Drone Tracking System Using GPS and Barometer Sensor

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Abstract. In general, base station or Ground Control Station (GCS) use directional antenna to comunicate with the moving object such as drone or Unmanned Aerial Vehicle (UAV). Directional antenna has a long transmission range but narrow transmission angle. In order to overcome this shortcoming, a device that can move the antenna towards a moving object is needed. This paper designs a device which can controls the movement of antenna to follow an object (drone). This tracker moves on the yaw and pitch axis by using servo motor. This device is using Proportional, Integral, dan Derivative (PID) control method to track moving object base on Global Positioning System (GPS) and barometer sensor. From the PID parameter that used at pitch angle (Kp=0.05, Ti=100, and Td=0.35), the plant can reach the setpoint (37^o) within 1.3 sec. From the PID parameter that used at yaw angle (Kp=3.5, Ki=0, and Td=0.08), the plant can reach the setpoint (90^o) within 0.7 sec. Based on the test result, tracker can move to follow drone with the average time 0.5 sec on the yaw plant and 0.4 sec on the pitch plant. The Mean Absolute Error (MAE) at yaw plant is 6.67^o and the MAE at pitch plant is 1.54^o

Keyword: Drone Tracking, GPS, Baromater sensor

1. Introduction

Directional antenna has a long transmission range but narrow transmission angle. In order to overcome this shortcoming, a device that can move the antenna towards a moving object is needed. One of the methods that can be used to track a moving object like a drone is using Global Positioning System (GPS) receiver, barometer pressure sensor, and Inertial Measurement Unit (IMU). GPS, barometer pressure sensor, and IMU sensor can be used to obtain information about location object and attitude the tracker.

From research and development about tracking object system that has been done before [1]–[5], the most commonly used tracking method is Received Signal Strength Indicator (RSSI). This paper discusses about drone tracking system based on GPS receiver, barometer pressure sensor, and Inertial Measurement Unit (IMU) sensors (such as accelerometer, gyroscope, and magnetometer). The control method used are Proportional, Integral, and Derviative (PID). The obtained data is processed by microcontroller to control the motor servo so the antenna direction toward the moving object. Tracking object is monitored by computer in real time.

2. Methodology

2.1. Desain System

The GPS receiver and barometer pressure are used as input of the system which is put in moving object's payload to represent location of drone. The accelerometer, gyroscope, and magnetometer sensor are used as input of the system which is put on drone tracker to represent attitude of drone tracker. Microcontroller is used to process input-output data. Receiver and

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transmitter module that used is 433MHz telemetry radio. Both servo (pitch and yaw) is used as output to move the antenna. Block diagram of drone tracking system is shown by Figure 1.

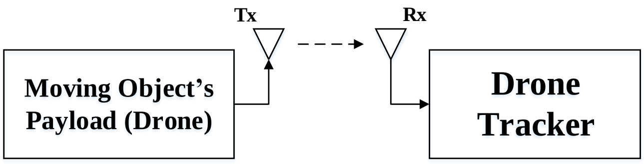

Fig. 1. Block diagram of drone tracking system.

GPS receiver is giving information of location object (from latitude and longitude coordinate). Barometer pressure is giving information of altitude object. Accelerometer, gyroscope, and magnetometer sensor are giving information about the antenna's direction (at pitch and yaw angle). The data from GPS receiver and barometer pressure are processed on microntroller (at moving object's payload) then sent to drone tracker via radio transmitter. Data that received by drone tracker from payload, accelerometer, gyroscope, and magnetometer then processed by microcontroller (at drone tracker) to produce pitch and yaw setpoint of drone tracker and set the Pulse Width Modulation (PWM) of pitch and yaw servo so that the antenna move toward moving object.

2.2. Design of Hardware

The assembly of hardware components at the moving object's payload is made by following components as shown in Figure 2. Barometer pressure sensor is connected to microcontroller via I2C pin (A4 = SDA and A5 = SCL), GPS receiver module is connected to microcontroller via software serial asynchronous communication pin (D5 = Tx and D6 = Rx), radio telemetry is connected to microcontroller via serial asynchronous communication pin (D0 = Tx and D1 = Rx), all of them is supplied with 5V DC voltage. The assembly result of the moving object's payload can be seen in Figure 3.

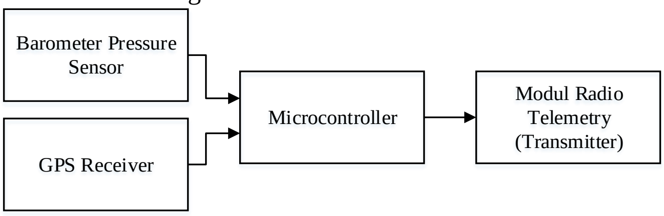

Fig. 2. Design of hardware components at moving object's payload.

Fig. 3. Aseembly result of moving object's payload.

The assembly of hardware components at the drone tracker is made by following components as shown in Figure 4. Radio telemetry is connected to microcontroller via serial asynchronous communication pin (D0 = Tx and D1 = Rx), gyroscope, accelerometer, and magnetometer sensor is connected to microcontroller via I2C pin (A4 = SDA and A5 = SCL), yaw servo is connected to microcontroller via pin D10, and pitch servo is connected to microcontroller via pin D9. all of sensor, radio telemetry, and microcontroller is supplied with 5V DC voltage. Yaw servo is supplied with 6V DC voltage and pitch servo is supplied with 7V DC voltage. The assembly result of drone tracker can be seen in Figure 5.

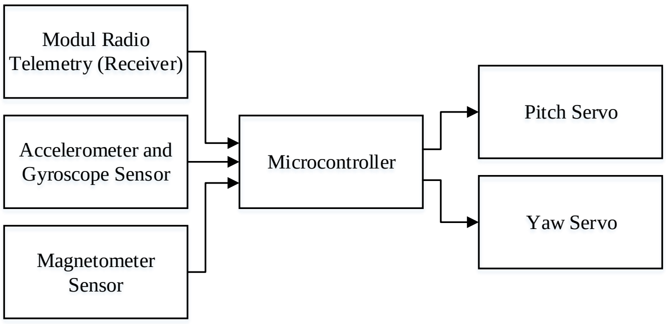

Fig. 4. Design of hardware components at drone tracker

Fig. 5. Aseembly result of drone tracker.

MPU6050 is a module that consist of accelerometer and gyroscope sensor in one board. Accelerometer measures the linear motion of an object acceleration by gravity reference. Accelerometer gives information about roll (ϕ) and pitch (θ) angles, which is given in

Equation 1 and Equation 2 [6]. Gyroscope measures the angular velocity of an object. Gyroscope gives information about roll (ϕ), pitch (θ), and yaw (ψ) angles, which is given in Equation 3 [7]. Both of accelerometer and gyroscope work using the principle of capacitance change. HMC5883L is a magnetometer sensor module that measures direction and magnitude of the earth's magnetic field. Magnetometer only gives information about yaw (ψ) angles, which is given in Equation 4 [7]. This sensor work using the principle of Hall-effect or magneto-resistive effect. Accelerometer, gyroscope, and magnetometer is connected to microcontroller by Inter-Integrated Circuit (I2C) using Serial Data (SDA) and Serial Clock (SCL) pin.

$$\phi = \tan^{-1}\left(\frac{f_y}{f_z}\right) \tag{1}$$

$$\theta = \tan^{-1}\left(\frac{-f_x}{\sqrt{{f_y}^2+{f_z}^2}}\right) \tag{2}$$

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} 1 & \sin\phi\tan\theta & \cos\phi\tan\theta \\ 0 & \cos\phi & -\sin\phi \\ 0 & \frac{\sin\phi}{\cos\theta} & \frac{\cos\phi}{\cos\theta} \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} \tag{3}$$

$$\psi = atan\left(\frac{-m_y cos\phi + m_z sin\phi}{m_x cos\theta + m_y sin\theta sin\phi + m_z sin\theta cos\phi}\right) \tag{4}$$

GPS is a system that consist of space segment (transmitter) and user segment (receiver). Satellites as space segment provides information about coordinate values (latitude and longitude). Latitude coordinate represent x-axis of the earth and longitude coordinate represent y-axis of the earth. GPS is connected to microcontroller by serial communication pin (Rx and Tx) with baudrate used is 9600 bps. The data from GPS receiver is written in National Marine Electronics Association (NMEA) standard with decimal minute coordinate type format, so it must be change to decimal degree coordinate type format in order to validate in Google Maps [8].

BMP280 is a Barometer pressure sensor that measures air pressure in the range 300hPa to 1100hPa or equal to 9000 Meter Above Sea Level (MASL) to -500 MASL. This sensor is used to measures height of moving object. This sensor work using the principle of piezo-resistive. Barometer pressure is connected to microcontroller by Inter-Integrated Circuit (I2C) using Serial Data (SDA) and Serial Clock (SCL) pin.

Bearing theorem (Equation 5) used to calculate the angle between object and drone tracker. X and Y can be clculated using Equation 6 and 7. Haversine theorem (Equation 8) used to calculate the distance between object and drone tracker. R is the radius of earth that given value 6.371 km.

$$\text{Bearing} = \text{atan}\,(\text{X}, \text{Y}) \tag{5}$$

$$\text{X} = \sin\Delta\lambda \;* \cos\varphi_a \tag{6}$$

$$\text{Y} = \cos\varphi_o \,*\, \sin\varphi_a \text{-} \sin\varphi_o \,*\, \cos\varphi_a * \cos\Delta\lambda \tag{7}$$

$$d = R * 2 * arcsin\sqrt{sin^2(\frac{\Delta\varphi}{2}) + cos\,\varphi_1 * cos\,\varphi_2 * sin^2(\frac{\Delta\lambda}{2})} \quad (8)$$

Complementary filter is used to combine the same data from several different sensors to get a good data. Complementary filter is used also to remove noise signals. Complementary filter consists of two filter (high pass filter is used to remove the high frequency noise and low pass filter is used to remove the low frequency noise). Accelerometer and magnetometer have signal with high frequency noise, while gyroscope has signal with low frequency noise. The equation of complementary filter is given by Equation 9. K_G is coefficient for gyroscope and K_A for accelerometer and magnetometer (provided $K_A + K_G = 1$).

$$Angle = (K_G) \times \left(\int \omega_{Giroskop} dt\right) + (K_A) \times (\Theta_{Akselero}) \quad (9)$$

A microcontroller is an Integrated Circuit (IC) which can be reprogrammed repeatedly to control electronic devices. Atmega328p that embedded in Arduino Nano has a total 22 pins I/O which 8 pins can be used as analog input, 2 pins can be used as serial asynchronous port, 14 pins can be used as digital I/O, 6 pins can be used as PWM output and some pins has special function like Serial Pheripheral Interface (SPI), Light Emitting Diode (LED), and Inter Integrated Circuit (I2C). The microcontroller is used to process data from sensors into setpoint and PWM value.

Antena is a device that has two function (transmit and receive). Transmit is radiate data (electromagnetic waves) to free space, while receive is to capture data from free space. The antenna can be divided into directional and omnidirectional type of antennas. Directional antenna only has signal radiation pattern in one direction, whereas omnidirectional antenna has signal radiation pattern in all direction in 360° angles. This paper used omnidirectional antenna on moving object's payload and directional antenna on drone tracker (as shown in Figure 6). This directional antenna has a value of VSWR = 1.078, return loss = -28.436 dB, impedance = 49.352 Ω, and gain = 10.63 dB. Radio module that used to convert data into electromagnetic waves are 433MHz radio telemetry. Radio telemetry is connected to microcontroller using serial asynchronous communication. The radio telemetry works on baudrate 57600 bps.

Fig. 6. Antenna Yagi-Uda 433MHz.

Servo motor is an actuator designed to be able to determine the angular position of the motor output shaft. The rotation angle position of servo motor can be adjusted based on the PWM signal that transmitted from microcontroller. In this paper, motor servo that used is 180° motor servo RDS3135MG and 360° continuous motor servo DS04-NFC.

2.3. Design of Flow Diagram

Moving object's payload has flow diagram program as shown on Figure 7 and drone tracker has flow diagram program as shown in Figure 8.

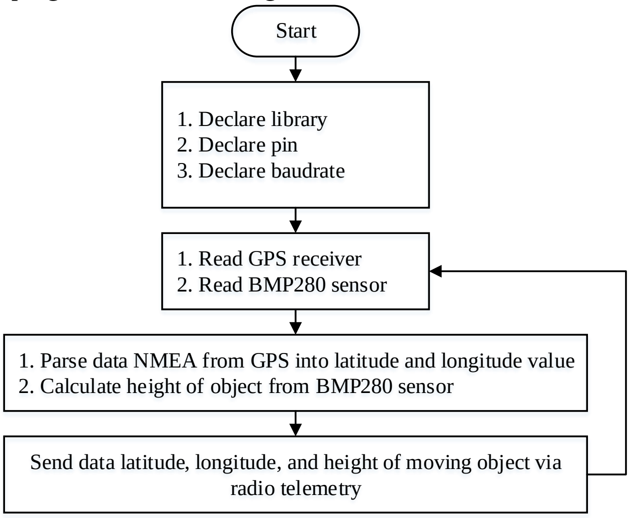

Fig. 7. Moving object's payload program flow diagram.

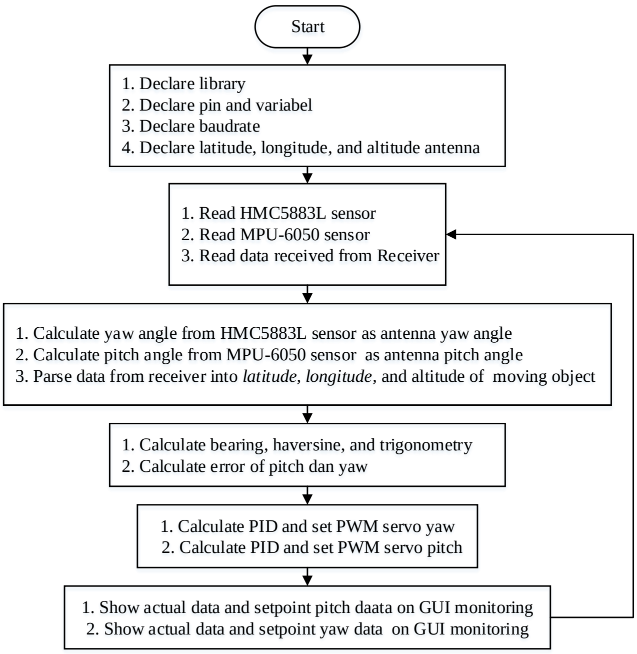

Fig. 8. Drone tracker program flow diagram.

3. Result

The test is done to know the accuracy of the GPS receiver in representing the moving object. The test is done at the distance between moving object and tracker is 30m in circular path. The test is done at Diponegoro University Stadion, Semarang. From the result of the test as shown in Figure 9, it is known that the GPS receiver has an error in determining the location up to 10m. From the test result can be concluded that GPS does not show the location of the actual object.

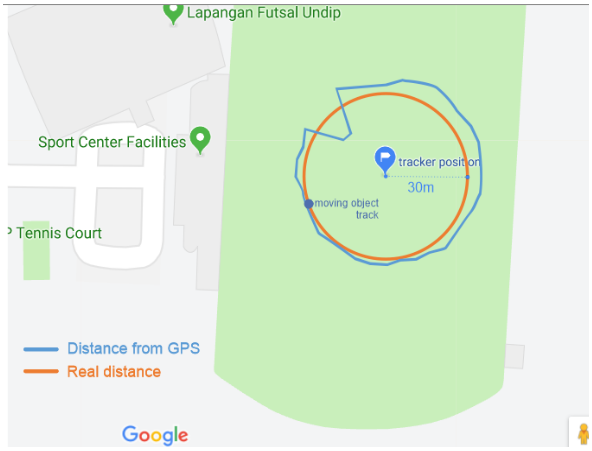

Fig. 9. Comparison of object distance from GPS with actual locaton.

The test is done to determine the response of tracker when receiveing setpoint changes. The setpoint value is sent through the Graphical User Interface (GUI). Testing at pitch plant was performed on the change of setpoints 0^o, 10^o, 20^o, 30^o, 40^o, 50^o, 60^o, 70^o, and 74^o by the change lowered and rised. testing at yaw plant was performed on the setpoint change of 30 in the range 0^o to 360^o by the change lowered and rised.

Attitude Testing

This test is performed to determine the response of tracker to the moving object (drone). Mounting the moving object's payload on the drone is shown in Figure 10.


(a) top view

(b) side view

Fig. 10. Mounting payload on the drone

From the test result at the yaw plant, plant is able to reach the setpoint in an average time = 500ms and has Mean Absolute Error (MAE) = 6.67^o. The test result is shown in Figure 11. From the test result at the pitch plant, plant is able to reach the setpoint in an average 400ms and has MAE = 1.54^o. The test result is shown in Figure 12.

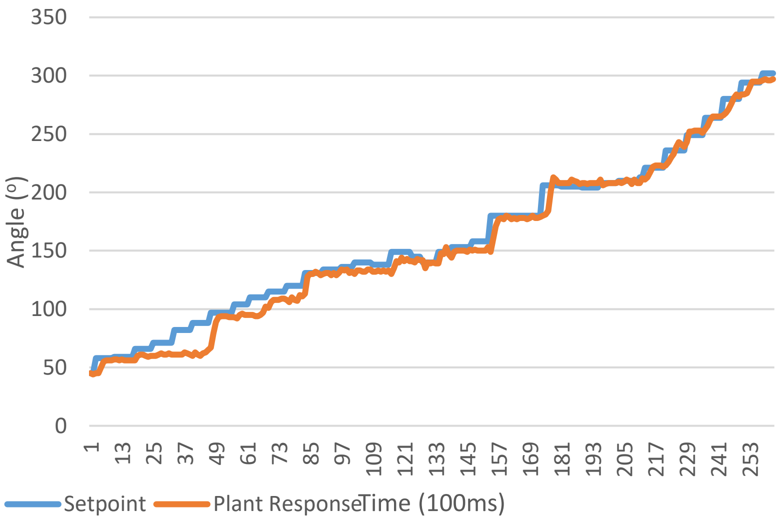

Fig. 11. The yaw plant response to drone

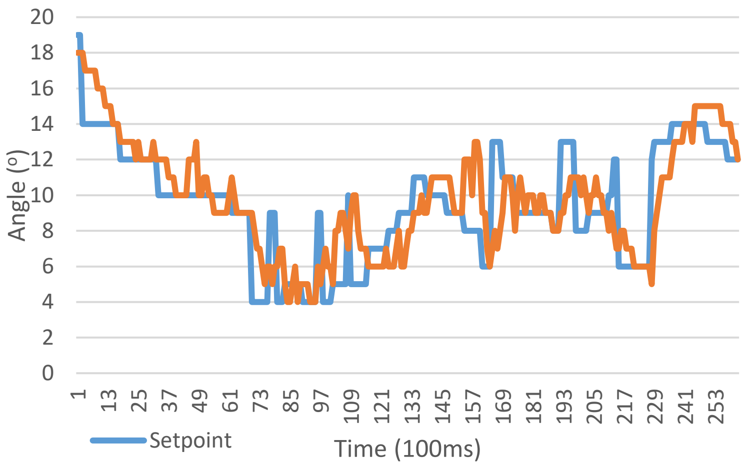

Fig. 12. The pitch plant response to drone

4. Conclusion

Drone tracking system has been successfully designed. The tracker can follow the moving object (drone) with the average time 500ms on the yaw plant and 400ms on the pitch plant. In following object, the tracker has a MAE of 1.54º on the pitch plant and 6.67º on the yaw plant. There is an error between the antenna's real direction and the antenna's direction data from the computer monitor, it is because the sensor that used (HMC5883L, BMP280, and GPS U-Blox M8N) in tracker and moving object's payload are not precise in representing actual position of the object and tracker.

Acknowledgments

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