

# Multi-Parameter Wireless Monitoring and Telecommand of a Rocket Payload: Design and Implementation

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**Abstract.** A rocket system generally consists of two parts, the rocket motor and the payload. The payload system is built of several sensors such as accelerometer, gyroscope, magnetometer, and also a surveillance camera. These sensors are used to monitor the rocket in a three-dimensional axis which determine its attitude. Additionally, the payload must be able to perform image capturing in a certain distance using telecommand. This article is intended to describe the design and also the implementation of a rocket payload which has attitude monitoring and telecommand ability from the ground control station using a long-range wireless module Digi XBee Pro 900 HP.

## 1. Introduction

As one of the aerospace vehicles, rocket plays an important role in a various purpose from military to commercial use. A rocket is usually equipped with a set of sensors for monitoring the rocket behaviour or attitude and also surveillance. Many countries develop prototypes of rocket payload to aim a recognition for its aerospace technology [1]. The Indonesian National Institute of Aeronautics and Space (LAPAN) cooperate with the Ministry of Research and Higher Education (Kemenristek Dikti) have been organising a rocket competition called Komurindo since 2009 as an incubator for the next Indonesian satellite system.

A rocket itself usually consist of at least, two parts: the rocket control system and the payload. The payload has several sensors for monitoring the trajectory monitoring and surveillance, then a wireless module to send the monitored data to the ground control station (GCS) [2]. One of the mission carried is the rocket's attitude monitoring which usually performed by using accelerometer and gyroscope sensor to get the 3-dimensional movement data [3]. A compass and a GPS sensor also being used to sense the location of the rocket. Additionally, the payload system also has a camera to capture image in a certain distance.

In [4] the attitude monitoring is proposed using 3 axis gyroscope to measure the angle of rocket payload. However, the use of gyroscope itself has some lacks since it cannot sense the acceleration and forces that occurs to the rocket. Meanwhile, accelerometer itself cannot measure the orientation of the rocket. So that, the use of both sensors, accelerometer and gyroscope are essential to get a more accurate result.

Beside attitude monitoring, a payload can also have surveillance feature. The design of a rocket payload surveillance system has been proposed in [5] by using the uCam-TTL camera to capture 200×200 pixel grey-scale still image. This system has succeeded in capturing an image of a coastline though it suffered some losses.



Furthermore, for the telemetry function, a payload must be equipped with a wireless module as the transmitter of the payload data to the GCS. Prades et al in [6] designed a broadband 3-dimensional biconical antenna which works on 869.4–869.65 MHz and 2.4–2.4835 GHz frequency bands.

Reinaldo et al in [7] has developed a prototype of a rocket dynamics attitude monitoring. It uses an IMU system which is able to sense 3-degree movement such as yaw, pitch, and roll of a rocket. Nevertheless, this system uses the 2.4 GHz of frequency performed by the XBee S2.

Meanwhile, this paper comes up with a payload system with accelerometer and gyroscope for attitude monitoring, compass and GPS sensors for positioning, also a VC0706 serial camera to capture a 300×300 pixel still image. The organization of this paper as it follows the literature review of the components, the system design, the presented data from the experiments, and conclusion. Additionally, this system is using only a single band 900 MHz Digi XBee Pro HP wireless communication module since the rulebook of Komurindo 2017 only allows a single band communication either 433 or 900 MHz working frequencies.

## 2. Literature Review

The rocket payload system in this paper is equipped with a GY-80 multi sensor board which has accelerometer and gyroscope sensors, a VC0706 serial camera for surveillance, a compass sensor Devantech CMPS10, and a GPS sensor Ublox Neo M8N.

### 2.1. Arduino Mega 2560 Board

The *Arduino Mega 2560* is a microcontroller board based on the Atmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analogue inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with USB cable or power it with a AC-to-DC adapter or battery to get started. The Mega 2560 board is compatible with most shields designed for the Uno and the former boards Duemilanove or Diecimila. Figure 1 shows the *Arduino Mega 2560 Board*.

### 2.2. GY-80 Multi Sensor Board

The GY-80 board combines 5 sensors in a single tiny board which consists of ADXL345 accelerometer, L3G4200D gyroscope, MC5883L magnetometer, and BMP085 as the barometer and temperature sensor. However, this paper only uses two parameters: the linear motion data from the 3-axis accelerometer and the angular rotation from the 3-axis gyroscope [8]. Figure 2 shows the board of GY-08.



Figure 1. Arduino Mega 2560



Figure 2. GY-80 multi sensor board

### 2.3. VC0706 Serial Camera

The VC0706 is an UART VGA camera which has an active pixel array of 649×489. It also has sophisticated functions such as windowing, and mirroring. It uses 1/4 CMOS image sensor MT9V011 and the resulted picture from this camera is in JPEG format [9]. Since this system only requires 300×300 pixel of image, the speed of image transfer is supposed to be faster. The figure 3 below shows the VC0706 camera.

#### 2.4. U-Blox NEO-M8N GPS module

The u-blox NEO-M8N utilizes concurrent reception of the global navigation satellite system (GNSS), simultaneously recognizes multiple constellations, and provides accuracy in positioning. It supports UART, USB, SPI, and DDC interfaces and works in a range of 2.7 – 3.6 V supply. This module can also be used in data logging applications which includes continuous storage of position, velocity, and time information to an onboard SQI flash memory. The information then can be downloaded from the receiver, which is the GCS for location analysis [10]. The figure 4 shows the picture of u-blox NEO-M8.

#### 2.5. Digi XBee Pro 900HP

This wireless module works in 902 – 928 MHz band of frequencies which supports serial data transmission up to 200 kbps of data rate and a maximum line-of-sight range of 15.5 km. It is equipped with ADF7023 transceiver, cortex-M3 EFM32G230 @ 28 MHz processor. The module also needs transmit power up to 24 dBm or 250 mW software selectable [11]. Though it supports several networking topologies, in this paper it will be used in a point-to-point communication between the payload and the ground control station. The following figure shows the XBee Pro 900HP wireless module.



### 3. System Design

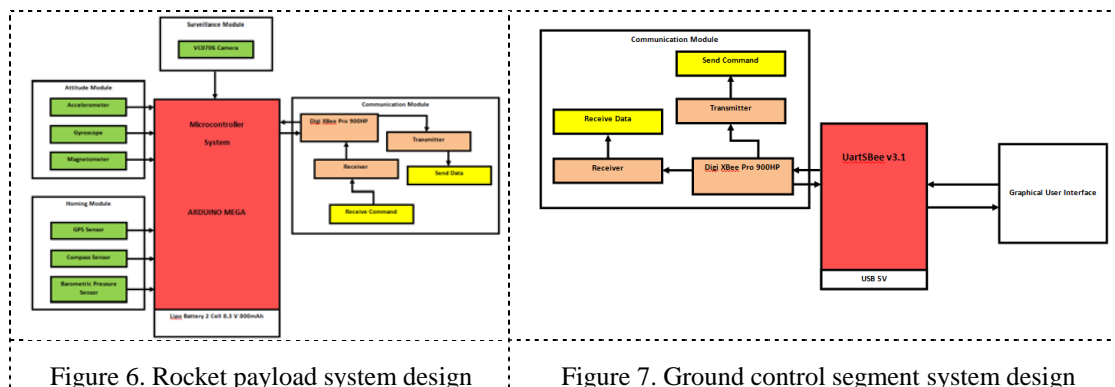
The system design for developing a rocket payload dynamics attitude monitoring system divided into two main parts. First, the rocket payload transmitter and the second is ground segment receiver. Figure 6 is a block diagram of the rocket payload and the block diagram of ground control segment shown in Figure 7. And the system was worked on one of three modes, i.e. idle mode, attitude monitoring mode, surveillance mode. As shown in Figure 8.

**Idle Mode**, Where the payload is powered on and no data being transmitted to the Ground Control Segment (GCS). In addition the GCS could send a command to the payload to start the attitude monitoring mode or surveillance mode.

**Attitude Monitoring Mode**, Continuously sends the rocket's 3-dimensional movement data to the Ground Control Segment (GCS).

And this mode, the GCS can send a command to stop monitoring the attitude.

**Surveillance Mode**, The payload sends a 200 x 200 pixels still image to the Ground Control Segment (GCS). The payload will return to the idle mode after the data transmission was completed.



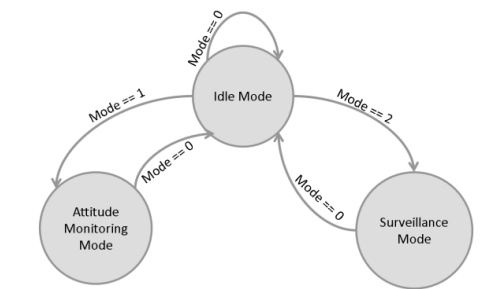


Figure 8. Rocket payload system modes

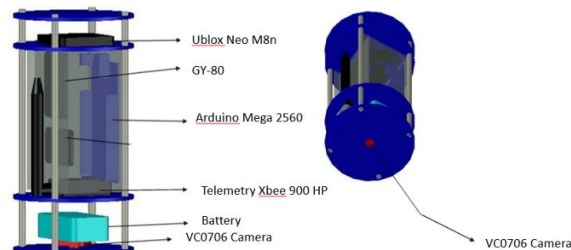


Figure 9. Rocket Payload Design

### 3.1. Rocket Payload System Design

Rocket payload system consists of Arduino Mega2560, GY-80 module, Ublox Neo M8N GPS module, VC0706 camera module, Lipo Battery 2 cell 8.3 V 800 mAh. It has a mission to process data from GY-80 into a dynamics rocket attitude, and capture the aerial photography also track the rocket through the GPS. These data then sent to the ground control segment by the radio telemetry communication, Digi Xbee Pro 900HP. The following figure shows the rocket payload design

## 4. Experimental Result and Implementation

Testing system in this research is done experimentally, i.e. by testing functionality, responsiveness and system endurance against some variety of testing methods. Test method is test-based mechanics such as G-Force test and G-Shock test. Function test of telecommand was also performed in this study simultaneously on any mechanical test, i.e. by turning On/Off the telecommand through Ground Control Segment while the hardware on testing. Also, there are some more test, Capture test from camera on the rocket payload and 3-dimensional representation (pitch, roll, yaw).

### 4.1. G-Force Test

In the G-Force test, the result of the automatic chart plot feature GCS for telemetry data can be seen in the Figure 10. Based on the graph plot, the acceleration of inertia that is measured by the accelerometer sensor is not constant, but varies against time with a maximum value about 2 G. This is an accordance with the actual treatment given to the system during the test, which provides a variation of inertial acceleration through spinning the rocket payload hardware with unstable speed and angular acceleration.

### 4.2. G-Shock Test

In the G-Shock test, the GCS automatic chart plot for telemetry data accelerometer sensor can be seen in the Figure 11. Based on the graph plot, the accelerometer sensor reads every beat that is applied with a fairly good response as one of the accelerometer sensor functions as a mechanical shock sensor.

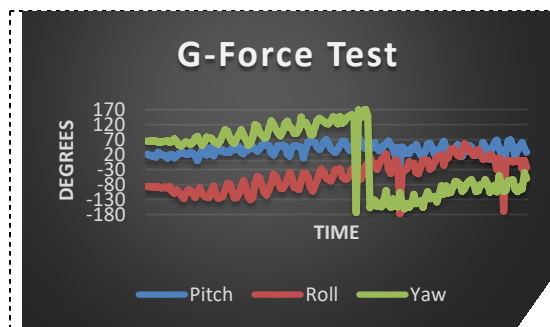


Figure 10. G-Force test chart

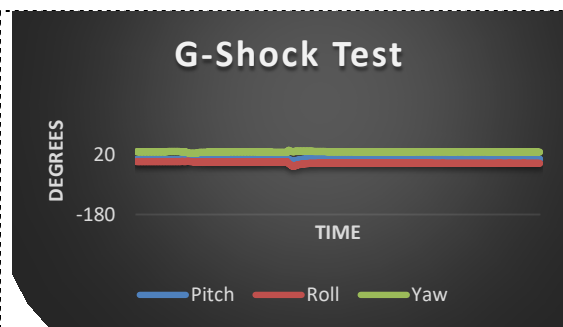


Figure 11. G-Shock test chart

This is evidenced by the emergence of peaks such as spectrum on the graph. This spectrum basically means the magnitude and timing of the pounding. The rise of the spectrum peaks on this result coincides very closely with the time of striking and has a maximum value about 2G. This is also evidenced by the periodicity of the readable signal corresponding to the actual state in which the vibrational frequency applied in the test is constant. In addition, the signal-readability patterns read by the accelerometer sensor in this test can also be interpreted as measurable vibrational characteristics or patterns.

## 5. Capture Test

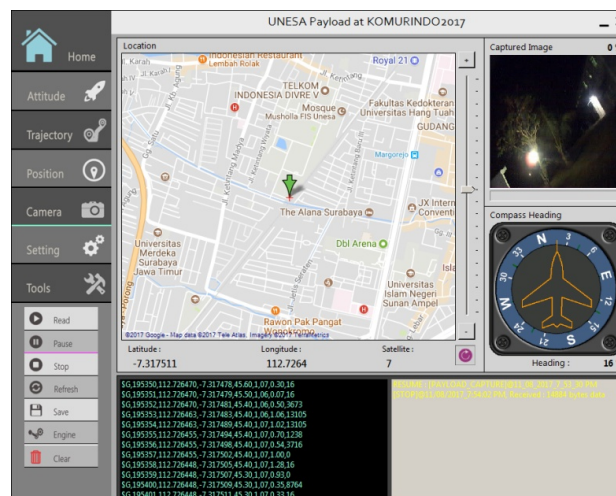


Figure 12. GPS location monitoring shown in GUI

### 5.1. 3-Dimensional Representation

3-Dimensional representation of rocket payload attitude was displayed on Ground Control Segment and the values of pitch, roll, yaw to determine the movement are also shown in graphic.

#### 5.1.1. Idle Condition

This the idle condition where the rocket payload was not moving yet. All the three-line results just straight line which means, the orientation was 0 degree on all movement.

#### 5.1.2. Pitch Movement

Based on the test results shown in Figure 14, it appears that the gyroscope sensor module can work well to detect angular velocity. This can be seen in the sensor module testing while moving. While

pitching, there is a change in blue line. The overall test aims to analyze of the system in the rocket payload in measuring the orientation angle.

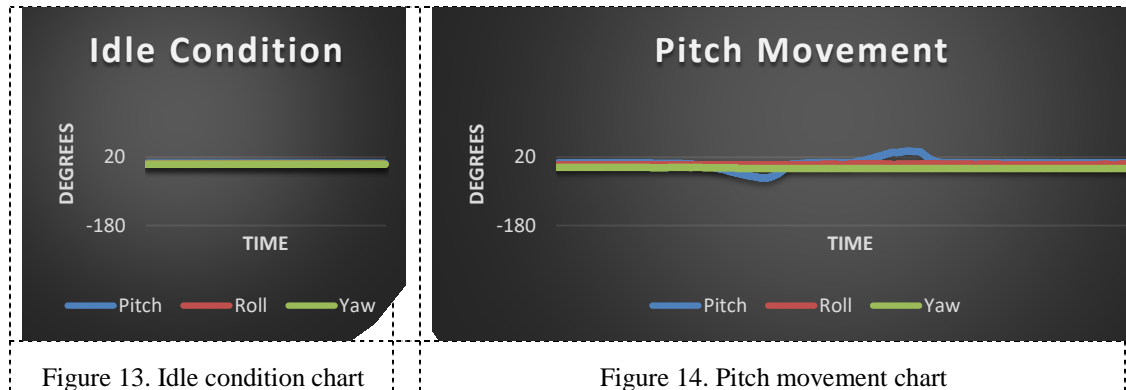


Figure 13. Idle condition chart

Figure 14. Pitch movement chart

#### 5.1.3. Roll Movement

Based on the test results shown in Figure 14, it appears that the gyroscope sensor module can work well to detect angular velocity. This can be seen in the sensor module testing while moving. While rolling, there is a change in red line.

This test is carried out by connecting the circuit according to the block diagram in Figure 6. A protactor is used as a reference to compare the magnitude of the orientation angle of the gyroscope.

#### 5.1.4. Yaw Movement

Based on the test results shown in Figure 16 it appears that the gyroscope sensor module can work well to detect angular velocity. This can be seen in the sensor module testing while moving. While pitching, there is a change in green line. The measured angles of orientation are sent to the GCS via a Digi XBee Pro 900HP. Then the data is observed and recorded for analysis for each orientation angle.

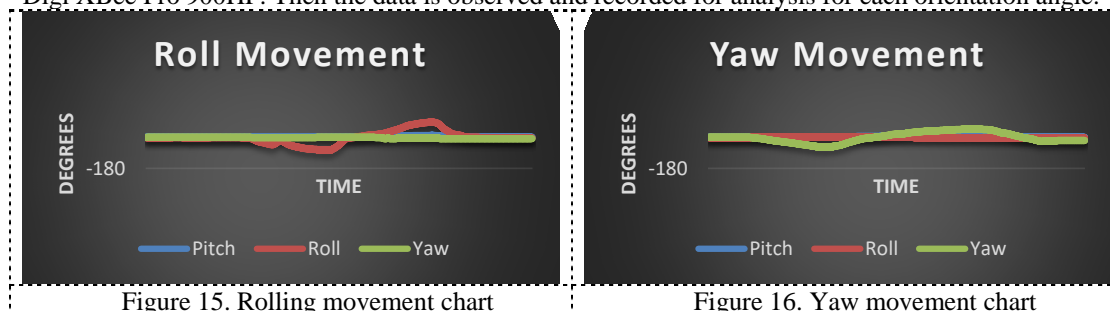


Figure 15. Rolling movement chart

Figure 16. Yaw movement chart

## 6. Conclusions

Based on the results, it can be concluded that the designed payload system is succeed to monitor the attitude of the rocket and has the ability of telecommand for surveillance. Although the GUI has not meet the 3D movement animation yet, the payload is still functional and can be developed into a better system.

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