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LoRa SV611-Based Communication System To Monitor Behaviour of Rocket Using Inertial Measurement Unit Sensor

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Abstract*—A payload is a material carried by a rocket that acts as telemetry, monitoring environmental conditions and transmitting them to earth-based receiving stations. The goal of this study is to design, build, and test a rocket payload monitoring system that will track the rocket's position, behaviour, and trajectory. The rocket payload and the Ground Control Station are designed and manufactured separately (GCS). The payload is made up of a variety of components, including an Arduino Uno, an MPU-6050 sensor, a GPS Neo-7M, and a LoRa SV611 transmitter. The GCS is made up of a raspberry Pi, a LoRa SV611 receiver, USB TTL, and python idle. Pitch, roll, yaw, longitude, latitude, and altitude are among the six characteristics that the rocket payload monitoring system can track. The results of the tests show the rocket payload monitoring system can track six parameters and trajectory in real time with a high degree of accuracy. All payload measurement parameters are clearly displayed in the GCS interface as graphs that are updated every 1000 milliseconds.

Keywords*—Ground Control Station, LoRa V611, MPU-6050 Sensor, GPS Neo-7M, Raspberry Pi Rocket Payload.

I. INTRODUCTION

One of the leading technologies for developed countries is the advancement of aviation and space technology. Indonesia is one of the countries that has reached a fairly advanced level of mastery of ballistic rocket technology. The ballistic rockets and their payloads that feature rudder and elevator control systems can support the application of rocket control technology. Real-time monitoring of the rocket's behaviour during flight is essential to manage the rocket optimally, which modifies the behaviour of the rudder and elevator. Therefore, a more in-depth investigation is required to track the rocket's progress. A rocket payload and a ground control station (GSC) make up the rocket monitoring system. The rocket payload, which consists of sensors and radio telemetry, monitors the rocket's activity during flight. Meanwhile, the GSC receives rocket behaviour data via radio telemetry from the rocket payload.

Several researchers have conducted study concerning the monitoring system of the rocket's behaviour. The National Aeronautics and Space Agency (LAPAN) developed a telemetry system to measure temperature, pressure, and humidity at a certain altitude [1]. The system is used for weather monitoring or atmospheric research. The use of a KYL-200L Low Power Wireless Transceiver as radio telemetry in a rocket payload system that works as an attitude monitoring and surveillance system was designed and implemented by [2]. Furthermore, with nRF24L01 Serial Wireless Module Kits 2.4 GHz as the radio telemetry, an Inertial Measurement Units (IMUs) with 9 DOF and Direction Cosine Matrix algorithm were utilized to monitor the rocket dynamics attitude [3]. Radio telemetry devices with a limited range and higher energy consumption were utilized in the three experiments.

Therefore, a rocket behaviour monitoring system comprised of a rocket payload and a GSC was developed in this work. The rocket payload includes a GPS for tracking the rocket's position [4], an accelerometer sensor for tracking the rocket's acceleration and speed [5], a barometer sensor for measuring the rocket's heigh [6], and a gyroscope sensor for tracking the rocket's orientation [7], [8]. Radio telemetry, on the other hand, makes use of Long Range (LoRa) wireless communication equipment. This study makes a contribution by using a LoRa device as a radio telemetry device. Because of their extended range, low energy consumption, and lack of signal interference, LoRa devices are commonly employed in internet of things applications [9].

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II. METHODOLOGY

A. Overview of Rocket's Payload Monitoring System

The design of the rocket's payload monitoring system is depicted in Figure 1 as a block diagram. The rocket payload and the ground control station (GSC) are the two subsystems that make up the monitoring system. The MPU-6050 sensor, GPS Neo-7M, Arduino Uno R3, and LoRa SV611 transmitter make up the payload. On the GCS side, there's a LoRa SV611 receiver, a Raspberry Pi, and a display. The following is a description of the functions of each device:

- MPU-6050 measures tilt angle (pitch and roll), direction (yaw) consisting of accelerometer and gyroscope
- GPS NEO-7M measures latitude, longitude, distance and altitude of rocket payload
- Arduino Uno as a microcontroller process data that is read by the sensor and stored serially to LoRa SV611.
- The LoRa SV611 transmitter sends the data generated by the Arduino uno to be sent to the GCS system.
- The SV611 LoRa receiver receives data sent from the SV611 LoRa transmitter.
- The Raspberry Pi receives data from the LoRa SV611 receiver and processes it for display on the screen.
- The display shows graphical information on the measuring parameters of the rocket payload.

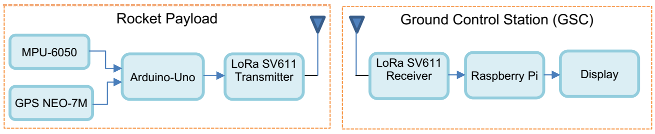

Fig. 1. Block diagram of rocket's payload monitoring system

B. Rocket Payload

The task of payload is to read data from sensors and GPS, which will be transmitted in real time to the ground control station via LoRa SV611. The MPU-6050 sensor then measures pitch, yaw, and roll angles [10], while the GPS NEO-7M measures latitude, longitude, and altitude [11]. After both of sensors measure their data, the LoRa SV611 send the data to the ground control station (GSC) to be shown in the display. The operation flow gram presented in Figure 2 depicts the payload's functioning procedure.

The payload module consists of three major components: an Arduino uno, MPU-6050 Sensor, GPS Neo-7M, and LoRa SV611. First, the Arduino Uno is a microcontroller based on the ATmega328P processor, which operates on a 16 MHz crystal. The Arduino Uno includes 14 digital I/O pins, 14 of which may be used as PWM outputs (pins 0 to 13), 6 analog input pins (A0 to A5), a USB connection, a power supply connector, an ICSP header, and a reset button. Second, the MPU-6050 is a sensor made up of a Micro Electro Mechanical System (MEMS) with a 3-axis accelerometer and a 3-axis gyroscope integrated onto a single chip [12]. The sensor also includes a temperature sensor, a magnetometer, and the capacity to detect inertia (velocity, orientation, gravitational force), as well as tilt. The sensor's value is derived from the rotation of the three axes x, y, and z. Third, the GPS NEO-7M module has a high sensitivity and capacity in tracking the conditions of an area, as well as a high solution in location and speed information. In order to communicate data to the microcontroller, this GPS employs RX/TX serial connection. This GPS module is capable of reading coordinates (latitude and longitude) as well as altitude. Fourth, the LoRa SV611 is a highly integrated multi-port radio data transceiver module with low reception sensitivity and 100mW output power for increased RF range and high link quality.

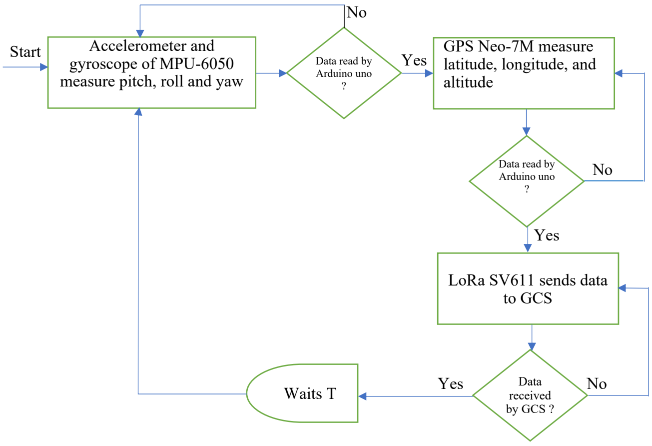

Fig. 2. Operation flow gram of the rocket payload

The payload module's configuration begins with defining the input and output pins on the Arduino Uno, which are listed in Table 1. As illustrated in Figure 3, the MPU-6050 sensor, GPS module, and LoRa SV611 are then connected to the Arduino Uno.

TABLE I. I/O PIN SETTING OF ARDUINO UNO

Arduino uno pin	Device	Role
A4	MPU-6050	Input from SDA pin
A5		Input from SCL pin
D2	GPS NEO-7M	Input from Tx pin
D3		Input from Rx pin
RX0	LoRa SV611	Input from Tx pin
TX1		Output to Rx pin

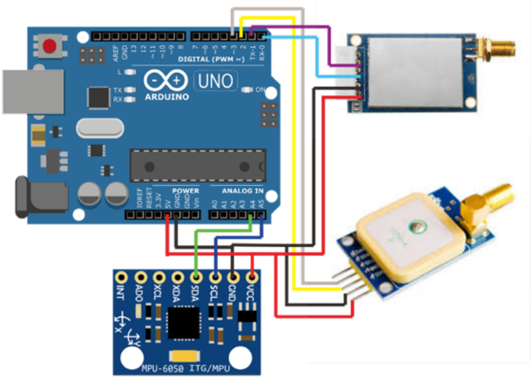

Fig. 3. The physical connection of Arduino uno, LoRa SV611, MPU-6050, and GPS NEO-7M

B.1. Pitch, Roll, and Yaw Angle

In Figure 4, when an object rotates clockwise around each axis looking from the origin in the positive direction, this is referred to as positive rotation. Therefore, the longitudinal axis or roll (+) by rotating clockwise around the x-axis. The lateral axis or pitch (+) is obtained by rotating clockwise

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around the y-axis. The vertical axis or yaw (+) is achieved by rotating clockwise around the z-axis.

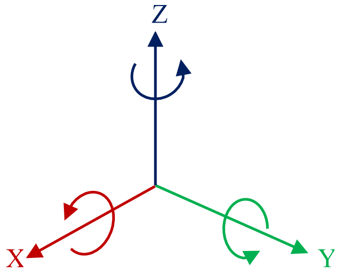

Fig. 4. Pitch, roll, and yaw rotation

Using raw data from the MEMS accelerometer, the MPU-6050 sensor read pitch, roll, and yaw angles in degrees. The underlying idea of the MEMS sensor is that variations in vibration acceleration cause changes in capacitance, which causes changes in the MEMS sensor's output voltage. The acceleration of the vibration is related to the change in capacitance. The full scale acceleration range is +/- 2g, +/- 4g, +/- 8g, +/-16g, with a Sensitivity Scale Factor of 16,384 LSB (count)/g. Accelerometer raw data in the form of x, y, and z axes recorded in units of gravitational force (). The following equation is used to obtain acceleration data for the x, y, and z axes:

acceleration along the x-axis = (raw accelerometer x-axis data/16384)g. (1)

acceleration along the y-axis = (raw data on the y-axis accelerometer/16384)g. (2)

acceleration along the z axis = (raw data of the z/16384) accelerometer axis. (3)

The following equation can be used to calculate the pitch and roll in degree from the x-axis, y-axis acceleration:

$$pitch_{deg} = \text{atan}\left(\frac{x}{\sqrt{y^2 + z^2}}\right) \times \left(\frac{180}{3.14}\right) \quad (4)$$

$$roll_{deg} = \text{atan}\left(\frac{y}{\sqrt{x^2 + z^2}}\right) \times \left(\frac{180}{3.14}\right) \quad (5)$$

A MEMS gyroscope detects rotation along the x, y, and z axes to determine the yaw angle. The following is the MEMS gyroscope's working principle:

- The Coriolis effect creates vibrations that are detected by the MEM when the gyroscope is turned around one of its axes.
- The resulting signal is amplified, demodulated, and filtered to produce a voltage proportionate to the angular velocity, which is then transformed to digital using a 16-bit ADC to sample each axis.
- The full-scale output range is +/- 250, +/- 500, +/- 1000, +/- 2000.
- In degrees per second, the angular velocity along each axis is measured.

With the following equation, the yaw angle may be calculated from the velocity along the z-axis:

angular velocity along the z-axis = (gyroscope/131 z-axis raw data) °/s. (6)

B.2. Distance of Payload

The Global Positioning System (GPS) can read the coordinates (latitude and longitude), altitude, and the number of satellites involved. Calculating the precise distance between two points involves the mathematical functions of geometry and trigonometry due to the shape of the earth. Calculating distance necessitates the use of latitude and longitude coordinates. In geometric science, The latitude and longitude coordinates are used to calculate cathetus A, cathetus B, and hypotenuse d. The following formula (7) through (9) [13] are be used to compute the distance between two GPS coordinates:

$$A = 69.1 \times (Lat_1 - Lat_2) \quad (7)$$

where Lat_1 is the coordinate-1's latitude and Lat_2 is the coordinate-2's latitude.

$$B = 69.1 \times (Lon_1 - Lon_2) \times \cos(Lat_1/57.3) \quad (8)$$

where Lon_1 is the coordinate-1's longitude and Lon_2 is the coordinate-2's longitude.

To translate coordinate degrees to ground distance in miles, it is used two constants 69.1 and 57.3. One degree of latitude equals 69.1 miles, and one degree of longitude equals 53 miles.

$$d = \sqrt[2]{A^2 + B^2} \times 1609.344 \quad (9)$$

The constant 1609.344 is used to convert miles to meters, where *d* is the overall distance in meters.

C. Ground Control Station

As illustrated in Figure 5, the Ground Control Station is made up of the following components: Raspberry Pi, LoRa SV611, SU108-TTL, and Display. The SU108 TTL module is used to connected the LoRa SV611 receiver to the Raspberry Pi's USB ports. Meanwhile, the monitor is directly l connected to one of the Raspberry Pi's USB ports.

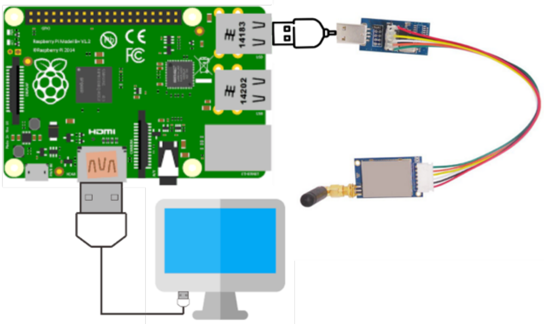

Fig. 5. The physical connection of Raspberry Pi, LoRa SV611, and display in ground control station

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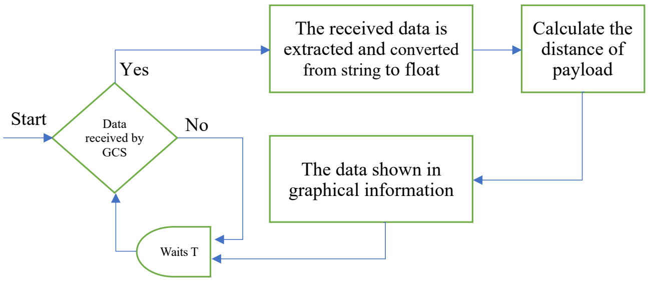

Fig. 6. Operation flow gram of the ground control station

Figure 6 depicts the usage of Python as the operation procedure to show data on the GSC's display. LoRa SV661 receiver will continue to wait for payload data. When data is received by the LoRa SV611, it sends it to the Raspberry Pi to be extracted into many parameters, including angle (pitch, roll, and yaw), coordinates (latitude and longitude), and altitude. The trajectory payload is displayed using the latitude, longitude, and altitude parameters. Meanwhile, pitch, roll and yaw are used to show the movement of payload.

III. RESULT AND DISCUSSION

The performance of the rocket payload, which was developed as shown in Fig. 7, was determined by measuring several parameters. LoRa SV611 transmission range, pitch angle and roll angle, yaw direction, distance and altitude of payload from Ground Control Station (GCS) are the metrics measured. The standard deviation was derived as a measure of the precision of its performance after all performance parameters were measured 30 times and the average value was obtained. Moreover, connectivity between GCS and Payload is also evaluated the performance.

Fig. 7. The hardware component of rocket payload

A. *Transmission Range Testing of LoRa*

The greatest transmission range that may be achieved was determined by conducting transmission range testing between the LoRa SV611 transmitter in the payload and the LoRa SV611 receiver in the GSC. Table 2 shows the LoRa transmission settings that were employed. This setting is similar to the one explored in the study [14].

TABLE II. LORA TRANSMISSION SETTINGS

Parameter	Value
Frequency	433 MHz
Power Transmission	17 dBm
Coding Rate (CR)	4/7
Bandwidth (BW)	125 kHz
Spreading Factor (SF)	7

Antennas having a gain of 1 dBi are used for both the transmitter and reception devices. The Raspberry Pi can receive the data and the light indicator in the LoRa SV611 receiver is on indicating excellent connectivity. The distance was measured in 50 meter increments. As demonstrated in Table 3, the maximum distance that can be achieved during testing is 500 meters with an RSSI of -114 dBm. This result is in line with that investigated by the study in [15].

TABLE III. TRANSMISSION RANGE TESTING

Distance (meter)	RSSI (dBm)	Connectivity
50	-84	Connected
100	-91	Connected
150	-102	Connected
200	-103	Connected
250	-105	Connected
300	-108	Connected
350	-109	Connected
400	-110	Connected
450	-111	Connected
500	-112	Connected
550	-114	Not connected

Fig. 8. Pitch angle initialized at 0°

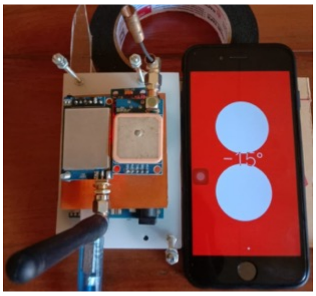

Fig. 9. Pitch angle measurement at -15°

TABLE IV. PICTH ANGLE TESTING IN PAYLOAD

Pitch in iPhone (degree)	Average of pitch in MPU-6050 (degree)	Deviation Standard
-15	-14	0.8
-30	-28	1.5
-45	-43	1.3
0	0	0
15	14	1.0
30	27	1.9
45	44	1.3
	Average	1.3

B. *Roll Angle Testing*

The roll angle test is likewise initialized at 0 degrees, as is the case with the pitch angle test, as seen in Figure 10. The payload is then rotated counter clockwise from -45 to -90 degrees and clockwise from 45 to 90 degrees, as shown in Figure 11. When comparing the angle readings from the iPhone and the MPU-6050 sensor, the results are nearly identical, with a minimal standard deviation. However, there

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is a significant discrepancy at 90 degrees, with a standard deviation of 2.6.

Fig. 10. Roll angle initialized at 0º

Fig. 11. Roll angle measurement at -90º

TABLE V. ROLL ANGLE TESTING IN PAYLOAD

Pitch in iPhone (degree)	Average of pitch in MPU-6050 (degree)	Deviation Standard
-45	-44	0.7
-60	-60	0.3
-90	-87	1.9
0	0	0
45	43	1.5
60	60	0.7
90	86	2.6
Average		1.28

C. Yaw Angle Testing

The iPhone's compass is used as a reference for measuring yaw angle. As seen in Figure 12, the initial position is set at a 0º. The payload is then rotated counter clockwise around the z-axis. When measuring from 90 to 270 degrees, the results are accurate with a low standard deviation, but when measuring from 360 degrees, the difference is greater but still within reasonable bounds.

Fig. 12. Yaw angle initialized at 0º

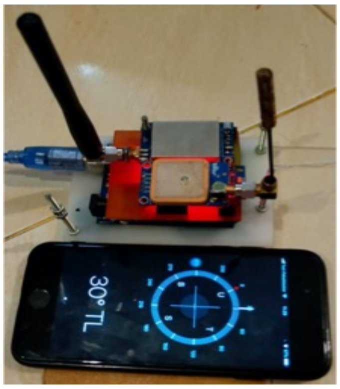

Fig.13. Yaw angle measurement at 30º

TABLE VI. YAW ANGLE TESTING IN PAYLOAD

Yaw using Compass of iPhone (degree)	Average of yaw in MPU-6050 (degree)	Deviation Standard
0	0	0
90	91	0.5
180	183	0.2
270	271	0.4
360	360	1.5
Average		0.65

D. Payload Distance Testing

A GPS attached to the payload measures the payload's distance from the GCS, which is subsequently sent to the GCS. The use of GPS to estimate distance is compared to the use of a roll meter to calculate distance manually. To assure data accuracy, measurements are taken at a distance of 5 to 30 meters in increments of 5, with each measurement lasting 5 minutes. As demonstrated in Table 7, the distance accuracy utilizing GPS is very high, with a standard deviation of 0.4.

TABLE 7. PAYLOAD DISTANCE FROM GSC

Distance (meter) using roll meter	Distance (meter) using GPS	Deviation Standard
0	1	0.7
5	7	1.4
10	10	0
15	15	0
20	21	0.7
25	25	0
30	30	0
Average		0.4

E. Payload Altitude Testing

The altitude measurement, like the payload distance from the GCS, with on GPS embedded into the payload. The GPS must be calibrated to zero at the GSC site because the altitude measurement on GPS refers to the altitude above sea level. The payload is suspended from a rope and measured from a distance of 5 to 15 meters in 5 meter increments. The accuracy of the measurement is compared to that of manually measuring with a roll meter. As demonstrated in Table 8, the accuracy of altitude measurement using GPS is fairly high, with a standard deviation of 1.2.

TABLE 8. PAYLOAD ALTITUDE FROM GCS

Altitude (meter) using roll meter	Altitude (meter) using GPS	Deviation Standard
0	0	0
5	5	0
10	13	2.1
15	11	2.8
Average		1.2

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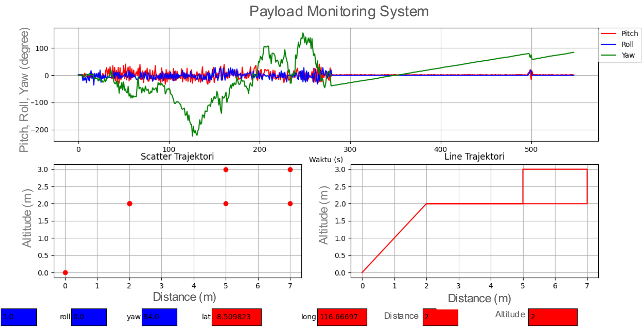
F. Functional System Testing between GCS and Payload

Figure 14 depicts the GCS interface for presenting updated data in each 1000 milliseconds on pitch, roll, yaw, longitude, latitude, distance, altitude, and movement and trajectory of payload. The GSC interface clearly displays all metric information, as well as movement and trajectories of payload.



Pitch 1.0 roll 0.0 yaw 84.0 lat -8.509823 long 116.66697 Distance 2 Altitude 2

Fig. 14. Interface of Payload Monitoring in GCS

Caption:

1. Pitch: to show the payload's slope (nod) in degrees.
2. Roll: to show the slope load (shaking) in degrees.
3. Yaw: to show the angle (direction) of the payload in degrees.
4. Pitch, Roll, and Yaw Graph: to present information about the pitch roll yaw state on a graph.
5. Scatter trajectory: to show the position of the payload as a scatter plot
6. Trajectory line: this option displays the payload trajectory as a line graph.

IV. CONCLUSION

The rocket payload monitoring system can track seven payload characteristics in real time (pitch, roll, yaw, distance, altitude, and trajectory) with a high degree of accuracy (low standard deviation value). All payload measurement parameters are clearly displayed in the GCS interface as graphs that are refreshed every 1000 milliseconds. The transmission range of LoRa was only 500 meters.

V. ACKNOWLEDGMENT

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