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EVALUATION OF UNMANNED AERIAL VEHICLE (UAV) CONTROL RANGE SYSTEM USING LORA-BASED COMMUNICATION SYSTEM USING PATH LOSS

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Abstract

This research aims to evaluate the communication system between the ground control system and the Unmanned Aerial Vehicle (UAV) using the Lora communication system based on its Path Loss data. Lora itself is a 433 MHz-based communication system used for very long-distance communication. As we know, today UAV market used a 2.4 GHz-based communication system because it is cheaper than using 433MHz. But, although it is cheaper than 433MHz, a lot of devices used the same frequency like WiFi systems and other wireless electrical component. That condition creates a lot of signal interference so communication between the ground control system and the UAV becomes shorter. 433MHz is not a new technology for a communication system, this frequency is usually used for radio news and long-range data logging. It is rarely used 433 MHz frequency for transmitting a big package of data because 433Mhz frequency has a slow data transfer rate but has a long data transfer distance. From testing, we got an improvement of control range more than twice with Lo-Ra 433 MHz compared to the 2.4 GHz module.

Keywords*:* *Control System, Lo-Ra, Long Range System, Radio Frequency, Transmission system, UAV*

1. INTRODUCTION

As for a device to monitor and collect bird's view images, Unmanned Aerial Vehicle (UAV) needs a reliable communication system from the ground control system. Without a reliable system, it will shorten UAV exploring distance. Besides that, flying a UAV without a dependable system will make a fearsome feeling about crashing. Because when a UAV crash, it always has serious damage to the device and costs a lot of money to make it can fly again. Today market released many types of UAVs and control systems for UAVs, but many of them are based on 2.4 GHz frequency. And when in an urban area there are a lot of citizens using WiFi systems in their homes, it will create a lot of interference to the UAV and that is one of the reasons a UAV control system becomes short.

To supply long-distance communication systems, LoRa WAN technology released a product called Lo-Ra E32-433XX that supports 433MHz communication systems between two modules[1], [2]. With this module, data can be driven from transmitter to receiver for more than 2km away. With the help of LoRa technology, we want to create a communication module for a UAV so we can improve its flying control distance.

Even though LoRa 433 has a great distance to communicate with other modules, they have a disadvantage in data transfer rate and it causes the signal that UAVs receive when flying to be laggy and unresponsive. Comes with that problem, this study uses a PID system for smoothing UAVs movement so although it is still unresponsive, the UAV is still controllable. This research follows a research diagram like Figure 1.

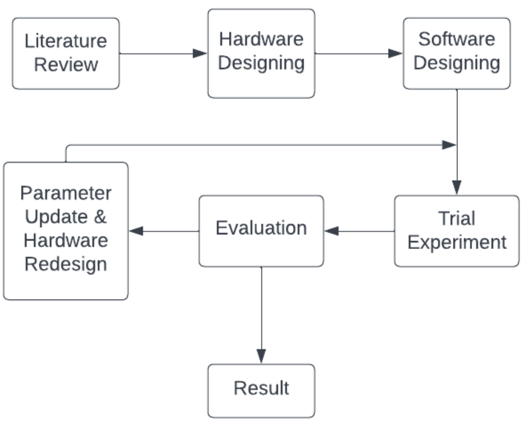


Figure 1. Research Diagram

2. RESEARCH METHOD

A. Radio Frequency

Radio Frequency has divided into several groups based on its function, from VLF(Very Low Frequency) up to EHF(Extremely High Frequency) as we can see in Figure 2[3]. Each group has its clients such as VLF and LF, it used for maritime radio & navigation systems. VHF and UHF are used for television and cellular phone. Then the highest one, EHF, was used for astronomical satellites.

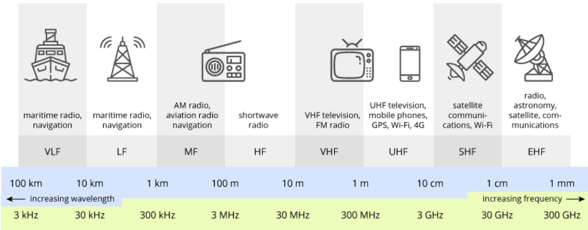


Figure 2. RF Band Groups (https://terasense.com/terahertz-technology/radio-frequency-bands/)

As we can see in Figure 1, the difference between each group, or we can say it the RF Band, is their wavelength. VLF has the longest wavelength and as compensation, it only generates a few frequencies per second. On the other hand, EHF has the greatest frequency with only around 1 mm wavelength. Low-frequency and high-frequency wave comparisons can be seen in Figure 3 [4].

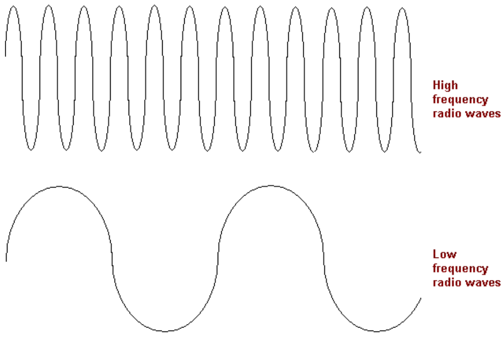


Figure 3. Wavelength and Frequency comparison

The number of waves and the length of each wave determined the system's ability to transmit data to another module. Thicker frequency can improve data transfer rate quality because data will transmit more stable. Vice versa, the longer wavelength will give the ability for data to transmit a longer distance but only a small portion of data can be transmitted[5].

Previous studies said that several 2-way communication wireless devices can be used for creating a communication system between UAV and ground control system. Bluetooth, Wi-Fi, Cellular, and WAN for example. Their relation can be described in Figure 4[6].

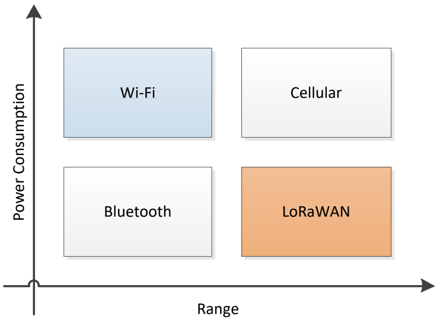


Figure 4. Radio Frequency Device Comparison in Power Consumption and Range

As Figure 4 described that Wi-Fi module is the module with high power consumption but produces a short distance of data communication but LoRaWAN offers low power consumption and longer distance of 2-ways communication modules [7][8], [9].

Some fellow researchers, study the implementation of LoRa Technology in rural areas and make evaluations about it. The result is that on the field test in the rural sector, Colombia, LoRa technology can establish the machine-to-machine (M2M) communication within a radius no greater than 500 m[10].

B. LoRa Communication Module

Lora provides the market with several types of communication modules, for example, SX1278 and SX1276 models. This SX1278 is produced to handle 433 MHz communication and SX1276 is for 915 or 866 MHz[11]. Lora modules adopt Compressed High-Intensity Radar Pulse (CHIRP) Signal technology that is used for military radar systems to locate another unidentified object[12]. It is a signal modulation technique with increasing (up-chirp) or decreasing (down-chirp) frequency over time[13]. There are three major types of modulation, Amplitude Shift Keying (ASK), Phase Shift Keying (PSK), and Frequency Shift Keying (FSK) (see Figure 5). This Lora chirp signal is based on FSK Modulation[12].

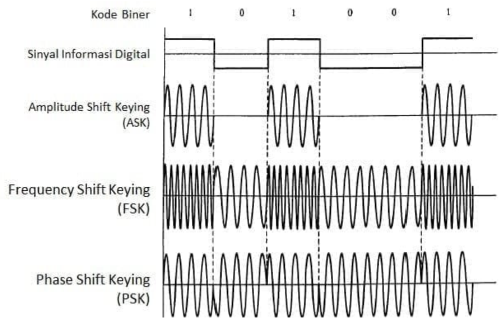


Figure 5. Types of signal modulation

FSK for Lora signal modulation is called Chirp Spread Spectrum (CSS). On CSS, the chirp signal is divided into two types: Frequency Increase (Up-Chirp) and Frequency Decrease (Down-Chirp) with time. It is as sown in Figure 6.[14].

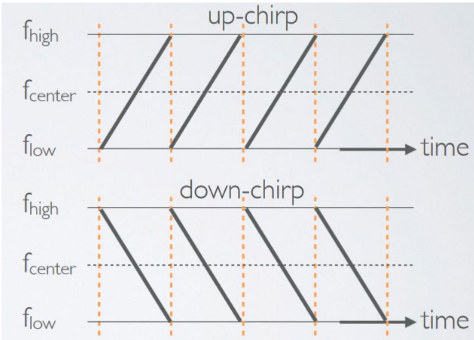


Figure 6. LoRa Chirp Up--Chirp and Down Chirp Signal

Other studies already experimented with this technology. Research by [6] evaluated LoRa performance for small transfer rates and push it to its limitation by transmitting image data. [15] experiments, testing LoRa technology on its Quality of Services (QoS)by evaluating RSSI, SNR, Payload size, and Spreading Factor of the module. Another research [11] compares LoRa with the Sigfox module to check if there are Bit Errors in their transmission. And research about the limitation of LoRa technology for transmitting on multiple end devices with multiple Payload data[2].

C. Wireless Communication Range Calculations

To calculate the wireless communication range between UAVs with the ground control system, we used power & dBm value to calculate the range[16].

Power and dBm Value

The Power of wireless systems is usually described by the decibel (dBm) value of its module with a milliwatt (mW) as reference[3]. Decibel is a measurement of frequency wave and it is equivalent to ten bells. Though it is for measuring frequency waves, its logarithmic can be used for describing some ratios too, like power, sound pressure, current or voltage, intensity, and the others ratio[17]. Decibel or we can say it dBm, can be used for measuring power based on its logarithmic scale. For an increment of 3 dBm value, it means that the power increases twice. For example, when the module indicator shows the dBm value is 20 dBm, the output power of that module is 100mW. We can calculate this value conversion using function numbers (1-2)[18].

$$P_{dBm} = 10\ Log_{10}(P_{mW}) \tag{1}$$

$$P_{mW} = 10^{\frac{P_{dBm}}{10}} \tag{2}$$

We use function number 1 and 2, to estimate the power of devices by showing them on First Person Viewer (FPV) On-Screen Display(OSD). On the display, RSSI will be shown at dBm value, so we can estimate the power used for data communication.

Path Loss

This path loss was a power density reduction between devices. When two devices separate over d distances, we can calculate the density of radio power value (I) with equation (3) and then simplify to equation (4).

$$I \propto \frac{\cancel{4\pi P^2}}{\cancel{4\pi P^2} d^2} \tag{3}$$

$$I \propto \frac{1}{d^2} \tag{4}$$

That equation comes with the assumption of each device transmit radio wave in a spherical range and multiply by device power. The intensity of power equals the inverse square of the distance from the source and it can represent in Figure 7.

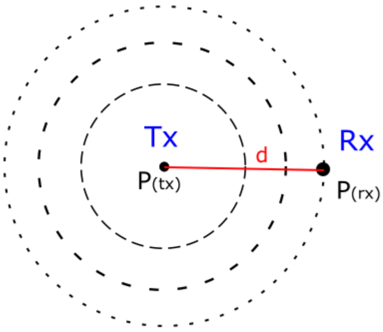


Figure 7. Spread of Radio Wave

There is another affecting factor when calculating range called receiver sensitivity. This receiver sensitivity is expressed in (-dBm) the same as stated with the transmitting power (stated in dBm) and can be calculated with simple addition and subtraction to calculate the maximum path loss equation (5).

$$\max_{pL} = P_{tx} - S_{rx} + g - l \tag{5}$$

To compute maximum path loss ($\max_{pL}$), transmitter power (P_{tx}) subtract with receiver sensitivity (S_{rx}) and add it with antenna gain (g) subtraction with the losses (l). g are the total gains of the transmitter and receiver antenna. This gain is generally expressed in dB value referenced to an isotropic antenna. And losses (l) are degradation because of resistances and assuming there will no resistance on the test, we can ignore l value. The estimation of transmission distance can be like equation (6-9).

$$\max_{pL} = 20\log(d) + 20\log(\lambda) + c \tag{6}$$

$$20\log(d) = \max_{pL} - c - 20\log(\lambda) \tag{7}$$

$$\log(d) = \frac{\max_{pL} - c - 20\log(\lambda)}{20} \quad (8)$$

$$d = 10^{\max_{pL} - c - 20\log(f)/20} \quad (9)$$

c is 32.44 when we calculate distances in kilometers and frequency in MHz or c is -27.55 when we calculate distances in meters and frequency in MHz and when we calculate distances in meters and frequency in kHz, c is -87.55.

3. DESIGN SYSTEMS

This research wants to evaluate how far LoRa technology can be used for communication between the UAV and Ground Control System (GCS). Then, of course, we need to build a communication module for transmitting control data to the UAV.

A. LoRa Control System

To get a control signal from remotes, the PPM signal must be supported by remote output for input on LoRa. Another thing that we considered transmitting was telemetry from UAV to remote so we know the condition of UAV sensors. Micro Air Vehicle Communication Protocol (MAVLINK) Telemetry has been chosen as a telemetry protocol because of its ability. This protocol is based on modern communication technology using a hybrid publish-subscribe and point-to-point design pattern.

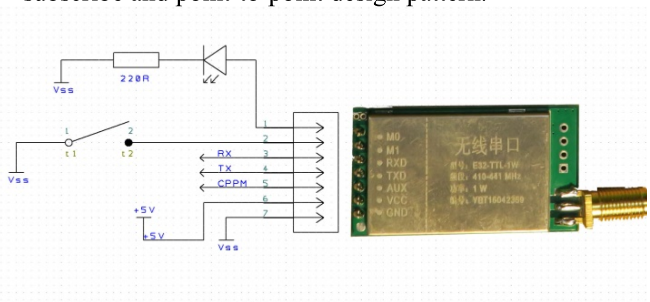


Figure 8. Lora wiring diagram

Based on the diagram in Figure 8, the M1 pin is for entering settings mode by using a switch as the trigger, and the M0 pin was used for the LED indicator of data transfer. RX-TX pin was a serial port used for MAVLINK data communication and the AUX pin was used for receiving the PPM signal from the remote.

B. Transmitter & Receiver System

This study uses two LoRa devices, one connects to the remote as a transmitter PPM signal the other one is glued to the aircraft and connected to the flight controller for controlling the airplane. From the remote datasheet, LoRa connected to the remote using the output port on the backside of the remote shown in Figure 9.

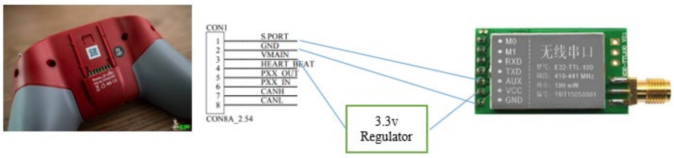


Figure 9. Remote to Lora System

From the latest results, Lora give a bad effect on the remote. When turning on the Lora module, it brings a lot of electromagnetic pulses that are enough to turn off remote electricity. To solve that problem we separate the Lora module from the remote using a 2.4gHz communication protocol shown in Figure 10.

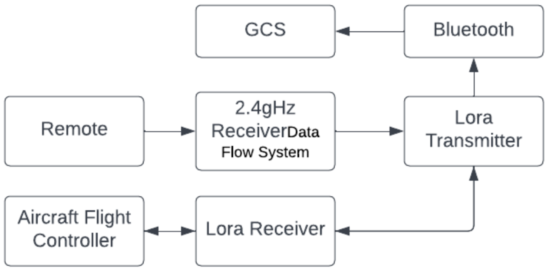
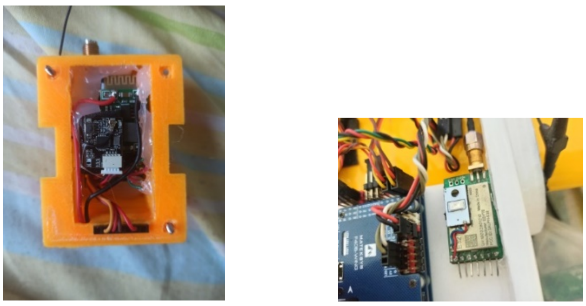


Figure 10. Flow diagram of signal control

By separating the Lora transmitter using 2.4gHz, the PPM signal will transmit over 2.4gHz first to Lora. This can prevent electromagnetic pulses to take an effect on the remote because we can place the devices several meters over the remote. The receiver device on the airplane has to transfer what signal it received from the transmitter to the flight controller and then transmit other packages from the flight controller containing sensor data back to the Lora transmitter. On the transmitter, it will send again not through 2.4gHz communication, but through Bluetooth or USB serial communication to the PC or Phone.

4. RESULT AND DISCUSSION

The transmitter and receiver devices used for this study can be seen in Figure 11.



Lora Transmitter Lora Receiver

Figure 11. Lora Transmitter and Receiver for UAV Control System

The UAV that carried the receiver was a foam plane with 1900mm of wingspan and powered by a 16.8 voltage Li-Ion battery (see Figure 12).

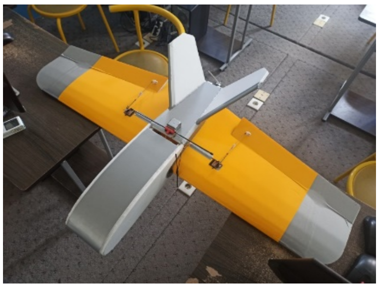


Figure 12. UAV Used for Research

We organized several trials to estimate the performance of the communication module on the ground. Using the equation of path loss (Equation 9) we got a graph of distance by Path Loss like Figure 13. Not only calculate only Lora 433 MHz module but also estimated a 915 MHz module by Team Black Sheep product.

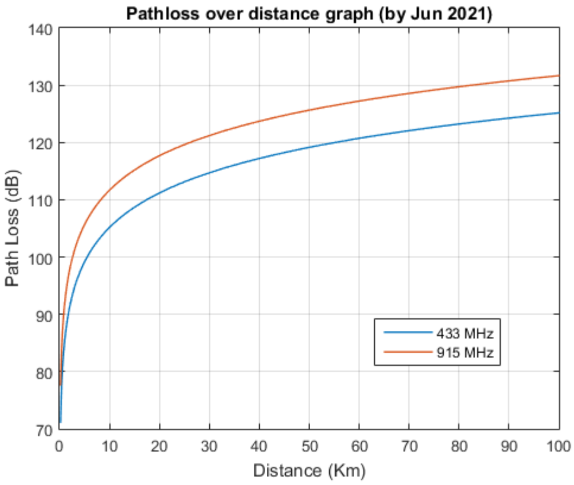


Figure 13. Graph Transmission Distance vs Communication Path Loss

As we can see on the graph, we got comparison data of two modules, 433 MHz and 915 Mhz. It can be said that over distance, 433 modules produced lower path loss than 915 modules. It means that the 433 module has a smaller loss than the 915 modules on the way it transmits the data. Another experiment to compare LoRa with standard NRF2401 has already been done and shows results that Lora produces longer communication distance compare to NRF2401 but LoRa consumes more energy for transmitting on a longer distance. (See Table 1).

Table 1. Distance and Draw Amp Test for Lora and NRF24

No	Distance (Meter)	Draw Amp (mA)		Transmitting speed (μS)	
		NRF24	LoRa 433	NRF24	LoRa 433
1	100	180,13	189,52	10131,1	132081
2	200	184,36	3435,66	10647,6	132810
3	350	201,25	4866,15	14030,4	145243
4	500	-	5469,21	-	121240
5	1 K	-	5338,008	-	182320
6	1,5 K	-	6933,93	-	281909

From table 1, we can analyze that NRF24 only can reach 350 meters to communicate with the receiver. But Lora can reach up to 1.5 kilometers and it is still connected. On Lora devices, when it still communicates in the near area, it still uses a small portion of amperage. But when it becomes further, the device draw amp can reach up to tenth times. Though that Lora has a greater distance on the communications system, when we see about transmitter speed, Lora seems to be laggy. As we can see in table 1, Lora transmitting speed is much slower than NRF24. There are around 0.1 – 0.3 second delays when some instructions are to be delivered to the receiver.

As we were confident with the performance of Lora, we conducted some flight tests to compare which is the longest one between LoRa 433, TBS 915, and NRF24 then we obtained a result graph like in Figure 14.

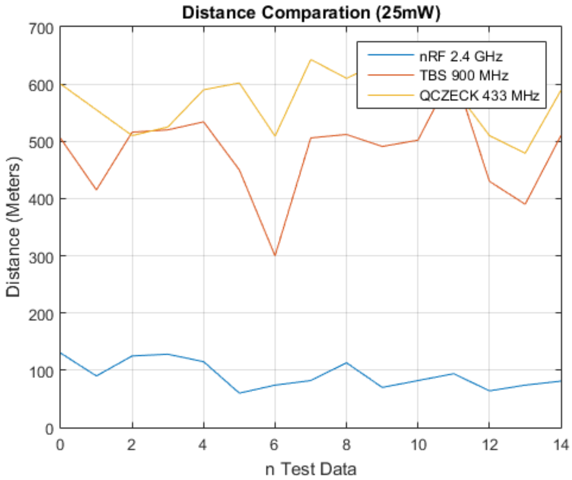


Figure 14. Testing result of 3 different modules with power only 25mW

Due to the graph, when we set the power of the device to only 25mW, NRF24 was still left behind. TBS and Lora which have smaller bands than NRF24 still can reach around 500-600 meters in radius but NRF24 only reaches around 110 meters. After that, we established another experiment to see how far the modules work with full power applied to each module. The result was calculated by reading link quality on the video receiver based on function (1) and (2) to know how far the plane flight was already. Link quality is based on path loss estimation to give the user information on whether the communication will be lost or not. The result of the experiment can be seen in Figure 15

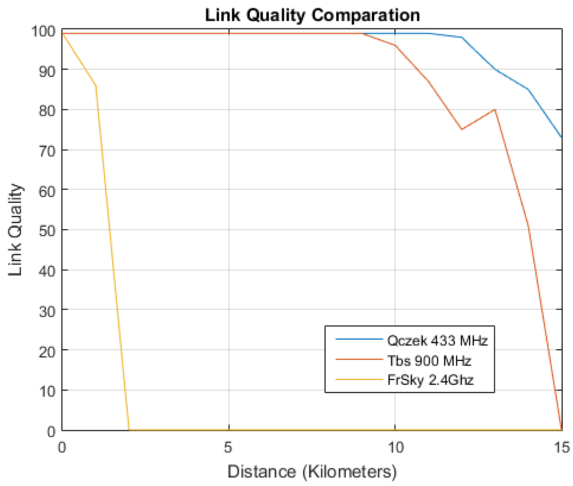


Figure 15. Link quality result for each module when traveling until signal lost

Figure 15. explain that the 2.4GHz module got the fastest loss among the modules. It lost its signal with the transmitter when the UAV was still around 2 kilometers. But other modules can go through up to 15 kilometers. The Lora module has a better link quality than the 915 TBS module which is on 10 kilometers TBS has indicates that its link quality goes down when the Lora module is still stable. From the test data, we can analyze that although Lora has disadvantages in the transmitting speed of data and make the movement a little bit laggy when comparing in transmitting distance, Lora overcomes the other modules. Lora can reach more than 300% percent of the distance compared to the 2.4GHz module but it cost a lot of power when transmitting data from a great distance.

5. CONCLUSION

Many types of communication data modules can be used for transmitting data and each of them has its specifications. LoRa which has a 433MHz configuration on which band it uses for communication has an advantage in the communication distance. On the ground, it can reach more than a kilometer when the standard 2.4GHz only reaches 300 meters. When Lora uses it as a communication device for controlling the airplane model, the airplane can reach the greatest distance. The disadvantage of using Lora is it generates a lot of draw amp or consumes a lot of energy to transmit data from far away, and the data that it sent seems to be laggy. We suggest improving the draw amp problem, by using optimizing the power module system that manages the power adaptively on the next research.

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