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Quadrotor Control System with Hand Movement Sign as an Alternative Remote Control

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ABSTRACT

Quadrotor is an unmanned aerial vehicle which is controlled by remote control. Unfortunately, not all of the remote control are easy to use, especially for people who have lacking abilities in piloting. This study aims to design a prototype system to control quadrotor using hand movements, as an alternative to the conventional remote control that more simple. This system is consists of 2 parts, quadrotor and handheld. Both systems can communicate wirelessly using radio frequency 2.4 GHz. The handheld system will read the orientation angle of the hand by IMU sensor and it will be converted into a command to determine the direction motion of the quadrotor. To get the orientation angle from the IMU sensor data, we used DCM sensor fusion method. Quadrotor needs a control system that can make its respond runs optimally. In this study, the method of the control system that used is PID controller. The PID gain obtained using Ziegler-Nichols oscillation method and then fixed again by fine-tuned method.

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1. INTRODUCTION

UAVs or Unmanned Aerial Vehicles are unmanned aircraft that can be operated autonomously or be controlled remotely by a pilot at a ground station [1]. At first, UAV was developed to fulfill military purposes only, but as time goes by now, the UAV has been used for other fields than the militaries. Nowadays this technology is often used for missions with a very dangerous situation for people to take it. These missions are surveillance, reconnaissance, monitoring, air patrol, aerial photography and soon [2].

Nowadays controlling method of UAVs particularly quadrotor is already experiencing growth, ranging from a remote control, smart phone and also direct control from the Ground Segment. Controlling quadrotor using remote control is the most used by pilots. The reason is that not all quadrotor system can be controlled using the smartphone, on the other hand controlling quadrotor with Ground Segment becomes less desirable because it requires some equipment such as a computer, so it is quite difficult to be taken while performing piloting.

On the other hand, controlling quadrotor for some people is not an easy thing, even when using the remote control. Pilot’s knowledge about the function of each channel on the remote control becomes the primary requirement to be able to control the movement of the quadrotor well.

Quadrotor can be designed to move by commands that sent from the pilot. To explain the behavior of the quadrotor’s movement, we used three pieces of dynamic parameters, i.e., the angle of roll, pitch and yaw. These parameters will be very helpful. It is because the force that used to control the motion of the quadrotor will affect these three parameters directly [3]. The quadrotor’s pitch angle changes caused by the variations in the speed of the propeller front and rear, which will produce forward and backward motion. Same as the pitch, the action from propeller left and right will make the roll angle to changes that make the quadrotor move to the right and left. Yaw angle is affected by the aerodynamic torque balance between the two pairs of blades (clockwise rotation and counter-clockwise rotation) so that if one of the two pairs of the propeller is spinning faster, it will make the quadrotor spin in either direction.

In conventional remote control, there are four main channels at least, as well as some additional channels that are used to control the movement of a quadrotor. That four channels in a conventional remote control will affect the flight parameters of quadrotor namely throttle, pitch, roll and yaw. The throttle is used to speed up or slow down the rotation of the four pieces of the propeller quadrotor so quadrotor will move up or down. While the channel pitch, roll and yaw are used to control the flight parameters of a quadrotor, each pitch, roll, and yaw.

Lack of pilot's knowledge of the function of each channel on a remote control will be one of the factors that make the pilot hardly to control the quadrotor well. Moreover, the role of each channel can be different for each remote controls of the various types.

The handheld system offered as an alternative to conventional remote controls that exist today. As well as a remote control, this handheld system will regulate the movement of quadrotor by changing the parameters of flight. The quadrotor's flight parameter will be influenced by the position of the user's hand. The parameter that was changed is the amount of orientation angle to be formed by the quadrotor (roll, pitch and yaw). For pitch and roll angle will be directed by -15^0 or 15^0. To make the quadrotor's control easier, it needs a good control system. On this research, we used PID control method.

2. RESEARCH METHOD

2.1. System Analysis

Quadrotor can be designed to move by commands that sent from pilot. To explain the behavior of the quadrotor's movement, we used three pieces of dynamic parameters ie the angle of roll, pitch and yaw. These parameters will be very helpful. It is because the force that used to control the motion of the quadrotor will affect these 3 parameters directly [3]. The quadrotor's pitch angle changes caused by the variations in the speed of the propeller front and rear, which will produce forward and backward motion. Same as the pitch, the action from propeller left and right will produce the roll angle to changes that makes the quadrotor move to the right and left. Yaw angle is affected by the aerodynamic torque balance between the two pairs of blades (clockwise rotation and counter-clockwise rotation) so that if one of the two pairs of propeller is spinning faster, it will make the quadrotor spin in either direction. Figure 1 shows the quadrotor flight behavior.

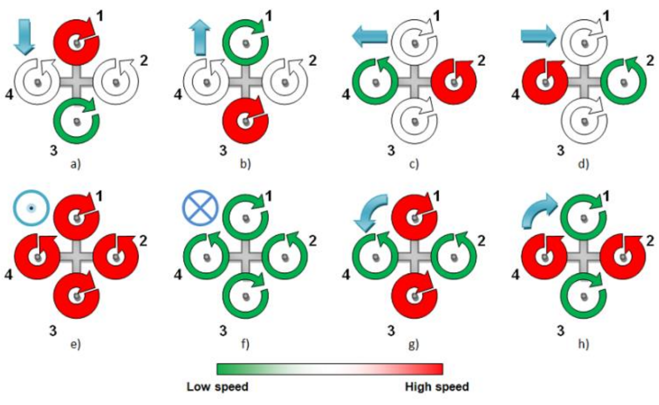


Figure 1. Behavior of quadrotor flight system [3]

To detect the orientation angle, pitch, roll and yaw, in a quadrotor, we need a sensor fusion, one of the sensor fusion method is DCM or Direction Cosine Matrix method. We chose DCM method cause it gives better accuracy than other method such as quaternion and euler based attitude estimation [4]. DCM method reads the value of a gyroscope sensor as the main reference, then the value is fixed by the values from accelerometer and magnetometer [5]. Blok diagram of DCM sensor fusion metthode is shown in Figure 2.

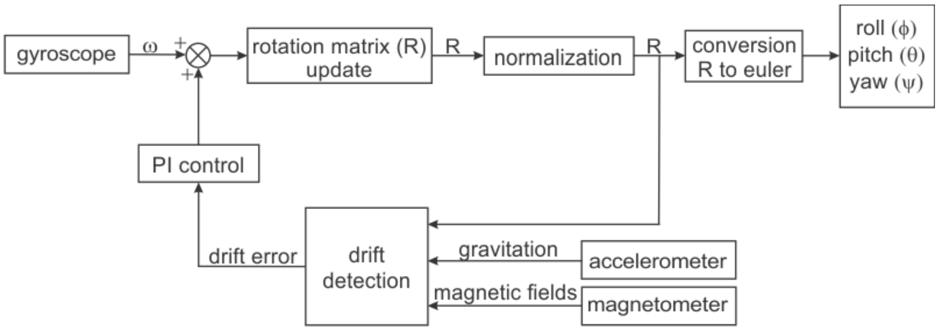


Figure 2. Blok diagram of DCM sensor fusion method

We can get the rotation matrix (R) by multiply each rotation axis. Equation (1), (2) and (3) show how we can get the rotation matrix (R).

$$R = R_z R_y R_x \tag{1}$$

where,

$$Rx = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & -\sin\phi \\ 0 & \sin\phi & \cos\phi \end{bmatrix}, Ry = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix}, Rz = \begin{bmatrix} \cos\Psi & -\sin\Psi & 0 \\ \sin\Psi & \cos\Psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{2}$$

From the equation (1) and (2) above, we get a rotation matrix (R) that shown on the equation (3) below.

$$\mathrm{R} = \begin{bmatrix} \cos\theta\cos\Psi & \sin\phi\sin\theta\cos\Psi - \cos\phi\sin\Psi & \cos\phi\sin\theta\cos\Psi + \sin\phi\sin\Psi \\ \cos\theta\sin\psi & \sin\phi\sin\theta\sin\Psi + \cos\phi\cos\Psi & \cos\phi\sin\theta\sin\Psi - \sin\phi\cos\Psi \\ -\sin\theta & \sin\phi\cos\theta & \cos\phi\cos\theta \end{bmatrix} \tag{3}$$

The general structure of the rotation matrix is shown on the equation (4) below.

$$R = \begin{bmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{bmatrix} \tag{4}$$

From the equation (4), we can get the value for each angle, roll, pitch and yaw, that shown on the equation (5), (6) and (7) below.

1. roll (ϕ)

$$\frac{(R_{32})}{(R_{33})} = \tan\phi, \qquad \phi = \mathrm{arc}\tan2(\mathrm{R}_{32}, \mathrm{R}_{33}) \tag{5}$$

2. pitch (θ)

$$R_{31} = -\sin\theta, \qquad \theta = -\mathrm{arc}\sin(\mathrm{R}_{31}) \tag{6}$$

3. yaw (Ψ)

$$\frac{(R_{21})}{(R_{11})} = \tan\Psi, \qquad \Psi = \mathrm{arc}\tan2(\mathrm{R}_{21}, \mathrm{R}_{11}) \tag{7}$$

In a conventional remote control there are four main channels at least, as well as some additional channels that are used to control the movement of a quadrotor. That four channels in a conventional remote control will affect the flight parameters of quadrotor namely throttle, pitch, roll and yaw. Throttle is used to speed up or slow down the rotation of the four pieces of the propeller quadrotor so quadrotor will move up or down. While the channel pitch, roll and yaw are used to control the flight parameters of a quadrotor, each pitch, roll, and yaw.

Lack of pilot's knowledge for the function of each channel on a remote control will be one of the factors that make the pilot hardly to control the quadrotor well. Moreover, the function of each channel can be different for each remote controls of different types.

The handheld system offered as an alternative to conventional remote controls that exist today. As well as a remote control, this handheld system will regulate the movement of quadrotor by changing the parameters of flight. The quadrotor's flight parameter will be influenced by the position of the user's hand. The parameter that was changed is the amount of orientation angle to be formed by the quadrotor (roll, pitch and yaw). For pitch and roll angle will be directed by -15^0 or 15^0. In order to make the quadrotor's control easier, it needs a good control system.

The handheld system designed to be able to read the position of the user's hand movements and convert them into commands that will change the flight parameters of the quadrotor, and then sends these commands to the quadrotor. To detect the user's hand movement, an IMU sensor must be used to measure the orientation of the user's hand [6]. The movement's scenario that will be read by a handheld system is presented in Figure 3 and Table 1 below.

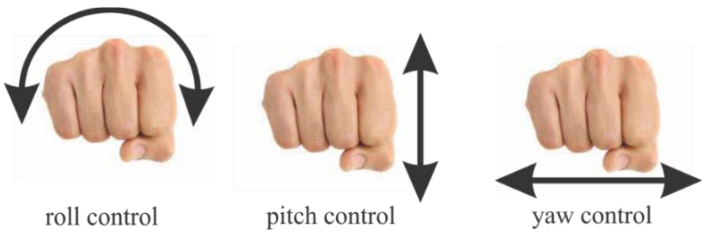


Figure 3. Hand movements scenario

Table 1. Hand Movements Scenario

Number	Hand movements	Commands
1	Fist downward	Quadrotor moves forward
2	Fist upward	Quadrotor moves backward
3	Fist tilted to the left	Quadrotor moves to the left
4	Fist tiltet to the right	Quadrotor moves to the right
5	Tip of the hand to the left	Quadrotor is yawing to the left
6	Tip of the hand to the right	Quadrotor is yawing to the right

2.2. System Architecture

The system architecture is presented in Figure 4 above. Of the system, it appears that the controller quadrotor get inputs from multiple sensors, such as accelerometer, gyroscope, magnetometer and proximity sensor and output is received by the ESC (Electronic Speed Controller) which is then given to the brushless motor. The quadrotor's main controller used in this system is arduino nano. To optimize the control system on the quadrotor we use PID control system. PID controller is one of the most common controller used today [7]. A lot of refining, chemicals, and pulp and paper industries used PID structured controllers [8]. Even in the embedded system we can see the used of PID controller [9]. And moreover, PID can be combined with another algorithm like fuzzy algorithm [10] or ant colony algorithm [11] and [12].

The handheld system is using a microcontroller that is arduino pro-mini that gets input from the sensor accelerometer, gyroscope and magnetometer to read the position of the user's hand. Having obtained the position of the user's hand, then the algorithms that have been implemeted in this handheld system will turn them into specific commands that will change the flight parameters of quadrotor. To send a command from the handheld to the quadrotor system we used Xbee wireless communication module.

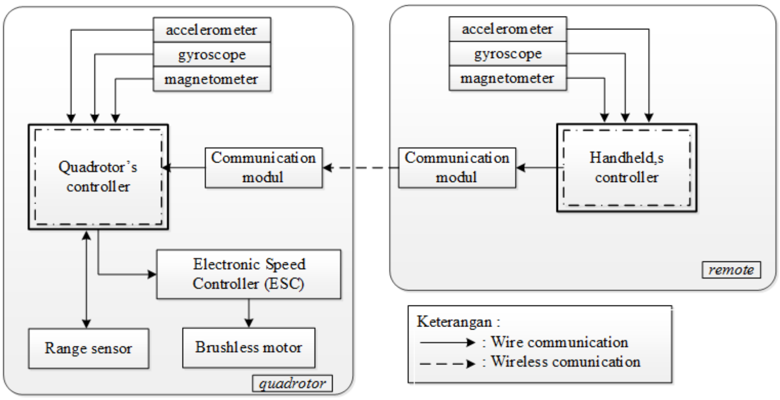


Figure 4. system architecture

2.3. Control system

This control system is intended to make the quadrotor flight optimally. The control system that we used is a PID control system with the constant value obtained by using the Ziegler-Nichols method tuning for each angle. Figure 5 shows that the position information detected by the sensor IMU on the quadrotor where the values are converted into the form of a roll angle (φ), pitch angle (θ) and yaw angle (ψ) using DCM method by the microcontroller on the quadrotor. This values will be compared with the predetermined values that is set point. The comparison results are called error value (e (t)). By using the PID control calculations the value of e (t) which will be used to work the actuator in the form of a PWM signal that has previously been converted beforehand by the microcontroller on the quadrotor.

The determination of the set point value in PID control is done by reading the position of the user's hand ithat detected by the IMU sensor on the handheld system. Furthermore, the value of the sensor readings are converted into the form of a roll angle (φ), pitch angle (θ) and yaw angle (ψ) using DCM method by the microcontroller on the handheld and then turn it into a set point value that will be given to the PID control systems at the quadrotor.

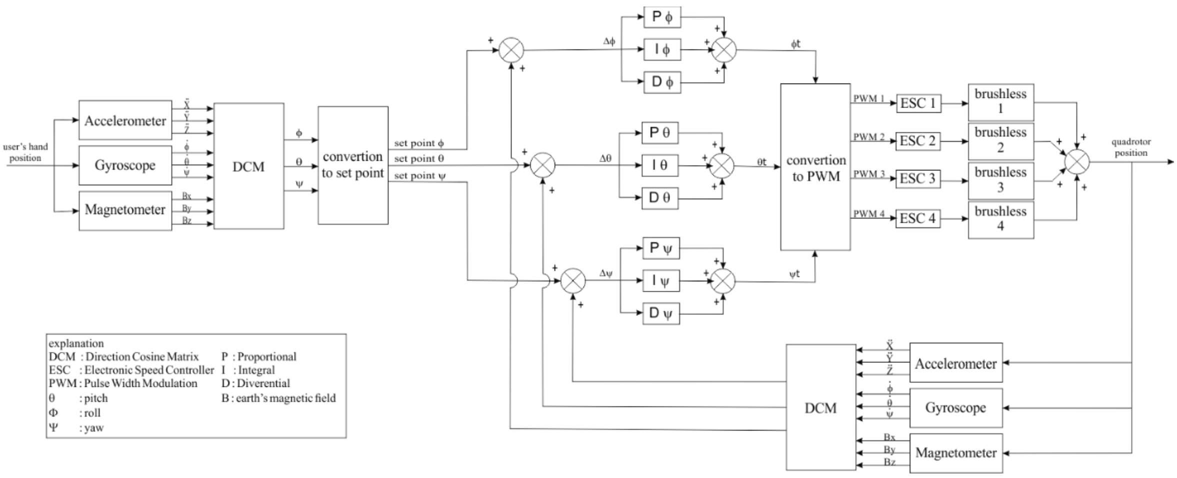
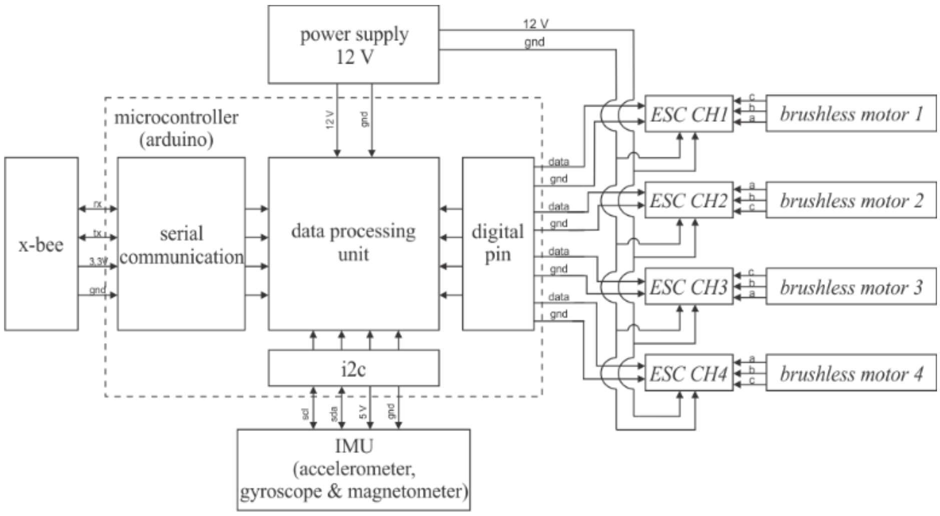


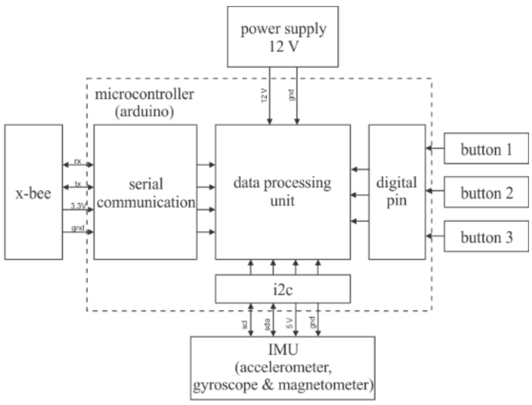
Figure 5. control system diagram

2.4. Electronics

The electronics is divided into two main parts, namely quadrotor's electronic and handheld's electronics. Quadrotor's electronic consists of a power supply, a microcontroller, sensors, actuators, and data communications hardware. The microcontroller used in this quadrotor system is arduino nano.The handheld's electronic system consists of a power supply, a microcontroller, sensor and data communication hardware. The microcontroller used in this handheld system is arduino pro mini-5V models. Electronic system chart is presented in Figure 6 below.



(a)



(b)

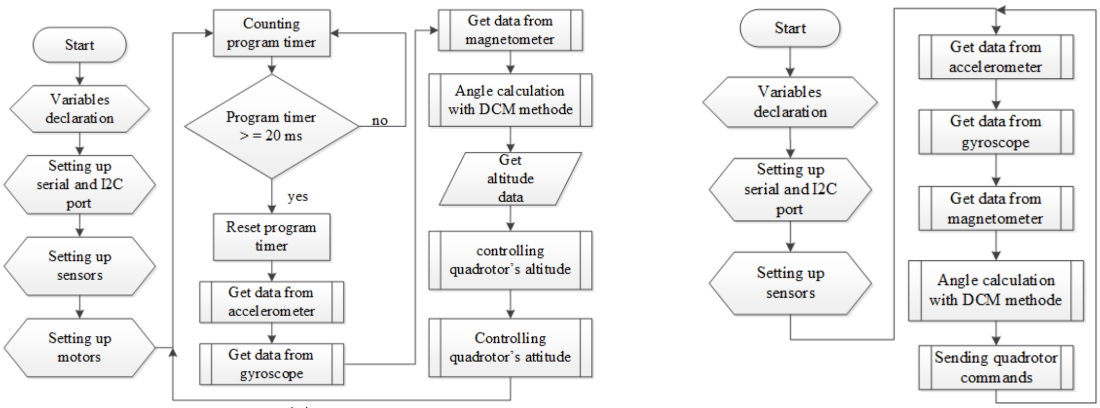
Figure 6. electronic system : (a) quadrotor, (b) handheld

2.5. Software

The software is also divided into two, namely quadrotor's software and hadheld's software as shown in Figure 7. This programming is done with the arduino programming language which is a derivative of the C and C ++ programming languages and done on Arduino IDE (Integrated Development Environment).

The quadrotor's software is embedded in arduino nano as a component of the quadrotor control system. This software will collect data from the orientation sensor and process it to make the quadrotor flight optimaly accordance with the instructions given by the handheld system.

The handheld's software is embedded in the arduino pro mini to access the orientation sensor and provide algorithms to process inputs as a command to the quadrotor system that will be transmitted via the XBee communication module.

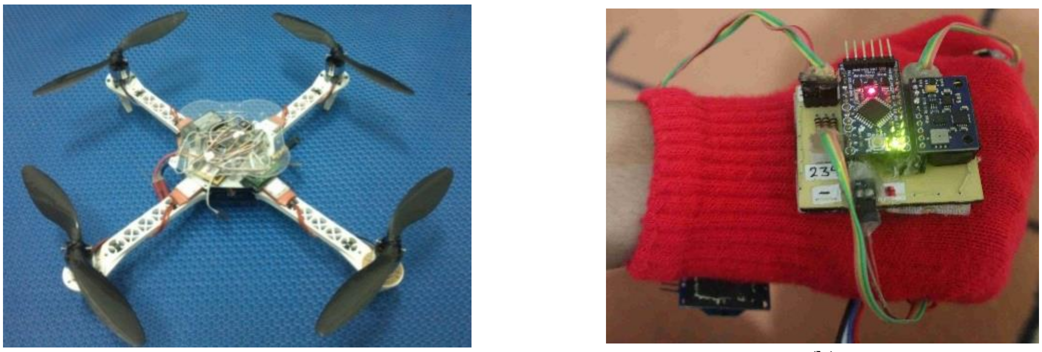


(a) (b)

Figure 7. software system : (a) quadrotor, (b) handheld

2.6. Mechanics

Mechanic system is divided into two parts, namely mechanical handheld and mechanical quadrotor as shown in Figure 8. The mechanic is based on SK450. Quadrotor's mechanic has 4 arms with a box-shaped body in the middle and the diameter frame size is 47 cm. The size of the body is 10xcm. The handheld size is 5 x 4.5 cm were placed on the glove (at the back of the hand).



(a) (b)

Figure 8. mechanic system : (a) quadrotor, (b) handheld

3. RESULTS AND DISCUSSION

3.1. Handheld system testing result

Handheld testing done to see the outcome of the algorithms that have been implemented on the system. This algorithm is used to determine the order from the handheld to the qudarotor. This algorithm is determined by the value from the DCM calculation result of IMU sensor that detects the orientation angle of the user's hand. This testing is done by moving the handheld in accordance with the position described in section Analysis System, then viewed the commands produced by the handheld system.

3.2. Control system testing result

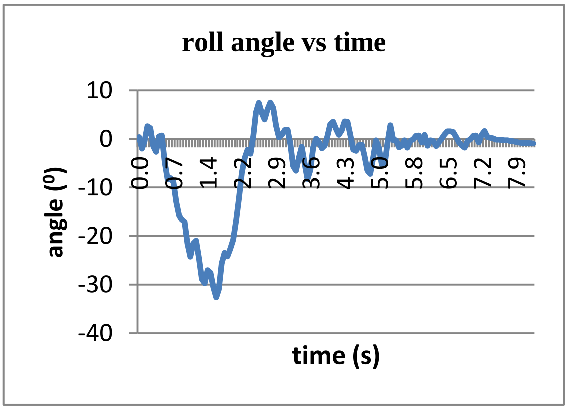
Quadrotor has three orientation angles that must be controlled in order to be able to fly. The tree anglea are Θ (pitch angle), φ (roll angle) and ψ (yaw angle). This test is done by attached the quadrotor into a static pole in a closed place, so the effect of wind is not included on this system.

Quadrotor control process carried out by arduino using PID algorithm, this is because the PID control system is able to produce a more optimal control for quadrotor compared with the control systems P and PI control system [13]. PID algorithm is performed on each orientation angle of the quadrotor. Output value of each PID will generate PWM signals that will control the speed of the brushless motor on the quadrotor. The output value is influenced by the constant Kp, Ki, and Kd. In this research, the determination of these constants using the Ziegler-Nichols oscillation method. The Ziegler-Nichols tuning method is based on the idea of simple features of the step response tuning method [14]. Ziegler-Nichols tuning method can be used in open loop systems and closed loop systems that developed from trial and error method, one of Ziegler-Nichols tuning method is to use oscillation. In this case, we can use the Ziegler-Nichols tuning methods to tune the PID parameter on the quadrotor [15].

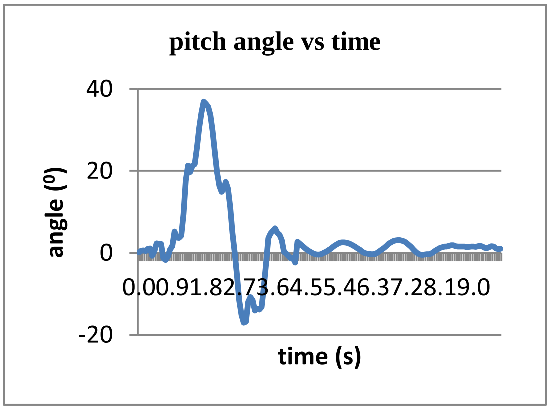
The test that used the Ziegler-Nichols oscillation method is done by giving the variation of the proportional constant (Kp) value. Whereas the value of the integral constant (Ki) and the value of the derivative constant (Kd) is rated 0. This is done to obtain Kp values that can make the quadrotor oscillates continuously. If the oscillating system is progressively enlarged, then the value of Kp is too large and should be reduced. If the oscillating system is becoming increasingly smaller, the value of Kp is too small and should be enlarged. Then the value of Kp resulting in an oscillating system is referred to as the Ku (ultimate gain constant). The next step is to find the value of Pu, that is the period of oscillation of the waves formed by the Ku value. Then the value of Kp, Ki, and Kd is calculated based on Table 2 [16]. The response of the system as shown in Figure 9.

Table 2. PID *Ziegler-Nichols* oscilation method [16]

Controller types	Kp	τi	Td
P	0,5 Ku	0	0
PI	0,45 Ku	Pu / 1,2	-
PID	0,6 Ku	Pu / 2	Pu / 8



(a)



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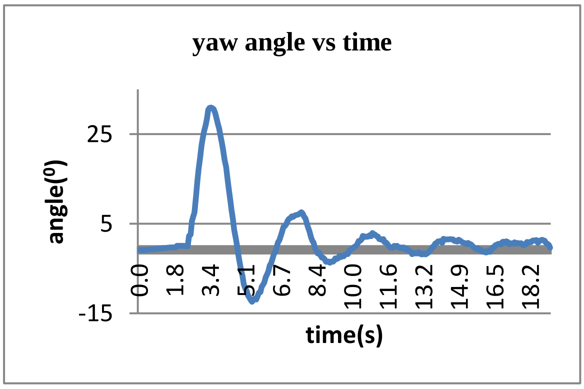

(c)

Figure 9. Response of the system: (a) roll angle, (b) pitch angle and (c) yaw angle

Ku of the value that has been obtained is then used to search for the value of the controller constants Kp, Ki and Kd for later implemented in the quadrotor control system. From the results of the Ziegler Nichols tuning method gained control system capable of maintaining quadrotor to be in accordance with the conditions that given by the set point. However, from that results still visible deficiencies in the system such as overshoot and also the response time still not fast enough. To improve the performance of this control system, then we re-tuned the system on each of the controller constants Kp, Ki and Kd. Tuning is done with the results based on the value of Ziegler Nichols tuning method, thus further tuning of this nature is only correct deficiencies arising from Ziegler Nichols tuning before. So in other words Ziegler Nichols tuning method can be used to help the process of PID tuning to obtain reference values to perform the next tuning process. Figure 9 above displays system response after Ziegler Nichols tuning method and subsequently re-tuned to improve response. We call this second tuning process tuning as a fine tuned method.

3.3. Integration quadrotor and handheld system testing result

This test aims to determine the behavioral response of the quadrotor based commands control given by the handheld. Orders will be sent by the handheld that will change the set point on the quadrotor's control system on each angle. For pitch and roll angles, quadrotor will move to -15^0 and then returned to the next 0^0 and directed into 15^0 and then returned again toward 0^0. The -15^0 and 15^0 value is based on the handheld algorithm that also refers to the analysis system that has presented earlier. For yaw angle command will cause the quadrotor rotated clockwise or counter-clockwise in accordance with the commands from the handheld.

Figure 10 shows the graphs of the results for the testing response of each quadrotor's angle to the control signal sent by the handheld. From these graphs it appears that the quadrotor able to move in accordance with instructions given by handheld although there is still a deviation in the movement and oscillation is possible because both the value of the sensor and the control system implemented yet very optimal. From the test is also seen that there is a lag between the time when the handheld sends a command to the time when quadrotor move in accordance with the order, or in other words in response to commands from a handheld quadrotor slightly delayed.

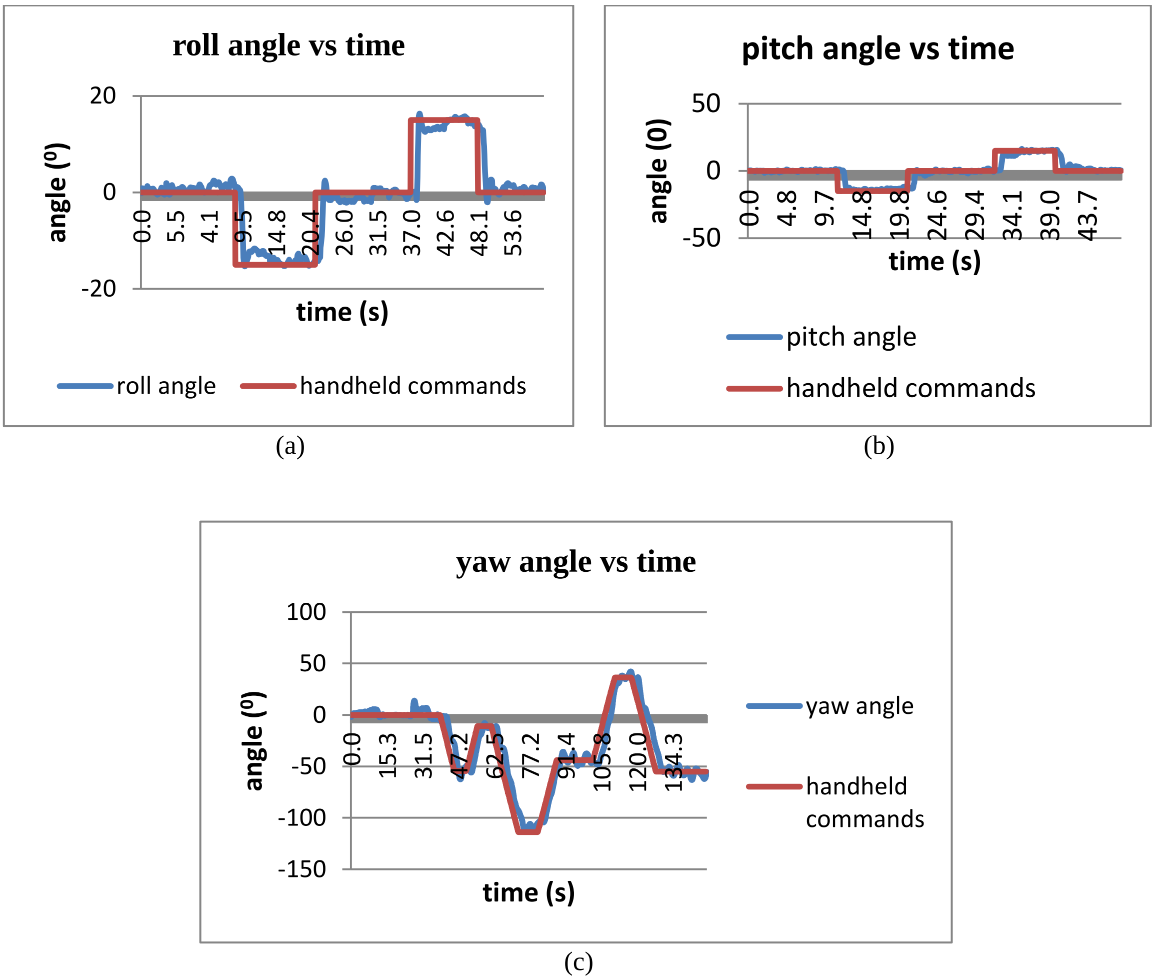

Figure 10. Response of the integration system: (a) roll, (b) pitch and (c) yaw

4. CONCLUSION

Has done research on the quadrotor control system with commands given by the user's hand movements. To read commands from the user's hand, we made a handheld system. This handheld system will read the user's hand movements then converted it into the form of instructions. To read the user's hand movement we used the IMU sensor, while to send the instructions to the quadrotor we used x-bee communication module. To get the orientation angle from the IMU sensor data, we used DCM sensor fusion method. In order to coontrol the quadrotor optimally, then we used PID control. To assist the tuning of each controller constants Kp, Ki and Kd, Ziegler Nichols tuning method is used, then the results of this tuning is used as a basic value for further tuning.

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