by offering economic benefits and security, governments will greatly reduce the current limitations of communications, allowing companies to make use of the technology to solve problems and needs.

2.1 An Interesting Solution

An acceptable solution for BVLOS and BRLOS is to develop a web system that allows the user to plan a flight, with the implementation of a connection between a web platform and the drone, with the MP tool as support. For the system testing, the SITL simulator is proposed, some specific objectives are described then:

- Develop a friendly interface that allows the user to select data for pre-established routes in a database, define flight routes, show feedback of the status of the drone from SITL and view them in the web application.
- Integrate the developed system and SITL to create routes that will be sent to the drone.
- Send routes from the web application to SITL for the drone flight simulation.
- Allow the use of MP as a support tool to handle more advanced operations on the drone, for example sensors calibrations.

3 Proposed Solution

The proposed solution (Fig. 1) consists of an architecture comprising a client module, a main server and an additional server called the "drone server", in addition to an administrator component and connection to open source tools. The drone server runs SITL which will be activated by an administrator using any of the TCP or UDP communication protocols. The simulated drone in SITL can optionally be calibrated via MP. Subsequently, SITL communicates with the Backend of this same server who collects the data and sends it to the main server. The latter in turn communicates with the client allowing him to perform all actions on the simulated drone as well as view its progress and status as shown in Fig. 11.

3.1 Client Component

The client component is subdivided into four components, the details of which are explained below:

- Drone module: Allows the customer to create and edit drones. It also gives the option to list the existing drones in the database (DB).
- Routes module: Allows the customer to create and edit routes.
- Mission module: Gives the option of creating and executing missions, as well as viewing their progress.
- Communication module: It communicates with the three previously mentioned modules. It allows the latter to communicate with the endpoints of the main server through messages in JavaScript Object Notation (JSON) format (Fig. 2).

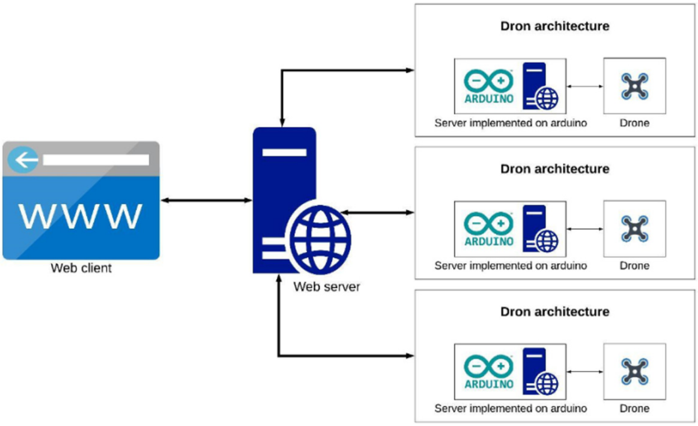

Fig. 1. Diagram of the proposed solution.

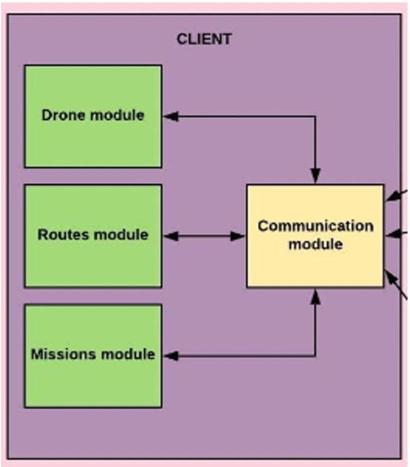

Fig. 2. Client modules.

3.2 Main Server

This component has been subdivided into five endpoints, the details of which are explained below:

- Drone endpoint: It communicates with the client's drone module through the client's communication module. Save the drones sent from the client in the DB. It also reads all the drones in the DB and returns them to the client.
- Routes endpoint: It communicates with the customer's routes module through its communication module. It saves the routes sent from the client in the DB. It is also in charge of editing the routes sent from the client in the DB.

- Mission endpoint: It communicates with the client's mission module through the client's communication module. Saves the initial data of a mission sent from the client in the DB. It also orders the execution of the mission through a connection with a suitable endpoint on the drone's server. During the mission, it receives the mission data from the drone server and stores it in the DB. At the end of the mission, save the final data of the same in the DB.
- Positioning endpoint: When a drone is being simulated, it receives its information from an endpoint on the drone's server and saves the information regarding its positions in the DB.
- Login/status endpoint: It communicates with an endpoint on the drone server and is responsible for saving the status of the drone (valid or invalid drone) simulated in the DB (Fig. 3).

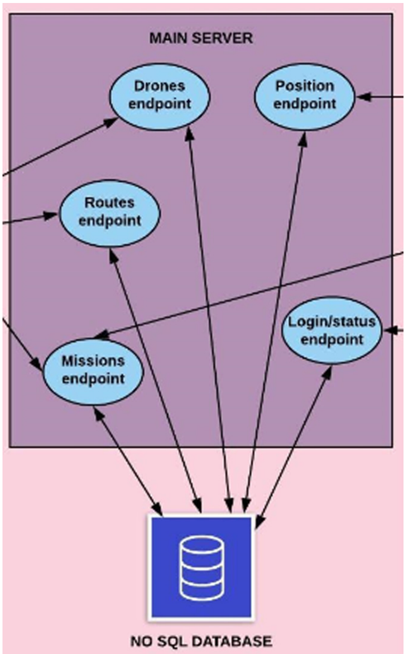

Fig. 3. Main server modules.

3.3 Drone Server

This component has three endpoints, their specifications are as follows:

- SITL connection endpoint: It communicates with an administrator module which sends the execution order through the TCP or UDP protocol. Subsequently, once the execution of the simulation begins, it takes the position data of the drone and returns it to the positioning endpoint in the main server, which saves it in the DB.

- Mission endpoint: Receives mission data continuously from SITL and sends it to the mission endpoint on the main server.
- Web connection endpoint: It communicates with the login/status endpoint present on the main server by sending data about the status of the drone. It also saves this information in the second DB (Fig. 4).

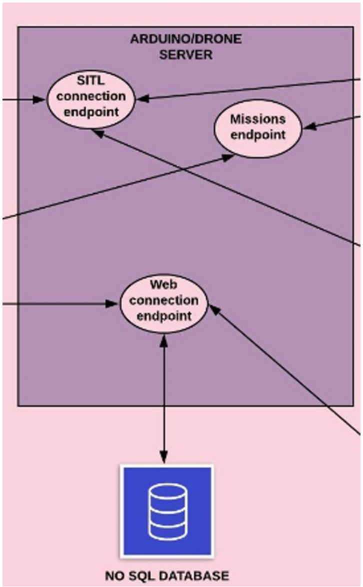

Fig. 4. Drone server modules.

3.4 Administrator Component

The administrator consists of two modules which are detailed below:

- SITL connection module: Communicates with the SITL connection endpoint on the drone server. It allows making the connection with SITL choosing a protocol between TCP and UDP, in order to set the simulator ready for the execution of a flight.
- Web connection module: Communicates with the web connection endpoint on the drone server. It allows obtaining data about the status of the simulated drone in order to know if it is suitable to use it in subsequent simulations, then it sends this data to the login/status endpoint on the main server (Fig. 5).

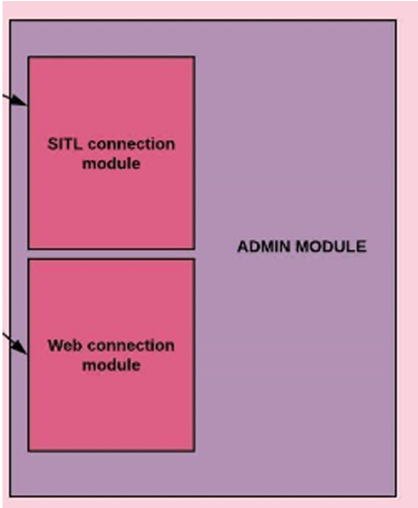

Fig. 5. Administrator modules.

3.5 Open Source Tools

The open source tools used are:

- SITL: Allows simulating the drone.
- MP: Auxiliary tool that allows performing more complex operations on the simulated drone (calibrations, among others). It is also used to generate routes quickly through a file with a "waypoints" extension (Fig. 6).

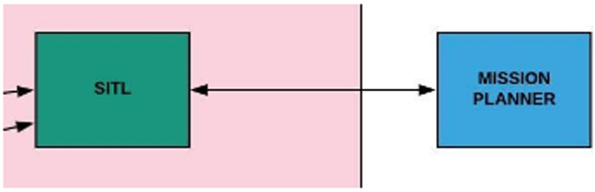

Fig. 6. Open source tools .

3.6 Tools Used for Implementation

The tools used for implementation are the following:

- Angular Framework: This Framework is currently used in large-scale projects, and it is inferred that this project is of that type. Performance issues at compile time are rare [15].

- Angular Material: Style library based on the "Material Design" design guide [16].
- JQuery Library: minimalist JavaScript library, allows you to write code quickly and easily. It has remained for years as one of the pillars of web development.
- Leaflet: It offers multiple functionalities; it is an excellent option when developing an application that includes maps since it is open-source and free [17].
- Framework Flask: Backend framework oriented towards microservices, allows the development of web applications in a simple and agile way, as well as being able to integrate with multiple Python libraries [18].
- Dronekit Library: Library implemented for Python that allows communication with drones and their simulators.
- MongoDB: It is scalable, decentralized, and its transactional costs are much lower than those of a SQL database [19].
- SITL: Open source simulator with a high learning curve and specifically implemented to work with drones.
- MP: Open source software with great documentation and relatively easy to use that allows communication with a simulator (Fig. 7).

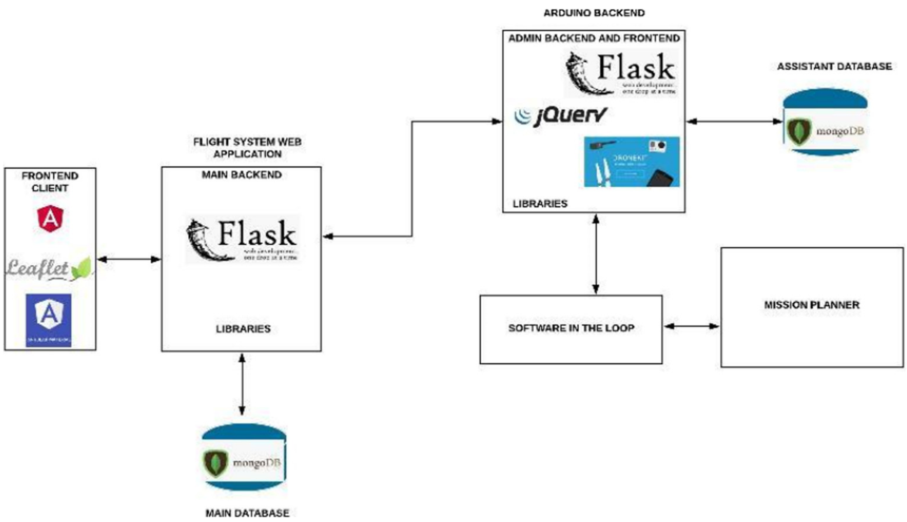

Fig. 7. Implementation architecture with chosen tools.

4 Hardware and Software Architecture

This section details the creation phase of the tests carried out on the chosen hardware and software infrastructure, as well as their real-time execution. Table 1 specifies the different physical and virtual machines used, a more specific detail on these infrastructures will be given in the next paragraphs.

The system was implemented locally on a physical machine using Pop! _OS, since it has high efficiency and high performance during the processes related to data compilation

Table 1. Description of physical and virtual machines used.

Computer	Processor	RAM	Hard disk	Operating system	Machine type
Client	AMD Ryzen 7 2700	16 GB	1 TB	Pop!_OS	Physic
Main server	AMD Ryzen 7 2700	8 GB	1 TB	Elementary-OS	Virtual
Drone server 1	AMD Ryzen 7 2700	8 GB	1 TB	Elementary-OS	Virtual
Drone server 2	AMD Ryzen 7 2700	8 GB	1 TB	Elementary-OS	Virtual

and handling. The Angular framework for client development was installed on this machine. In addition, an Elementary-OS virtual machine was used. The server that run on the drone was also implemented with Flask on an Elementary-OS virtual machine. This is done in order to be able to simulate a web server in the cloud and to simulate the flight of several drones simultaneously, which can connect from different machines and whose IP addresses are also different. These servers are in charge of communicating with the main server to send it the data regarding the current location of each drone in real time during a mission, then the main server sends the data to the client so the flight of the drones can be visualized.

The drone server that each simulated device uses is a small cog of the entire functional mechanism of the application, since these small servers as a whole make up the engine of the operation of the application since they are responsible for making the connection with the UAV and to send their data to the main server, which later sends them to the client allowing drones monitoring (Fig. 11).

5 Results

This project focuses on tracking UAVs flight in real time without losing the line of sight, which was achieved. Several tests were carried out with the purpose of monitoring the flight of drones in an Open Source simulator, below is attached the information regarding three of these scenarios. It is important to emphasize the fact that the tests were carried out on common physical and virtual machines, nevertheless, it is suggested to run the servers on several processors, as it would haven when implementing the system on real drones. The hardware architecture of the machines used was an AMD Ryzen 7 2700 processor, 8 cores, 16 threads and 16 GB RAM.

5.1 Long-Distance Flight

It consisted of a flight of 10.54 km from the Center for Research, Development and Innovation of Computer Systems (CIDIS) to the city's downtown (Fig. 8 and Table 2).

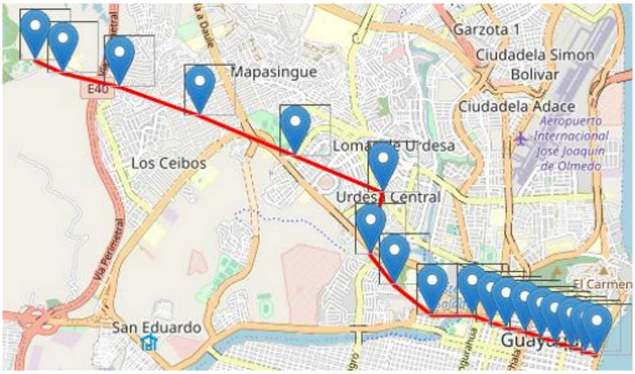

Fig. 8. Route for the long-distance flight.

Table 2. Results for flight from CIDIS to downtown Guayaquil.

Min altitude	Max altitude	Mean altitude	Mean velocity	Flight time	Battery
9.59 m	37.04m	35.013 m	2.62 m/s		3%

5.2 Short-Distance Flight

It consisted of a flight of 0.23 km at ESPOL university (Fig. 9 and Table 3).

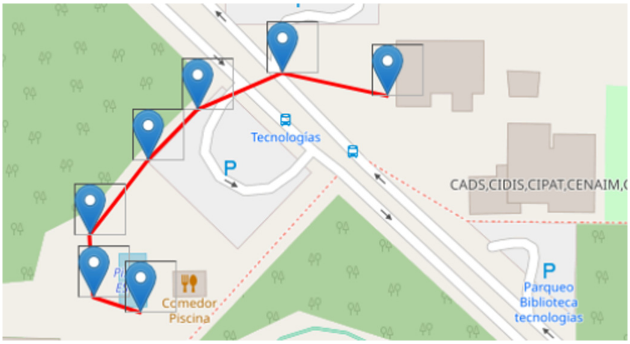

Fig. 9. Route for the short-distance flight.

Table 3. Results for flight inside ESPOL campus.

Min altitude	Max altitude	Mean altitude	Mean velocity	Flight time	Battery
9.61 m	111.07 m	103.27 m	2.44 m/s	70 s	68%

5.3 Flight with Two Drones

It was a simultaneous flight of two drones from CIDIS to two points near this research center. The first one consisted of a 0.21 km flight and the second one consisted of a flight of 0.62 km (Fig. 10).

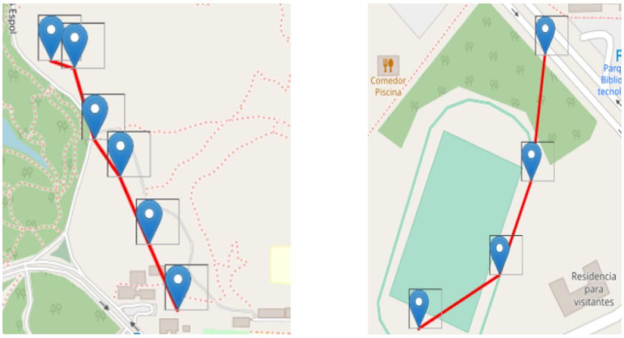

Fig. 10. Routes for simultaneous flight of two drones.

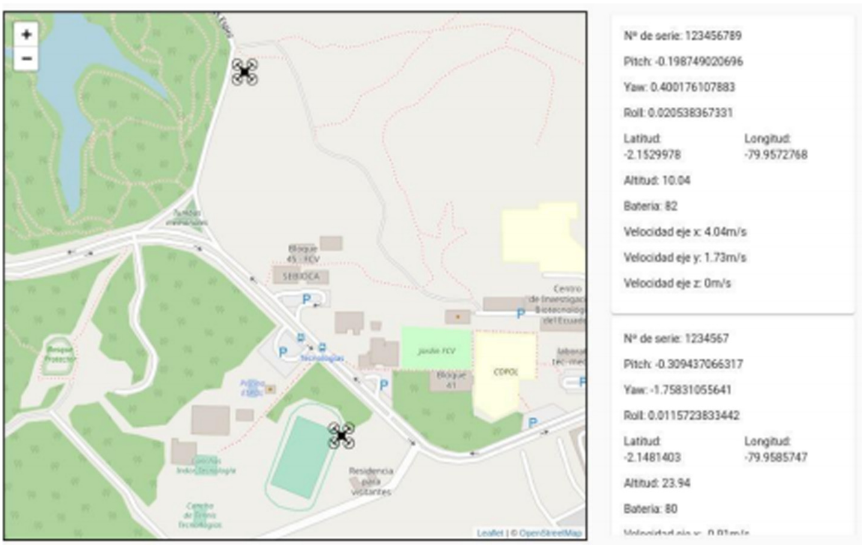

Fig. 11. User interface for simultaneous flight of two drones.

6 Conclusions

UAVs are being applied in diverse types of activities by users with different capabilities and training. However, a user-friendly system that allows flying BVLOS and BRLOS would notably increase the applications where user may operate UAVs. The implementation of a web application that allows controlling the drone through a wireless Internet network is an innovative and striking alternative to be able to dissipate the loss of line of sight of the device; also adding a pleasant human-computer interaction to the developed system. The proposed system is available on [20], it was test using SITL and virtual machines, but it can easily be implemented on real drones applying small changes in the drone server and loading it in on-board microcomputers on physical drones. Finally, some conclusions are presented:

- Communication over the Internet between the main server and the drone server allows data to be sent over long distances, even if both servers are in remote geographic locations.
- Using a NoSQL database like MongoDB provides great scalability since large amounts of data can be stored. The absence of the entity-relationship model also means that transactions are carried out at great speed.
- The use of parallelism through the threads was essential to be able to run the drone, this because the main thread of execution was the drone server itself serving the address and ports associated with it.
- In the future it is possible that the project could be put into production on servers in the cloud whose costs are convenient for the final client.

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