Quadcopter Stability Control System Using PID And Kalman Filter

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***Abstract*—Quadcopter is an Unmanned Aerial Vehicle (UAV) that uses 4 motors arranged crosswise as a propulsion system. The quadcopter's capabilities are supported by a main component called the flight controller or control system. The operation of this unmanned aircraft is controlled automatically through a program run from the GCS (Ground Control Station) so that the quadcopter can fly according to the desired destination. The control system is needed to maintain the balance of the quadcopter while flying and maneuvering to remain stable. PID (Proposional Integral Derivative) method as a counterweight when manoeuvring on the y-axis (pitch) and x-axis (roll) and Kalman Filter as processing the resulting sensor output. The results of this study show that setting the value for the proportional constant (Kp), integral constant (Ki) and derivative constant (Kd) determines the quadcopter can fly or maneuver well. The gain values used are Kp of 0.135, Ki of 0.135 and Kd of 0.003. However, the output generated by the gyroscope in pitch and roll still has noise caused by the vibration of the mover during flight and maneuvering. So the Kalman filter is needed to find out the value that is close to the actual output of the gyroscope.**

Keywords— ***Derivative, flight controller, integral, kalman filter, proporsional, quadcopter, tuning PID.***

I. INTRODUCTION

UAV (Unmanned Aerial Vehicles) has been widely used in various fields, both military and civil. In the military field, UAVs are used for combat operations and decision-making, intelligence, ISR (Intelligent Surveillance and Reconnaissance), and atmospheric research. In addition, UAVs are used for SAR (Search and Rescue), real-time surveillance, reconnaissance, inspection of dangerous places, traffic monitoring, natural disaster monitoring, pest and disease control, inspection of electrical networks and in the field of meteorology. Quadrotor is one of the Unmanned Aircraft Vehicles (UAV) that can fly autonomously or remotely. Recently, the quadrotor has become a topic of interest in many research fields, including in the civil and military fields. Quadrotor does not require a large area for landing, can take off vertically and has high maneuverability compared to other vehicles.

In determining the correct UAV quadcopter position control system method, it is very necessary to reduce the risk of the quadcopter when flying so that it becomes stable. The design of controls for roll and pitch movements on the quadcopter is expected to be able to control the roll and pitch positions according to the references given when there is interference with the maneuvering flight process. The process of making the quadcopter to remain stable found problems such as the four propellers not having lift, because 2 motors are designed to rotate Counter Clock Wise (CCW) and 2 motors are designed to rotate Counter Wise (CW), especially when flying stably carrying loads or when there is interference [1].

Kalman filter with optical flow method to estimate the position and velocity of the quadcopter without a Global Positioning System (GPS). Kalman filter is effective for reducing noise and estimating the position of the velocity. However, the optical flow algorithm cannot detect movement if the image has a uniform color over the coverage area, because of this, optical flow cannot be used as a standalone algorithm for indoor estimation [2].

Rosalia H. Subrata, Raymond Tarumasely & Calvin Dwianto S explains the Proportional Integral Derivative Controller to be able to restore pitch and roll positions according to the references entered when given a boost to the quadcopter. The roll angle is controlled by increasing or decreasing the speed of one of the left or right motors. Meanwhile, the pitch angle is controlled by increasing or decreasing the speed of one of the front or rear motors [3].

In Unmanned vertical takeoff and landing (VTOL) by applying optical flow as an increase in GPS which has disadvantages in indoor. Optical flow is used for collision avoidance, measuring altitude and for position stabilization during the landing stage. Optical flow is used for collision avoidance, measuring altitude and for position stabilization during the landing stage [4].

The design of the flight controller with balance control using PID control. The quadcopter can hover properly in about 3 seconds to return to the setpoint without the help of remote control. With PID parameters for KP value of 2.5, KI of 0.6, and KD of 1.0, it can beat Quadcopter with a response time of 3s [5][6].

This study aims to control the stability of the quadcopter using a PID controller and Kalman Filter. This system uses an IMU (inertial measurement unit) sensor which is a combination of a gyroscope sensor and an accelerometer found on the Pixhawk. The PID controller in the form of a combination of proportional control, integral control, and derivative control aims to make the process complementary between types of control, because each control action has advantages and disadvantages. Meanwhile, the Kalman filter algorithm is applied to remove noise from the sensor signal to produce good aggregated data, for example, estimating the smoothed pitch and roll position values at a series of points in the track [7][8].

II. METHOD

A. *Block Diagram System*

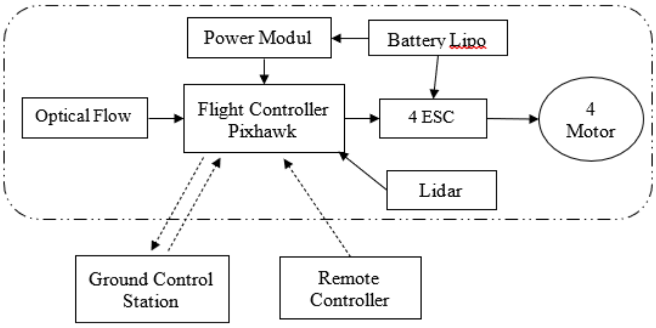


Figure 1. Block Diagram System

In Figure 1 there is a block diagram of the system regarding the planning of a quadcopter stability control system using PID and kalman filter. In this system there are 4 Brushless DC motors which will be controlled by the Flight Controller using an Electronic Speed Controller (ESC) for each motor which is supplied directly from the Lipo Battery. Apart from providing it to the ESC, the battery also supplies the Flight Controller through the power module to be stabilized as a voltage regulator. For altitude sensors using Lidar which is connected via serial 4 on the Flight Controller. The Flight Controller system communicates with the Ground Control Station (GCS) using radio telemetry [9]. Meanwhile, Optical Flow is connected to Pixhawk via I2C, where the sensor is used to lock the quadcopter's position when hovering [10]. The quadcopter itself can be operated through a program like a drone kit, but due to security reasons if the drone fails to maneuver it would be better to still be accompanied by a remote control [11][12].

B. *System Planning*

The results of system planning are divided into 2 parts, namely mechanic planning and software planning.

- Hardware Planning

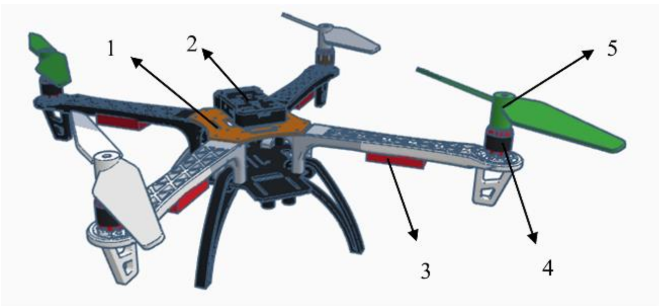


Figure 2. Design from above

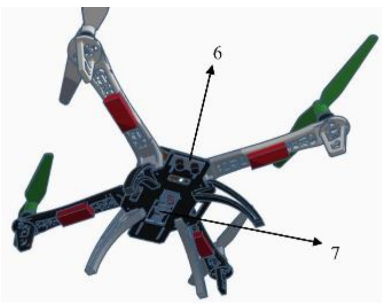


Figure 3. Design from bottom

Hardware planning is as follows:

1) Frame as the main frame of the quadcopter to put all the components like Flight Controller, ESC, Lidar, Optical Flow, Battery Lipo, etc
2) Flight Controller (FC) Pixhawk will connect with ESC, Lidar, Optical Flow, Telemetry and Battery Lipo
3) Electronic Speed Controller (ESC) will control the speed and direction of rotation of the brushless motor. There are 4 ESC that will drive each motor.
4) There are 2 brushless motors are designed to rotate Counter Clock Wise (CCW) and 2 brushless motors are designed to rotate Counter Wise (CW).
5) There are 4 propeller will connect on each Brushless motor.
6) Lidar functions as an altitude sensor on the quadcopter that connect to FC.
7) Optical Flow as a quadcopter stabilizer sensor while flying will connect to FC.

C. *Electric Planning*

- Flight Controller with Brushless DC Motor

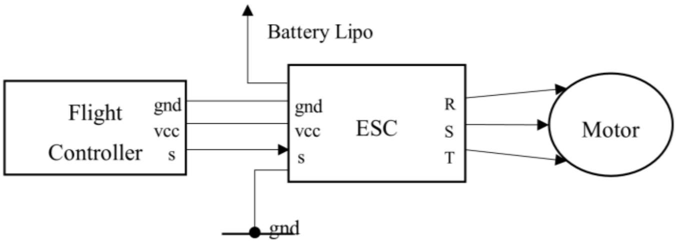


Figure 4. FC with Motor

The picture above shows the electrical connection used to regulate the speed of the motor which is controlled by the ESC as pulse management. The ESC gets its source directly from the battery and supplies voltage to the motor according to FC [13].

- Flight Controller with Optical Flow

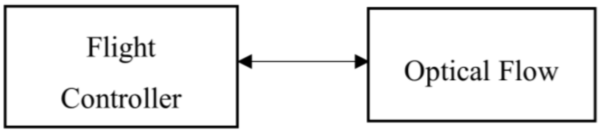


Figure 5. Optical Flow connection with FC

The picture above describes the connection between Optical Flow which is connected using port I2C 4 pin on the Flight Controller [14].

- Flight Controller with Lidar sensor

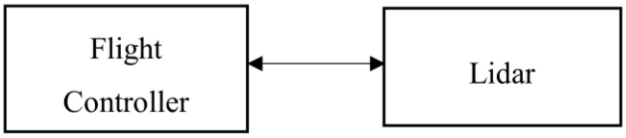


Figure 6. Lidar connection with FC

The picture above shows the Lidar connection with serial 4 on the Flight Controller. Pin 1 lidar as ground is connected to pin 6 Pixhawk, pin 2 lidar is connected to pin 1 as vcc 5V, then pin 3 is connected to pin 2 of Pixhawk as RX and pin 4 lidar is connected to pin 3 as TX [15].

- Ground Control Station (GCS) with Flight Controller (FC)

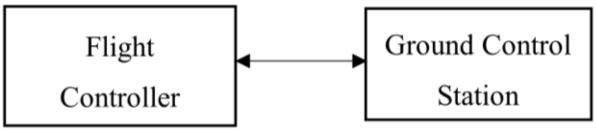


Figure 7. GCS (Laptop) connection with FC

The picture above shows the connection between the Laptop and the FC that is connected via radio telemetry, this communication is needed to send the program and the output value obtained while flying which will later be processed on the laptop [7].

III. RESULTS AND DISCUSSION

A. *Hardware Circuit Results*

Figure 8. Quadcopter from above

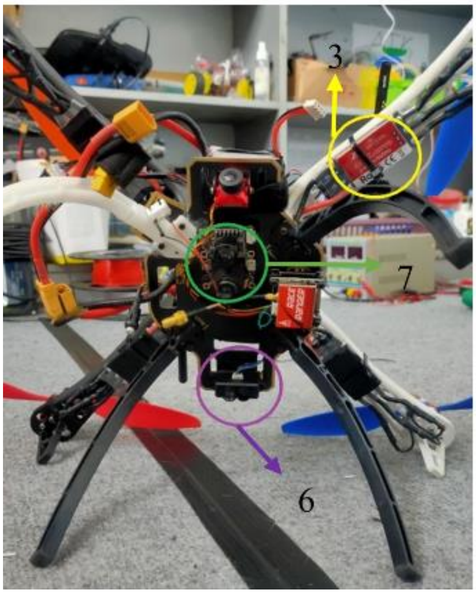


Figure 9. Quadcopter from bottom

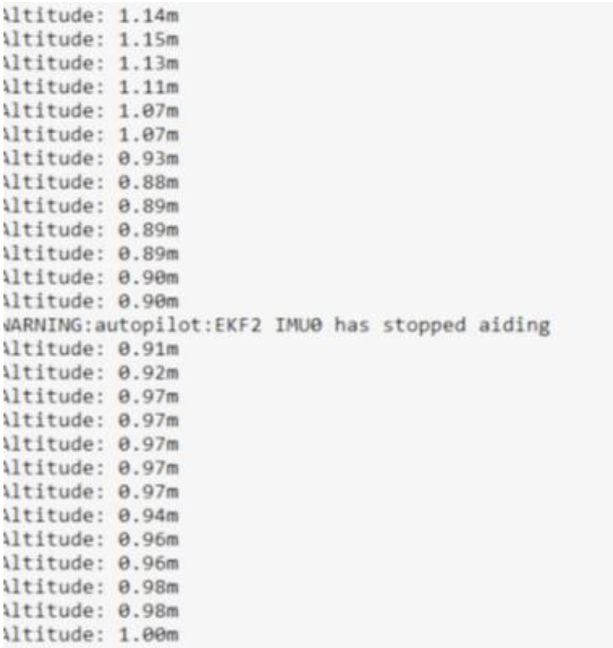
The results of mechanical planning are as follows:

1) Frame as the main frame of the quadcopter to put all the components.
2) Flight Controller (FC) Pixhawk as a quadcopter controller so that it can fly according to the algorithm.
3) Electronic Speed Controller (ESC) to control the speed and direction of rotation of the brushless motor.
4) Brushless DC motor as propeller drive.
5) Propeller as a quadcopter wing in order to fly.
6) Lidar functions as an altitude sensor on the quadcopter.
7) Optical Flow as a quadcopter stabilizer sensor while flying.

B. *Lidar Sensor Testing Results*

Measurement from the lidar sensor with the actual distance so that the accuracy value can be known by calculating the total error value divided by the total test using the following formula:

$$Error(\%) = \frac{Lidar\ Sensor\ Value - Actual\ Distance\ Value}{Lidar\ Sensor\ Value} x100\%$$



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Altitude: 1.14m
Altitude: 1.15m
Altitude: 1.13m
Altitude: 1.11m
Altitude: 1.07m
Altitude: 1.07m
Altitude: 0.93m
Altitude: 0.88m
Altitude: 0.89m
Altitude: 0.89m
Altitude: 0.89m
Altitude: 0.90m
Altitude: 0.90m
WARNING:autopilot:EKF2 IMU0 has stopped aiding
Altitude: 0.91m
Altitude: 0.92m
Altitude: 0.97m
Altitude: 0.97m
Altitude: 0.97m
Altitude: 0.97m
Altitude: 0.97m
Altitude: 0.94m
Altitude: 0.96m
Altitude: 0.96m
Altitude: 0.98m
Altitude: 0.98m
Altitude: 1.00m
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Figure 10. Testing Lidar Sensor

The error percentage calculation is performed between the values obtained from the Lidar Sensor and Actual Distance using tape measure, which are presented in the Table I.

TABLE I
MEASUREMENT RESULT OF LIDAR SENSOR

No.	Actual distance (cm)	Lidar (cm)	Difference (cm)	Percentage error (%)
1.	10	8	2	2
2.	30	31	1	3.33
3.	50	50	0	0
4.	80	79	1	1.25
5.	100	101	1	1
6.	120	120	0	0
7.	140	138	2	1.428
8.	150	150	0	0
9.	180	182	2	1.11
10.	200	203	3	1.5

C. *PID Test Result on Quadcopter*

The test is carried out by running the program on the GCS (Laptop) with the gain value determined by the PID tuning process.

- Testing without adding Kp, Ki, Kd values

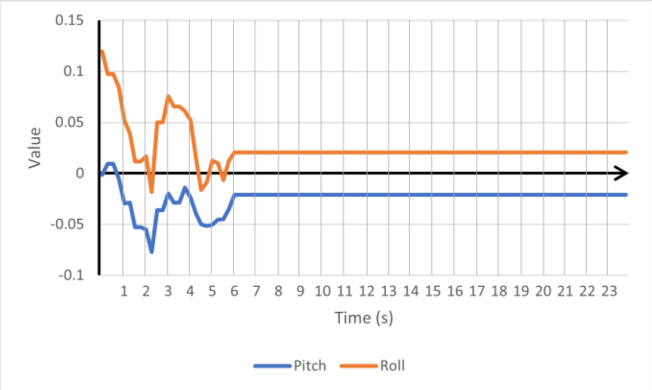

Figure 11. value Kp, Ki, Kd is 0

The quadcopter is unable to fly so it immediately falls to the ground after rising for 2 seconds. The output response taken only captures the pitch and roll values for 6 seconds. It can be concluded that if the PID value is eliminated, the quadcopter cannot fly safely

- Testing by giving Kp and Ki of 0.05

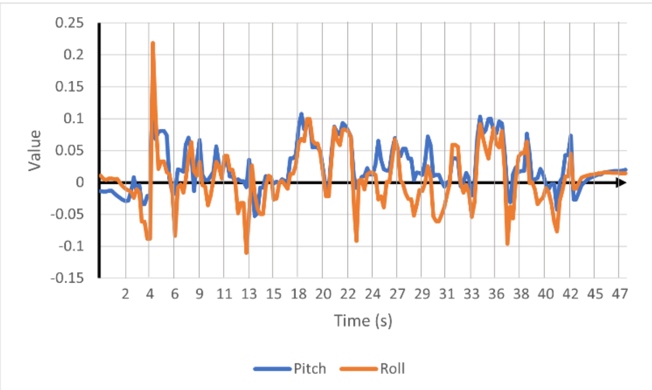

Figure 12.Value Kp, Ki is 0.05

The response captured by the gyroscope by giving a Kp and Ki gain value of 0.05 can make the quadcopter fly, but when moving forward there is a jolt so that the response at 5 seconds is very high.

- Testing by giving Kp, Ki 0.2 and Kd 0.002

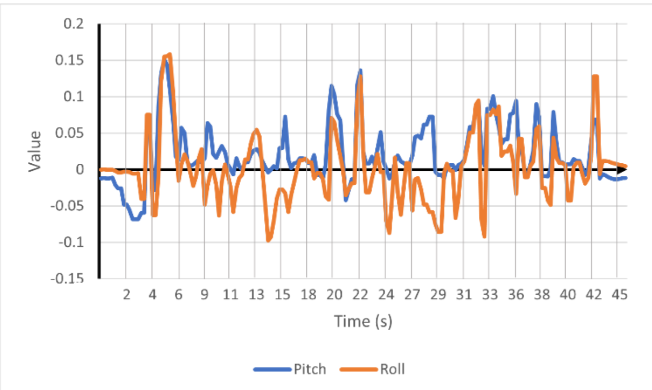

Figure 13. Value Kd Ki is 0.2 and Kd 0.002

The results obtained from the gyroscope output show that the response received is more unstable than the Kp and Ki tests of 0.05.

- Testing by giving Kp and Ki 0.135 and then Kd 0.003

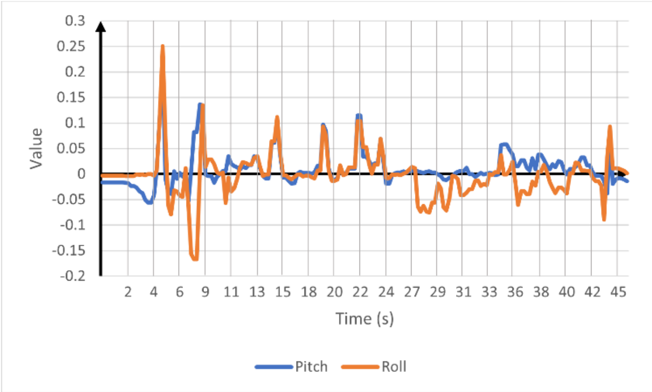

Figure 14. Kalman Filter on Pitch

The output values of pitch and roll in the Kp and Ki values of 0.135 and Kd of 0.003 were better than the previous tests. This can be seen from the graph shown in Figure 4.10, the closer the response is to 0, the more stable the movement of the quadcopter is.

D. Kalman Filter Test Result on Quadcopter

The main purpose of using Kalman filter is to combine accelerometer and gyroscope data and eliminate sensor measurement noise. This test is carried out to determine the sensor output results and produce pitch and roll angles that are close to the actual value. The results of the Kalman filter test are depicted in graphic form

- Kalman filter testing on Pitch

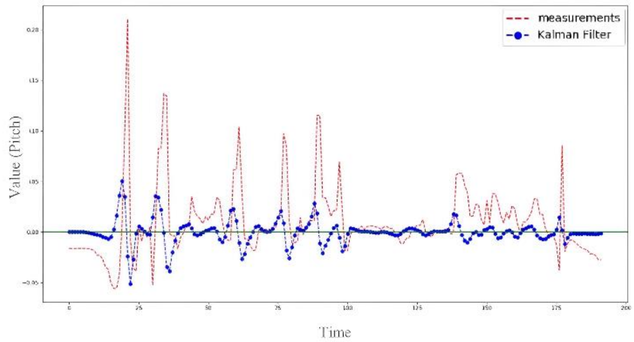

Figure 15. Kalman Filter on Pitch

The Kalman filter test on the pitch above shows that the blue dot line is the result of the filtered pitch data. The graph shows that the filter results are closer to the 0° angle or setpoint than the sensor measurement value which has a large enough noise.

- Kalman filter testing on Roll

The results of the Kalman filter on the roll from the MPU Pixhawk sensor with the red filter output show that the value is close to 0° compared to the sensor without using the Kalman filter.

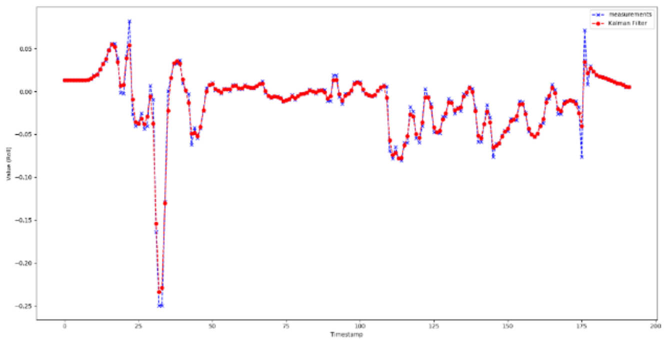
Figure 16. Kalman Filter on Roll

Testing the Kalman filter with Kp and Ki values of 0.135 and Kd of 0.003 in the table above shows that after being given a filter the pitch and roll results are smaller than without the addition of a filter.

IV. CONCLUSIONS

In this study successfully implemented PID to obtain stability when the quadcopter maneuvers with a gain value of Kp = 0.135, Ki = 0.135 and Kd = 0.003 at a height of 1 meter. This value starts with testing without PID, because the gain value obtained by each quadcopter is different even though it has identical components, so the gain value is not universal. Based on the PID test, if the Kp value is small, the proportional controller is only able to make small error corrections, so the resulting system response is slow. However, if it is too large, the system will not work stably. The Kd value is very sensitive so only a very small value is needed. In testing the Kalman filter with Kp and Ki values of 0.135, it can be seen that the Kalman filter succeeded in smoothing the IMU sensor readings to reduce noise from the gyroscope so that the output from the Kalman filter is the true value. This noise is caused by motor vibrations and is captured by the gyroscope, so a Kalman filter is needed to get a value close to the real one. Future research can try by adding a load to the drone so that PID testing is more effective to find out the difference when the quadcopter is given an additional load. Subsequent research can add light intensity to the quadcopter so that the Optical Flow (PX4Flow) sensor can work better in rooms with low light intensity.

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