Electric Ducted Fan (EDF) Rocket Attitude Telemetry Using 2.4 GHz Radio Frequency

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Abstract. On a rocket, control requires monitoring to determine its position and attitude. Rocket stance includes roll, pitch, and yaw angles. Monitoring can be done manually without the help of tools while the object's position is still within reach. It is difficult to carry out monitoring when the object is moving far and beyond the reach of the operator. This observation requires a monitoring system to monitor the object further. This research applies a telemetry system to a target tracking rocket. The measurement results from the IMU and GPS sensors on the rocket body will be processed by the ATmega 2560 microcontroller and sent via a 2.4 GHz RF signal to Ground Control Station. The rocket telemetry data that has been sent to the GCS can be viewed by the operator through the GUI system in a computer program using the C# language in Visual Studio. Tests on latitude and longitude are carried out by tracking the trajectory of objects while testing for roll, pitch, and yaw angles is carried out by placing objects according to the reference angle. The results of the position obtained the values of altitude, latitude, and longitude of 0.5364 m, 0.000012°, and 0.000023°, respectively. An attitude tests for roll position, pitch, and compass heading have values of 0.35°, 0.07, and 2.90°, respectively. The telemetry data transmission distance test is still well-received at a distance of 200 with a test speed of 70 KM/hour.

Keywords: Telemetry, GPS, IMU, Attitude, and Position

1. Introduction

Moving objects such as control rockets require monitoring to determine the position and attitude of the object. Attitude includes roll, pitch, and yaw angles. Monitoring can be done manually without the aid of tools when the object's position is still within reach. It is difficult to carry out monitoring when objects are moving far away and are out of reach of the operator. This monitoring requires a monitoring system to further monitor the object [1].

One method that can be used to determine the position and attitude of an object is by combining Global Positioning System (GPS) technology and inertial sensors which are incorporated in the Inertial Navigation System. GPS is a radio navigation and positioning system [2] using navigation satellites owned and managed by the United States Department of Defence. An inertia sensor is an electronic device that can measure and detect angular levels using a combination of an accelerometer, gyroscope [3], and magnetometer or a compass sensor. Accelerometer, gyroscope, and magnetometer data can be combined so that the resulting angle has a better value than the angle on each sensor. Combination of sensors can be done using complementary filters [3].

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Research on seekers and rocket control technology that has been carried out by Ahmad Dahlan University in collaboration with LAPAN [4] and BATAN [5]. This seeker system uses a PbS infrared detector which can capture radiation at a wavelength of 1.8 - 2.6 µm. This research has not used image processing technology [4].

Research conducted by Muhammad Hanifudin Al Fadli from Diponegoro University, used the IMU sensor for the control rocket's attitude telemetry which can measure the angle of the control rocket in the range of ± 15 ° with an average error of 0.108° for the x-axis and 0.137° for the axis. y. In this study, the results of telemetry-sensing rocket attitude were not discussed specifically because it was more specialized in research on the stability of the rocket control using the PID control method [5]. Research by Meita Sukma Listiyana from Diponegoro University. This study applies a telemetry system for UAV object attitude data acquisition using radio signals with a frequency of 433 MHz. In this study, the results of the maximum transmission range between the antenna transmitter and receiver as far as 125 meters [6].

Based on these problems and some research references that have been carried out, we conducted research on the radio frequency control rocket telemetry system. This rocket is also equipped with a long-range measurement system with a frequency of 2.4 GHz which allows the operator to monitor the rocket's attitude and position. The operator monitors the operation of the rocket on the GUI (Graphical User Interface) on the GCS (Ground Control Station).

2. System Overview and Design

2.1. System Flow Chart

The design of the software at the reception of telemetry data is done by designing a Graphical User Interface. The purpose of making GUI in this study is to monitor or monitor the position and attitude of objects in a place by the operator within a distance that cannot be reached. The GUI is created using the Visual Studio application using the C# programming language. The flow chart of the GUI display for the control rocket parameter data acquisition system is shown in Figure 1.

![Figure 1. Flow Chart of the Telemetry Program](image-url)
2.2. Hardware Design

In telemetry communication, the Atmega2560 microcontroller is designed to receive serial data from the Raspberry Pi, read data from the IMU GY-91 and GPS sensors with target coordinate data in the form of x, y from the frame, roll angle to the x axis, pitch angle to the y axis, yaw axis about the z axis.

![Telemetry data transmission device](image1)

*Figure 2. Telemetry data transmission device.*

The schematic of the telemetry data transmission hardware circuit can be seen in Figure 2. Data from the GPS sent in the form of latitude coordinate values (latitude) and longitude (longitude).

![Telemetry data receiving device](image2)

*Figure 3. Telemetry data receiving device.*

The schematic of the telemetry data reception hardware circuit can be seen in Figure 3. The control rocket data acquisition software is used to view the data sent by the rocket control which will then be displayed in a real time GUI display. The data is displayed in the form of a 2-dimensional avionics system and in the form of graphic data.

3. Result and Discussion

3.1. Altitude Testing

Altitude test results are carried out statically. Table 1 is a table of the results of the altitude test at three test points at the Diponegoro University stadium.

| No. | Altitude Reff (m) | Measured Altitude (m) | Error (m) |
|-----|-------------------|-----------------------|-----------|
| 1   | 200               | 200.516               | 0.516     |
| 2   | 203.86            | 204.44                | 0.58      |
| 3   | 205.66            | 206.346               | 0.686     |
| 4   | 209.26            | 209.698               | 0.438     |
| 5   | 214.06            | 214.522               | 0.462     |
|     | **Average error** |                       | **0.5364**|

Table 1. Altitude Test Result
Altitude testing by static means to get an average error value of 0.5364.

3.2. Testing latitude and longitude.

3.2.1. Static Testing
Static testing was carried out at three Geodetic Benchmark points in the Diponegoro University campus area. Bench mark I is located at the coordinates 7.049572S, 110.439143E. The test at point BM I was carried out by placing the object right on the BM GD-17 peg. Static GPS testing at Bench mark I point gets an error value at latitude of 0.000012° and longitude of 0.000023°. Every 1° implements a distance of 111,322 Km according to the length of the earth's equatorial line of 40,070 KM. The latitude error value is 1.335864 meters, and the longitude error is 2.560406 meters.

The benchmark II point with the code BM UNDIP GD 15 is located at coordinates 7.050281S, 110.438812E. Static GPS testing at the benchmark II point gets an error value at latitude of 0.000016° and longitude of 0.000032°. Every 1° implements a distance of 111,322 Km according to the length of the earth's equatorial line of 40,070 KM. The latitude error value is 1.781152 meters, and the longitude error is 3.56234 meters.

The benchmark III point with the code BM UNDIP GD 01 is located at coordinates 7.050281S, 110.438812E. Static GPS testing at the benchmark III point gets an error value at latitude of 0.00005° and longitude of 0.00009°. Every 1° implements a distance of 111,322 Km according to the length of the earth's equatorial line of 40,070 KM. The latitude error value is 0.55661 meters, and the longitude error is 1.001898 meters.

3.2.2. Dynamic Testing
Dynamic GPS testing is carried out by tracking the coordinates of the object's displacement route from three Geodetic Benchmark points in the Diponegoro University campus area. Tracking starts from point BM III, namely with the code BM UNDIP GD-01. The path that is traversed starts from the coordinates -7.053634, 110.439628 to the coordinates 7.050281S, 110.438812E. The results of dynamic GPS testing with tracking can be seen in Figure 4.

![Figure 4. GPS tracking results](image_url)

In Figure 8, the tracking for testing latitude and longitude data is in accordance with the path traversed by the object, but there are still differences in the results of the tracking test. Based on the test data in Appendix A, the average error obtained is 0.000012° and the average error at longitude is 0.000014°. The error in the distance is obtained the latitude 1.335864 meters error and the longitude error 1.558508.

3.3. Testing at Roll Angle (X).
The roll angle test is carried out by varying the angle on the x-axis. The error value of the test results is obtained by absolute reduction of the reference point value with the object angle. The roll angle
test results in an unstable graph, so that the value taken is the angle with the value farthest from the reference angle. The test results can be seen in Table 2.

**Table 2. Testing The Roll Angle on The X-Axis**

| No. | Reference Angle (°) | Rocket Angle (°) | Error (°) |
|-----|---------------------|-----------------|-----------|
| 1   | -90                 | -90.12          | 0.12      |
| 2   | -60                 | -60.68          | 0.68      |
| 3   | -45                 | -42.732         | 0.78      |
| 4   | -30                 | -27.824         | 0.17      |
| 5   | 0                   | 0.216           | 0.216     |
| 6   | 30                  | 29.342          | 0.27      |
| 7   | 45                  | 43.644          | 0.22      |
| 8   | 60                  | 57.796          | 0.17      |
| 9   | 90                  | 87.676          | 0.85      |
|     | **Average error**   |                 | **0.35°** |

From table 2 it can be seen that the 90° roll angle test has the farthest error value of 0.85°, the 0° roll angle test has the smallest error value of 0.06° and the average roll angle test error is 0.35°.

3.4. Testing at The Pitch Angle (Y)

Pitch angle testing is done by varying the angle on the y-axis. The error value of the test results is obtained by absolute reduction of the reference angle value with the object angle. The pitch angle test results in an unstable graph, so that the value taken is the angle with the farthest value from the reference angle. The test results can be seen in Table 3.

**Table 3. Testing The Pitch Angle on The Y-Axis**

| No. | Reference Angle (°) | Rocket Angle (°) | Error (°) |
|-----|---------------------|-----------------|-----------|
| 1   | -90                 | -89.58          | 0.42      |
| 2   | -60                 | -58.75          | 1.25      |
| 3   | -45                 | -45.51          | 0.51      |
| 4   | -30                 | -31.32          | 1.32      |
| 5   | 0                   | 0.07            | 0.07      |
| 6   | 30                  | 30.11           | 0.11      |
| 7   | 45                  | 45.69           | 0.69      |
| 8   | 60                  | 60.20           | 0.20      |
| 9   | 90                  | 90.64           | 0.64      |
|     | **Average error**   |                 | **0.61**  |

From table 3 the pitch angle test of -30° has the farthest error value of 1.32°, the 0° pitch angle test has the smallest error value of 0.07° and the average error value of the pitch angle test is 0.07°.

3.5. Testing at The Compass Heading Angle (Z)

Testing the compass heading angle on the rocket is done by aligning the object with a smartphone equipped with a compass application. The test is carried out with a variety of angles ranging from 0° to 6 times with a multiple test angle of 60°. The results of the object angle test against the compass can be seen in Table 4.
Table 4. Testing the Heading Angle on The Z-Axis of the North Magnetic Pole Of The Earth

| No. | Reference Angle (°) | Rocket Angle (°) | Error (°) |
|-----|---------------------|-----------------|-----------|
| 1   | 0                   | 1.30            | 1.30      |
| 2   | 60                  | 59.40           | 0.60      |
| 3   | 120                 | 121.50          | 1.50      |
| 4   | 180                 | 182.52          | 2.52      |
| 5   | 240                 | 234.65          | 5.35      |
| 6   | 300                 | 306.09          | 6.09      |

Average error 2.90

From table 4 in the heading test for the compass angle of 300°, the farthest error value is 6.09°, the heading test for the compass angle of 60° has the smallest error value of 0.60° and the average error for the heading test for the compass angle is 2.90°.

3.6. 2.4 GHz Radio Frequency Data Transfer Test

3.6.1. Static Testing
Static testing is done by placing the object at a test distance. The results of the data transfer test results on the position and attitude of the object using a 2.4 GHz radio frequency. The test results show that the position and attitude data of the object can only be received well up to a distance of 200 meters. Position and attitude data of objects are not well received at distances exceeding 250 meters.

3.6.2. Dynamic Testing
The dynamic test is carried out by carrying the object using a motorcycle at the test speed. This test is also carried out using a test point for the distance between the transmitter and receiver. The test results of the transfer of data on the position and attitude of objects using a 2.4 GHz radio frequency dynamically are shown in Tables 1 to 4.

Table 5. Testing Receiving Data with Variations in Object Speed

| No. | Motorcycle Speed | Receiving Data |
|-----|-----------------|----------------|
| 1   | 20 Km/h         | good           |
| 2   | 40 Km/h         | good           |
| 3   | 50 Km/h         | good           |
| 4   | 60 Km/h         | good           |
| 5   | 70 Km/h         | good           |

The test results on the object show that. The data sent by the rocket in the form of attitude and position can be well received at the tested speed variations.

3.7. GUI System Testing
The test was carried out in the area of the Diponegoro University Multipurpose Building. The test data is done by observing the coordinates of the location, 2-dimensional visuals and graphs of roll, pitch, and yaw. Figure 14 shows the position and attitude data of the object in that place.
Based on the examiner who shows the rank and attitude of the condition object in the multipurpose building, Diponegoro University, it can be monitored properly. The data obtained from this height are as follows:

1) The latitude and longitude values are -7.054016, 110.433273.
2) The value of the roll angle obtained is 0.72° against the x-axis.
3) The pitch angle value obtained is 1.75° to the y-axis.
4) The yaw angle value obtained is 10.33° to the compass angle.

4. Conclusion

Based on the tests and analyses carried out in the analysis, it can be concluded that the altitude test results statically get an average error value of 0.5364 meters. Static latitude and longitude test results data received from GPS have an average error value at latitude 0.000012° and longitude 0.000023°. Data from the dynamic latitude and longitude test results received from GPS have an average error value at latitude 0.000011° and longitude 0.000021. The attitude test for roll position has an average error value of 0.35°. The attitude test for pitch attitude has an average error value of 0.07°. The attitude test for the compass heading position has an average error value of 2.90°. The transmission range between the transmitter and receiver antenna is as far as 200 meters. Testing the transmission range of the telemetry antenna shows that until the object speed reaches 70 km/h or equivalent to 19.4 m/s, data can be received well at a distance of 200 meters. The object position and attitude data acquisition system has been successfully designed and the sensor reading value is still within the designed tolerance.

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