POLITECNICO DI TORINO
Master's Degree in Electronic engineering

Title: Optimization of an Ultralight Autonomous Drone for Service Robotics
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Abstract

Drone industry is constantly growing and evolving in time. Federal Aviation Administration Aerospace Forecast predicts that drone market volume will be about three times the actual one in 2023. This because UAVs are becoming more and more fundamental in the most various application like agriculture, emergency response, urban planning and maintenance, entertainment, security and so many others. For all these tasks, in the near future a large number of drones will fly over our heads. From here the necessity to build safe, lightweight and autonomous UAV for the drones colonization of the very lower part of the Earth atmosphere. Furthermore EASA fixed to 250 grams the limit of the C0 open UAS, category with quite few restrictions to fly.

PIC4SeR (PoliTO Interdepartmental Centre for Service Robotics) wants to keep up with this incoming demand and enter in this market, deciding to invest time and resources on the optimization of an ultralight autonomous drone, with the future intention of full customization with the needs of the end-user for different and specific cases such as service robotics, smart city search and rescue and precision agriculture that are the four fields of action of the interdepartmental centre where this thesis took place.

With the base of the first flying prototype and a deep research on the State Of Art literature on drones, in particular lightweight and autonomous ones, the work done for this thesis was to optimize the drone with special attention to hardware and weight, changing the usual construction method from carbon fiber frame to a newborn design using PCB and 3D printed plastic, and finally to make it intelligent and usable by non-expert users with basic knowledge. The improvements made and overall stability of the new prototype are satisfactory, a solid point from which to develop many ultralight drone based technologies.

1 OBJECTIVES

This thesis wants to explore a new integrated and modular design for small quadcopter builds, and to build and test a stable, autonomous and lightweight drone which will be the tiny alternative of the PIC4SeR fleet, to be adopted into service robotics, precision agriculture, city surveillance and maintenance for projects treated into the interdepartmental center.
The concept rotate around three aspects: the 250 grams MTOW limit for unregistered UAV regulations, open hardware and software suite for the autopilot, the new concept of a PCB-frame, that incorporates ESCs and Power module saving cable weights and also space.

2 Developed works

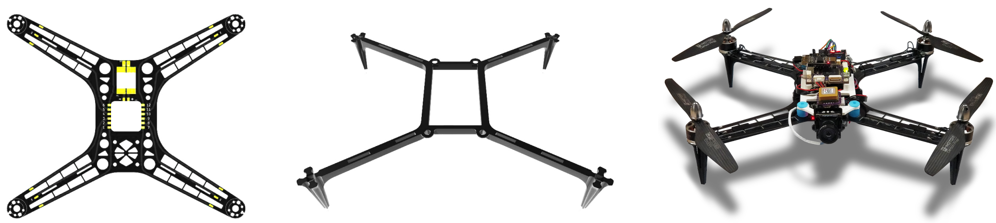
The work is divided in three fields, first of all a deep research on the State Of the Art in ultralight and autonomous drones literature, followed by a research on hardware and autopilot complete suites from firmware on flight controller to ground control desktop app. Second step was the design of the new PCB-frame with 3D printed supports paradigm, from dimensioning, mechanical analysis and then production. Last step was then the testing of the complete assembly in autonomous planned missions to check the quality of the work done.

2.1 SOA and Drones regulation

Initial research on projects already developed have been done using biblio.polito and Google Scholar portals, the first one connected to several organization through the Politecnico di Torino, the second one is one of the largest research gate for articles and papers. From the many readings here some projects have been selected and analyzed focusing on strengths and weaknesses of each one to select the direction to follow in my build. The resulting consideration is none of the project respected all the specifications imposed and this also is prove of the validity of my thesis work, so I decided to continue developing from the old prototype.
Drone regulations is also a crucial point, because the 250 grams weight limit is imposed by the European Aviation Safety Agency (EASA) and then in Italy took in charge by ENAC, the C0 ultralight drone class with no need for aircraft registration will remain, a law correction planned for June 2020 will introduce the obligation for operator registration, but still nothing for the drone.

2.2 Design and built of the prototype

The design started from the previous prototype frame shape result of a mechanical master thesis, shrinked down and adapted in a smaller structure, then imported into KiCad to draw DC-DC and ESCs footprints and connections to motors to weld all this components directly on the PCB. Then the finished design was imported again in Autocad to perform some static simulation to define PCB height looking at bending factor. To support the Printed Circuit Board then a unibody structure with legs have also been designed , in the best way to be 3D manufactured with any printer in PLA or ABS. Electronics and peripherals have also been deeply analyzed and some of them changed to more appropriate and lightweight ones.



(a) *PCB design* (b) *3D printed support* (c) *Complete build*

Figure 1: Hardware design and final assembly

2.3 Testing and Troubleshooting

Testing phase has had several different steps to validate the entire environments step by step in safety, starting from simulations as Software In The Loop and Hardware In the Loop with just the controller's firmware running on the PC or in the autopilot standalone, with the drone behavior simulated in a virtual environment called Gazebo, fully integrated with QGroundControl which is an open control station program running on Windows and Linux.
After software simulation to test that the flight stack works correctly, real flight test on the build have been made, initially manual flights in a drone facility cage at polito, log files analyzed to check power management, sensors and GNSS quality, and then after troubleshooting work to fix IMU and GPS problems, the prototype has been taken to a flight field to run autonomous missions.

2.4 Results

The results obtained are here highlighted:

- *Autonomous missions*: planned flight path now runs on GNSS waypoints and camera trigger.
- *Weight reduction*: the adopted PCB solution and selection of most appropriate components result in a 216 grams total MTOW with payload.
- *More common materials*: carbon fiber replaced with standard PCB and 3D printed material, very easy to manufacture and to customize for the applications needs.
- *Dimension reduction*: 2-3 cm reduction on the 3 dimensions, resulting into a more acceptable drone.
- *Better image quality*: 1080p 60fps image recording is way better for image post-processing than analog video, permitting scan structure or field mapping.
- *Longer Time Of Flight*: thanks to the extra 34 grams gained, a larger battery with 1300mAh capacity can be adopted reaching 14 min flight time instead of the actual 8 min.
- *Integrability*: The PCB frame leave a whole world of possible integration directly on the electronic design, power management and custom ESC but also Ultra Wide Band or patch antennas for Wifi or other kind of radio transmissions.

With this thesis **PIC**COLO is born, the autonomous and ultralight drone of the PIC4SeR.