ASEAN Engineering Journal

Full Paper

A NOVEL FLIGHT CONTROLLER DESIGN FOR MODULAR APPLICATIONS

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Article history
Received
02 September 2021
Received in revised form
23 February 2022
Accepted
01 March 2022
Published online
30 November 2022

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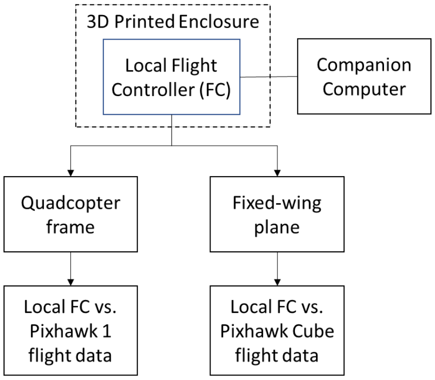
Graphical abstract



Abstract

A local flight controller was developed for modular applications based on the Pixhawk 1 flight controller with modifications to accommodate companion computer provision for future integration. This design is made for future modular applications, but for now, the functionality and performance of the local flight controller were tested and compared to the Pixhawk flight controller. A simple 3D printed enclosure was made to house the local flight controller for easier mounting on UAV frames. To compare the performance of the developed controller, two setups were made: local flight controller and Pixhawk 1 on separate quadcopter frames, and local flight controller and Pixhawk Cube on separate fixed-wing frames. The flight controllers made use of the Ardupilot firmware, specifically ArduCopter and ArduPlane in conducting the flight tests. Auto flight mode was used to have autonomous flights which were then used to compare the flight data between test setups. The desired position and actual position were compared for each flight controller, and their differences with the other flight controllers were compared to see the variation between the different controllers used. After analyzing the data, the local flight controller developed was proven able to produce comparable results with the Pixhawk flight controllers. The percent difference between the mean values of the Pixhawk 1 and the local flight controller were 3.7064% and 8.6128% using the quadcopter frame for Position X and Y, respectively, while for the Pixhawk Cube and the local flight controller, the values were 12.6866% and 1.1045% using the fixed-wing frame, respectively.

Keywords: Casing, Flight controller, Pixhawk, Pixhawk cube, UAV

1.0 INTRODUCTION

Unmanned aerial vehicles (UAV) are gaining momentum in applications, some of which are surveying [1], mapping [2], security, disaster evaluation, aerial photography, swarm [3]-[6] and entertainment to name a few. Different kinds of UAV frames are available such as multirotor [7]-[11], fixed-wing plane [12], and blimp [13] that are being used from research and development to practical applications.

For the UAV to be capable of making such applications, there must be a flight controller that controls the movement of the UAV in the desired manner. It is responsible for converting and filtering raw sensor data inputs into accurate 3D orientation in space. It also controls the motors and receives information from the user through the remote controller. The flight controller also sends telemetry data to a ground control station for real-time viewing and control of the UAV. The flight controller mainly focuses on the stabilization of the UAV, on some occasions, it can do application processes, but this can hinder the processing speed for the stabilization of the UAV. One commonly used application is post-image processing since a UAV is usually mounted with a camera to capture images and videos that a person cannot reach [14],[15].

To address this, mounting a companion computer to do the extra processing can help. The role of the companion computer is to carry the application processing so that the flight controller focuses on the flight control of the UAV. One application the companion computer can do is human tracking and detection. Algorithms involved in image processing can be data-heavy that the flight controller cannot handle while doing flight stabilization. Some applications are seen in Hu [16] and Gonzalez [17], where the former made use of a Pixhawk 1 with a RealSense camera, and the latter made use of a Pixhawk 1 with an Odroid and Lidar both for obstacle avoidance. Both were made to avoid simple obstacles through a low-cost system.

In this paper, the Pixhawk 1 flight controller is used as the basis to develop the local flight controller (FC). According to the PIxhawk website, “Pixhawk is an open-hardware autopilot that supports PX4 and ArduPilot open-source software [18].” The Pixhawk project allows developer communities to create and build from the platform that has been made open to the public. There have been many variations of the Pixhawk created by different companies and have been used by hobbyists, developers, and researchers. This collaboration allowed innovations to form because of the open accessibility that the project offers. A research was also made by Lin [19] focusing on the Extended Kalman Filter (EKF) algorithm that Pixhawk uses for state estimation and prediction. Even with the issues of the individual sensors inside the Pixhawk, the algorithm made use of these issues as input to help compensate and provide high accuracy information that is reliable for applications [20].

To have a system with flight control and application processing, the combination of both the flight controller and companion computer is needed. This becomes the motivation to develop a local flight controller with provision for companion computer to make the connections between the two faster, but for this paper, the focus is on the developed local flight controller and its performance compared to the Pixhawk 1 flight controller.

2.0 METHODOLOGY

Fabrication of Flight Controller

The local FC developed has six layers like the Pixhawk 1 and the actual board is shown in Figure 1. The difference between this local FC with the Pixhawk 1 is that the provision for the companion computer was made readily available. The connector ports were also moved to the side to allow a companion computer to be mounted on top of it without covering any ports as shown in Figure 2. The dimension of this board is 86 x 80mm. The PCB fabrication was made in China, and the soldering of the sourced-out components was done locally. The testing of the FC can be broken down into four major blocks listed below.

1. Power selector
2. Low-dropout regulator
3. Overvoltage and overcurrent ICs
4. IO and FMU microcontrollers

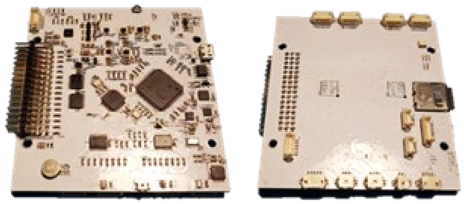


Figure 1 Local FC top and bottom view (L-R)

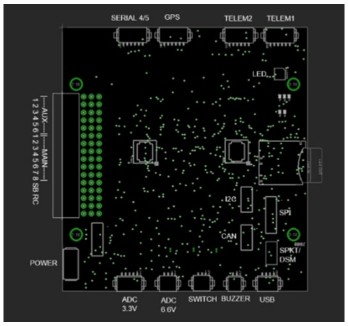


Figure 2 Local FC port locations

Casing Design of Local Flight Controller

As the fabricated local FC is bare, a casing is needed to protect the board and for it to be used and mounted on a UAV frame. A simple enclosure having a square-like shape and closely following the outline of the local FC was used to make the external connections close to the opening of the casing. As the Pixhawk 1 has a casing which houses the PCB board itself, it should also follow that the local FC should have a form of the casing and not just using the bare PCB board. The dimension of the casing is 91x84x17.5mm and the local FC is fastened using four screws on the bottom part of the case. Once the local FC is fastened, the casing is closed and secured by another set of four screws on the side to lock the top and bottom parts of the case together. The blowup design of the casing is seen in Figure 3, and the actual 3D printed casing with the local FC is seen in Figure 4 using tough PLA filament.

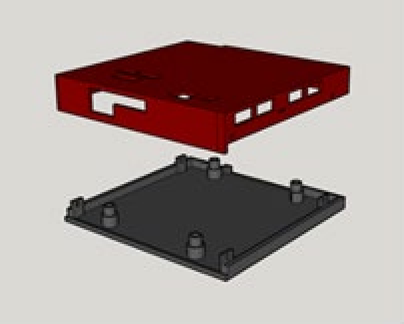


Figure 3 Local FC casing design

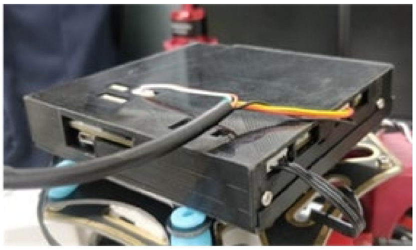


Figure 4 3D printed casing with the local FC

3.0 RESULTS AND DISCUSSION

Testing of the Local FC – F450 Quadcopter Frame

The local FC complete with its casing was mounted on an F450 quadcopter frame. An antivibration mount was placed between the F450 quadcopter mount and the local FC. Figure 5 shows the fully assembled quadcopter setup. For the test comparison, the local FC was compared to the Pixhawk 1 which are mounted on separate quadcopter frames.

Figure 5 Local FC mounted on F450 frame

Figure 6 shows the Google Earth flight path taken by the Pixhawk 1 and local FC to compare the two flight controllers; this was done to compare the performance of the Pixhawk 1 and local FC. Several flights were conducted for both setups having the same flight plan using Auto mode in Mission Planner. Given the same waypoint path and the actual paths taken by both test setups, it is visually seen that there is little difference between the flight of the Pixhawk 1 and the local FC.

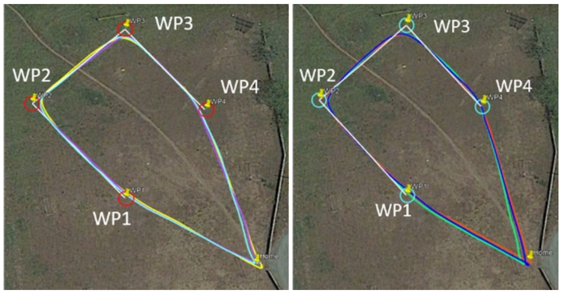


Figure 6 Pixhawk flight and local FC flight (L-R)

Figure 7 presents the flight data of the Pixhawk 1 and local FC respectively. The data shows the desired GPS location and actual GPS location the quadcopter flew. This was broken down into the X and Y component of the GPS location producing the desired X and Y position (DPosX and DPosY), and the actual X and Y position (APosX and APosY). The absolute percent error between the desired and actual value is also plotted to show the comparison of the two.

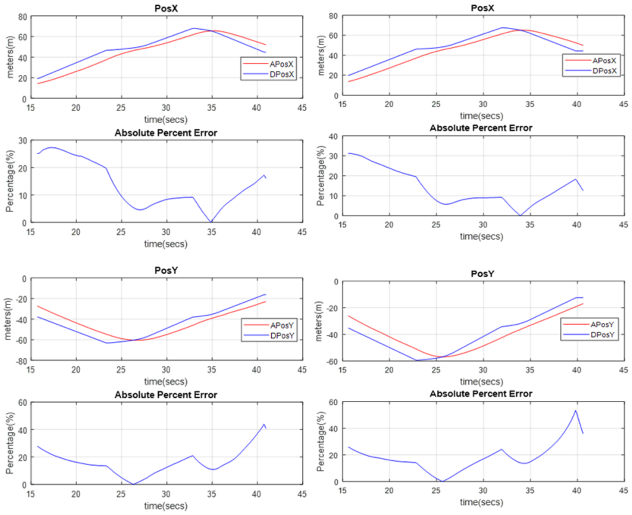


Figure 7 Pixhawk 1 flight and local FC fight (L-R)

The mean absolute percent error (MAPE) between the desired and actual position were taken for the flights using Pixhawk 1 and local FC are presented in Table 1. This MAPE is used to quantify the difference between the target GPS location and the actual GPS location taken by the quadcopter during flight classified as the PosX and PosY. Then the percent differences (PD) between the mean of PosX and PosY for Pixhawk 1 and the local FC were summarized in Table 2, with values 3.7064% and 8.6128%, respectively. Then this PD between the mean value compares the value of PosX and PosY from the Pixhawk 1 and local FC in Table 1. It goes to show that the performance of the local FC is comparable to the Pixhawk 1 based on the values computed. It is to be noted that the computations of the values below were computed from WP1 to WP4, which can be seen in Figure 6 because the home points for each test varies quite significantly.

Table 1 MAPE of Pixhawk 1 and Local FC

Pixhawk 1		Local FC	
PosX	**PosY**	**PosX**	**PosY**
13.229	16.14	13.728	17.593

Table 2 PD of the Mean Value of Pixhawk 1 and Local FC

Position X	Position Y
3.7064	8.6128

Testing of the Local FC – Skyhunter 1880mm Fixed-Wing Plane

The local FC is also mounted inside a Skyhunter 1800mm wingspan fixed-wing plane as shown in Figure 8. For this test, the Pixhawk Cube was used to compare with the local FC and the flight paths taken are seen in Figure 9.

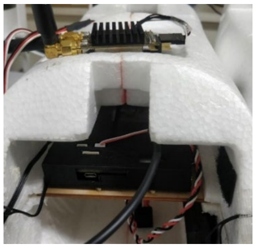


Figure 8 Local FC mounted on Skyhunter frame

The white lines with yellow pins in Figure 9 represent the set waypoint path for the plane to fly set in Mission Planner. The Pixhawk Cube flight (blue line) and the local FC flight (red line) are the Auto mode flight path taken by the respective flight controllers. Auto mode allows the plane to fly autonomously following the set mission saved in the flight controller. A simple mapping waypoint was made to observe the flight performance of the plane. It took some time for the two flights to follow the set waypoint path because it was flown in a different mode before changed to Auto mode. Takeoff was done in a manual flight mode and then changed to Auto mode as it approaches WP1. The plane is always forward moving, and it would need time to change directions especially when during sharp turns. It was at WP3 to WP7 that the paths of both flights were similar and during these points were the data analyzed in Table 3.

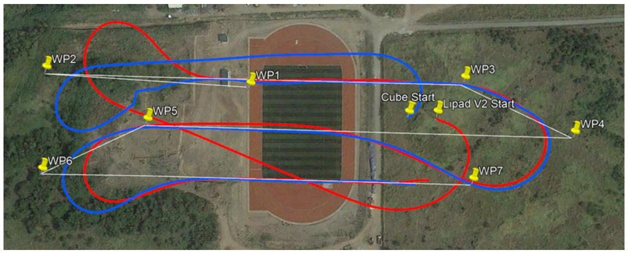


Figure 9 Pixhawk Cube (blue) and local FC flight (red)

Figures 10 presents the Pixhawk Cube flight and the local FC flight, respectively. The data presented in these figures have the same parameters as with Table 1 and Table 2, but the comparison is with the Pixhawk Cube. From inspection, the pattern of the graphs for the two flight controllers is the same and it shows that the local FC can produce a comparable result based on the waypoint path.

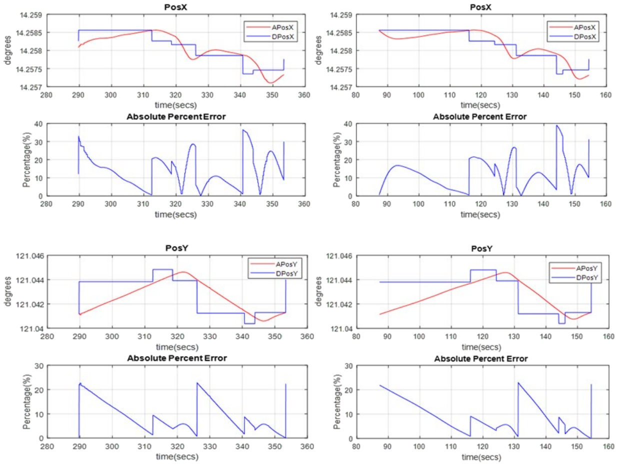


Figure 10 Pixhawk Cube flight and Local FC flight using Skyhunter (L-R)

Table 3 presents the MAPE between the desired position with the actual desired GPS position for X and Y, for the Pixhawk Cube and the local FC, while Table 4 summarizes the PD of the mean values from Table 3. These tables have the same parameters as Table 1, and Table 2. Having the PD of 12.6866% and 1.1045% for Position X and Position Y, respectively, shows that the performance of the local FC is comparable in terms of being able to follow the set waypoints to the Pixhawk Cube.

Table 3 MAPE of Pixhawk Cube and Local FC

Pixhawk Cube		Local FC	
PosX	**PosY**	**PosX**	**PosY**
13.6699	9.0216	12.0391	9.1218

Table 4 PD of the Mean Value of Pixhawk Cube and Local FC

Position X	Position Y
12.6866	1.1045

4.0 CONCLUSION

A local FC was developed based on the Pixhawk 1 flight controller. Modifications made involved the size and port positions of the peripherals for easier connection to the companion computer for future use. A 3D printed casing was built to house the local FC so that it can protect the board and be mounted easily on a UAV frame. It was mounted on an F450 quadcopter frame and a Skyhunter 1800mm fixed-wing plane to test in different UAV frames. For the quadcopter testing, two frames were used, one using the Pixhawk 1, and the other using the local FC. For the fixed-wing testing, two frames were also used, one using the Pixhawk Cube, and the other using the local FC. Google Earth images with plotted desired path, and actual paths were presented and observed to closely follow the desired path and were both comparable to the Pixhawk 1 and Pixhawk Cube performance. MAPE values were computed to compare the actual with the desired path, and it was seen to give low error values. After computing these, the PD computation was done, presenting how much the performance of the local FC varies with the Pixhawk flight controller. The results show that the development of the local FC is comparable based on the test setup made.

Plans for this would include a modular casing to house a companion computer, modified casing of the local flight controller, and another casing to house a separate power distribution board to create a modular flight controller system. Doing this will allow the flight controller system to be easily mounted on a UAV frame as the connection to the batteries, ESCs, flight controller, and companion computer will be included and accounted for. To be able to move forward with this development, the initial performance test was conducted purely on the local flight controller to verify its functionality before conducting other testing related to its modularity.

Acknowledgement

The authors would like to acknowledge the Department of Science and Technology - Philippine Council for Industry, Energy and Emerging Technology Research and Development (DOST-PCIEERD) with project number 04254, Center for

Engineering and Sustainable Development Research (CESDR), and the University Research Coordination Office (URCO) both of De La Salle University for funding and supporting this research.

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