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RESEARCH ARTICLE OPEN ACCESS

LOW-COST UAV FOR MEDICAL DELIVERY

Antonio Dantas*[1], Leandro Diniz[1], Lucas Gewehr[2], Chaquel Alcino[1], Wander Martins[3], Tales Pimenta[3] and Alexandre Ramos[1]

[1]Institute of Mathematics and Computation, Federal University of Itajuba, Brazil
[2]Institute of Mechanical Engineering, Federal University of Itajuba, Brazil
[3]Institute of Engineering, Systems and Information Technology, Federal University of Itajuba, Brazil

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Corresponding author: Antonio Dantas,

ABSTRACT

Due to the pandemic caused by the new coronavirus (COVID-19), many countries that already had financial and logistical difficulties in hospital medicines supplies were surprised by the contact restrictions that made this procedure difficult. As a solution for deliveries in a practical and efficient manner, unmanned aerial vehicles (UAVs), popularly known as drones, have been employed to carry out the agile delivery operation in hard-to-reach, both internally and externally. The purpose of this article is to present a specific set of tools to efficiently and customized solve this problem at the lowest possible cost. The study results in a model for use in this task.

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INTRODUCTION

In the light of modern challenges, unmanned aerial vehicles (UAVs) become a popular solution on issues such as aerial filming, entertainment, agriculture (de Jesus, et. al, 2019), high-precision monitoring (Martins, et. Al, 2020), tracking (Dantas Filho, et. al, 2020), law enforcement (Pinto, et. al, 2019), search and rescue (de Brito, et. al, 2019). Although the use of drones in these areas has been described as much more efficient as the solutions used previously, a specific application is still in the beginning of development: delivery of medical supplies and medicines. The main challenge of the allocation of medical supplies is the incessant battle between accessibility and waste: in an attempt to reduce waste or idleness of medical supplies and medicines, a more centralized system is needed and, therefore, access to remote regions can be compromised; if access is a priority, decentralization is the key, but waste and idleness increase greatly. This situation was aggravated by the pandemic of the new coronavirus (COVID-19), caused by the SARS-Cov2 virus. With lives at risk, a correct balance between waste and accessibility is essential, which would also be an asset to reducing the daily increase in carbon emissions and waste production. The use of UAVs for medical delivery can be a great solution, in addition, the time difference can be significant in a medical emergency, however some companies have already deployed systems for this purpose, but still in a complex way and with high costs. Some of the existing work in the drone delivery area will be resumed and explained. In Scott's article (Scott, *et al*, 2017), the author wrote that delivery UAVs have the potential to have the same effect on traditional transportation infrastructure. The drone operating system manages the network by monitoring weather data from all ground stations and perfects drone routes. Because a drone can fly over an inaccessible road, innovative organizations have begun using them to provide health services. A logistics network is designed to provide timely delivery of health items using a tandem strategy involving ground-based transportation and final delivery by drone. The delivery of the drone took 8 minutes, compared to a 30-minute trip in winter; its limit reaches 45 miles in 30 minutes. In the paper (Thiels, et. al, 2015) the author states that UAVs may soon be used for rapid transport of merchandise in a safe, economical way, both to accessible or remote locations, this perspective presents new and intriguing opportunities for health services workers as much in moments of critical need as routine circumstances. Significant advances in the variety of technologies designed to deliver cargo by drones, focusing on small packages (Frachtenberg, 2019). This article exposes that the use of drones has the potential to significantly reduce the cost and carbon emissions. For this, the author presents data on carbon emission and savings in return for truck delivery, but does not conclude that the autonomy of drones requires the acquisition and interpretation of sensor data with limited time and energy. Focusing on the architecture part of the article addresses that the focus should be on humanitarian aid, providing essential supplies to people who would otherwise be inaccessible in areas of war or disaster. Similarly, the medical distribution of supplies, medicines, organs and blood are vital and critical applications, which has already been field tested with robust and expensive vehicles. The aim of this article is to propose a cheap and reliable alternative that can be implemented at smaller scales. The rest of the article presents the methodology used in the experiments in second section; the results of the applications carried out in third section; and finally, the discussion and conclusion carried out by the team in fourth section.

METHODOLOGY

UAV and prototype: In this work an experimental testing a prototype for better simulation of real conditions was developed. The prototypes had some requirements: to have an enclosure for retaining the medical goods safely, a release mechanism for delivery and the UAV itself, with the required hardware for the mission completion (Figures 1 e 2). The main possibilities were explored in regard of the low budget objective, and the main options found were:

- Reinforced cardboard box with automatic release system and a device for slowing the box down during the drop;
- Metallic structure, with simple holding mechanism and manual release system by pressure;
- A compressed envelope with fall absorbing features, held by a simple claw for automatic release.

Figure 1. Isometric view of the prototype

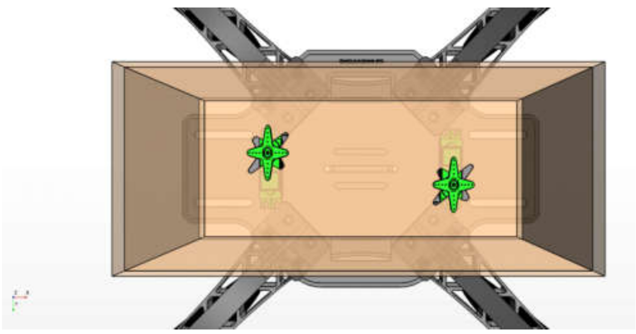

Figure 2. Release mechanism view of the prototype

Out of the options showed above, a simple Ishikawa diagram (Ishikawa, 1976) was made for each possibility with special regards to cost and weight of the solution. The first prototype used for the study was a 45cm F450 quadcopter model. Its motors are 1000kV with Electronic Speed Controller (ESC) of 30A, propeller size 10x4.5”, and 6600mAh battery. The Q450 has components similar to the F450, with a difference of 450mm diagonal size, triple propeller size 9x5”,2300Kv, ESC 20A and 5600mAh battery. The last UAV manufactured was a balloon airship, with four engines CCW, 1500mAh battery, propeller size 3x2”, 1.8m long and 1.3m3 in volume. These mounted UAVs are equipped with a radio-controller receptor and a PixHawk 4 flight controller board (Pixhalk, 2020). These boards have all the usual components for UAV stabilization with a main processor unit (FMU STM32F765) that allows programming of movement control parameters. A serial telemetry of 915MHz was also used for connecting with the Ground Control Station (GCS), which enables sending and receiving flight control data. Finally, servomotors were also used in the release mechanism: when linked with the flight controller these can be automatically actuated (Figure 3).

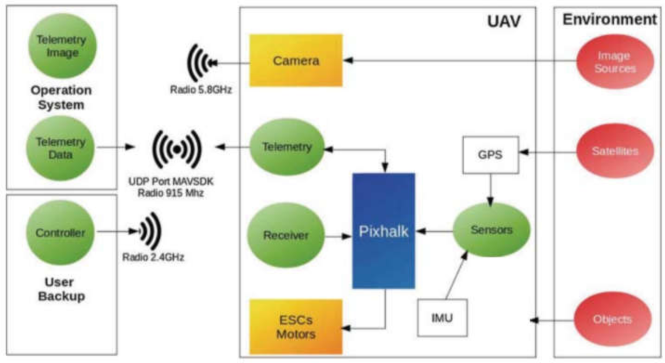

Figure 3. Hardware and communication architecture

The commercial UAV (DJI, 2020) chosen for comparison was the Mavic Pro Platinum©, with a diagonal dimension of 335 mm, ESC type sinusoidal driver, a 1400kV motor and 3830mAh battery.

Mission: In this work, the main task of the delivery mission is to transfer medical supplies between points A and B. Aiming at the best possible efficiency and stability. This first step of the development will not cover long range routes, with a maximum radius limitation for experimental purposes of 300m (outside) and 40m (inside), as shown in Figure 4. Nonetheless, the main objective of the project will be to attain both local deliveries and areas of difficult access.

Figure 4. Mission example. Images Adapted (Google, 2020)

In the external mode, a previously reserved area was used, with little circulation of people, well wooded, and high incidence of winds, the barriers are up to 40 meters. Indoors, a totally closed sports court was used, with a maximum altitude of 6 meters. Both areas have little or no visualization of the destination point, requiring the use of cameras or communications with auxiliary operators. Taking this into account, the proposed method put forward for a general solution of the problem was the parallel dissolution of sub-problems for subsequent fusion, as described in (Alatartsev, et. al, 2015). At first, it is necessary to position the UAV in a fixed or moving takeoff platform, with the medical supplies already disposed in the container. The second sub-task is uploading the mission to the UAV's flight controller. Next, takeoff and transport tracking must be carried out, insuring safe and correct execution of the flight plan. The last sub-task before the Return To Home (RTH) command is the air drop of the supplies at the desired location. The possibility of simultaneous takeoff for multiple drones will also be evaluated, with one operator responsible for designating and tracking the various UAV's missions. Finally, the legislative questions must be evaluated regarding the proposed mission. The impact of each technique and model should be evaluated in face of the current legislation. Moreover, some laws could be reassessed with formal requests to the competent bodies.

Ground Control Stations: In order to evaluate which of the GCS is better suited for the specified mission, many options of prototype compatible open-source software (GPLv3) were analyzed (Ardupilot, 2020). All possible Ground Control Stations must have an integrated planner for automated flight, real time flight map with vehicle tracking, waypoints setting capabilities and vehicle custom configuration. The evaluated GCSs to be used were:

- **Mission Planner**: One of the most used tools because of its consolidated integration with Ardupilot. It possesses various sources for maps, such as Google Maps, Bing, Open Street and Custom WMS. With a simple interface, it allows for easy configuration of Ardupilot vehicles.
- **APM Planner 2 Home:** Suited for Mac and Linux operating systems, with better performance due to reduced resources and oversimplified interface. Based on MAVlink and able to handle APM in PixHawk vehicles.
- **MAVProxy**: Made for fixed wing aircraft. Its interface is made in the form of command lines, with graphic modules used only for map editing. Fully extendable as it is written in Python language. And it has resources such as messaging via UDP to other GCSs.
- **QGroundControl**: Available for all MAVlink aircraft, with a user-friendly interface and full high-end vehicle configuration. This software comes with an integrated module for multi-vehicle management.

Performance: With the use of data from the frame, motor and battery manufacturers, a full performance study was carried out. The calculations were performed following (Biczyski, 2020). This performance will be measured taking into account the best frame comparing the payload, the maximum speed of ascent, battery time in stationary mode and the average price units (considering US$ 1000). First, a propeller analysis was made among the motor-compatible options, for the selection of which one was best suited for the delivery application. All propellers were evaluated with the comparison of their Pitch-Diameter ratio (P/D) and the performance parameters listed below:

- Propeller efficiency;
- Mechanical power;
- Electric power;
- Overall motor efficiency;
- RPM.

Based on estimates for empty weight and payload, calculations of disk area and disk loading were executed with the chosen propeller to ensure safety margins were respected. After the disk load calculations, a thorough static thrust analysis was made, allowing check if the intended payload could be carried and proposed range could be reached.

RESULTS AND DISCUSSION

For obtaining the results, four drones were mounted, as shows the Figure 5.

Figure 5. Image of the frames used in the study

Software: With those prototypes, each one of the ground stations was tested regarding some aspects like ease of use; precision in calibration, evaluating the software's capability of drone stabilization after calibration; and Mission creation: the ability to plan precise missions for automated delivery, and its capability of tracking. All of the ground stations tested was very similar, especially Mission Planner and APM Planner 2 Home. However, regarding the ease of use, it was noted that QGroundControl software was more didactic and user friendly during all the phases of configuration, firmware update, airframe setup, radio configuration, calibration, flight modes settings, power, safety and tuning options. With respect to the calibration process, essential for reducing risks of crashes and guaranteeing good stability during flight, even with high wind gusts, the same drone had its compass, gyroscope, accelerometer and horizon calibrated multiple times with all the softwares. Even though all showed similar results, the steps for calibration with QGroundControl's interface has some advantages when it comes to preventing user error. Due to its highly visual process, interpretation errors are greatly reduced and a more thorough calibration can be obtained. Another advantage becomes evident when it comes to Proportional, Integral and Derivative (PID) tuning, with a very intuitive and automated process. Other results may be obtained with very little input and very little changes in gains for pitch and roll only. For the mission creation process, all softwares presented very close performances, but once again, QGroundControl's better user interface made the process less prone to inaccuracies or mistakes, and made the mission tracking process easier, mainly when multiple drones were taken into account, as shown in Figure 6.

Figure 6. QGroundControl PID tuning (up) Mission Planner (down)

It was observed that some of the most advanced PixHawk's parameters were difficult to find in some softwares and sometimes required a combination of more than one ground station to be correctly tweaked. The MAVProxy interface was little explored due to its harder use and dependability on other softwares for its correct setup.

Frame: When considering the physical drone used in the study, some much consolidated commercial models were evaluated in comparison with models assembled at the team's laboratory. The results comparing are shown in Table 1.

Table 1. Comparison Payload and Velocity of frames

UAV	Payload	Velocity	Battery	Price
Q250	1000g	5 m/s	720s	0.2
F450	1600g	4 m/s	880s	0.2
Airship	300g	2 m/s	3110s	1.0
Mavic	900g	4 m/s	1440s	1.0

Good results for stability and the delivery itself were obtained with all tested types of UAVs. Even though the laboratory built ones required bigger attention to the calibration and PID tuning process, in terms of costs and configuration flexibility they had a huge advantage. Consequently, the F450 were chosen to proceed to the next phases of the study. For the delivery system, all configurations were preliminarily tested and evaluated according to an Ishikawa diagram. The cardboard box configuration with two servos and one simple parachute proved to be the most efficient in terms of cost, weight and sustainability, with the cardboard box being disposable and recyclable.

Performance: Based on the results obtained in the performance analysis for the propeller performance are demonstrated in Figures7 to 10.

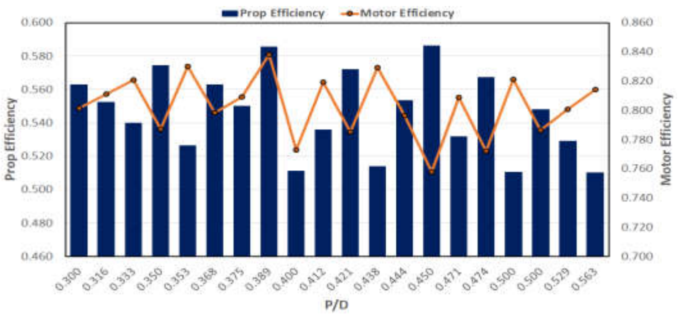

Figure 7. Pitch-Diameter ratio and efficiency comparison

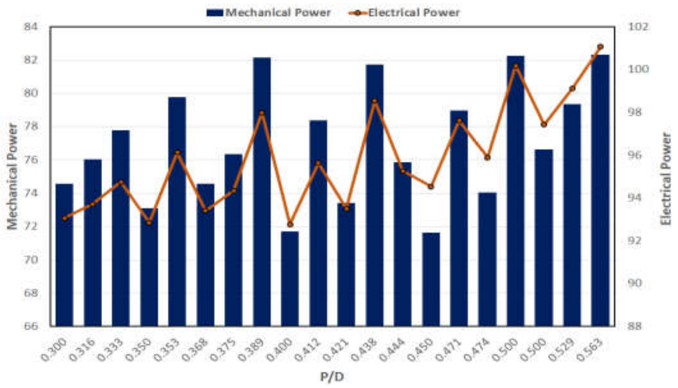

Figure 8. Pitch-Diameter ratio vs. Power

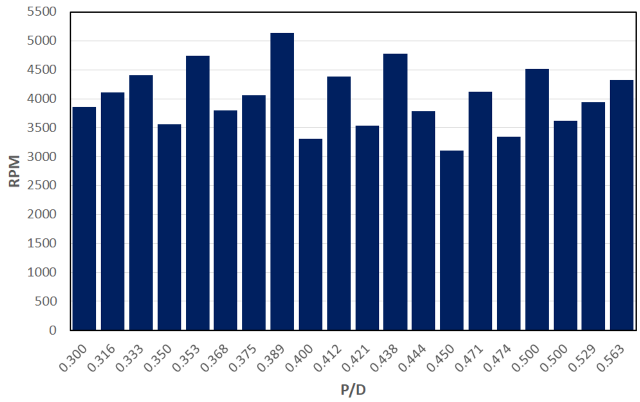

Figure 9. Pitch-Diameter ratio and RPM comparison

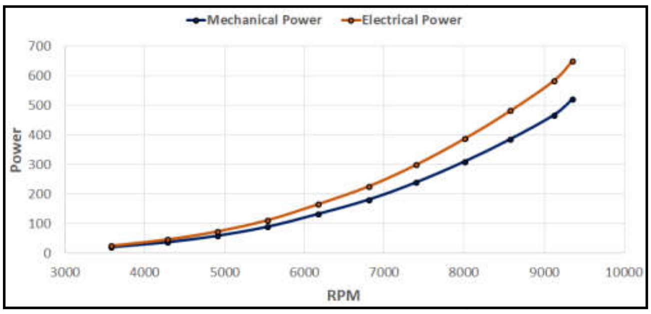

Figure 10. Power and RPM correlation for operational margins

With the results presented above, the chosen propeller has 9in in diameter and 3.5in of pitch. This propeller ensured an optimal relationship between mechanical and electrical power while still maintaining high RPM and efficiencies. As stated before, disk loading calculation was executed and 95.6 N/m^2. For the static thrust evaluation, the presented parameters were evaluated for the full RPM range of operations, including hover and maximum conditions. The detailed results showed no prohibitive value, ultimately validating the chosen propulsive group for the intended payload of approximately 1.6kg.

Regulations: The Brazilian air space control agency responsible for UAV regulations is the DECEA (Air Space Control Department) under the Defense Ministry's administration. However, aircraft registrations and control are responsibilities of ANAC (National Agency of Civil Aviation). Commercial items aerial delivery was only partially granted this year for two companies. Even though airborne deliveries were allowed, it came with limitations: for residential areas the drone must not be further than 2.5km from the takeoff location; the maximum payload is 2kg. For obtaining the authorization to these kinds of flight, a CAVE (Experimental Flight Certificate of Authorization) must be issued. The certificate requires, beyond usual rules, supervised security tests for safety insurances to be done in reserved areas and with previous NOTAMs (Notice to Airman). The Federal University of Itajuba possesses registered aircrafts with the correspondent SISANT (Unmanned Aircraft System) identification. Every flight has a specific location on campus to be operated.

CONCLUSION

This work presented, based on the data presented, an efficient and low-cost way for delivery of medicines and supplies, to the most diverse places that need agility and efficiency. The use of open-source software, a very cheap framework and flight controller board, as well as a very simple but effective mechanism for the drop in supply, allowed this work in progress to be able to propose an efficient and low-cost way of making reliable deliveries of medical supplies in emergency or high demand situations. The main objective of this project was achieved using a four-rotor F450 UAV to deliver medical supplies at a given point. However, there are some limitations to its use, such as the weight of the load and speed. In addition, the delivery interval is limited as the battery capacity is not sufficient to handle long distances. An alternative to this problem is the use of a fixed wing VTOL (Jo, 2017) aircraft, which is an aircraft that can take off and land vertically. In addition to the continued development of the proposed solution, some extra features are planned for this study. The use of artificial intelligence (AI) is one of the lines of work to be followed, especially in regards to the identification of people and places, fostering a more precise delivery. AI can also be used to enable autonomous passage through doors and windows, with a better control for indoor environments and better peer-to-peer delivery. Another line of possible development would be use of fixed wing aircraft equipped with solar panels for longer range operations and better energy efficiency, but maintaining the same low-cost, high efficiency philosophy.

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