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PID Control for Attitude Stabilization of an Unmanned Aerial Vehicle Quad-copter

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***Abstract*— Quad-copter is a type of Unmanned Aerial Vehicle (UAV) which has four rotors as its lifter. This type can do lot movements in the air while flying, such as yaw, roll, and pitch. This movement can work well by maintaining stability, direction, and the height of that quad-copter. Roll corner, pitch, and yaw are controlled so the quad-copter can move stably. Proportional Integral Derivative (PID) is one of the controlling methods which can use to stabilize the quad-copter movements. The parameters used in this modeling were mass, arm length, radius, motor torsi, and motor speed. Some assumptions applied in modeling were the structure of quad-copter is rigid, symmetric, and the load heavy point of quad-copter is assumed located right in the middle (mass center), and vibration effect in each propeller is ignored. The design is stable with proportional gain of roll and pitches are 1.3 and 1.5, integral gains are 0.04 and 0.05, and derivative gains are 18 and 15.**

Keywords- PID, Quad-copter, Roll, Pitch, Yaw, Attitude.

I. INTRODUCTION

In the last decade, the demand of unmanned aerial systems has rapidly increased. This is mainly because the UAVs incredibly carry out a wide range of applications at minimal cost and without endangering any risk to human life [1]. The quad-rotor is a famous type of UAV with an extensive attention amongst the researchers due to its small size, light weight, effortless assembling of the mechanical structure and itsability to complete the tasks efficiently and autonomously. Its ability to Vertically Take-Off and Land (VTOL) and hovering categorizes it into helicopter UAVs. It is a distinctive type of UAV because of its unique shape and functioning.

Quad-copter is a type of flying robot or an unmanned aircraft that flying by using the thrust generated from its four rotors. It is controlled by adjusting the angular velocity produced by the rotating rotor [2]. The center area is used to put the resources (batteries), control systems, and sensors. Control system is used to adjust the speed of each motor in accordance with the desired movements.

The most research interest on quad-copter is the attitude stabilization that can be shown by smooth flying movements. However, like other dynamic systems, disturbances and uncertainties caused by disruption from the wind for example, make inconsistencies to the systems [3]. In the last few years, attitude of the controller remains problems because of its unstable kinematics and dynamics.

To avoid the problem, a kind of control algorithm is necessary to get better attitude during its hovering. In this research, PID control is used to control the rotational speed of each quad-copter's rotor and maintain stability according to desired set point. Generally, the tuning is performed on the PID control system. Both ground and unmanned aerial are still using manual tuning. The coefficient gains of PID are set from the lowest value until the coefficients are match with the best response.

II. QUAD-COPTER SYSTEM

Structure of the quad-copter systems usually consist of mechanical and electrical parts. PID control algorithm can be used to keep the stability of the quad-copter.

This research uses X-Fame with mechanical part shown in Fig. 1 and 3-D design shown in Fig. 2. It is selected because it has a symmetrical design motor propeller units spaced by the same distance from each other and from the center of the copter. The weight (or mass) is also concentrated in the center of the copter. Symmetry means that all motor speed and propeller size should be the same. So when it is flying, the lift power of the quad-copter becomes balanced [4].

Fig. 1. Quad-copter.

Fig. 2. 3D Quad-copter design

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The arm length is 41,576 cm which also contains of power distribution as voltage divider from battery. This mechanical side has been created in such a way as not to disturb the performance of quad-copter flying (see Fig. 3).

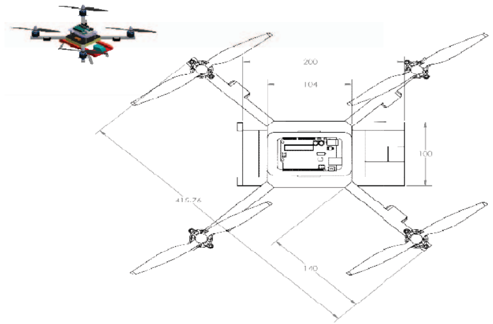

Fig. 3. Top view of 3D Quad-copter.

The electronic system shown in Fig. 4 consists of IMU MPU-6050 sensor as input, Arduino as processor, and Electronic Speed Controller (ESC) as output. The processor getsposition signal from MPU-6050 (accelerometer and gyro) attached at quad-copter and sends a PWM signal to ESC to run the motor.

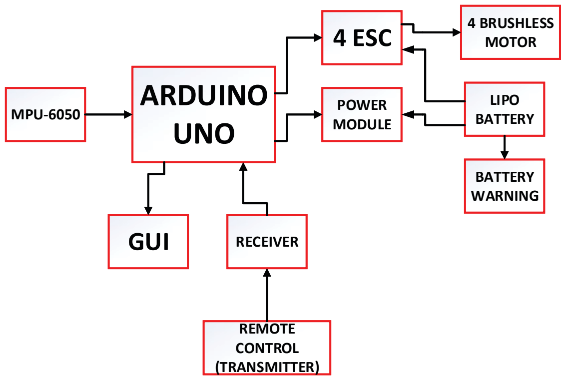

Fig. 4. Electronics Schematic of Quad-copter.

III. PID Controller Synthesis

PID controls are the most classical type of control. PIDs apply feedback mechanisms that are widely used in industrial setting systems [5]. A PID controller calculated the error value as the difference between the measured process variable and the desired set point. By tuning one of the three controllers, one of the controllers will be more prominent and will have an effect on achieving the desired system response with minimal errors. Standard diagram of PID controller blocks are presented in Fig. 5.

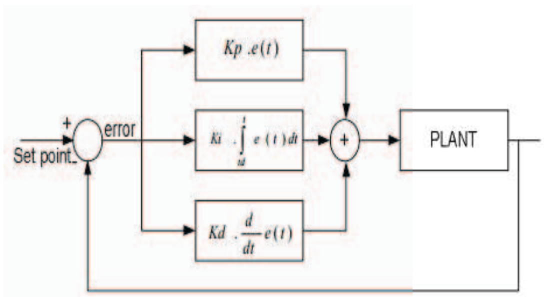

Fig. 5.Structure of PID controller.

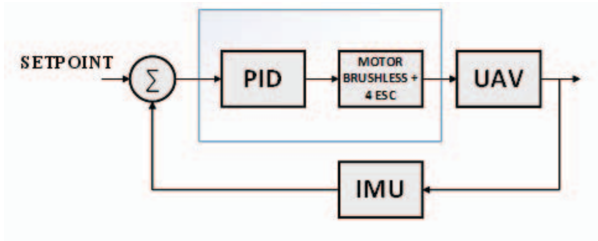

Fig. 6. Block diagram of the system.

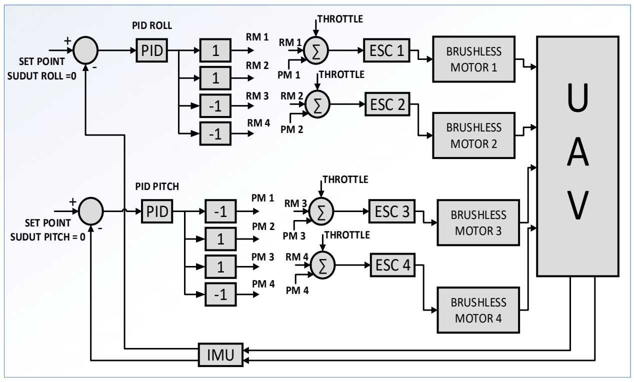

Fig. 7. Block Diagram of PID.

Figs. 6-7 show system design of the quad-copter. The angle value of the roll, pitch and yaw were be summed and used as references for the actuator movements that is in this case is the motor. Roll, pitch, and yaw can be controlled just like in stable position. The output of the block diagram above is the speed of ESC which will affect the movement and actuator of the quad-copter. The control method used is the PID control method and in the feedback section there is a value of the IMU sensor. Proportional, integral and derivative controller gains are given by

$$u(t) = K_p e(t) \tag{1}$$

$$u(t) = K_i \int_0^T e(t)\,dt \tag{2}$$

$$u(t) = K_d \frac{de(t)}{dt} \tag{3}$$

IV. Implementation

Digital pin of Arduino (PWM) is connected to signal pin of ESC. Fig. 8 shows the connections among the devices. The equations for determining the PID gain in coding routine can be seen in Fig. 9 and the flowchart of the algorithm is depicted in Fig. 10.

The detailed gain output is calculated as follows:

- Roll output

pid_output_roll = pid_p_gain_roll * pid_error_temp + pid_i_mem_roll + pid_d_gain_roll * (pid_error_temp - pid_last_roll_d_error);

- Pitch output

pid_output_pitch = pid_p_gain_pitch * pid_error_temp + pid_i_mem_pitch + pid_d_gain_pitch * (pid_error_temp - pid_last_pitch_d_error);

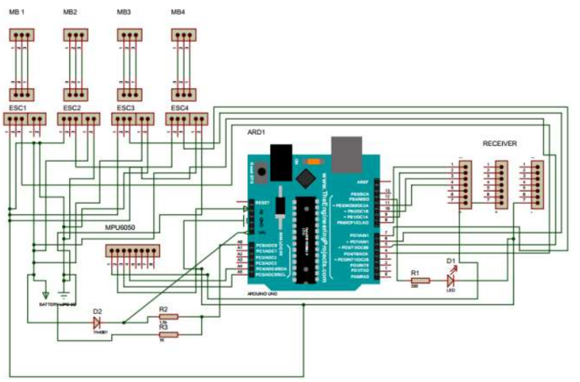

Fig. 8. Hardware connection.

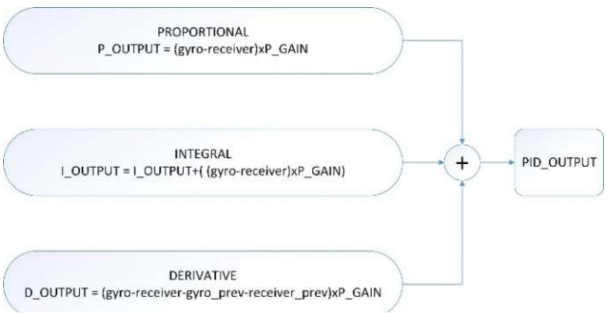

Fig. 9. PID output equation.

- Yaw output

pid_output_yaw = pid_p_gain_yaw * pid_error_temp + pid_i_mem_yaw + pid_d_gain_yaw * (pid_error_temp - pid_last_yaw_d_error);

V. SIMULATION RESULTS

Test and analysis results of hardware and software that have been made in the design and implementation of PID control for attitude stabilization on quad-copter. It is intended to know the tool works properly and as expected. Modeling of quad-copter will be beneficial to comprehend the copter dynamics to control and stabilize accurately [6]. Quad-copter can move in six directions: forward, backward, right, left, up and down by varying the speeds of four motors. Applying Newton-Euler formulation, roll and pitch movements of quad-copter are derived as [1]:

$$\ddot{\phi} = \frac{I_{yy}I_{zz}}{I_{xx}}\theta\varphi - \frac{J_{tp}}{I_{xx}}\theta\omega + l\frac{U_2}{I_{xx}} \tag{4}$$

$$\ddot{\theta} = \frac{I_{xx}I_{zz}}{I_{yy}}\theta\varphi - \frac{J_{tp}}{I_{yy}}\theta\omega + l\frac{U_3}{I_{yy}} \tag{5}$$

where,

$$U_2 = b\left(w_2{}^2 + w_1{}^2 - (w_3{}^2 + w_4{}^2)\right)$$

$$U_3 = b\left(w_2{}^2 + w_3{}^2 - (w_1{}^2 + w_4{}^2)\right)$$

Gyroscopic torque and centripetal terms are neglected to reduce the complexity of copter modeling while hovering [7]. After simplification, the quad-copter dynamic becomes:

$$\ddot{\phi} = l\frac{U_2}{I_{xx}} \tag{6}$$

$$\ddot{\theta} = l\frac{U_3}{I_{yy}} \tag{7}$$

Apply the Laplace transform to (6) and (7),

$$\frac{\phi(s)}{U_2(s)} = \frac{lb}{I_{xx}s^2} \tag{8}$$

$$\frac{\theta(s)}{U_3(s)} = \frac{lb}{I_{yy}s^2} \tag{9}$$

where,

l = armlength, b = thrust coefficient

I_{xx}, I_{yy} = moment Inertia along x-axis and y-axis

w = maximum rotation speed of motors

The parameter of quad-copter is shown in TABLE I [8]

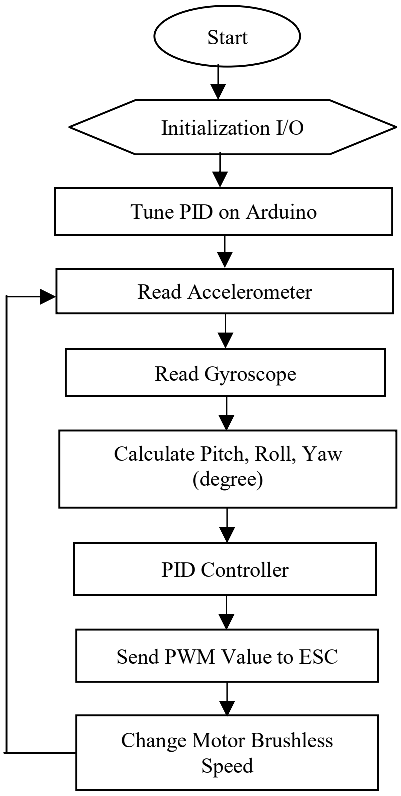

Fig. 10. Flow chart.

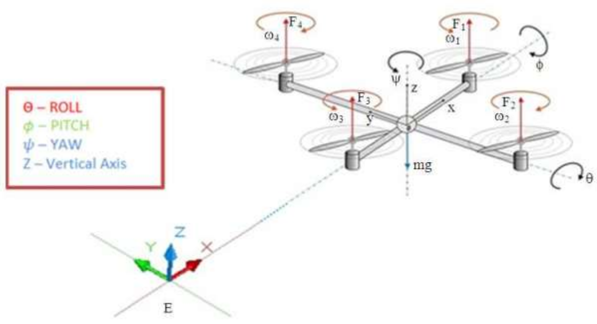

Fig. 11. Free body force [1].

TABLE I. Parameters of Quad-copter

Parameters	Measurement Results
l (meters)	0.415
Thrust (b)	$0.937 kg$
I_{xx}	$0.0024519\ kg.m^2$
I_{yy}	$0.005224\ kg.m^2$
w	637.75 rad/s

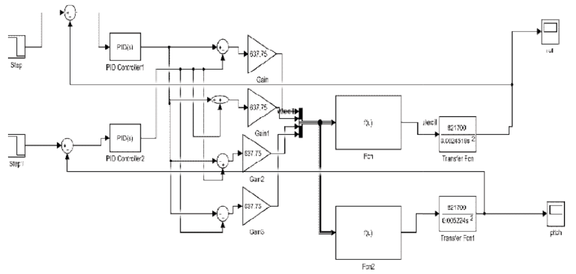

Fig. 12. Simulink model of quad-copter with PID.

TABLE II. PID Roll Value From Simulink

Roll	PID Value
P	6.82349220134256e-13
I	5.77300507465117e-15
D	2.5595171501736e-12

TABLE III. PID Pitch Value From Simulink

Pitch	PID Value
P	1.57286277070872e-13
I	1.33528482185367e-15
D	5.30864943389222e-12

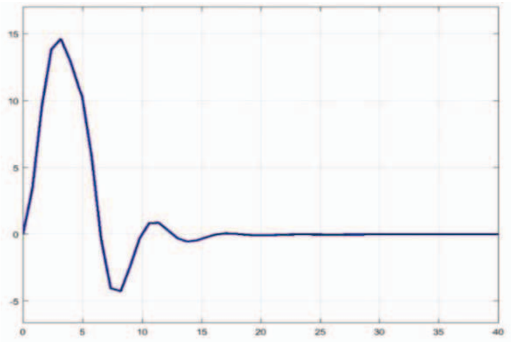

Fig. 13. Pitch single response.

Using PID tune tool in Simulink we can get response from a system according to what we want. By using PID tune tool we get PID value in TABLEs II-III. Figs. 13 and 14 are the roll and pitch responses of the quad-copter.

VI. EXPERIMENTAL RESULT

This chapter explains the results of experiment and analysis of hardware and software. The objective is to design PID control for attitude stabilization on quad-copter. It is intended to know the tool works properly as expected.

6.1 Angle Error

Angle error experiment is to determine the accuracy of the value of the sensor GY-521 MPU-6050. This angle error testing is done by comparing it to the arc angle with the sensor output value GY-521 MPU-6050. The measured angle is the angle X (roll) and the angle Y (pitch).

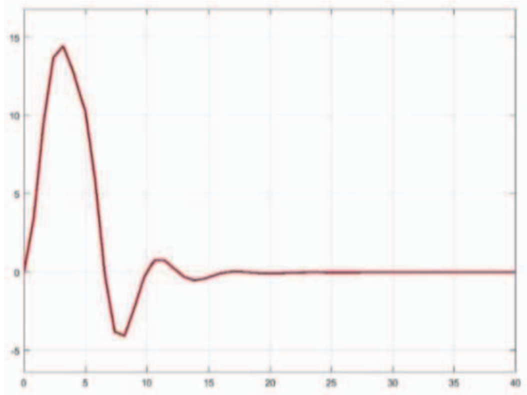

Fig. 14. Roll angle response.

TABLE IV. Error Sensor Measurement at Angle X

No.	Angle of arc degrees	Angle of GY-521 MPU6050 Sensor	Difference
1.	0°	2°	2°
2.	15°	17°	2°
3.	30°	32°	2°
4.	90°	91°	1°
5.	180°	181°	1°
6.	360°	360°	0°
7.	-15°	-13°	2°
8.	-30°	-28°	2°
9.	-90°	-88°	2°
10.	-180°	-178°	2°
11.	-360°	-359°	1°
Average Difference			1.54°

TABLE V. Error Sensor Measurement at Angle Y

No.	Angle of arc degrees	Angle of GY-521 MPU6050 Sensor	Difference
1.	0°	-2°	2°
2.	15°	13°	2°
3.	30°	28°	2°
4.	90°	88°	2°
5.	180°	179°	1°
6.	360°	360°	0°
7.	-15°	-17°	2°
8.	-30°	-32°	2°
9.	-90°	-92°	2°
10.	-180°	-181°	1°
11.	-360°	-359°	1°
Average Difference			1.54°

Fig. 15. Loaded roll position.

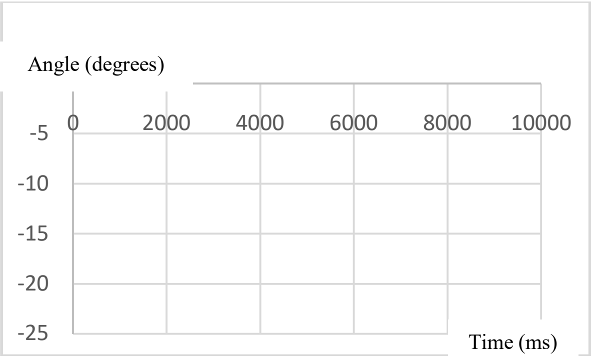

Fig. 16. Roll response with proportional gain.

TABLE IV and TABLE V are the ratio of X-angle and Y-Angle output between the angle of the arc angle and the angle of the GY-521 MPU-6050 sensor. There is a difference between 1 degree to 2 degrees with an average difference is about 1.54 degree for each measurement..

6.2 Roll Responsewith Initial Angular Disturbance

This experiment is to determine the response of quad-copter by adding an initial angle of 15 degrees. The disturbance test is done by added loadabout 300 grams on the quad-copter. The load is given according to the position of the attitude. At this stage the attitude of the roll is measured by giving a load on the right side that will make the quad-copterroll to the right.

6.2.1 Effects on proportional gain

Testing is done with 0% throttle, setpoint 0^0 and proportional gain 1.3.The trajectory never achieve the goal.

6.2.2 Effects on proportional and integral gains

Testing is done with 0% throttle, setpoint $0^0$and proportional and integral gains are 1.3 and 0.04. The quad-copter quickly reached the setpoint although inference is given. Small overshoot is also occurred.

6.2.3 Effects on proportional, integral and derivative gains

Testing is done with 0% throttle, setpoint 0^0 and proportional, integral and derivative gains are 1.3, 0.04 and 18.

The overshoot can be slightly damped to produce a small overshoot and the motor speed is more stable if using all proportional, integral and derivative gains. The response of the quad-copter to reach the set point is also better than using proportional and integral gains only. The ripple is also reduced.

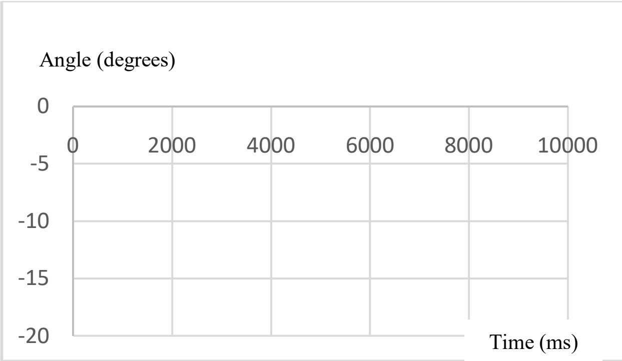

Fig. 17. Roll response with proportional and integral gains.

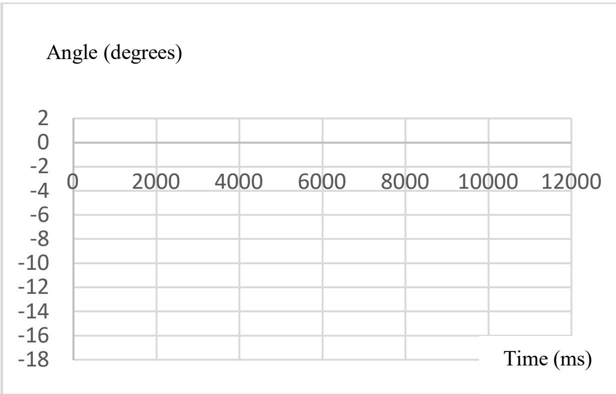

Fig. 18.Roll response with proportional, integral and derivative gains.

Fig. 19. Given load for pitch position test

6.3 Pitch Responsewith Initial Angular Disturbance

The test procedure is similar to roll response testing.The pitch angle testing is done by giving load behind the vehicle which will make the vehicle nose up.

The experiment showed that by using all proportional, integral and derivative gains, the system will accelerate in reaching the set point. Overshoot and ripple decrease compared to use of proportional and integral gains only.

VII. Conclusion

This paper presents the attitude stabilization design on quad-copter with PID controller. The experiments show that the quad-copter attitude can maintain its stability. Selections of proper PID gains are able to change PWM of motor to reach equilibrium position. There are three conclusions on this research.

a. Designed PID control for quad-copter required to used three value kp, ki and kd variables to get angular attitude response.

b. From some experiments still often occur even though the error is stability using PID. This is likely due to the characteristics of the brushless motor and the ESC (electronic speed controller) and there is also noise on the sensor.
c. This quad-copter design is stable with 1.3 kp roll gain while kp pitch is 1.5, ki roll is 0.04 while ki pitch is 0.05, kd roll is 18.0 while kd pitch is 15.0

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REFERENCES

[1] M. H. Tanveer, S. F. Ahmed, D. Hazry, F. A. Warsi, and M. K. Joyo, "Stabilized Controller Design for Attitude and Altitude Controlling of Quad-Rotor under Disturbance and Noisy Conditions," American Journal of Applied SciencesVol. 10, no. 8, 2013, pp. 819-831.

[2] A. Dharmawan, Y. Y. Simanungkalit, and N. Y. Megawati, "PID Control Model for Quadcopter with Euler Lagrange," IJEIS, Vol. 4, no. 1, 2014, pp. 13-24.(in Indonesia)

[3] E. Susanto, "A DC Motor-Reaction Wheel Control Design via Guaranteed Cost Output Feedback Controller of Uncertain Neutral Systems," ICIC Express Letters, Vol. 9, no. 10, 2015, pp.2717-2722.

[4] Introduction to Quadcopter [Online]. Available at: https://droneflyers.wordpress.com/introduction-to-quadcopters/[Accessed at 14June 2017].

[5] K. H. Ang, C. Gregory, and Y. Li, "PID Control System Analysis, Design, and Technology," IEEE Transaction on Control System Technology, vol. 13, no. 4, 2005, pp. 559-576

[6] J.Brokking, "Brokking.net," [Online]. Available: http://www.brokking.net/ymfc-al_main.html. [Accessed at 21 May 2017].

[7] V. Praveen and S. Pillai, A., "Modeling and Simulation of Quadcopter using PID Controller", International Journal of Control Theory and Applications, Vol. 9, no. 15, 2016, pp. 7151-7158.

[8] T. Sudewo, E. Iskandar, and K. Astrowulan, "Design and Implementation of PID Model Reference Adaptive Control for Automatic Safe Landing of UAV Quadcopter," Jurnal Teknik ITS, Vol. 1, no. 1, 2012, pp. 1–6. (in Indonesian).