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Quadcopter Main Board Design with PID Algorithm as Controller

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Abstract— *Kontes Robot Terbang Indonesia (KRTI)* Flight controller division has a mission to independently make an unmanned aerial vehicle (UAV) controller. UAV controllers are usually made by non-local manufacturers, who have a package between the controller and the aircraft. Due to limited pins and specific functions, most controllers cannot adapt to user requirements. For this reason, in this study, we made a UAV controller with a more significant number of pins that can be programmed independently. Main Controller is a master board device used to control the stability of the UAV when flying. The main controller has been designed specifically for certain products so that the UAV cannot be modified. In this study, it is proposed to make the main controller that is specifically designed to fly a Quadcopter UAV. Movement control for quadcopter stability when flying using the Proportional Integral Derivative (PID) method. The main controller has a function that is to regulate the entire course of flight on unmanned vehicles. PID control can adapt to changes so that the system becomes stable. The PID control on the Main Controller is intended to balance the quadcopter concerning its orientation angle. The Main Controller is also tasked with recording data from sensors such as the Inertial Measurement Unit (IMU) and reading data from the remote. The controller successfully flew the quadcopter with a P value of 0.245, an I value of 0.0139, and a D value of 0.0085.

Keywords— Main Board, Quadcopter, PID Algorithm, UAV, IMU.

I. INTRODUCTION

Technological developments in the transportation sector are overgrowing, especially in unmanned aerial vehicles (UAVs). The UAV does not require a crew to fly and is controlled remotely using a wireless communication system. In Indonesia, UAVs have begun to be used in various fields, including photography and agriculture. One of the UAV developments at the university level is the *Kontes Robot Terbang Indonesia (KRTI)*. Multiple universities from all over *Indonesia attended KRTI*. One of the divisions of KRTI is Technology Development (TD) which develops UAV vehicle technology. The TD Division develops the Flight Controller (FC) or Main Controller system.

Main Board FC has a function that is to regulate the entire course of flight on unmanned vehicles. The FC controls the stability of an unmanned vehicle. FC is also tasked with recording data from sensors such as the Inertial Measurement Unit (IMU). For the vehicle to fly stably, the FC must be able to perform multitasking tasks due to the need for a fast update frequency to changes.

In the quadcopter, there are four motor brushless, each controlled by the Electronic Speed Controller (ESC). The Main Controller commands the ESC. There is a hierarchy of interconnected master enslaved people between the Main Controller and the ESC. Master-slave is a communication model in which a device or process has direct access control over one or more other devices [1]. In a quadcopter with four BLDC motors, four slaves are needed to control each BLDC motor. In paper [2], a low-cost quadcopter can be built using the STM32F103C8T6 microcontroller, IMU MPU6050, and ultrasonic sensor HC-SR04. This study uses control PID as a quadcopter control algorithm but has not found a suitable PID value to get a good response. This study [3] presents a methodology for determining dynamic models for the Firefly FY450 quadcopter. The Pixhawk controller with factory-made firmware is implemented as a flight controller. With the dynamic method in all response changes, a satisfactory flight balance is obtained. This main controller is also used to drive the BLDC motor in research [4] and uses a Sliding Mode Observer (SMO) to estimate the current for each phase. Back EMF observer is used to estimating the position and speed of the rotor. This method is suitable for use at medium to high speeds. In paper [5] described the comparison of conventional PID control with auto-tuned PID control with the results of auto-tuned PID control having higher efficiency and better tracking performance. Different from [6], where the main controller board has large dimensions that make it difficult to install.

The solution to this problem is the proportional Integral Derivative (PID) control used on the FC so that the system can respond quickly to changes. PID control can adapt to changes so that the system becomes stable. The PID control on the FC is intended to balance the quadcopter concerning its orientation angle. This FC has a board with small dimensions. This research will be aimed at designing and implementing integrated main board technology so that the quadcopter vehicle has a fast response to changes and becomes more stable.

II. RESEARCH METHODOLOGY

A. Unmanned Aerial Vehicle (UAV)

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An Unmanned Aerial Vehicle (UAV) is an unmanned aerial vehicle controlled remotely. UAVs are widely used in the military field because without a crew. It makes the vehicle easier to carry out maneuvering complex and safer for the pilot. But now, the UAV has entered the general public and is usually used in photography, transportation, etc. UAV requires several components, such as a control system for the UAV vehicle while flying in the air. The UAV also requires a propulsion system to lift the UAV load while flying.

B. Quadcopter

The quadcopter is an unmanned flying vehicle with four main drives, namely the Brushless DC Motor at each end of its arm. It is necessary to have a flight controller which handles all of the functions of the quadcopter to manage the movement of the quadcopter. Figure 1 is a picture of the EFRISA quadcopter.

Figure 1. Quadcopter

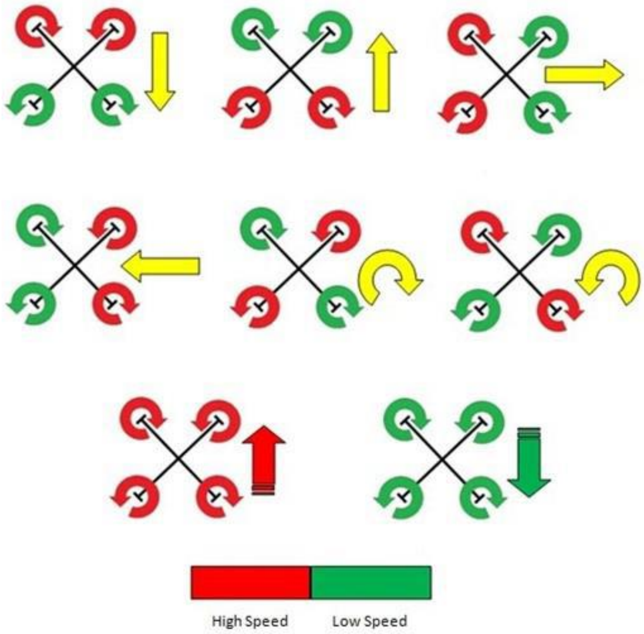

Figure 2. Quadcopter Maneuver

Referred to from Kyaw Myat Thu [7], a Quadcopter has four propeller motors, so there are four input forces, also known as thrust. There are two configurations on the quadcopter: ' x' and '+'. The 'x' configuration is more commonly used and stable than the '+' one. Propellers 1 and 3 move clockwise (CW), and propellers 2 and 4 move counter clockwise (CCW). The direction in which the quadcopter is facing can be changed by accelerating the rotation of the motor on one of its four sides. This enables the quadcopter to perform manoeuvres. The illustration of how the quadcopter moves is shown in Figure 2, which may be found here.

C. Main Board Flight Controller

A flight Controller is a control system on an Unmanned Aerial Vehicle (UAV) that regulates all activities in flight. A flight controller regulates the maneuver of the UAV to be stable, records flight data, processes user input, and performs vehicle tracking. In Figure 3, one type of flight controller is named the Pixhawk

Figure 3. Pixhawk Controller

The flight control system has various components, such as the Inertial Measurement Unit (IMU) sensor, altimeter, and compass. To record data using storage media such as Micro SD. For remote communication with users using radio remote control and radio telemetry communication. In general, the block diagram of the flight controller is depicted in Figure 4.

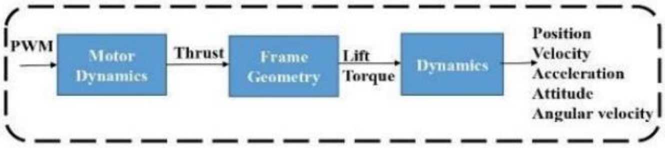

Figure 4. Flight Controller Diagram Block

FC receives input from the Remote Control, which is then processed into a setpoint. IMU provides angular orientation data to be used to find angle errors in orientation to the setpoint. The difference between input and data will be an error and processed in the PID control block. The output of the PID is entered into the vehicle's kinematics model which calculates the rotational speed of the BLDC motor so that the error value is close to zero according to the input. The output is a PWM signal which is given to the ESC to rotate the BLDC motor according to the kinematics.

D. Proportional Integral Derivative (PID)

Proportional Integral Derivative (PID) control is a control algorithm used to control the output results to achieve the desired set point results using the mathematical concepts of proportional, integral, and derivative. PID control is commonly used in industry to control the value of desired variables such as temperature, pressure, and others. PID control is easy to use and responds quickly to changes, so it is widely implemented in various systems that require precise regulation of variable values. Figure 5 explains the block diagram of a general PID:

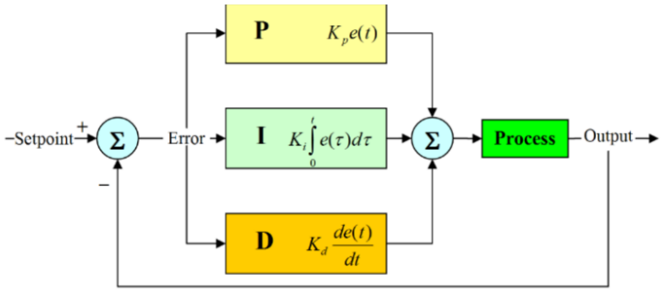

Figure 5. PID Design

The set point is the ideal value to be achieved by the system output. Error is the output value minus the setpoint. The PID implemented using three constants must be included in each control block. These constants are denoted by the letters Kp, Ki, and Kd. The amount that the system should react in response to faults is determined by each constant. A tuning process is required to determine the value of *Kp*, *Ki*, and *Kd*. The tuning process is used to determine the appropriate *Kp*, *Ki*, and *Kd*, values by looking at the system response. If the system response is inappropriate, the *Kp*, *Ki*, and *Kd* values must be changed. If the system response is appropriate, that constant value will be used.

III. RESULT AND DISCUSSION

A. Design

This section describes the design of the flight controller that will develop. Figure 6 explains the process of the work order of the system.

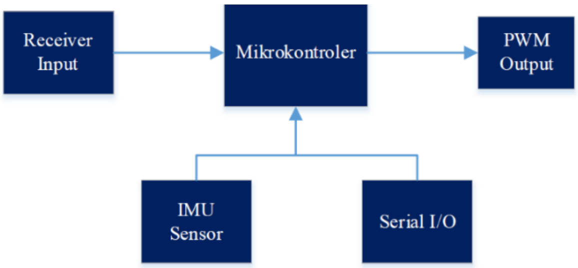

Figure 6. System Diagram

The microcontroller used is the STM32F407 microcontroller. Specifications of the STM32F407 microcontroller. The STM32F407 microcontroller provides various functions and peripherals that can be used in the development of this flight controller, including:

- The clock speed is 168 MHz.
- Peripheral USART for serial-based communication.
- Peripheral SPI for communication with sensors.
- Peripheral ADC to read analog data.
- Peripheral Timer for PWM input and output.

It is necessary to have a minimal system that fulfills the purpose of using the STM32F407 microcontroller. This is the primary prerequisite for the microcontroller to operate. The receiver is used to read input from the user. At the receiver, several communication protocols can be used, namely:

- Pulse Width Modulation (PWM) uses PWM pins on each channel. The value of each channel depends on the pulse width.
- Pulse Position Modulation (PPM), this protocol uses one pin for the entire channel. The value of each channel depends on the position and width of the pulse
- SBUS, this protocol uses Serial UART peripherals to communicate.

Figure 7 is a schematic of the circuit to build the main controller with an ARM IC base.

B. Inertial Measurement Unit

The IMU used is the MPU9250 type. The MPU9250 has three sensors: an accelerometer, gyroscope, and magnetometer. The three sensors are combined to produce yaw, pitch, and roll orientation data. The GY-91 module has MPU9250 and BMP280 sensors. Figure 8 is a schematic of the GY-91 sensor circuit on the flight controller

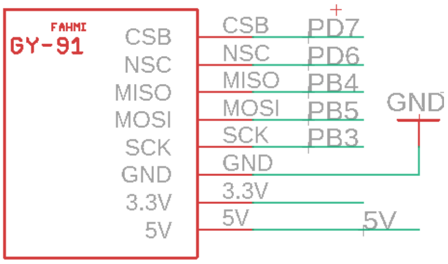

Figure 8. IMU Circuit

C. Main Board Design Control

This section discusses the control design of the flight controller in this final project. There are several blocks to be built, as shown in Figure 9.

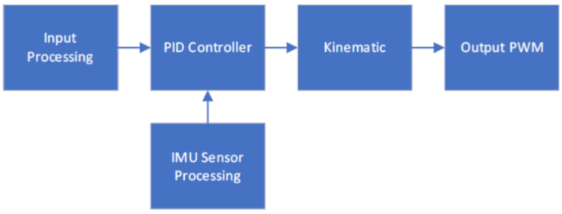

Figure 9. Main Board Design & Controller

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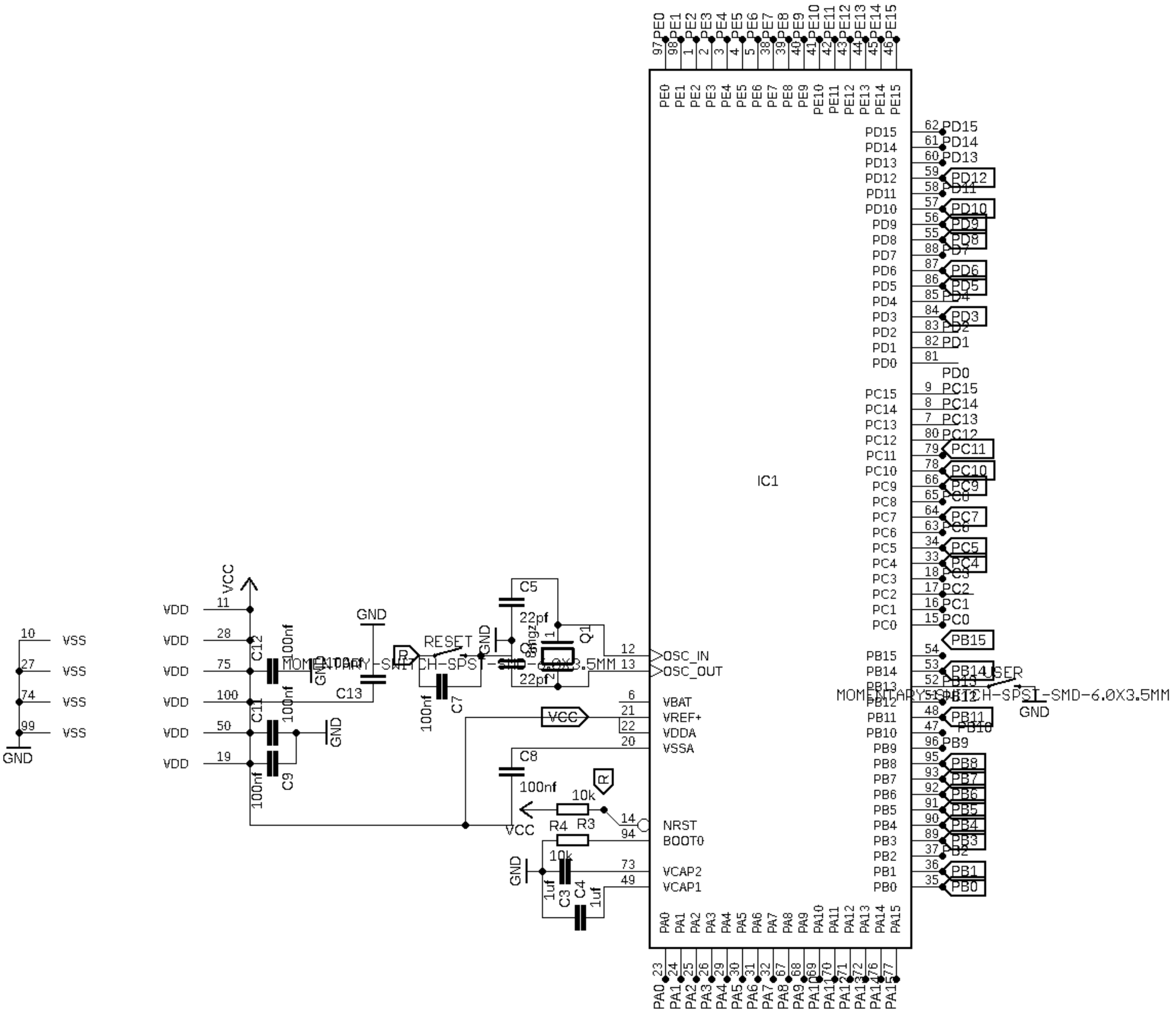

Figure 7. The Main Board Circuit

D. PID Controller

PID control aims to stabilize the quadcopter vehicle to match the setpoint desired by the user. The PID process in a quadcopter study case is shown in Figure 10.

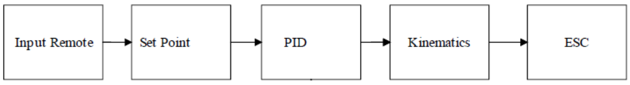

Figure 10. The PID Controller on Quadcopter

In PID control, the orientation angle of the quadcopter is the data that will be processed to produce output. There are three PID controls for each orientation angle. The system's error in PID control must be known first by finding the difference between the setpoint and the data from the sensor. Equation (1) is the mathematical model for error from *yaw*, *pitch*, and *roll angle*.

$$\begin{gathered} e_{yaw} = SP_{yaw} - PV_{yaw} \\ e_{pitch} = SP_{pitch} - PV_{pitch} \\ e_{roll} = SP_{roll} - PV_{roll} \end{gathered} \tag{1}$$

Where the *e* variable is an error, the *SP* variable is setpoint, and the *PV* variable is the process variable, sensor feedback data. After searching for errors, each error value is entered into the PID control using Equation (2), the mathematical model.

$$PID\,(t) = kp * e\,(t) + ki * \int_0^t e(t)\,dt + kd * \frac{de(t)}{dt} \tag{2}$$

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Where, the *PID(t)* variable is the result of the PID output, the *kp* variable is the proportional constant, the *ki* variable is the integral constant, and the *kd* variable is the differential constant. From the PID output, it is entered into the block diagram of the quadcopter kinematic part to calculate the speed of each motor.

E. Quadcopter Installation

The vehicle design is a quadcopter vehicle using an F450 frame. The F450 frame has four arms to mount each bike. Figure 11 is the F450 quadcopter frame model.

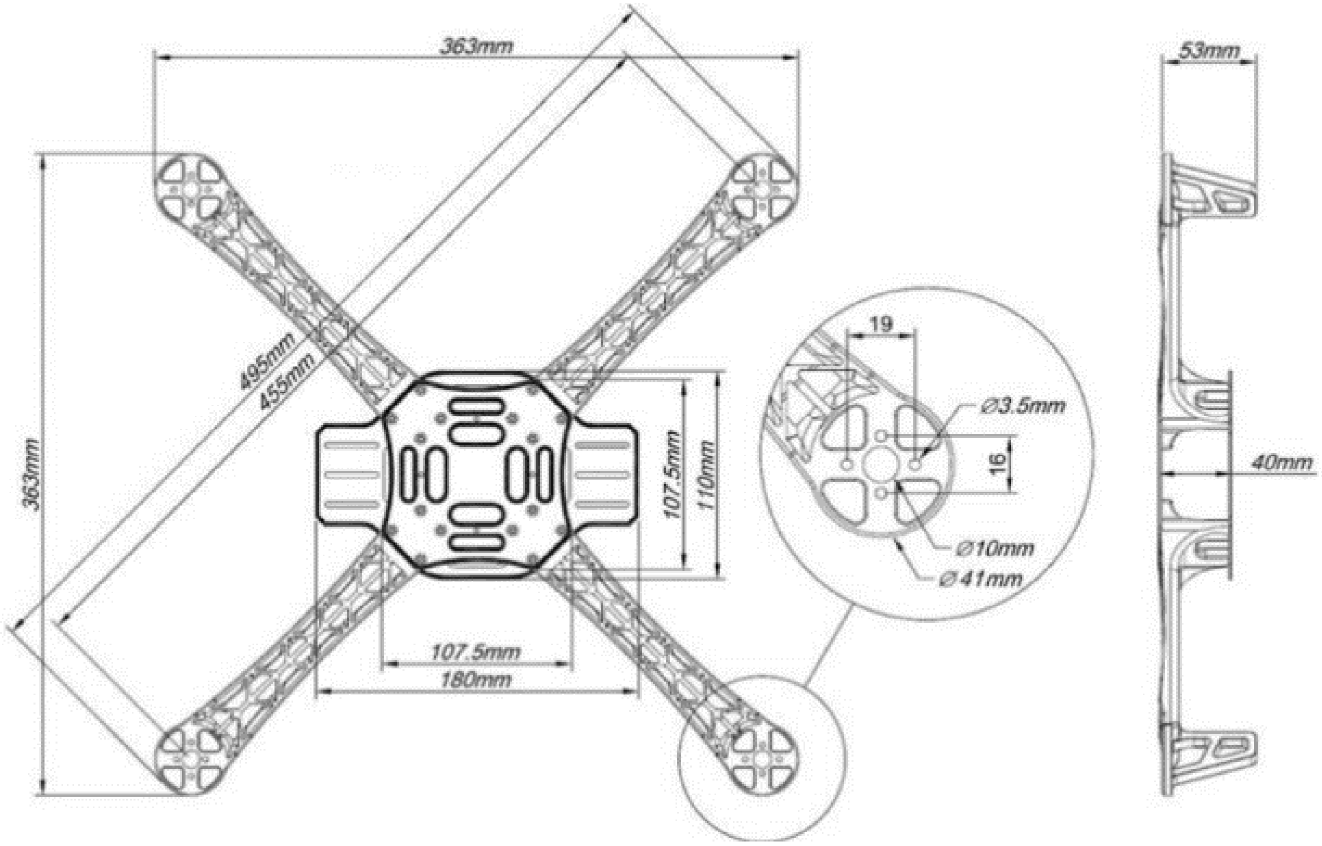

Figure 11. Quadcopter Frame

Figure 12 is a picture of the quadcopter vehicle that will be developed. The Flight Controller is mounted in the centre of the quadcopter. The ESC is installed in each quadcopter arm connected to a BLDC motor. In the BLDC motor, a propeller is installed to generate thrust so that the quadcopter can fly.

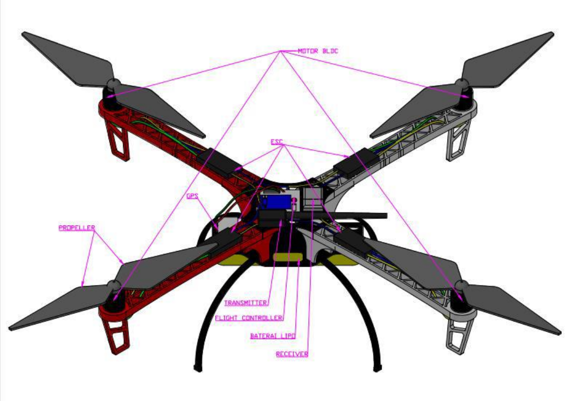

Figure 12. Quadcopter Installation

F. Serial Communication Testing

Testing is done by sending a text that contains "Testing Serial Count: count" with the count value increasing each data sent. Data is sent to the PC in the PuTTY software. Figure 13 shows the process of sending data to the ground control station via serial communication.

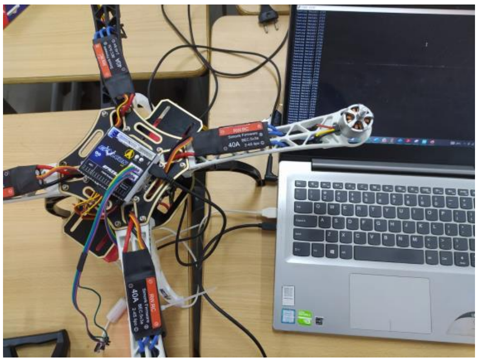

Figure 13. Send Serial

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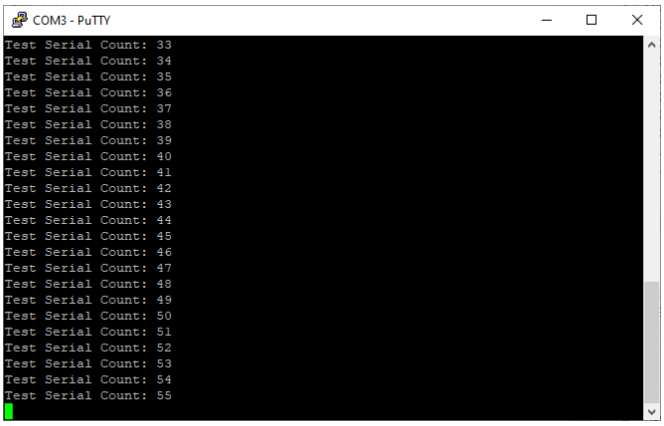
From the results obtained, as shown in Figure 14, it can be concluded that the master flight controller board can transmit data via UART.



```
Test Serial Count: 33
Test Serial Count: 34
Test Serial Count: 35
Test Serial Count: 36
Test Serial Count: 37
Test Serial Count: 38
Test Serial Count: 39
Test Serial Count: 40
Test Serial Count: 41
Test Serial Count: 42
Test Serial Count: 43
Test Serial Count: 44
Test Serial Count: 45
Test Serial Count: 46
Test Serial Count: 47
Test Serial Count: 48
Test Serial Count: 49
Test Serial Count: 50
Test Serial Count: 51
Test Serial Count: 52
Test Serial Count: 53
Test Serial Count: 54
Test Serial Count: 55
```

Figure 14. Serial Plot Result

G. *Remote Input Testing*

Testing is done by moving the stick from the remote-control transmitter and sending it to a PC which can be seen in the PuTTY application. Figure 15 shows you how to test the remote control. The minimum value of each channel is 1000 S, while the maximum value is 2000µS.

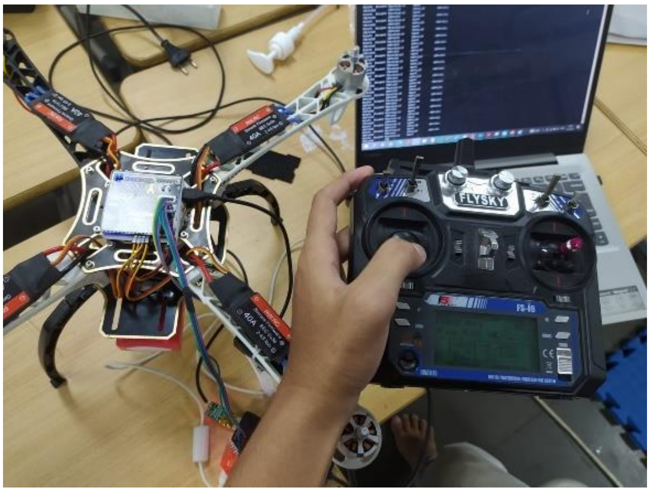


Figure 15. Send Remote Data

From this test, according to Table I, it can be concluded that the master board flight controller can receive input from a remote radio transmitter via a remote radio receiver with data ranging from 1000 to 2000 in S units.

TABLE I
REMOTE CHANNEL TESTING

CH4 (µS)	1000	1200	1400	1500	1600	1800	2000
Yaw (°)	-15	-9	-3	0	3	9	15

H. *IMU Testing*

The test is carried out by slowly rotating the quadcopter on each yaw, pitch, and roll orientation axes. Figure 16 shows the IMU test at the yaw, pitch, and roll orientation angles with a value of 0°.

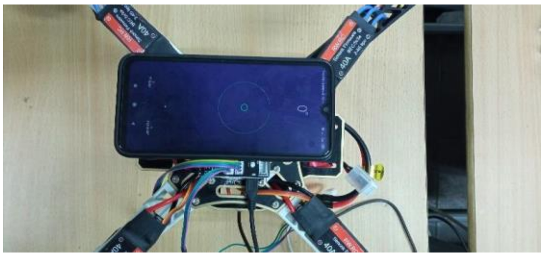


Figure 16. IMU Testing on The Quadcopter

It is shown that the error value at point 0° is very small. The error value increases as you move further away from the 0° point. The error value is caused by several things, including noise from the sensor and less accurate data taken.

According to Table II, the IMU test shows that the master board flight controller has successfully communicated with the IMU, combining sensors for conversion to yaw, pitch, and roll orientation axes.

TABLE II
IMU TESTING

Degree	Yaw	Error Yaw	Pitch	Error Pitch	Roll	Error Roll
-60	-56.903	3.097	-63.382	6.479	-58.63	4.752
-45	-45.463	0.463	-48.69	3.227	-47.069	1.621
-30	-31.561	1.561	-32.262	0.701	-27.246	5.016
0	0.002	0.002	0.001	0.001	0.021	0.02
30	33.214	3.214	26.453	6.761	27.358	0.905
45	48.512	3.512	45.382	3.13	47.221	1.839
60	63.265	3.265	57.221	6.044	63.097	5.876

I. *PID Controller Responses*

Controller testing is done by setting the PID constant value, which is carried out on the controller testing table according to Figure 17.

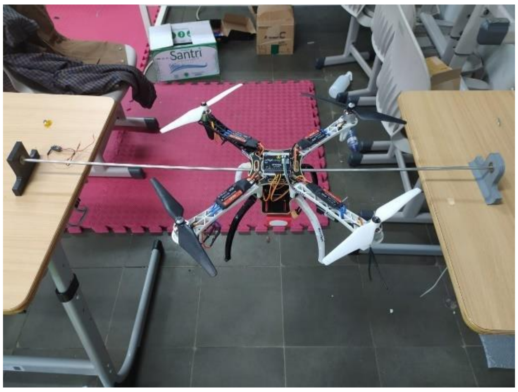


Figure 17. PID Testing

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Yaw, pitch, and roll were the three different directions in which the tests were conducted. A series of tests evaluate the flight stability of the quadcopter, and the kinematics of the quadcopter's response is also analyzed. After completing several PID tuning experiments utilizing the manual technique at each angle of yaw, pitch, and roll orientation, the quadcopter's stability was determined using the PID constants presented in Table III.

TABLE III
PID VALUE

	KP	KI	KD
Yaw	0.2450	0.0139	0.0085
Pitch	0.0284	0.0177	0.0100
Roll	0.0315	0.0200	0.0085

The controller test results show that the master board flight controller has a stable control response after manually tuning the PID constant at every angle of yaw, pitch, and roll orientation. In figure 18 data, it can be concluded that the PID pitch with a disturbance of 9.869638 takes 720 ms to return to a stable position.

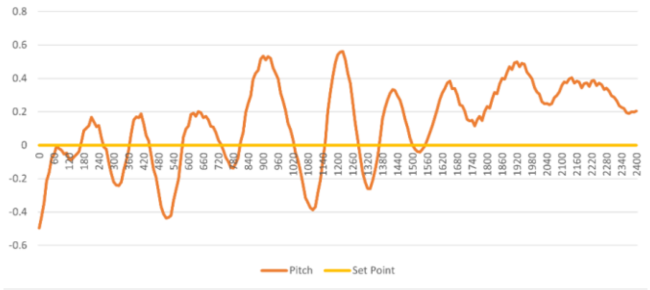

Figure 18. PID Graph for The Pitch Movement

From Figure 19 data, it can be concluded that with a disturbance of 22.842354, the PID roll takes 680 ms to return to a stable position.

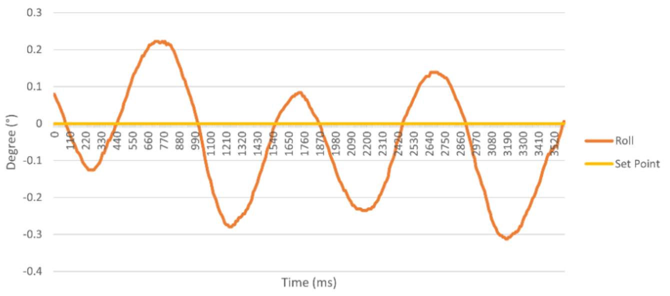

Figure 19. PID Graph for Roll Movement

From Figure 20 tests, the lowest yaw value is -6.244715, and the highest yaw value is 6.468002

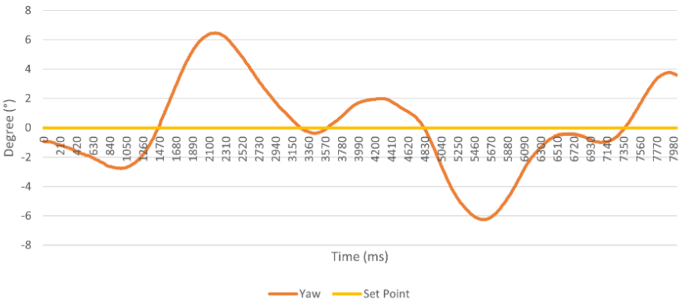

Figure 20. PID Graph for Roll Movement

J. *Quadcopter Fly Testing*

The quadcopter flies by being controlled by remote control. The quadcopter must always be monitored and controlled to fly stably, because it cannot maintain its position with the help of the remote control. The quadcopter can fly steadily with a height of up to 2 m.

Figure 21. Quadcopter Fly

In the flight test in Figure 21, it can be concluded that the master board flight controller can be used to fly the quadcopter vehicle stably with the help of remote control. Control response for the main board when controlling the brushless motor is more stable than before with disturbances in pitch, roll, and yaw conditions.

IV. CONCLUSION

Master board flight controller is made by implementing a controller capable of receiving data from the remote control as setpoint input, IMU sensor as feedback, and PWM output as system output. One of the control mechanisms that can be used is PID. It takes a master board flight controller and four slave boards' electronic speed controllers to build a quadcopter. A PWM signal is one communication media for the master and slave board on the quadcopter. The controller successfully flew the quadcopter with the *Kp* value of 0.245, the *Ki* value of 0.0139, and the *Kd* value of 0.0085.

Apply altitude control to the master board flight controller so that the height of the quadcopter can be adjusted and implement PID control on the slave board electronic speed

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controller which can be used for the rotational speed of the BLDC motor.

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