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To cite this article: Kamolwat Chaisena *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **886** 012006

IOP Conf. Series: Materials Science and Engineering **886** (2020) 012006 doi:10.1088/1757-899X/886/1/012006

Automatic Balancing System in Quadcopter with Change in Center of Gravity

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Abstract
The purpose of this paper is to explore an automatic balancing system using the proportional integral derivative or PID feedback control algorithm in quad-rotor Helicopter, so-called quadcopter, with the center of gravity, moved on account of payload. Nowadays, the quadcopter widely used for a variety of applications due to high stability performance. In many applications in quadcopter usually carried a payload in the middle of its frame to maintain the balance during flight. However, the application of quadcopter could be a contributing factor to increase a payload on one side and can lead to an improper position of the center of gravity. This study set out to investigate the use of the mass of battery and landing gear to create a counterbalance to compensate for the payload. The stabilization of the balancing system was implemented by the PID control algorithm to control the counterbalancing of the quadcopter. The current study found that the PID control algorithm works well to maintain the balance in a quadcopter with the center of gravity moving during flight.

Keywords: Balancing System, PID control, Unbalance of Quadcopter

1. Introduction
Since it reported in the early 1900s, a multi-rotor helicopter has been attracting a lot of interest. In the 1920s, there has been an increasing interest in multi-rotor helicopter since it has been used in the military. One of the greatest challenges of the application of a multi-rotor helicopter is its huge, overweight, and instability in control. In a few decades, the technology in the field of Unmanned Aerial Vehicle or UAV has been developing continuously. This type of UAV aircraft was developed to a smaller size to suit the application. It also used in military and civil missions.

Nowadays, a quadcopter is considered as multi-rotor aircraft and has been widely used due to its lightweight and high-lift force, vertically take-off and landing. It has become a central issue for hovering in the air and remains stable for flight control. This type of UAV aircraft consists of four rotors at the end of the arm. Its movement is allowed an adjustment of the rotor speed independently so that it can control a pitch, roll and yaw. The quadcopter can play an important role in addressing the issue of carrying a payload. For instance, it can be used as a camera for aerial video and photography, gripper for pick and place the object, transportation of goods. Generally, the payload is usually attached in the center of mass of the aircraft body to maintain stability during flight. However, in some applications, the payload is mounted out in front of the body because there is not enough space in the center of the aircraft frame.

Studies of quadcopter show the importance of improving PID control so that it can increase the stability in aircraft control [1-4]. Moreover, several attempts have been made to investigate an effect of variations in center of gravity such as the response of rotating speed of the rotors [5], the PID control used to stabilize the quadrotor with dynamic change in center of gravity on account of payload [6]. In particular [7], this research has established the solution to maintain the stability of multi-rotor during flight using landing gear. And, it has been acting as a tail in a mechanical system to create a counterbalance to compensate the payload.

In previous research [8], we have presented an automatic balancing system in quadcopter using the aircraft component as lithium polymer battery, which energizes the whole system to create a counterbalance to compensate the payload attached on the front of the quadcopter frame. The method of the balancing system implemented by PID, which was used to control the stabilization. The battery had linearly driven a servomotor to create a counterbalance. As a result, the response of the previous system was quite slow because the movement was changed from rotation to translation. In the previous work, it had not been mentioned about the improvement of PID control.

This paper is to explore the relationship between a new model of a quadcopter and automatic balancing system using a combination of the mass of battery and landing gear. It is also to create a counterbalance to have a faster response and to present the process of improvements in PID control of stabilization.

2. Concept and Method

This section discusses the model and design of the quadcopter and concept of balancing system. The S-500 PCB quad-rotor frame was used. The quadcopter consists of four motors, there are two motors rotate clockwise (CW) direction and two motors rotate counterclockwise (CCW) direction as shown in Figure1. The moment force around the vertical axis of the aircraft body was compensated for each other.

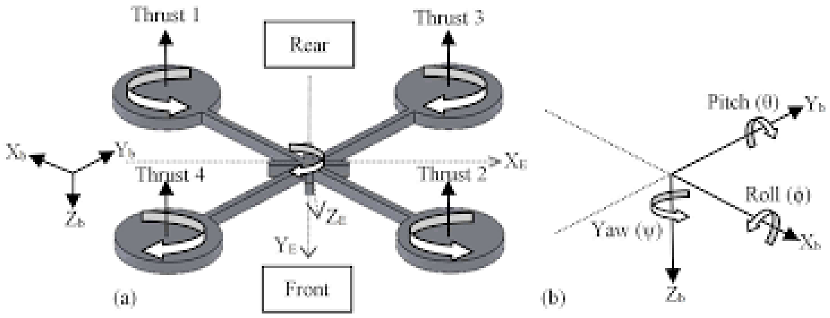
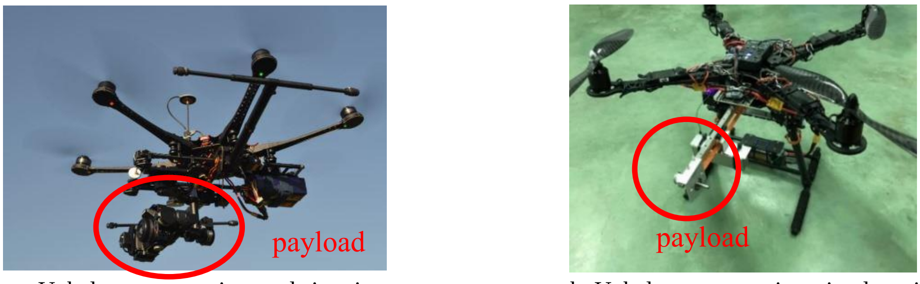


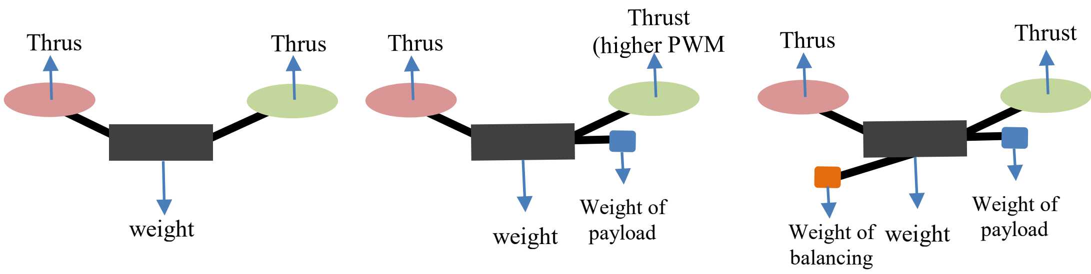
Figure 1. A free body diagram of quadcopter X [9]

In this study, the balance situation with the equally PWM signal value of four motors used as a condition. The unbalance situation simulated by installing a payload on the front of the aircraft frame. The PWM signal value of four motors was unable to have equal values. From this data, the PWM signal values of a pair of front motors showed greater value than a pair of rear motors. The lightweight aluminum bar is attached to the front of the aircraft frame so that it was able to adjust the position of aluminum block to simulate the movement of the center of gravity when carrying a payload (see Figure 2). Figure 3 provides a free body diagram of a quadcopter with three situations.



a. Unbalance system in a real situation b. Unbalance system in a simulate situation

Figure 2. Qu.adcopters with payload



a. Balance situation b. Unbalance situation c. Balancing

Figure 3. Free body diagram of a quadcopter with three situations

For the balancing mechanism, a couple of high - torque RC servo motor was used as an actuator at the landing gear joints to fold the rear of the aircraft frame and to compensate the payload. As can be seen from Figure 4 below, the battery was mounted at the bottom of the landing gear to increase a balancing capacity.

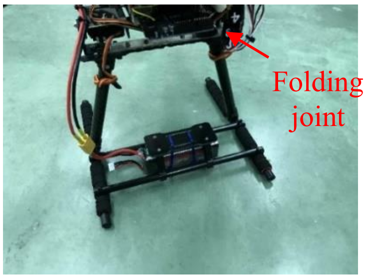


Figure 4. Battery attached with landing gear

The advantage of this balancing mechanism is a faster response than previous research [8] because the folding angle of landing gear depends on the angular angle of faster servomotor. Table 1 shows the aircraft specifications of some parameters.

Table 1. Quadcopter Specifications

Parameter	Size (grams)
Take-off Weight	1,695
Battery	235
Payload	330
Landing Gear	240

3. System Integration

The method of the study based on the main hardware of the quadcopter using the lithium battery as a payload and power source to create the balancing force. Pixhawk board for control stability and movement of quadcopter and receive PWM signal from the transmitter through the receiver.

Moreover, there is an Arduino board as a processing unit to control the servo motor for controlling and balancing the system (see Figure 5 below).

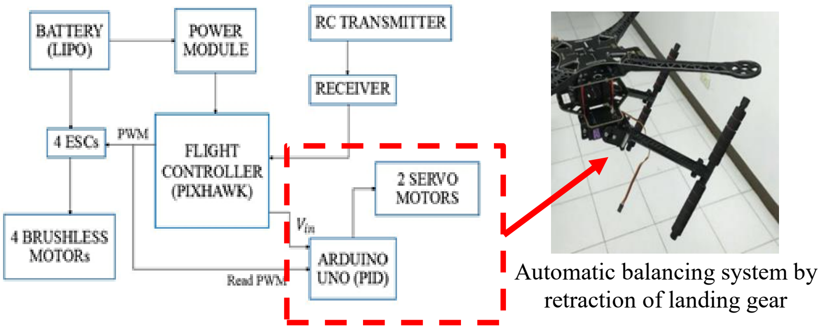
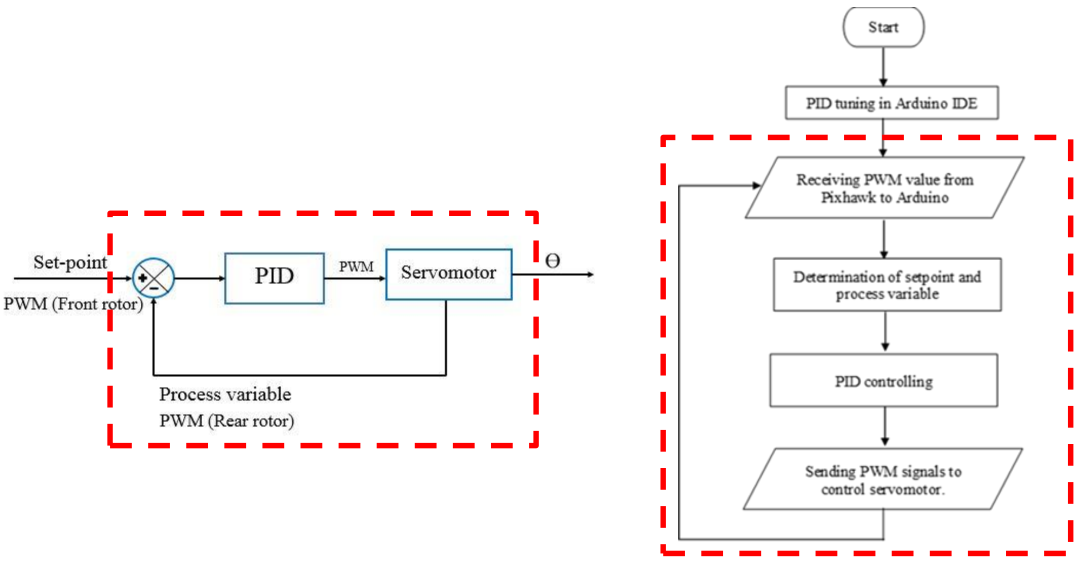


Figure 5. A diagram of a hardware system

By the way, it can be seen that complete systems need more than one hardware system, it also needs software and controller to control the systems. It is apparent from the diagram that the proportional – integral – derivative or PID control is applicable in many industrials and a wide range of research. This controller response is able to correct by tuning three values as Kp, Ki and Kd to create minimum errors.

It suggested that PWM values of a pair of front rotors have equal value and set as a set point. It also has equal value and set as a process variable. As shown in Figure 6a, the setpoint value as an input was sent to the PID controller to control servomotor until a process variable converges effectively to a set point. Besides, the process balancing system starts with tuning PID value with trial and error method in the Arduino board. Arduino board receives PWM values from Pixhawk and sets these values as setpoint and process variable. These values sent to the PID controlling process to control servomotor for balancing system. The schematic diagram provided in Figure 6b.



a. A PID block diagram

b. A schematic diagram of the balancing system

Figure 6. An automatic balancing system diagram

4. Experiments and Results analysis

This section shows the experiments and results of the study in four cases. It consists of a test that is with a payload and the test without a payload. It also comprises of a test that is with balancing and a test with a static balancing. To study the behavior of the PWM signal in various cases, a flight plotter program was used to analyze the data.

4.1 Testing without a payload

From the data in Figure 7, it is apparent that the stability of quadcopter is the most important issue since the position of any devices that set in quadcopter has an effect on PWM signals. We can see that the PWM signal values almost have equal values about 1700 (see Figure 7 below).

Figure 7. PWM values response in case with balance.

4.2 Testing with a payload

As Figure 8 shows, there is the 330 grams payload attached in front of the frame (15 cm), and it displaces between payload and center of gravity. The result shows that the PWM mean value of a pair of front motors (approx. 1700) was greater than a pair of rear motors (approx. 1550). Hence, the system of quadcopter has to maintain stability by increasing PWM values of the heavier side, as shown in Figure 8.

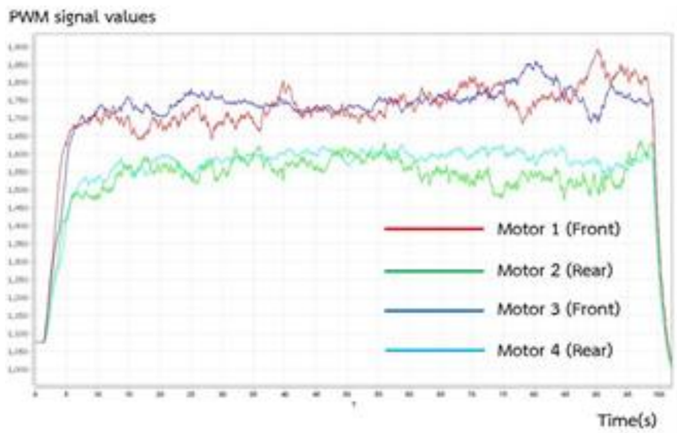


Figure 8. PWM values response in case with unbalance

4.3 Testing with balancing

As seen from the data in Figure 9, the folding of landing gear to the backside used as a counterbalance for the balancing system. The trial and error method used to find PID gain value (Kp, Ki, and Kd). It also used to control the rotation of the servo motor. After trial and error tuning, there are Kp, Ki, and Kd values that suit this system and they have chosen as 0.0375, 0.0175 and 0, respectively.

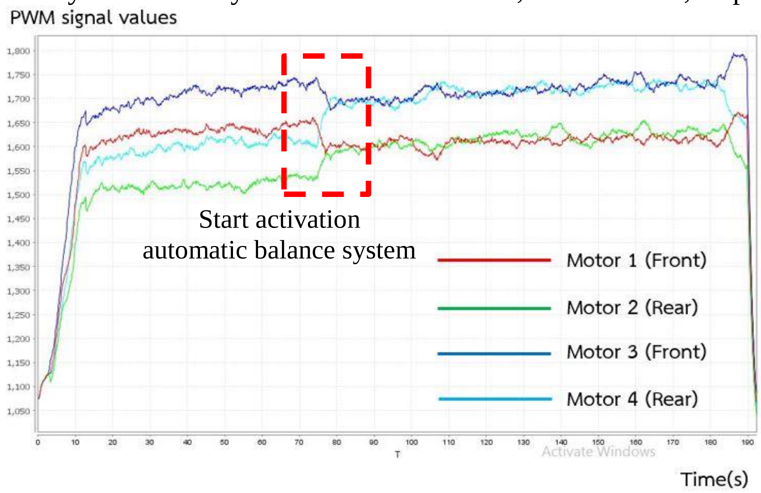


Figure 9. PWM values response in case with balancing.

As can be seen from Figure 8, the result demonstrates that the PWM value of a pair of the motor in the same diagonal line has converged to each other. The settling time is about three seconds and without overshoot of servomotor.

4.4 Static balancing test

After testing all cases, there is a static balancing test to make sure that these gain values are able to maintain the stability of the quadcopter. By testing the tilt angle of the quadcopter in three cases, the data shows balance, unbalance, and balancing. The 330 grams payload was attached at front of the frame in unbalance and balancing test with displacement 15, 17.5 and 20 cm, respectively. A payload at the center of gravity of quadcopter (Kp, Ki, and Kd values) was chosen in testing 4.3, and used in balancing test (see Table 2)

Table 2. Result of static balancing test

Displacement (cm.)	Angle (Deg.)				
	Balance	Unbalance	Balancing	error	Landing gear retraction
15	0.91	15.09	2.70	1.78	44.95
17.5	0.93	17.88	1.86	0.92	45.58
20	0.54	20.54	1.60	1.06	76.08

As shown in Table 2, it is apparent that the displacement of the payload has an effect on the angle of landing gear retraction by increasing displacement. Also, it is able to increase the angle of landing gear retraction. From the data, we can see that displacement of the payload has direct variation to an angle of landing gear retraction (see Figure 10 below).

Balance Unbalance Balancing

Figure 10. Tilt angle in any static testing case.

IOP Conf. Series: Materials Science and Engineering **886** (2020) 012006 doi:10.1088/1757-899X/886/1/012006

5. Conclusion

This study has found that generally, the balancing system by folding landing gear with 475 grams counterbalance payload due to the building of quadcopter with 330 grams of payload. The most obvious finding to emerge from this study is that the PID controller used in this balancing system for maintaining the stability of quadcopter with Kp, Ki and Kd values as 0.0375, 0.0175 and 0, respectively. The results can also be summarised as follow:

5.1 In balance case (without payload): PWM signal values of 4 motor have equal value about 1700.

5.2 In unbalance case (with payload): PWM signal values of a pair of the front motor is greater than a pair of the rear motor.

5.3 In balancing case: PID controller able to control a servo motor with three seconds of settling time, without overshoot and maintain the stability of a quadcopter.

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