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GPS-Based Rocket Payload Position Tracking System

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ABSTRAK

Kementerian Riset, Teknologi, dan Pendidikan Tinggi Indonesia secara rutin menyelenggarakan kompetisi payload tracking system yang ditempatkan di roket dengan Ground Control Station, kompetisi yang dikenal dengan Kompetisi Muatan Roket dan Roket Indonesia. Antena GCS dengan posisi tetap menyebabkan beberapa masalah, termasuk komunikasi yang buruk antara payload dan GCS dan deteksi posisi payload. Penelitian ini dilakukan untuk membuat sistem tracking yang mampu menggerakkan antena pada GCS ke arah posisi payload. Penelitian ini menggunakan dua buah servo untuk menggerakkan antena. Sistem bekerja dengan cara menghitung sudut azimuth koordinat GCS dan sudut payload, kemudian mengubah nilai azimuth menjadi nilai sudut servo. Perhitungan dilakukan oleh Arduino Mega 2560 yang kemudian memerintahkan servo horizontal dan vertikal untuk mengarahkan antena menuju posisi payload. Eksperimen dilakukan dengan tiga pengujian utama yaitu pelacakan posisi payload berdasarkan data GPS, pergerakan arah antena dengan arah gerak servo horizontal, dan pergerakan arah antena dengan arah gerak vertikal servo. Pengujian dilakukan dengan meletakkan muatan pada drone dan mengatur posisi dan ketinggian drone secara manual. Hasil percobaan menunjukkan bahwa perbedaan sudut terbesar antara sistem pelacakan dan muatan uji adalah 8 derajat azimuth. Perbedaan sudut rata-rata adalah 4,7 derajat. Penyimpangan sudut ini terjadi karena instruksi sudut servo hanya bisa dengan nilai integer.

ABSTRACT

The Ministry of Research, Technology and Higher Education Indonesia routinely hosts a competition of payload tracking system placed on a rocket with a Ground Control Station (GCS), a competition known as Kompetisi Muatan Roket dan Roket Indonesia. Fixed GCS antenna causes some problems, including poor communication between payload and GCS, and position detection of the payload. This research was conducted to create a tracking system capable of moving the GCS antenna towards the payload position. In this research, we use two servos to move the antenna. This payload position tracking system works by calculating the azimuth angle of GCS coordinate and of the payload, then converting the azimuth value into the servo angle value. The calculation performs by Arduino Mega 2560 which then commands both the horizontal and vertical servos to direct the antenna towards the payload position. The experiments are performed with three main tests that are of tracking payload position based on GPS data, of antenna direction movement with servo horizontal motion direction, and of antenna direction movement with servo vertical motion direction. Testing are carried out by laying the payload on a drone and adjust the position and height of the drone manually. Experimental results show that the largest angular difference between the tracking system and the payload is 8 degrees azimuth. The mean angle difference is 4.7 degrees. This angle deviation occurs because the servo angle instruction can only be with an integer value.

1. INTRODUCTION

Rocket payload is a substance that is carried inside the rocket, either as a dynamic payload from the rocket itself, or certain data that is the result of sensing and data collection for meteorological, military, mapping, or other purposes (Kelechi et al., 2021; Restrepo et al., 2018). The systems within the rocket payload deal not only with the specific onboard technology and radio systems assigned to convey mission objectives, but also the supporting ground equipment and telecommunication systems through which the spacecraft payload is controlled and results communicated to mission control (Mudarris, Basirung & Sumariyanto, 2022). Indonesia, as a large and broad maritime country, must be able to be independent in rocket technology (Putra & Zuhrie, 2019). The national agency responsible for research and development of this technology is the National Institute of Aeronautics and Space of Indonesia (LAPAN) (LAPAN, 2020). Given that Indonesia's sovereignty consists of thousands of islands stretching over long distances, mastery of this rocket technology must be a priority in mitigating threats (Salim, 2021). One of the efforts to achieve this independence is through continuous research and innovation in

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the development of technology, especially rocket technology, as a means of education and to attract interest, as well as preparing reliable prospective researchers and engineers in the National Rocket System (LAPAN, 2020; Mudarris, Basirung & Sumariyanto, 2022) The communication system commonly used in long-distance data exchange is telemetry (Hidayah, Salamah, & Sasono, 2022). The telemetry system sends data from sensor measurements placed in remote areas to a command center wirelessly. In payload rocket technology, data transmission is carried out wirelessly using this telemetry technology. With the help of telemetry, communication between transmitter and receiver can be done in real time (A.El., K., A., & H., 2021; R. et al., 2017).

The problem that still needs to be overcome in the payload rocket system is the quality of the received signal from the payload to the Ground Control Station (GCS) which often changes due to changes in the position of the rocket (Mudarris, Basirung & Sumariyanto, 2022). This condition occurs especially in the GCS which is equipped with an antenna with a fixed orientation. The maximum received signal is obtained if the alignment of the antenna on the GCS is done correctly (Kelechi et al., 2021). In this case, the antenna on the GCS must have the ability to change its direction, towards the rocket to be monitored. To do this, we need a mechanism that can track the position of the rocket. This payload is at least capable of sending altitude, coordinates, and temperature data at a certain altitude. The payload uses an omni-directional antenna, while the GCS uses a directional type antenna. To obtain good signal quality, the directional antenna on the GCS must always be pointed at the payload's position (Kelechi et al., 2021; Riyandi, Sumardi, & Prakoso, 2018). In this research, a tracking antenna prototype is designed that can direct the antenna to the position of the payload rocket. The prototype designed in this study is an automatic antenna tracking system using Arduino as the main controller in GCS. The control system on the GCS moves the antenna towards the payload position. Testing is carried out using a drone equipped with the payload. Data from payload is sent to the antenna on the ground receiver using telemetry. The drone is moved vertically and horizontally to test the tracking capabilities of the designed system. This study aims to overcome problems related to signal quality as stated by Riyandi (Riyandi et al., 2018). The problem is solved by aligning the antenna according to the payload position.This research was conducted with the consideration that rockets have become one of the crucial technologies to be developed independently by Indonesia. Rocket technology is urgently needed to be developed because other countries already have independence in this technology. Rocket development has become a long-term strategic policy that must be a concern of the nation.

2. METHOD

The prototype designed in this study is an automatic antenna tracking system using Arduino as the main controller. The scenario built is to place the payload on a drone, which moves in a certain direction. Payload sends its position (coordinates and altitude) to the receiver in GCS. Data is processed by the microcontroller in GCS to get the azimuth value. The control system on the GCS then moves the direction of the antenna towards the payload position. This scenario is described in Figure 1 The main controller is Arduino Mega 2560 (Arduino, 2022). This Arduino has multiple serial communication pins. Arduino computes the relative angle between payload and GCS based on their coordinates. The coordinates are detected by GPS modules using Ublox Neo-6M series.

The communication between both side is based on XBee technology, which is a low cost and low power consumption device. We use Xbee-Pro 900HP electronic module that is able to communicate between two microcontrollers wirelessly (Nugraha, Desnanjaya, Pranata, & Harianto, 2021). This tracking system uses two servo which have different work functions. The first servo is called for the horizontal movement of the antenna, which is based on the azimuth. The other is called for vertical movement of the antenna that based on the payload height. The MG995 Tower Pro Servos , are used which capable of achieving 10 kgf.cm of torque at a working voltage of 6 volts. Payload height is obtained using a barometer sensor, BMP180. The antenna attached to the GCS is a yagi antenna (Griffiths, 2022). The hardware block diagram is shown in Figure 2. This design includes Arduino Mega 2560 microcontroller shield, power supply unit, LCD unit, servo motor circuit, Global Positioning System sensor, Compass sensor, Barometer sensor, Xbee-Pro 900HP circuit, and Keypad Matrix circuit.

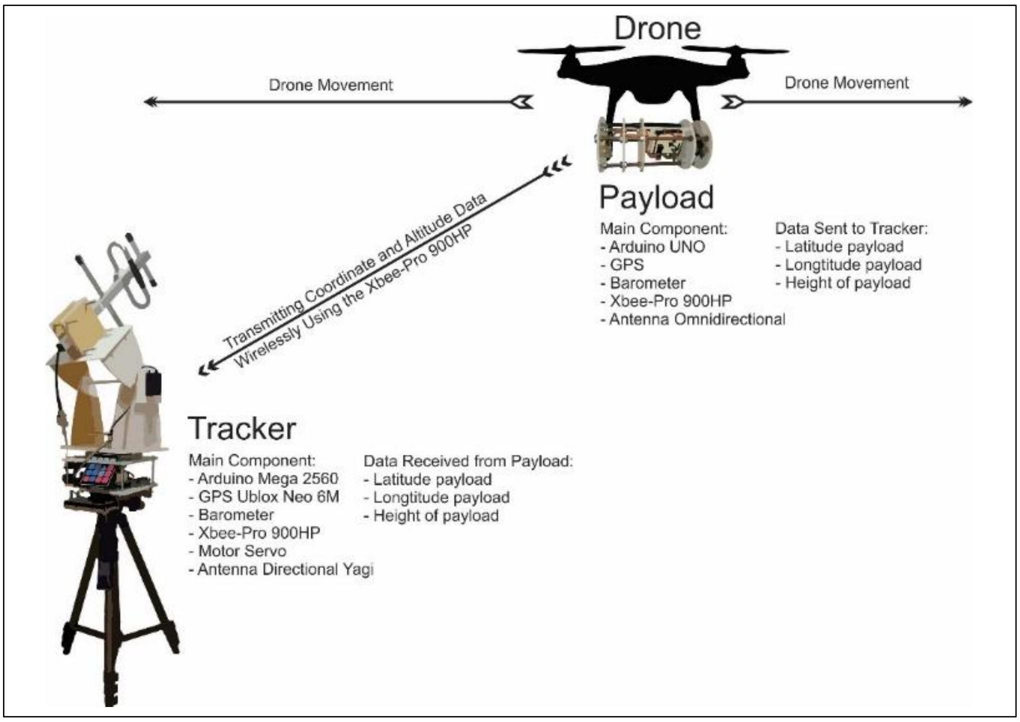

Figure 1. Model of the Tracking Systems

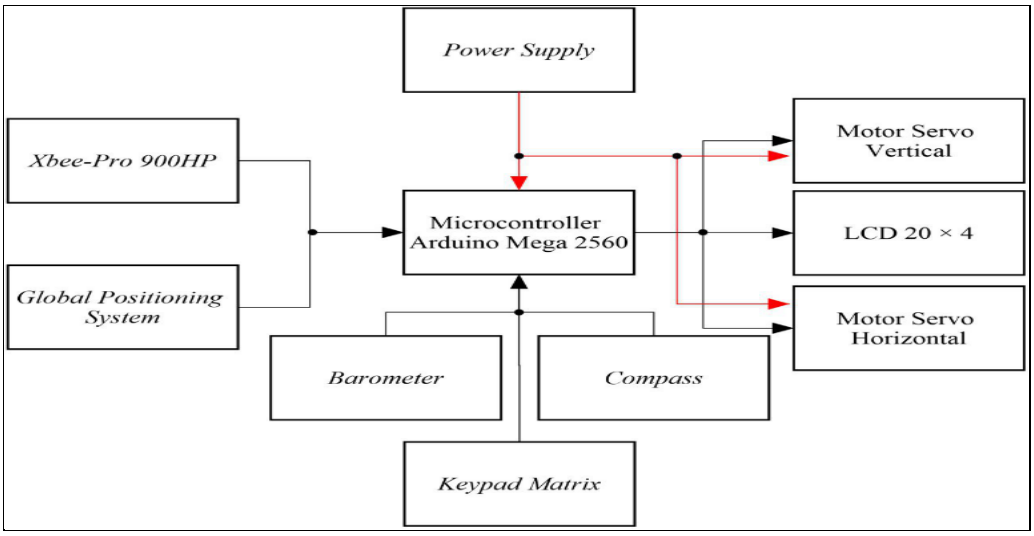

Figure 2. The Hardware Design Block Diagram

The system works as follows: The first is the initiation of the port and the variable used. After initiation, the program reads the input from the keypad, if there is a command from the keypad, the program automatically moves the servo and calibrates the azimuth angle reached by the servo. GPS sensor provides position information for tracking systems. After that the program will read the azimuth value via the compass sensor. This program will check whether there is data entered from the Xbee Pro-900HP sent by the payload. If there is data entered, the program will separate the data into coordinates and height of the payload. The program then calculate the servo angle required based on the coordinate and height. Finally, Arduino commands the servo to rotate accordingly. We work on the Arduino IDE 1.8.5 software with the C ++ programming language. The first step in changing the payload coordinates is done by activating the system on payload and waiting for the system to be ready. Next, we need to ensure that the Xbee-Pro 900HP on the payload is properly connected with the tracking system. Little delay is needed to allow the GPS on payload gets the correct reading. After GPS reading, activate the drone and wait for the drone to be ready. Then, fly the drone manually with the drone remote controller to change the position and height of the drone. Wait a moment until the payload position tracking system receives the data sent by the payload.

3. RESULT AND DISCUSSION

Result

The realization of the GPS-based Rocket Payload Position Tracking System research is shown in Figure 3 and Table 1. Two testing scenario were carried out, i.e. horizontal movement test and vertical movement test.

Horizontal Movement Test

This test aims to determine the required servo angle based on the azimuth data obtained. The position of the GCS is fixed, that is the latitude of -8.53500 and longitude of 115.14802. The payload position is shifted horizontally to the left and right. The azimuth value is obtained through the following formula (Azdy & F., 2020).

$$\beta = \operatorname{atan2}\big((\cos\theta_b \times \sin\Delta L), (\cos\theta_a \times \sin\theta_b - \sin\theta_a \times \cos\Delta L)\big) \tag{1}$$

and

$$Azimuth\ Degrees = \frac{(\beta \times 180)}{\pi} \tag{2}$$

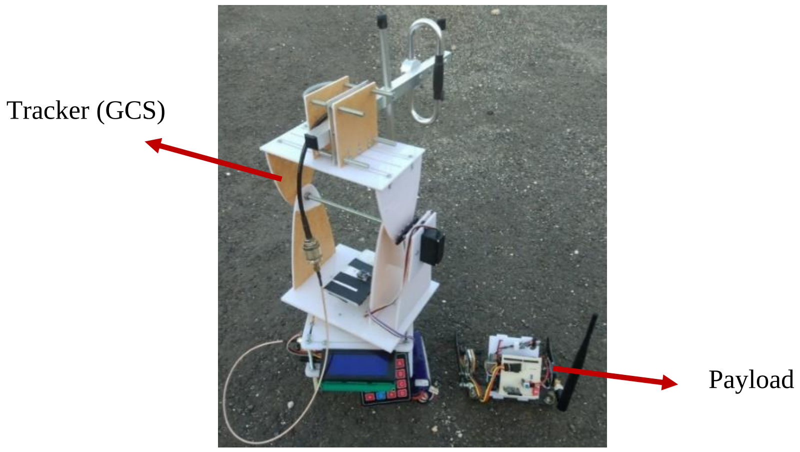

Figure 3. The Tracking System

where

β is bearing of two points
ΔL is the difference of longitude of two points
θ_a is the latitude of ground station
θ_b is the latitude of the payload

Table 1 shows the results of the experiments.

Table 1. Horizontal Servo Movement Tests

No	Payload Position		Angle (°)			Azimuth Difference (°)
	Latitude	Longitude	Azimuth Calculation	Azimuth Experiments	Servo	
1	-8.53526	115.14813	157	162	118	5
2	-8.53528	115.14801	182	183	95	1
3	-8.53521	115.14801	183	189	92	6
4	-8.53521	115.14797	193	198	80	5
5	-8.53525	115.14791	204	209	71	5
6	-8.53522	115.14791	206	204	70	2

No	Payload Position		Angle (°)			Azimuth Difference (°)
	Latitude	Longitude	Azimuth		Servo	
7	-8.53533	115.14782	211	203	70	8
8	-8.53521	115.14791	207	210	65	3
9	-8.53524	115.14783	218	213	60	5
10	-8.53518	115.14782	228	221	52	7

Those equations calculate the azimuth angle from the payload to the tracking system. Eq. (1) defined the angle in the Euclidean plane, given in radians, between two variables. Conversion to azimuth is done by Eq. (2) (Azdy & F., 2020). The second equation can produce positive and negative values, positive values mean north to south, while negative means south to north. The atan2 equation which is written in the first equation is the writing code on the Arduino microcontroller. The equation atan2 (x, y) is equal to the mathematical equation arctan = x / y (A.M. & H., 2020).

Vertical Antenna Movement Test

This test aims to obtain vertical servo angle values based on height and distance of the payload from ground station. The position of the ground station is fixed as before. Table 2 shows the experiment results.

Table 2. Vertical Servo Movement Tests

No	Payload Position		Height (m)	Angle (°)				Distance (m)
	Latitude	Longitude	Payload	Test	Servo	Calc	Deviation	
1	-8.53518	115.14782	163	4	73	5	1	29
2	-8.53528	115.14779	164	7	75	6	1	35
3	-8.53525	115.14791	165	12	79	11	1	24
4	-8.53522	115.14803	165	16	82	15	1	18
5	-8.53525	115.14791	170	20	85	21	1	25
6	-8.53528	115.14779	176	25	89	25	0	35
7	-8.53525	115.14791	173	28	91	27	1	25
8	-8.53528	115.14779	180	30	93	29	1	36
9	-8.53522	115.14803	173	34	96	34	0	19
10	-8.53522	115.14803	175	40	101	38	2	19

The calculated angle is the angle based on the arc tangent, while the servo angle is the angle given to the vertical direction servo based on the comparison of the tangent arc value. These results can be seen in figure 4.

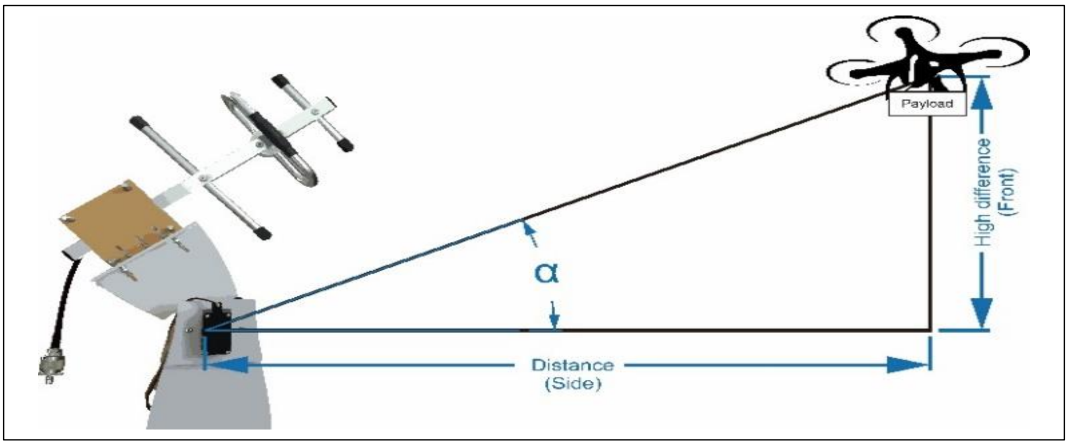

Figure 4. Arc Tangent Calculation

The arc tangent is computed as (T. & Schlicker S., 2022):

$$\alpha = tan^{-1}\left(\frac{Front}{Side}\right) \tag{3}$$

The front value is the height difference between the payload and the ground station, and side value is the distance between payload and ground station, at the surface of the earth. To find the distance between payload and ground station, we use the Haversine Formula (N. A., R., & N.F, 2020). Haversine formula is an equation to compute the distance between two coordinates (latitudes and longitudes) above the earth. Very small error in vertical direction acquires by the system, as shown in Figure 5.

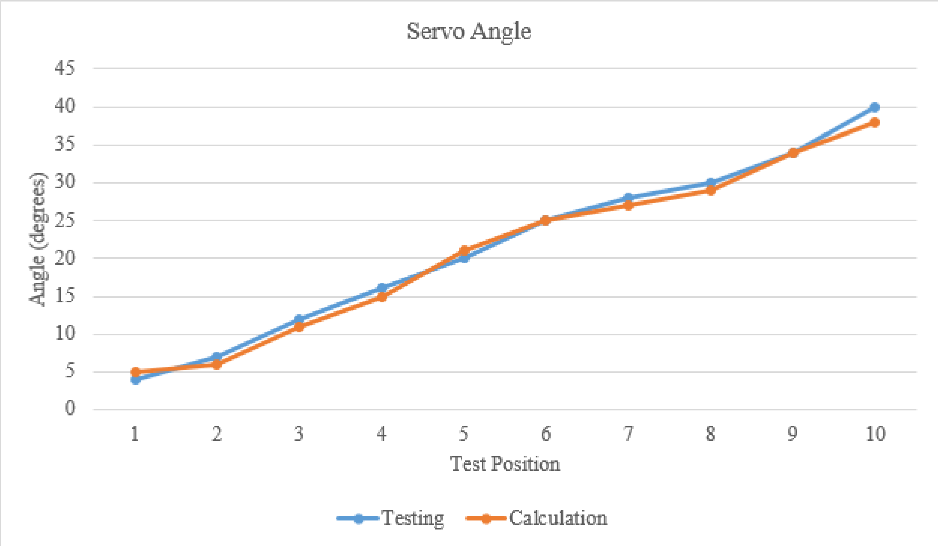

Figure 5. Vertical Movement Deviation

Discussion

The tracking system built in this study uses a Yagi directional antenna. Yagi antennas are widely used because of their high gain capability, low cost and ease of construction. This antenna is used in systems where the frequency range used is quite small. An Arduino Mega is used as a data processing center for sensors and servo controllers and another Arduino is placed on the payload. The payload contains an air pressure sensor to measure altitude, a position coordinate sensor or Global Positioning System (GPS), and Xbee-Pro 900HP as a data communication device. The payload is placed on a drone to make it easier to control its position and altitude. The advantage of this GPS-based payload position tracking system compared to similar studies lies in the use of a Yagi antenna so that the antenna beam is more focused and allows receiving data with a longer line-of-sight distance (R.E., H.A., M., M., & M.E.M., 2019; Z.B., Wardi, & G., 2019). The mechanical system uses a bearing mechanism so that the weight of the antenna can be supported evenly and does not affect the movement of the servo. Communication is carried out wirelessly using the Xbee-Pro 900HP which is technically capable of receiving data with a line-of-sight distance of up to 15.5 km with a data transfer rate of up to 200 kb/s (Buchori et al., 2018) The servo motor needs to be calibrated to find out the maximum movement of the servo so that the software does not give orders beyond the capabilities of the servo. In this tracking system, two servos are used, namely a servo for horizontal movement and a servo for vertical movement. The horizontal movement servo functions to move the tracking antenna according to the azimuth direction. The horizontal movement servo is located at the bottom of the antenna.

Experiments on the Global Positioning System (GPS) module were carried out to obtain the coordinates of the tracking system, that is –8.802288 latitude and 115.166580 longitude. Compass and barometer module experiments were carried out to obtain the azimuth direction and the altitude of the system based on air pressure. Compass sensor testing is assisted by the use of an analog compass as a reference value for the accuracy of the given azimuth value. The test is carried out by changing the position of the compass sensor so that the azimuth value given by the compass sensor is equal to the actual azimuth value (analog compass). Overall system testing is carried out by flying a drone carrying the payload. The payload send its position data in the form of latitude and longitude. This data is compared with the position of the tracking system to determine the rotation angle of the antenna directional servo.

This research focuses on payload tracking efforts, a bit different from research like Mudarris which focuses on rocket development (Mudarris, Basirung & Sumariyanto, 2022), Ashari which focused on control systems (A. A., A., H.A., & A.M., 2019), Hasanuddin on developing antennas (Mudarris, Basirung & Sumariyanto, 2022) Hidayah on rockets from carbon fiber (Hidayah et al., 2022) and (Putra & Zuhrie, 2019) on interfaces for monitoring.

According to the test results, the angle of the servo moves along with changing the position of the payload. The magnitude of the servo angle given is inversely proportional where the greater the azimuth angle, the smaller the servo angle given. Based on the test results it can be seen that the largest angular difference formed between the tracking system and the payload is 8 degree azimuth. Based on the result data in Table 1, the average angle difference (error) is 4.7 degree. This angle deviation occurs because the servo angle instructions can only be with integer values. The result data in table states that the horizontal movement of the antenna is close to conformity with the position of the payload. These results are better when compared to a similar study conducted by Riyandi which designed a tracker using PID control where the resulting average error reached 10.2 degrees (Cantanhede, Carvalho, Jesus, & Barros, 2022; Riyandi et al., 2018) The vertical direction of the servo movement represents the height ratio between the tracking system and the test payload. Servo vertical motion direction has an angle limit with the smallest value that can be achieved is 70 degree and the largest is 140 degree obtained based on previous vertical servo motion testing. The angle formed between the tracking system and the test payload has a minimum value of 0 degree and a maximum value of 90 degree . Adjustment of the magnitude of the servo value given is carried out so that the angle of the antenna formed is in accordance with the angle it should be. The adjustment is made by changing the actual angle value limit with the angle of the servo capability.

4. CONCLUSION

A Prototype of GPS based antenna tracker has been built. This tracker performs well in tracking payload position. The servo moves the antenna towards the payload based on the results of the payload coordinate readings that are converted into servo rotational angle. The test results show that the system works well seen from the small angle difference between reading and the actual angle. The GPS-based rocket payload tracking system has been able to track the position of the payload and is able to follow the movement of changes in the payload position based on the readings of the GPS sensors in the tracking system and the payload. The results of the GPS sensor readings on the test payload are sent via the Xbee-Pro 900HP, which supports RF Module with frequency of 902 and 928 MHz. The antenna direction of the GPS-based rocket tracking system has been able to approach the azimuth direction of the payload. The movement of the antenna direction servo is based on a comparison of the azimuth value obtained that calculated with the maximum angle value received by the vertical servo and the horizontal servo. The horizontal direction of the servo movement has approached the suitability of the payload position with the largest azimuth angle difference of 8 degree and the smallest angle difference is 1 degree. The vertical movement has an average angle difference of 0.9 degree, and the average angle difference (error) is 4.7 degree for horizontal servo movement.

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