FIREFLY: an autonomous drone for detection and monitoring of fires in rural areas

ABSTRACT

The drones that were initially used for military purposes have expanded their use in other areas. In this work the construction of a low cost drone is presented, which was applied to the monitoring and detection of fires in rural areas. A smoke sensor MQ-2 and a high-resolution camera was used for fire monitoring and detection. The GSM technology was used for communication between the use and the drone via SMS and there is a smartphone application where the user can configure the drone flight route and calibrate the sensors within it. The proposed drone proved to be efficient in the initial tests, but showed stability problems when the number of satellites was below 4 units identified or in the presence of strong winds. The MQ-2 smoke sensor proved to be efficient in collecting environmental and functional data in fire detection. The camera can get images every 5 seconds and help monitor the area of interest. In future works, we intend to explore images to improve fire detection and classification using the technology of image processing.

Keywords: Autonomous Monitoring; Quadcopter; Fire; Burned in Forests
RESUMO

Os drones que foram inicialmente utilizados para fins militares expandiram seu uso em outras áreas. Neste trabalho apresentamos a construção de um drone de baixo custo, que foi aplicado no monitoramento e detecção de incêndios em áreas rurais. Um sensor de fumaça MQ-2 e uma câmera de alta resolução foram usados para monitoramento e detecção de incêndios. A tecnologia GSM foi usada para comunicação entre o usuário e o drone via SMS, além de um aplicativo para smartphone, pelo qual o usuário pode configurar a rota de voo do drone e calibrar seus sensores. O drone proposto provou-se eficiente nos testes iniciais, mas demonstrou problemas de estabilidade quando o número de satélites estava abaixo de quatro unidades ou na presença de ventos fortes. O sensor de fumaça MQ-2 mostrou-se eficiente no levantamento de dados ambientais e funcionais na detecção de incêndios. A câmera consegue capturar imagens a cada cinco segundos e ajuda a monitorar a área de interesse. Em trabalhos futuros, pretendemos explorar as imagens para melhorar a detecção e a classificação de incêndios, usando a tecnologia de processamento de imagens.

Palavras chave: Monitoramento autônomo; Quadcóptero; Incêndio; Florestas queimadas.

1. INTRODUCTION

The Unmanned Aerial Vehicles (UAVs), commonly known as drones, were initially designed and built for military purposes, for missions that would be hard for humans to accomplish. These demands come mostly from military intelligence areas, such as artillery support and control, aerial support for infantry and cavalry troops on battlefields, cruise missile control, activities of urban, coast, environmental and border patrol, search and rescue activities, among others [16]. Drones are often chosen for burdensome and dangerous missions on airplanes [17], such as fire monitoring and combat, and but they are also used for non-military security and surveillance of pipes. However, drones are not only used for military purposes. Just like airplanes, unmanned vehicles have different characteristics to adapt to several types of use. Currently, TV stations have used drones to replace helicopters in video footage, because, in addition to saving fuel, these devices provide other resources as low maintenance cost. The type of drone used for this purpose cannot be the same as the ones used for military services, since they do not need to be fast, but stable at low speeds [4].

Drone manufacturers, such as company DJI, a pioneer in the area, manufacture high quality drones for specific purposes, such as Inspire 1, a high-tech model for high-resolution video footages in real time, an ideal model for TV stations. DJI also manufactures the line Phantom, used in rural sectors to help farmers in activities like irrigation, fertilization and, most recently, cattle drive. In larger fields, such as crops and forests, there are several problems with difficult solutions, like fires and pests, which increase according to the territorial extension. Forest fires,
on the other hand, have caused significant impacts to the atmosphere [12] and have threatened human safety, natural habitats, local economies, and the global climate [8].

Big farmers around the world struggle with fires that, in most cases, were detected too late (after a large area had already been taken). Regarding forests, the problem is much worse, due to lack of monitoring and because forests are usually dense, hard to access, and the alternative monitoring methods are not economically feasible. [3] showed that, for decades, the monitoring of forest fires and fires in other types of vegetation was mostly done by aircrafts and satellites. However, as technology and accessibility advanced, and as the price of sensors decreased, there was a revolution in detection and monitoring of fires, which helped decrease the destruction of forests.

[6] approach this topic from a problem that affects the French coast: the pollution caused by the accumulation and decay of green seaweed in the beaches, releasing sulfhydric gases, which are toxic and lethal. Therefore, developing a system capable of autonomously measuring gas levels in areas with dangerous concentrations or difficult access is highly necessary. The measure system sends out a drone to obtain data at an area defined by the user.

The analyzed samples can help map the polluted areas and show the places where the gases are coming from and where they are more concentrated. [9] motivated by the high prices of drones (US$6,000) that fly independently from a land control stations, and of drones used by the Norwegian Energy Company Trønder Energi, which perform autonomous landings, proposes a drone that uses image-recognition to locate a landing spot, and lands autonomously. [7] present an image digital processing software that is able to differentiate colors and detect hues of smoke and flames, thus detecting and describing the fire intensity. This work aims at building a low-cost, user-friendly standard drone, which can monitor and detect fires in rural areas and be controlled over a smartphone.

2. MATERIAL AND METHODS

2.1 CONFIGURATION OF THE STRUCTURE

Because this project aims at making viable the monitoring of crops and forests, in order to autonomously detect fires with low-cost drones, we carried out a survey of real prices, which are shown on Table 1. In this work, the drone consists of three independent modules that operate asynchronously. Module 1 of the standard drone developed in this study includes a landing gear, a frame kit, a battery of 4500mAh, a bridge, a Crius control panel, ESC
(Electronic Speed Control), brushless engines, helices, controllers, GPS (Global Positioning System) receptor and Bluetooth.

| Item                  | Price   | Seller    |
|-----------------------|---------|-----------|
| Arduino UNO R3        | R$98.00 | Robocore  |
| Motor Brushless       | US$40.54| DXSoul    |
| GPS Receiver          | US$34.43| DXSoul    |
| ESC 30A               | US$25.71| DXSoul    |
| Gimbal                | US$146.03| DXSoul   |
| Battery 4500mAh       | US$31.80| DXSoul    |
| Battery 2200mAh       | US$18.99| DXSoul    |
| Frame Kit             | US$111.80| DXSoul    |
| Helix                 | US$55.25| DXSoul    |
| Fly-Sky Control       | US$76.41| DXSoul    |
| CRIUS                 | US$32.64| DXSoul    |
| Undercarriage         | US$19.92| DXSoul    |
| Bridge                | US$3.84| DXSoul    |
| GSM GPRS              | R$289.00| FilipeFlo|
| Gas sensor            | R$19.90 | FilipeFlo|
| Bluetooth             | R$44.90 | FilipeFlo|
| GoPro Camera          | US$230.00| GoPro    |
| **Total**             | R$3,287.99 |           |
|                       | US$959.15 |           |
Module 2 consists of Arduino UNO R3, gas sensor (MQ-2) and shield GSM GPRS (General Packet Radio Service). Module 3, on its hand, includes gimbal, a battery of 2200mAh, and the camera. The (Fig. 1) illustrates the modules that compose the drone and their respective schematics of relations with other devices and the external medium.

Since the use of helicopters or satellites for monitoring practices is unfeasible, due to high costs, specialized labor and maintenance, the use of drones becomes a low-cost alternative, when compared to other methods. Therefore, this work was divided into four steps to reach its purpose. The first step comprised the search for adequate tools for this project, in order to create a list of requisites (components and specifications) to be applied. Afterwards, we planned the construction and development of the drone. The second step was the construction itself; the use of basic components to assemble its frame to make it fly. The Gimbal (stabilizer) was inserted in the third step, along with the battery, the camera (module 2), and the CRIUS peripherals (flight controller), which are: GPS receiver and Bluetooth, complementary components for the first module. Having two modules implemented, the device is already able to make a stable and autonomous flight, and map the route the drone should follow. In step 4, module 3 is added, which consists of Arduino and its peripherals: the smoke sensor and the GSM (Groupe Special
Mobile) board, which allows the user to communicate with the drone and receive the data collected by the smoke sensor.

After completing the four steps, the drone was connected to an Android cell phone via Bluetooth to start the flight settings by means of an application (Fig. 2), which also allows the user to map the entire area to be monitored and offers more advanced settings, such as calibration of CRIUS sensors (accelerometer, magnetometer, and altimeter). From these initial settings, the user can upload the information to the drone, which will follow the trajectory autonomously, going from its base, through the points defined by the GPS, until it reaches a stop condition.

During flight, the smoke sensor will be constantly active. At the sight of a possible fire, the GSM GPRS Shield board will send a reference photo to the user via Short Message Service (SMS), with the coordinates of the possible fire spot and the level of gas/smoke measured by the sensor. So, all these tasks may be completed and the communication may be done in real time, the drone should navigate in an area covered by phone signal. The user may also communicate with the drone before any warning occurs, requesting partial reports, such as images and signal quality. To return to its base, the drone will have an initial point recorded, so that, if necessary, it may return directly to the start point.

We used essays to test the flight modes, the commands for landing and returning to the start point, and the waypoints, from which we could receive information on telemetry through application EZ-GUI. MultiWii was used to provide a user-friendly interface, which, compared to Mission Planner or QGroundControl, offers a more intuitive control system, in such options as height analysis, tilting, the number of satellites available on field, the coordinates of global geographic positioning, battery available, or even flight speed. The (Fig. 2(a)) shows data from sensors as displayed by the app, such as graphs of accelerometer, gyro and magnetometer measurements, and Fig. 2(b) demonstrates the tool panel for the user, as reference of positioning and global angulation.
2.2 COMMUNICATION PROTOCOL

There are currently several types of drones with various communication protocols. Just like computers, drones also have operating systems with open and closed source codes. MavLink protocol was used in this work, because of its robustness and data safety and because it has an open source code, which allows future alterations that may become necessary in the project. MavLink protocol is compatible with controllers of both original and generic APM, PixHawk and CRIUS engines. PixHawk, for example, is commonly used in multirotor or fixed-wing mapping drones, which opens a wide range of interesting options, since agriculture is responsible for approximately 80% of drone-related businesses [10]. However, CRIUS has offered great cost-benefit, when compared to other systems, not only price-wise, but also because free control platforms, such as MultiWii, are easy to implement. MultiWii platform is presented on (Fig. 3), which also provides information on calibration and global positioning in tests carried out in Lab.
A MavLink Package is similar to the structure presented in (Fig. 4), in which a frame is represented by a set of mandatory equally-sized fields (1 bit) and an optional payload field with the message to be transmitted. The packages may have different sizes, depending on the total size of the loaded message. The content depends on the type of message being sent, which is specified in the message field. The two last fields of the package correspond to the bytes responsible for CRC. This technique allows the receiver to detect errors that may have occurred during transmission, and discard the corrupted file, since it is not possible to recover it.

Because MavLink is a light protocol, it is ideal to exchange small bits of information between the control station and the UAV, eliminating the need for costly manipulation and processing procedures. The pattern used in software that use this protocol is a sequence model that allows the alteration in isolated blocks, which makes it possible to enhance the system performance, both for identifying and solving possible errors.

Several companies are currently developing different drone models to meet the market demands. However, only a few drones provide the user with the possibility to change their firmware, according to their own purposes. Therefore, the new system should be able to control any drone that includes MavLink protocol in their settings, at a low computational cost [11]. Another advantage is related to the growing number of studies on this protocol in international forums, and its compatibility with the controllers used in this work.

2.3 STATE DIAGRAM

A status diagram describes the proposal of a user-friendly drone, so that any person with basic knowledge on drones may use it. Therefore, we created a status diagram (Fig. 5) that provides the system behavior as a whole, showing possible conditions or situations the drone may encounter. Thus, it is necessary to pre-set the EZ-GUI Ground Station application. When activated, the drone starts a telemetry process, which calibrates the CRIUS sensors (barometer, gyroscope, magnetometer) and the smoke sensor. Afterwards, the Groupe Special Mobile (GSM) starts performing its internal routines to connect to a mobile network. Then, the
telemetry process ends, when the GPS receiver connects to, at least, four satellites. The user should then be able to use EZ-GUI application to connect to the drone via Bluetooth and preset the flight, which consists of mapping the area to be monitored and sending the coordinates from the app to CRIUS, thus starting an autonomous flight. During flight, the user may communicate with the drone via SMS, by AT commands sent over the phone. At the end of the route, the drone will return to the starting point or landing spot, where the user may end the flight, repeat the route or create a new one.

The algorithm designed for Arduino is responsible for managing GSM shield and the smoke sensor MQ-2 (module 2), which collect data from the environment for smoke detection, and communicate with the user. At setup, the user informs the gateways used by the peripherals and the phone number to which the drone should send the data via SMS. During processing, Arduino has a loop with a conditional clause `if`, which is met when the smoke levels reach 225 ppm (parts per million), and unlocks a set of instructions to send a warning to the user with the GPS location, the risk levels, and a reference photo taken at detection. The reference photo works asynchronously with the camera. GoPro is set to obtain one photo every five seconds during the entire flight. The algorithm calculates the flight time in seconds and divides the number by five, thus finding the image closest to the moment in which the system detected a possible fire.

Fig. 5  System behaviour
3. RESULTS AND DISCUSSION

The prototype named Firefly (Fig. 6) was built with a low-cost open-source microcontroller board and had difficulties stabilizing the flight in places with strong wind, like Vila Velha - ES, where the first tests were run.

Satellite availability varies according to the location and the GPS signal. For autonomous flights with three satellites, the flights were quite unstable, due to the quality of GPS signal. The drone trajectory is made by coordinate points recorded to its internal memory. The drone flies point by point, in the order they were registered. With low GPS signal, the drone had some deviations during the route. This situation got worse on windy days. However, when connected to seven satellites, the drone traveled fast and efficiently from one point to another in straight lines. The drone feeds on a 4500 mHa battery, which allows it to fly for 30 minutes, thus limiting the monitoring scope to a few hectares. Because it is still in the initial phase, functional tests have not yet been performed to reach a conclusion about the territory the drone can cover.

The camera works asynchronously with Arduino. The photos are taken every five seconds, and the algorithm has been programmed with a crescent counter, which dividing the trajectory time by five, finds the reference photo. The smoke sensor MQ-2 is suspended on the drone during flight, which causes the wind moved by the helices to interfere with the results the sensor collects. Should the sensor be placed near the helices, the results collected would be less reliable, otherwise, the sensor is likely to be stuck on an obstacle, such as trees and other tall plants. For safety purposes, the practical tests for fire detection were performed on an environment controlled with propane (which has a similar behavior to the smoke created by
fires), in order to assess the sensor efficiency and sensitivity. The sensor detects the gas that has been spread in small amounts, reaching the level of 255 ppm, which was the level considered as a possible fire. For more realistic tests, it would be necessary to create a controlled fire in an open area, which was not possible, since it requires the presence of the fire brigade, along with an ambulance, a first aid team, and a permit from the local authorities.

4. CONCLUSION

In this work, it was possible to implement the construction of an open source drone for monitoring and detection of fires in rural areas. The drone in this study had good performance and stability when connected to more than five satellites; however, it loses stability when connected to less than four satellite. Another item to be considered is the wind effect, because CRIUS V2.5 SE accelerometer would become inefficient and would have to be replaced by a board equipped with a more precise accelerometer. The smoke sensor MQ-2 is efficient collecting data from the environment, being a good alternative for fire detection on a drone. The camera was used to obtain images every five seconds. These images will be analyzed in the future, with digital image processing techniques to, along with the smoke sensor, help classify the type of fire.

The authors thank Vila Velha University for the development and testing, and Federal University of Lavras for the publication resources.

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