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Autonomous Quadcopter Based Human Detection System for Search and Rescue

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ABSTRACT

The development of navigation and tracking of an object using unmanned aerial vehicles (UAV) has been evolved more advanced. The utilization of this technology is scattered throughout the area including for search and rescue in small and large areas. In this research, the UAV used is a multirotor based on camera for human detection that has been developed and integrated into a fully autonomous system. The first stage is designing a controller and the second step is to integrate the companion computer on the quadcopter that has the OpenCV library installed with the HOG and SVM methods. The system presented in this paper is able to perform the stable flying via PID controller. The output response of roll, pitch, and yaw has an overshoot of 0.5 %. Identify target in the form of human body in real-time and identify target location based on the direction of the Earth's compass with test result has average error, latitude 1 = 0.026%, longitude 1 = 0.034%, latitude 2 = 0.016%, and longitude 2 = 0.00168%.

Keywords: UAV; multirotor; HOG; SVM; PID

1. INTRODUCTION

Unmanned Aerial Vehicle (UAV) with an autonomous system developed rapidly in the last few years [1] including search and rescue purpose [2]. Search and rescue in disaster areas with extensive terrain or on locations with dangerous conditions that could threaten the rescue team. In this research, the UAV technology used is a quadcopter that can perform vertical take-off and landing (VTOL). In the process of search and rescue for disaster areas required autonomous quadcopter with knowing the real-time location and the position of starting point when flying. Previous research related to object detection has been conducted [3] [4] [5]. The first phase of the study was conducted in the design of a quadcopter control system aimed at stabilizing the quadcopter when hovering using Proportional Integral Derivative (PID) that we have designed. Then in the second phase, it performs human detection programming directly on the companion computer via the Histogram of Oriented (HOG) method and Support Vector Machine (SVM). In this research, quadcopter was built with a Pixhawk flight controller, odroid-xu4 as a companion computer to detect human objects, four BLDC motorcycles as well as a propeller, and used LiPo batteries as a source of the voltage.

2. METODOLOGY

A. Autonomous System

A companion computer system is required to control the quadcopter such as VTOL autonomous. The companion computer system

Odroid XU4 needed to control the Pixhawk in order to perform actions such as auto vertical takeoff, altitude hold for 30 seconds, to the specified waypoint and autoland. The serial for the UART driver module is required for Odroid communication XU4 Pixhawk through MavLink communication.

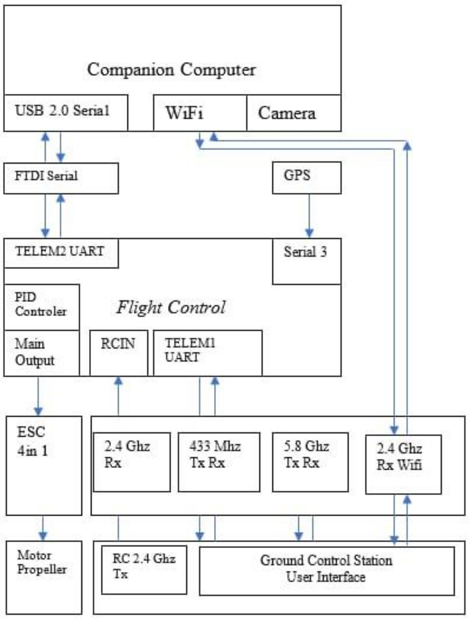

Fig. 1. Diagram of autonomous quadcopter

B. *PID Controller*

The PID controller is a feedback mechanism controller that is commonly used in industrial control systems. The PID controller consists of proportional, integral, and derivative. The block diagram of PID method can be seen in Fig. 1.

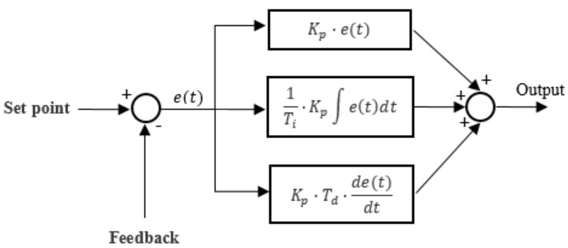

Fig. 2. Block control Diagram PID

The parameters of the PID are obtained using the Ziegler Nichols type 1. Tuning parameters of PID use S-shape reaction curve where consist of time constant T and delay time L.

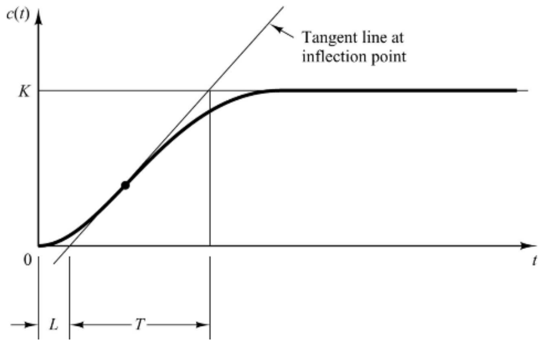

Fig. 3. S-shape reaction curve

The built-in PID control system will be used to set the pitch, roll, and yaw of the quadcopter. Based on graphic analyze, we get L and T then PID parameter will be obtained using Table 1.

Table 1. Tuning PID via Ziegler Nichols type 1

Controller Type	Kp	T_i	Td
P	T/L	-	0
PI	0,9 T/L	L/0,3	0
PID	1,2 T/L	2L	0,5L

C. *Histogram of Oriented Gradients* (HOG)

HOG is an image processing method used to detect objects (humans). This method calculate gradients within a given area in an image. The object detection process is performed per frame of the image captured as a result of video counting. The video counting frame has different characteristics shown through the gradient distribution. This characteristic is implemented by dividing the image into small windows (cells). Each of these cells will be merged back to a histogram of a gradient. The combination of this histogram will form the characteristic is the implementation of the image representing the object. The following extraction process of the HOG method is done which will be described in Fig. 4 [6].

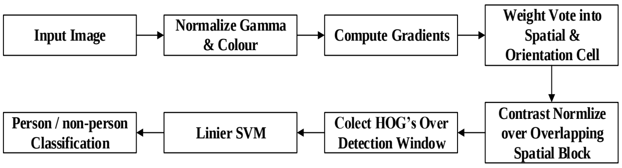

Fig. 4. HOG Method Extraction Process

D. Support Vector Machine (SVM)

The Support Vector Machine (SVM) is a method used to identify and distinguish humans or non-humans. The process of this method works when the HOG framework on OpenCV video counting results from video captured by webcam. In this process, SVM serves as a separator of two classes in input space between -1 and + 1. Class-1 is symbolized by a red box and class + 1 is symbolized by a yellow circle. The basic principle of SVM itself is as a linear classifier that can be seen in Fig. 5 [7].

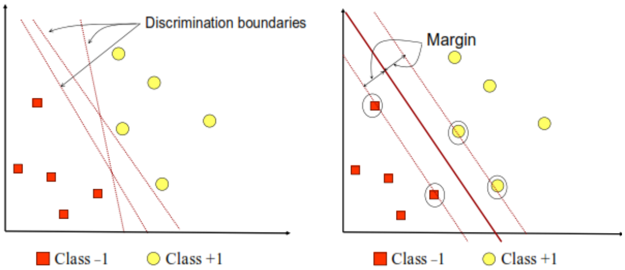

Fig. 5. The SVM process finds the best hyperplane to separate both class-1 and + 1

E. Mathematical Model of Quadcopter

The mathematical modelling of quadcopter essentially refers to the quadcopter motion or can be called degrees of freedom. The quadcopter has 6 Degree of Freedom (DoF) which is divided into two reference frames i.e. E-Frame is a fixed axis that is earth and B-Frame is a quadcopter moving axis that can be seen in Fig. 6 [8] [9].

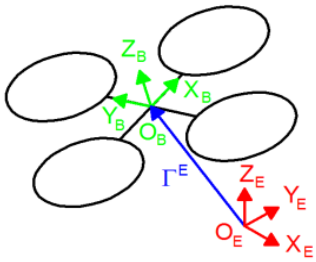

Fig. 6. Quadcopter Frame

The image above is a representation of the B-Frame and E-Frame that can determine the linear position of the Quadcopter (r^E).

$$r^E = [X \quad Y \quad Z]^T \tag{1}$$

$$\Theta^E = [\phi \quad \theta \quad \psi]^T \tag{2}$$

When flying, quadcopter will generate a rotation matrix is a B-Frame transformation into E-Frame use the matrix transfer T_θ :

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = T_\theta^{-1} \begin{bmatrix} \phi \\ \theta \\ \psi \end{bmatrix}, \tag{3}$$

where the transformation matrix from B-Frame to E-Frame:

$$T_\theta^{-1} = \begin{bmatrix} 1 & 0 & -s_\theta \\ 0 & c_\phi & c_\theta s_\phi \\ 0 & -s_\phi & c_\phi c_\theta \end{bmatrix} \tag{4}$$

$$T_\theta^{-1} = \begin{bmatrix} 1 & -s_\phi t_\theta & s_\theta t_\theta \\ 0 & c_\phi & -s_\phi \\ 0 & \frac{s_\phi}{c_\theta} & \frac{c_\phi}{c_\theta} \end{bmatrix} \tag{5}$$

The equation (6) – (11) was obtained a general quadcopter equation derived from the Euler-Newton method

$$\ddot{X} = \frac{U_1}{m}(sin\psi sin\phi + cos\psi sin\theta cos\phi) \tag{6}$$

$$\ddot{Y} = \frac{U_1}{m}(-cos\psi sin\phi + sin\psi sin\theta cos\phi) \tag{7}$$

$$\ddot{Z} = -g + \frac{U_1}{m}(cos\theta cos\phi) \tag{8}$$

$$\dot{p} = \frac{I_{YY} - I_{ZZ}}{I_{XX}} qr - \frac{J_{TP}}{I_{XX}} q\Omega + \frac{U_2}{I_{XX}} \tag{9}$$

$$\dot{q} = \frac{I_{ZZ} - I_{XX}}{I_{YY}} pr - \frac{J_{TP}}{I_{YY}} p\Omega + \frac{U_3}{I_{YY}} \tag{10}$$

$$\dot{r} = \frac{I_{XX} - I_{YY}}{I_{ZZ}} pr - \frac{U_4}{I_{ZZZ}} \tag{11}$$

While the input of the general equation quadcopter (6)-(11) is determined from the equation (12)-(16) which is the velocity of the propeller when add disturbance.

$$U_1 = b\,(\Omega_1^2 + \Omega_2^2 + \Omega_3^2 + \Omega_4^2) \quad (12)$$

$$U_2 = bl\,(-\Omega_2^2 + \Omega_4^2) \quad (13)$$

$$U_3 = bl\,(-\Omega_1^2 + \Omega_4^2) \quad (14)$$

$$U_4 = d\,(-\Omega_1^2 + \Omega_2^2 - \Omega_3^2 + \Omega_4^2) \quad (15)$$

$$\Omega = -\Omega_1 + \Omega_2 - \Omega_3 + \Omega_4 \quad (16)$$

After the transfer function is acquired from the general equation (6)-(11), that take part of the pitch, roll and yaw to be controlled using PID. The tuning of PID controller parameters (proportional Integral differential) is always based on the review of the regulated characteristics (plant).

F. Physical parameters identification

The moment of inertia calculation is necessary to know the value of Ixx, Iyy and Izz. In the moment of inertia required data specifications of the quadcopter physical parameters. The specification can be seen in Table 2.

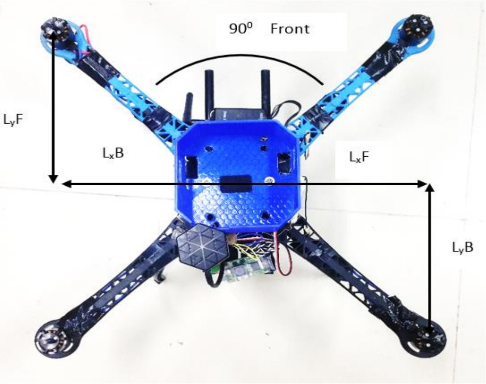

Fig. 7. Physical measuring parameters

Fig. 8. Complete Hardware of Quadcopter

Table 2. Physical measuring parameters

Physical measuring *quadcopter*	
Name	Value
LxF (m)	0,16
LyF (m)	0,17
LxB (m)	0,16
LyB (m)	0,17
Massa (kg)	1,82 kg

Parameter identification using experiment method. The experimental method is a technique of measuring characteristics of the quadcopter plant using physical measurements moment of inertia with trivial pendulum method. The trivial pendulum method is chosen because its implementation is very easy. Measurements are performed in X, Y and Z axes.

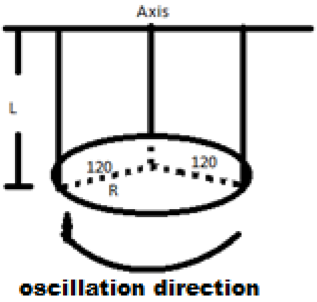

Fig. 9. Trivial Pendulum

After that a moment of inertial calculation with the equation (17):

$$I_{xx,yy,zz} = \frac{M.g.R^2T^2_{x,y,z}}{4.\pi^2.L} \quad (17)$$

Finally, the moment of inertia can be seen in Table 3.

Table 3. Moment of inertia

Moment of inertia (Kg.m^2)	
Ixx	0,0232
Iyy	0,0228
Izz	0,0298

3. RESULT AND DISCUSSION

A. Simulation of PID Controller

PID controller simulation using Simulink. The PID parameter is obtained using Ziegler Nichols type 1 shown in the Table 4. The output response of controller can be seen in Fig. 10. Fig. 10 show that the output have overshoot roll 6 %, pitch 5.5 %, and yaw 8 %.

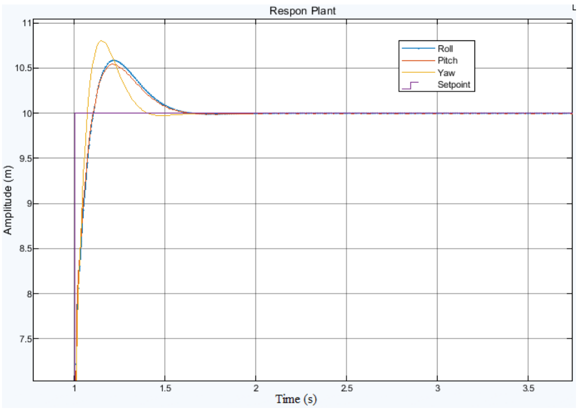

Fig. 10. Response of PID controller

Table 4. The value of PID

Name	P	I	D	Overshoot
Roll	1,05	6,562	0,042	6%
Pitch	1,05	6,562	0,042	5.5%
Yaw	1,44	14,4	0,036	8 %

B. Implementation Auto Take-off and Landing

The experiment was carried out by giving the auto take-off and landing command to odroid-xu4 which had been connected to the Pixhawk. In Figure 3.5, there are three parts of quadcopter condition. The first is the quadcopter position on hover in 10 seconds, the second is the quadcopter state while running the mission to the specified waypoint in 16 seconds while in the third part is the quadcopter state when it is landing.

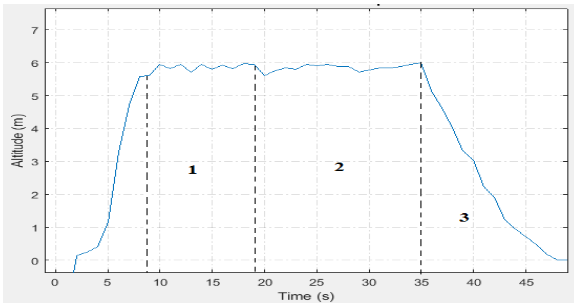

Fig. 11. Position of Quadcopter

The height of the quadcopter is detected using a barometer sensor. Quadcopter altitude never reaches at 6 meters according to the order in odroid-xu4. The measured average constant height value is 5.87 meters. However, In this implementation, the thrust issued a motor of 70% so it takes time to point the set-point about 8 seconds.

C. Object Detection

The following test results from the autonomous quadcopter program run with remote control of the PuTTY and VNC Viewer software on a PC. All results are displayed in Figure 3.6 with the parameter number of objects, altitude, coordinates, flight mode and local time. The results of the detection are taken based on four directions of scanning (north, east, south and west) at one coordinate point with latitude data =-5.3599526 and longitude = 105.3103595. In this coordinate point area, there is one sample prepared to test the program that was created. It can be seen in Figure 3.6 that detected 1 person in the scanning area to the east and west.

Fig. 12. Human detection east direction

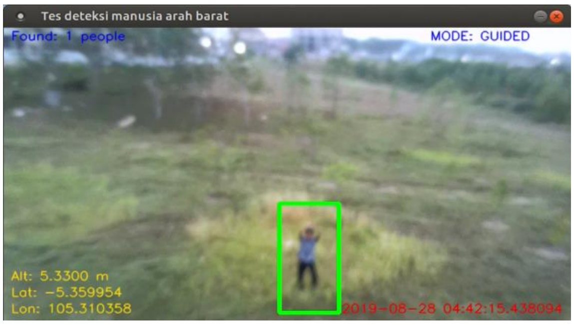

Fig. 13. Human detection west direction

Table 5. Result of measurement of coordinate value on Rill's condition

Original Coordinates		Rated Coordinates		% *Error*			
Point 1	Point 2	Point 1	Point 2	Lat 1	Lon 1	Lat 2	Lon2
-5.359952, 105.310359	-5.359954, 105.310218	-5.359956, 105.310352	-5.359952, 105.310217	0.04	0.067	0.02	0.009
-5.359952, 105.310359	-5.359954, 105.310218	-5.359954, 105.310358	-5.359953, 105.310222	0.02	0.009	0.01	0.038
-5.359952, 105.310359	-5.359954, 105.310218	-5.359953, 105.310362	-5.359955, 105.310221	0.01	0.028	0.01	0.028
-5.359952, 105.310359	-5.359954, 105.310218	-5.359957, 105.310353	-5.359952, 105.310217	0.05	0.057	0.02	0.009
-5.359952, 105.310359	-5.359954, 105.310218	-5.359953, 105.310358	-5.359956, 105.310220	0.01	0.009	0.02	0.0019
Average				0.026	0.034	0.016	0.0168

Table 5 is field test coordinates from point one and two which contain error values of measured coordinate values. The error value is obtained by changing each coordinate value to a time value (in seconds) so that the error value can be calculated. When seen in table 5, the error value is obtained nearly zero, so the level of accuracy is high on the system.

4. CONCLUSIONS

The result of the implementation hardware is quadcopter can detect the human object and fly stable with the average height that successfully performed is 5.78 meters from the specified 6 meters set-point. The result of the coordinate test is done with the test coordinate value obtained the measured coordinate value of the system with the average error value of each latitude 1 = 0.026%, longitude 1 = 0.034%, latitude 2 = 0.016%, and longitude 2 = 0.0168%. From the value, each of these errors can be stored system has a fairly high level of accuracy.

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