LoRa Transmission System for Weather Balloons

May Anne C. Valencia [1], Febus Reidj G. Cruz [1,2], Raymart B. Balakit [1]
[1] *School of Graduate Studies, Mapua University, Manila, Philippines*
[2] *School of Electrical Electronics and Computer Engineering, Mapua University, Manila, Philippines*
frgcruz@mapua.edu.ph

***Abstract*—Upper-air observation uses radiosonde, via weather balloon, to measure atmospheric data in order to make an accurate weather forecast. This observation includes the gathering of air pressure, temperature, and relative humidity from ground level to the above of the lower troposphere. In this study, Long-Range (LoRa) embedded modules are used to provide transmission of atmospheric data from the radiosonde carried by a balloon to the ground system for their low-cost, low-power and long-range characteristics. The data to be transmitted, received and saved in secure digital card includes sample atmospheric data, location coordinates, altitude, timestamps and data for power monitoring. Environmental tests and actual balloon flight test were conducted to determine the performance of the transmission of data. Based on the results of the tests, 433 MHz RFM96W LoRa RF transceiver module successfully transmit data up to approximately 10 kilometers of altitude as a transmitter of the payload. Transmission of every data happens once in a second. The payload has an output power of 300 mW, has a weight of 292 grams, and has 50% cost compared with commercial radiosondes. Supply voltage lasts for almost 57 hours.**

Keywords—weather balloon, atmospheric data, upper-air, radiosonde, LoRa technology

I. Introduction

Upper-air observation is one of the meteorological observations done throughout the world. It uses a radiosonde because it must measure the meteorology from the ground to the above of the lower troposphere, with an altitude of 6 to 11 kilometers from earth surface where most of the world's weather phenomena take place, in order to understand the air state and make an accurate weather forecast. Weather monitoring plays a significant role in the daily lives of people, especially in economic, civil protection, environmental, farming, and transportation activities. Instrumentation for the observation of the weather in the different countries has made great contributions in weather monitoring. For accuracy and real-time measurements, although advanced technology is used in the weather instruments nowadays, most of the upper-air observation agencies throughout the world still use some traditional instruments, like the radiosondes and weather balloon, to monitor weather-determining factors, such as temperature, pressure, and humidity.

Radiosonde defined as an upper-air weather instrument carried up by balloon, which measures atmospheric pressure, temperature and humidity [1]. However, the transmission of these data faces challenges. A weather balloon is used at least two kilometers of altitude, thus data are difficult to transmit in the receiver ground system. A transmitter must have good modulation and power efficiency properties. Design of antenna of both the transmitter and receiver must also have high gain. Furthermore, since the transmitter is carried by a balloon, it should be light in weight, and since most of the countries use weather balloon two to four times a day to get an accurate and real-time upper-air weather observation compared to the observations used by advanced weather instruments that used satellites, so the cost must be considered, too. Another problem is the power consumed by the transmitter. The higher the power is used, the bigger the battery required. This certainly affects the weight of the balloon.

Cost is one of the main issues in using weather balloon system. The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), an authorized agency of the Philippines to monitor daily weather, has seven upper-air stations throughout the country. Each station launches radiosondes twice daily. Costs of the balloon and the hydrogen for inflating the balloon are not yet included. Commercial high altitude radiosondes cost approximately $200 each [2]. Every launch of radiosonde cost $325 which includes the cost of the radiosonde, the balloon and the labor [3]. The lower altitude radiosondes cost around $155 [4].

In considering weight, cost, distance, and power, many types of research related to the consideration of commercially available embedded system and modules for the transmitter of weather balloon have been made. For example, in the study of Sankar and Norman, a hydrogen balloon with embedded sensors and RDM-A4FZ Radio Frequency transceiver module was introduced [5]. The RDM-A4FZ is a transceiver module that uses an external voltage-controlled oscillator (VCO) that allows users to set the operating frequency anywhere between 400 to 440 MHz. Another in Indonesia, Budi Setiyono and his colleagues proposed a measurement system of temperature, humidity and air pressure with 433MHz RF transmitter modules [6]. Tests for determining the maximum length of data transmission using the said modules in either without an obstacle or line of sight conditions were drawn. Both the previous studies mentioned have only tested their systems to a low altitude. Sankar and his colleague only tested their system to an altitude of approximately 100 to 200 meters. Similarly, Setiyono and his colleagues obtained optimal transmission distances as far as 97 meters without obstacle condition only. They even concluded that the data transmission requires module and RF antenna type with better gain so that it can reach longer distances.

For that matter, this study aims to design a low-cost, LoRa-based transmission system for weather balloons. Specifically, it aims to implement a LoRa transmitter for weather balloon; to construct a ground station that receives and saves the atmospheric data on the secure digital (SD) card; and to conduct weather balloon flight test.

This study would benefit PAGASA since this will allow them to use long-range, low-power, lightweight, low-cost and commercially-available transmitter that can contribute to the functionality of the weather balloon. This study will be also a step further into the many applications of data transmission with longer distance.

This study concentrates on the design of the transmission system of a weather balloon, and environmental sensors are not included. It focuses on the utilization of Long Range (LoRa) Radio Frequency (RF) transceiver module RFM96W

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and it is chosen for its long-range, low-cost and low-power characteristics. This is focused only on the determination of the characteristics of the transmitter, such as the power consumption, data errors, time interval of transmission for each string of data and maximum range of the transceiver module, and not to build a whole weather balloon system with environmental sensors and recovery system and its actual implementation in a specific location. The same module is used for the ground station as the receiver. It also focuses on location and altitude tracking, time stamping, power monitoring, and data logging capability of the weather balloon system. Sample atmospheric data are inputted in the program of microcontroller and they are limited to temperature, atmospheric pressure and relative humidity with units of a degree Centigrade (°C), hectopascal (hPa) and percent (%), respectively. Units to be received and saved are the sample atmospheric data with their time of transmission and reception in hour, minute and second format, the location in its latitude and longitude coordinates in decimal format with 4 decimal places of accuracy, the altitude in meter units, and the battery voltage, output current and power in volts, milliamperes and milliwatts units, consecutively.

II. Proposed System

A. Hardware Design

The prototype system consists of a weather balloon and a ground station. Figure 1 shows the prototype model. Weather balloon consists of the payload and the balloon itself. The ground station is the receiver end.

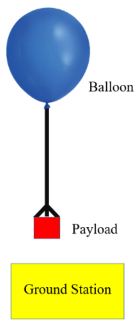

Fig. 1. Prototype model

Figure 2 presents the block diagram of the parts of the payload that will be sent in the atmosphere.

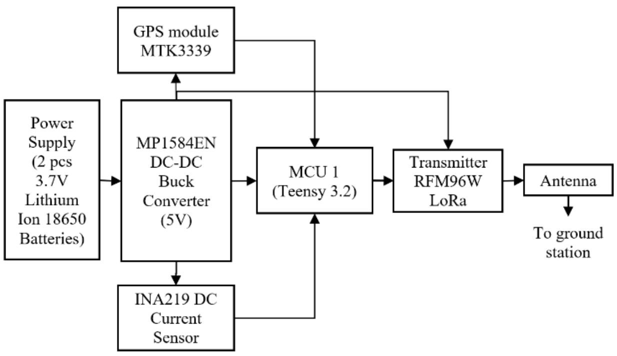

Fig. 2. Block diagram of the payload

The power supply consists of two pieces of 18650 lithium-ion batteries in series connection. One battery has 3.7-V nominal voltage and 2200-mAh capacity. It has a weight of 48 grams. But parts of the payload just need 5 volts as their supply, so MP1584EN DC-DC buck converter is connected after the power supply to convert the total battery output voltage 7.4 volts to 5 volts only. The output voltage of the buck converter is set manually by rotating the trimmer resistor. Then use the voltmeter to check the output voltage.

GPS module tracks the location coordinates (latitude and longitude) and altitude of the payload. Adafruit Ultimate GPS Breakout Version 3 is chosen as the GPS module. It is built around the MTK3339 chipset. Its operating current is 25 mA and it weighs 8.5 grams. It can track up to 22 satellites on 66 channels and has a built-in antenna and real-time clock (RTC). To use the clock, a CR1220 battery is attached. Based on its datasheet, only 7 μA is drawn to the RTC circuitry, so it can last up to 240 days continuously since CR1220 has 40-mAh current rating [7][8].

Teensy 3.2 is used as a microcontroller unit (MCU 1) and it processes time stamp, altitude and location coordinates and altitude from GPS module, the sample atmospheric data, and the voltage, current, and power from the current sensor. It has small dimensions, but high memory. It has 256 kB flash memory, 64 kB RAM and 2 kB EEPROM [9][10].

INA219 DC current sensor is added in the payload circuitry for power monitoring. It measures the supply voltage, current drawn in the output with approximately 1% precision and the output power.

The transmitter used is the RFM96W transceiver module which transmits data in radio frequency through an antenna to the ground station. Based on its datasheet, it incorporates the LoRa (Long Range) modem which uses a spread spectrum modulation technique based from Frequency Shift Keying (FSK). This permits an increase in link budget and increased immunity to in-band interference. This also permits simple coexistence with existing FSK-based systems. Standard GFSK, FSK, OOK, and GMSK modulation is also provided to allows compatibility with existing systems [11]. Its center operating frequency is 433 MHz [12].

The antenna used is a 433-MHz coil-loaded antenna. Like a whip antenna and dipole antennas, it has an omnidirectional radiation pattern, radiating equal radio power in all directions perpendicular to the antenna's axis. These antennas are widely used for communication where the direction of the transmitter is constantly changing. It is a simple alternative to the whip which is to add an inductor near the base of the whip to compensate for the resulting capacitive reactance as if it is not part of the length of the antenna. The antenna has a gain of 8 dB and an input impedance of 50 Ω.

Figure 3 shows the physical look of the payload. It was enclosed by styrofoam with a thickness of ½ inch. With the help of glue stick and Kapton tape, it prevents moisture from going inside and affects the circuitry. It is suspended to the balloon thru a 5.5-meter cotton 3-ply thread.

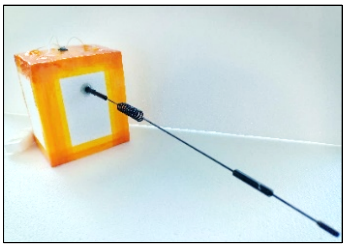

Fig. 3. The payload

Figure 4 shows the block diagram of the ground station that will receive and store the transmitted data. The same type of batteries of the payload is used in the ground station to supply the receiver and microcontroller (MCU 2). A DC-DC buck converter is also used to convert the voltage to 5 volts.

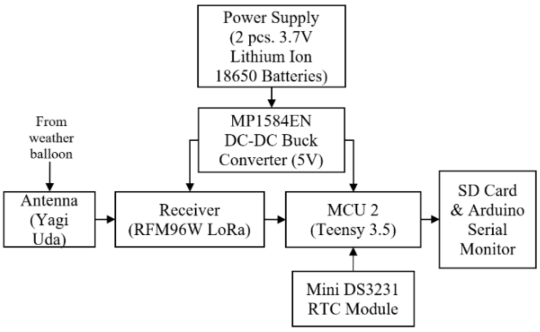

Fig. 4. Block diagram of ground station

Yagi Uda or Yagi antenna is used as the receiving antenna. Its frequency range is 390-480 MHz, but its center frequency is 435 MHz. It is a directional antenna with 7 elements and a gain of 9 dBi [13][14]. Since RFM96W is a transceiver module, it is also used as the receiver. For time stamping in the ground station, mini DS3231 RTC module is used. It has own battery backup for continuous timing. Teensy 3.5 is used as the MCU 2. The difference of Teensy 3.2 from 3.5 is that the latter has a built-in SD card adapter that saves the data into the SD card. For actual monitoring, the Arduino serial monitor is used. The SD card used in the ground station has a capacity of approximately 4 gigabytes (GB).

Figure 5 shows the physical setup of the ground station. A female UFL connector is used to connect the transmitter and the antenna. Micro-USB cable is also used to interface the MCU 2 to the serial monitor of the Arduino.

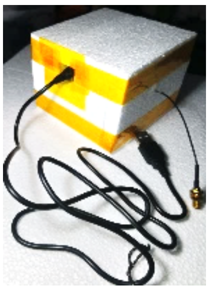

Fig. 5. The ground station

B. *Firmware Design*

Sample data consists of air temperature in degree Celsius (°C), the relative humidity in percent (%), and air pressure in hectopascal (hPa). These data will be inputted in the program of the MCU 1. Time, location coordinates and altitude from the GPS module, together with the power monitoring data from INA219, are also processed by the MCU 1 simultaneously with the sample data. The language to be used by MCU 1 is C language, and the program is based on Arduino libraries.

Then, a program in MCU 2 processes and save the received data. It also reads and saves the timestamp from the RTC. Since MCU 2 has already the capability of saving the data in SD card, so there is no need to use SD card adapter and additional program for it.

III. Results

Experimental trials were performed to test the performance of the radiosonde in terms of average power output during transmission, the interval of data transmitted, data storage capacity, error in the data transmitted and maximum range of transmission. These trials involve environmental tests, horizontal range test, and actual balloon flight test. Cost and weight are also evaluated after the tests.

To observe the operation of the payload at different environmental conditions, tests were conducted using Terchy MHK-408 Temperature and Humidity Chamber, and Theodor Friedrichs and Co. Pressure Chamber. It was observed under 25°C, 30°C and -40°C and the power outputs are computed by using standard deviation. The test shows that the colder the temperature, the lesser the output power. To relate in the weather balloon, since as the altitude goes higher, the temperature goes down, the lesser the output power of the payload. Then, the lower the altitude it may reach.

Under the same temperature conditions, the interval time between two strings of data being transmitted shown in Figure 6. It shows that the temperature less likely affects the sending time of strings of data because the average transmission interval time between two strings of data is approximately once per second.

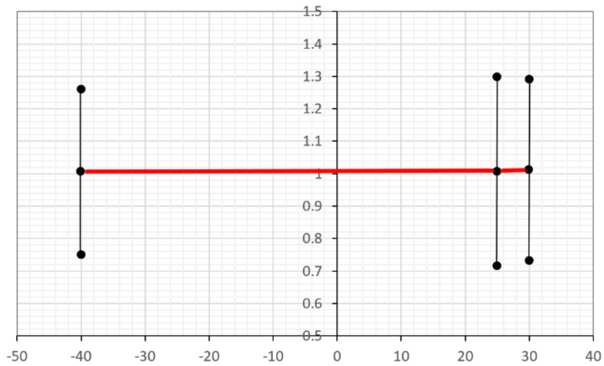

Fig. 6. Interval time of data transmitted under 25 °C, 30 °C and -40 °C

In terms of the data error during transmission, under the same temperature conditions, sample data of the temperature of 14.20 °C, relative humidity of 99% and pressure of 804.08 hPa were transmitted and observed for errors.

The operation of the payload under relative humidity conditions was also observed. It was done simultaneously with the temperature. For 25 °C, the relative humidity is 80%, while for 30 °C, it is 98%. So, the performance of the payload during these conditions was the same when it was under 25 °C and 30 °C. Relative humidity is measured only when the temperature is positive, thus, there is no observation in the operation of the payload when the temperature is going down to -40°C.

Figure 7 presents the power outputs during the pressure test. The payload was put in the pressure chamber with a pressure range capability of 1050 hPa to 700 hPa. Unfortunately, the pressure in the chamber was changed manually by rotating valves. Thus, as seen in the graph, the interval of pressure is not constant. But, it is still reliable. The trendline (line in yellow) shows that as the pressure gets stronger, the power output gets weaker. The transmission distance will be likely affected.

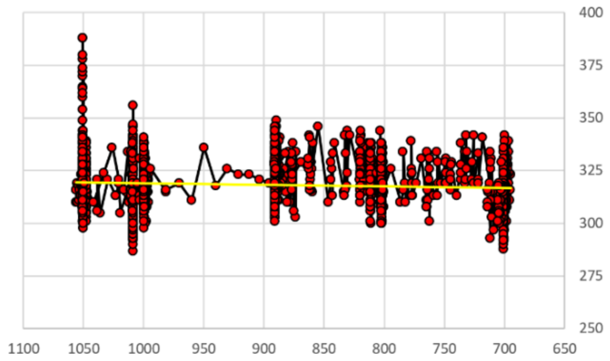

Fig. 7. Power output during pressure test

The environmental tests lasted for 2.75 hours. During that duration, 14682 strings of data were transmitted, received and recorded in an SD card in a text document. The total data capacity is only 1592 kilobytes (kB) for those strings of data.

To determine the maximum range of the payload to transmit data to the receiver, before it will be carried to a weather balloon, it was first tested in the ground horizontally. The receiver and the Yagi Uda antenna were temporarily installed in the rooftop of a dormitory in Alimannao Hills, Peñablanca, Cagayan (Point A), while the transmitter with dipole antenna was carried by a car going to Namabbalan Norte, Tuguegarao City where the transmitter stopped sending data (Point B). The coordinates of A given by the GPS of the receiver and from Google Earth is 17.6437° N, 121.7597°E, while the coordinates of B on its maximum functional distance is 17.5547° N, 121.7819°. Using Google Earth, the direct distance from A to B is 10.1 kilometers.

The actual balloon flight test of the weather balloon system was conducted in PAGASA Synoptic and Upper Station in Tanay, Rizal. A hydrogen balloon was used to carry the payload as shown in Figure 8.

Fig. 8. Actual flight test in Sitio Mayagay, Brgy. Sampaloc, Tanay, Rizal

During the flight test, Yagi Uda antenna was directed to the direction of the balloon manually. The flight test lasted for 24 minutes and the last string of data was transmitted and received when the altitude is 9995.4 m. That altitude is within the range of the above of the lower troposphere, where upper-air data on that region are analyzed and can already be used for forecast [1].

Figure 9 shows the plot for altitude versus time. For 1440 seconds or 24 minutes, the payload reached its maximum height it can transmit. The power output of the payload is almost constant in 677 mW throughout its flight. For interval time between each string of data, approximately each second, one string of data is sent, even if the altitude increases.

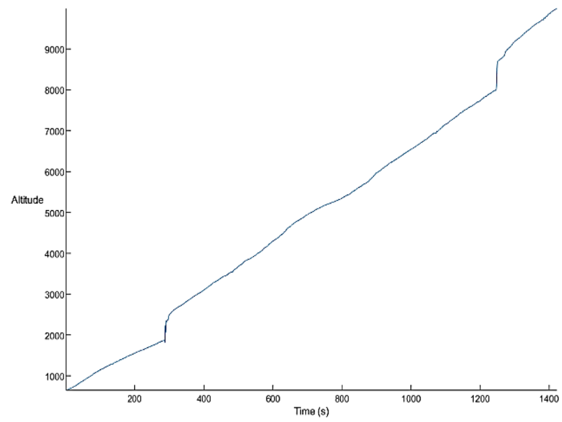

Fig. 9. The altitude of the payload at a certain time

During the test, the timestamp of RTC module for the reception of data in the receiver had 4-second delay compared to the timestamp of the GPS in the payload. When the flight started, batteries were fully charged, which the total battery voltage is 8.23 V (the nominal voltage of one battery is 3.7 V). The supply voltage decreases slowly. Until its last transmission of data, the supply voltage was still above the total of the nominal voltages of the batteries as 7.4 V. Assuming that the decrease of battery voltage is constant, the supply will last for almost 57 hours.

As for the data errors during transmission, even in the altitude of approximately 10 km, there were no errors in the sample data. The transmitted sample data were still the same as the received data.

The total storage of data logged on the SD card is 284 kB. So, if the SD card has approximately 4 GB of capacity, there will be approximately 14,000 weather balloon flights data that can be saved on it.

Since in this proposed system, sample atmospheric data is used, weight for the environmental sensors must be considered, too. A bead thermistor temperature sensor weighs 17 grams; thin film capacitor humidity sensor weighs 5 grams; and a barometric pressure sensor weighs 30 grams. So, the total weight for those environmental sensors is 52 grams. So if environmental sensors' weight is added, the total weight of the payload is 292 grams.

Compared to the commercial radiosonde which weighs 350 grams, the payload used in this proposed system is approximately 15.71% lighter. Compared to other radiosonde, which weighs 225 grams, the payload is approximately 23.73% heavier [7].

IV. CONCLUSION AND FUTURE WORKS

Based on the results of the tests, RFM96W LoRa RF transceiver module successfully transmits data up to approximately 10 kilometers of altitude as a transmitter of the payload. It operates in 433 MHz. Transmission of every data happens once in a second. The saved data in the SD card is the expected sample data. There were no errors, as far as the tests were done. The 4-GB SD card has the capacity to saved flight's data for more than 19 years. The payload has low output power of 300 mW. It weighs 292 grams and is approximately 50% cheaper than commercial radiosondes. Supply voltage lasts for almost 57 hours. The flight test was also conducted successfully. Working low-cost LoRa-based transmission of atmospheric data between weather balloon and ground station is achieved.

For further improvement of the project, the researcher proposes to design a transmitter that can transmit data from at least 35 km of altitude. Sensors can be added also. The payload should also undergo environmental test with a temperature lower than -40°C to check whether it performs well in the higher altitude but colder air. Same with the pressure test, it should be tested from 1050 hPA to 5 hPa. Consider the operating temperature range of each part of the circuit, too. The program of GPS and RTC should also be checked well so that there is better synchronization of the time between the payload and the ground station. In addition to that, use or design an antenna that has an omnidirectional pattern so that it can be fixed in one station, and not manually directing it to the direction of the balloon. Design a Graphic User Interface exclusively for real-time monitoring and data logging. Integrate the recovery system of the payload.

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