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The Design of Soil Temperature and Humidity Monitoring Systems with IoT-Based LoRa Technology

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A B S T R A C T

Soil temperature and humidity are important factors in affecting the condition of agricultural sector, which has an impact on the quality and quantity of the production. Lack of information on the condition of agricultural soil is one of the causes in productivity deficiency in the process of agricultural cultivation. The application of technology in the field of agriculture is expected to be able to reduce various adverse effects of agricultural soil conditions. One of which is by periodic monitoring, such as the temperature and humidity of agricultural soil. This research aims to design LoRa technology to be used as a data transmission medium for monitoring soil temperature and humidity by applying a system that is based on the Blynk application, which will make the users easier to monitor the system remotely. The temperature sensor was able to acquire data with 98.37% accuracy and the soil humidity sensor was able to acquire data with 91.63% accuracy. The changes in LoRa transmission parameters for monitoring data have an effect on the quality of its performance. The experimental results with Bandwidth variation (BW) from 31.25 kHz, 62.50 kHz, 125 kHz, 250 kHz, and 500 kHz at a distance of 15m, the best SNR and RSSI values were obtained for BW 31.25 kHz with values of 5.42 dB and -104.90 dBm. Whereas, the best ToA is obtained with a BW of 500 kHz with a value of 27.50 ms. While, the experimental result with the variation of *Coding Rate* (CR) from CR 4/5, 4/6, 4/7, and 4/8 at a distance of 15m, the best SNR and RSSI values were obtained CR 4/8 with values of 4.10 dB and -106.40 dBm and he best ToA was obtained CR 4/5 with a value of 112.70 ms. In testing by using variation *Spreading Factor* (SF) from SF7, SF9, and SF12, the higher the SF value used, the wider the range of area data communication will be. Configuration SF7 and SF9 were only able to reach a distance of 25m, while SF12 was able to reach a distance of 35m.

INTRODUCTION

Regular monitoring of soil temperature and humidity is one of the important factors in influencing the condition of agricultural land so that crops can grow in optimal conditions and are able to reduce adverse health effects on crops, thus increasing the quality and quantity of crop production [1]. Recently, the application of the Internet of Things (IoT) is widely used in agriculture, with the aim of making all aspects of agriculture and agricultural methods more effective and efficient with an automation system [2]. Among them is utilizing LoRa communication technology which is integrated with the Internet of Things (IoT) technology by applying the Blynk application to help facilitate the measurement and monitoring of temperature and soil humidity.

LoRa transmission media can cover a wide area of up to 15 km (depending on the propagation environment) as well as low power consumption which makes Lora more reliable compared to other wireless technologies, such as Wi-Fi, Bluetooth, GPRS, LTE, and EDGE that have not been able to produce efficient communication between power consumption and reachable area coverage [3]. Applications that support IoT such as Blynk, NETPIE, and Line Notify on smartphones that are connected to

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the internet network [4] become the solution provided to monitoring the temperature and humidity of the ground via the internet network by using smartphones. This study designed an IoT-integrated LoRa-based monitoring tool using Blynk application, as a temperature and soil humidity monitoring system that is expected to transmit data over long distances, as well as analyze its communication performance. Some previous studies dealing with IoT-integrated LoRa-based monitoring tool had been done such as The Development of Cloud Integrated LoRa Technology-Based Environmental Condition Monitoring System to Support the Implementation of Precision Agriculture in Rural Areas [5], The Design a LoRa End Device Based Soil Temperature and Humidity Monitoring Tool [6], and Implementation of Agricultural Sensor Data Acquisition System Using LoRa Communication Protocol [7].

This study includes the implementation of LoRa communication to be used as a medium for transmitting soil humidity sensor data, namely YL-69, then analyzing LoRa communication performance based on packet loss and delay parameters. The use of LoRa can make the farmers easier to monitor the environment of their agricultural land which is far from the location of the farmers' house. With LoRa technology, it will be more possible, the farmers will be more likely to adopt this technology on which ultimately improves sustainability, continuity, quality, and profit margins in agriculture.

IoT-Based Long Range (LoRa) Technology for Monitoring the Soil Temperature and Humidity

In this section, the overview of IoT-Based Long Range (LoRa) technology is discussed. The discussion are about LoRa, Microcontoller ESP32, and Blynk. They are discussed respectively.

Long Range

LoRa is a long-range wireless communication system promoted by the LoRa Alliance, using no electrical voltage or wire but using aerial media in its transmission process [8]. LoRa uses modulation Chirp Spread Spectrum (CSS) to create a stable frequency. Generally, there are 3 types of LoRa frequencies operating in the ISM band, namely 433 MHz, 868 MHz, or 915 MHz, depending on the operational area with a data speed of 50kbps.

Table 1 Wireless Technology Comparison [9]

No	Technology	Distance	*Max. Rate*	Power Consumption
1.	*Bluetooth*	10 m	2 MB/s	Low
2.	Wifi	0-60 m	54MB/s	High
3.	RFID	0-100 m	10 KB/s	Low
4.	Zigbee	0-1500 m	250 KB/s	Low
5.	Lora	0-15 km	600 KB/s	Low

Table 1 shows that LoRa communication technology has a long range compared to other communication technologies and has low power consumption. However, LoRa technology has disadvantages where the maximum rate value is not too large.

LoRa Parameter On Transmiter

LoRa has several transmission parameters that must be considered such as bandwidth, coding rate, and spreading factor. Bandwitdh is the frequency bandwidth used to modulate the information signal and used as the chip rate representation of the modulation signal. In RF communication, the magnitude of the bandwidth can be set according to the desired frequency ranging from 125 kHz, 250 kHz, up to 500 kHz [10]. Coding rate is one of the features of LoRa modulation that uses the Forward Error Correction (FEC) technique. The implementation of this technique is done by encoding 4 bits of data with redundancy, namely by duplicating into 5 bits, 6 bits, 7 bits, or 8 bits [10]. Spreading Factor (SF) is the number of chips or the number of bits that can be encoded to represent one symbol. The SF magnitude is set variously from 7, 8, 9, 10, 11, to 12 [11].

Lora Module

The Lora module in this study used LoRa RFM95W module as shown in Figure 1.

Figure 1 LoRa RFM95W

The following is LoRa RFM95W specification shown in Table 2.

Table 2. Lora RFM95W specification [6]

Specification	Description
Maximum Link Budget.	168 Db
Output Power	+20 dBm - 100 mW
High-Efficiency PA.	+14 dBm high-efficiency PA.
Programmable bit rate	up to 300 kbps.
High sensitivity:	down to -148 dBm.
Bullet-proof front end:	IIP3 = -12.5 dBm.
Low RX current	10.3 mA, 200 nA register retention.
Modulation	FSK, GFSK, MSK, GMSK, LoRaTM and OOK modulation.
Dynamic Range RSSI.	127 Db

Parameters On The Receiver

This study aims to determine the performance and the quality of LoRa communication. Three variables were determined, namely SNR, RSSI, and ToA. SNR (Signal to Noise Ratio) is the ratio of transmission signal strength and noise power. In the SNR parameters, it is preferable to use a miniaturized SNR to ensure easier demodulation on the receiver and the signal can be translated and read correctly. In LoRa Communication, its performance has been improved by using the FEC (Forward Error Correction) method and Spreading Factor, thus allowing the improvisation of SNR significantly with an SNR range between -20 dB and +10 dB [12].

RSSI (Received Signal Strength Indicator) is an indicator of the signal strength received and recorded by the receiver. This indicator is based on how far the RSSI value is from zero, where if the RSSI value is close to zero, then the received signal strength can be said to be good [10]. In LoRa communication, one factor that affects the RSSI value is the distance between the transmitter and the receiver. The indication of the range of RSSI values in LoRa is between -30 dBm to -120 dBm, where -30 dBm indicates a strong signal and -120 dBm indicates a weak signal [13]. ToA (Time on Air) is the waiting time between the sender and the recipient when transmitting data or it can be said that the delay time for data can be received by the recipient [10].

Microcontroller ESP32

ESP32 is the name of a microcontroller which is Espressif systems [14], where ESP32 offers a self-contained Wi-Fi network solution as an interface from the microcontroller to the Wi-Fi network. The ESP32 module is a development board module that makes it easy to learn the circuit that use the ESP-WROOM-32 chip, which is one of the advantages of ESP32 over previous ESPs. The ESP32 chip also has a higher speed of 32 bits, larger memory, and integrated with the Bluetooth module. ESP32 operates at a voltage of 3.3V so that in using ESP32 on an electronic circuit it must pay attention to the display so that it should not be more than 3.3V [15].

Blynk

Blynk is a server service platform used in supporting IoT projects with Ios and android-based applications that can be controlled using Arduino, ESP32, and other similar devices over the internet. Blynk is a digital dashboard that can build graphics for users with the drag and drop buttons. Blynk was created with the aim of monitoring and controlling hardware in real time remotely by using internet data communication[14].

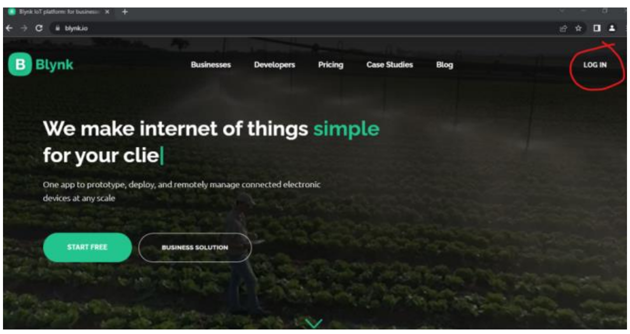

Figure 2 Blynk Application

METHOD

This research implemented a research approach in the form of problems identification, literature review, system design, system implementation, system testing, data and analysis, and conclusions. Figure 3 is the research flow used in this study.

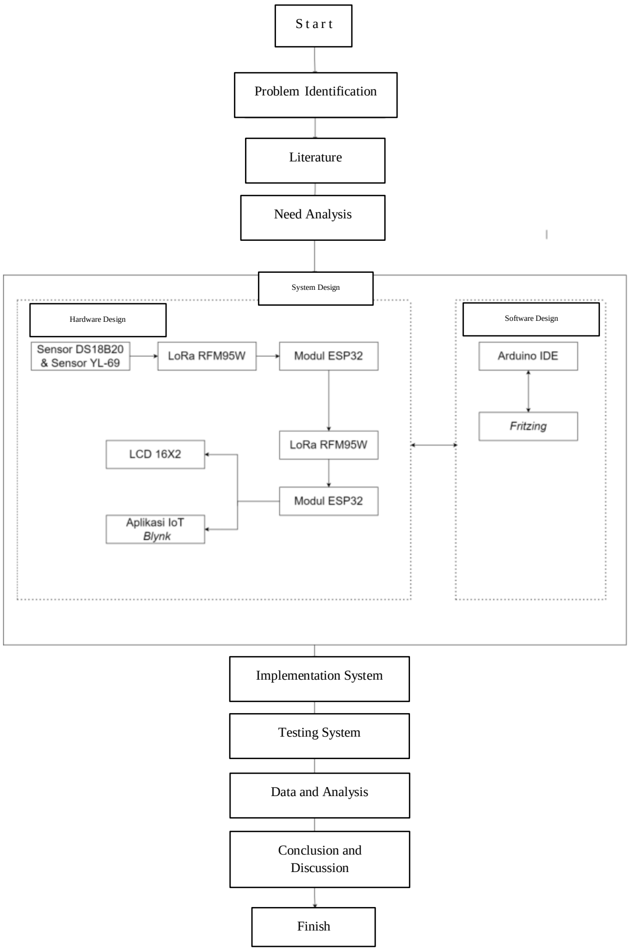

Figure 3 Research Flow Chart

System Design

An overview of the system in this study is shown in Figure 4.

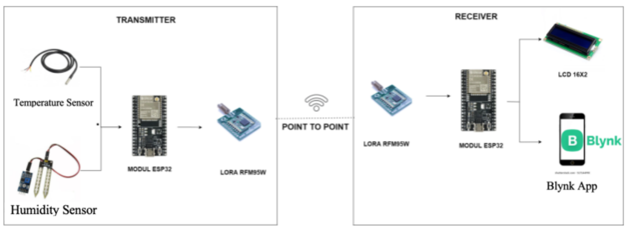

Figure 4 System overview

Based on Figure 4, the points that can be explained for system design are as follows: A transmitter is a set of components consisting of a sensor, a microcontroller for sensor data acquisition, and a LoRa communication module. The sensors used are temperature and humidity. The data obtained from the sensor will be processed by the ESP32 and then sent to the receiver via LoRa. The receiver is a device in charge of receiving data sent from the Transmitter and displaying the data to a 16x2 LCD and the ESP32 module will upload data to the Blynk application on a smartphone.

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The design of the system is shown in Figures 5 and 6.

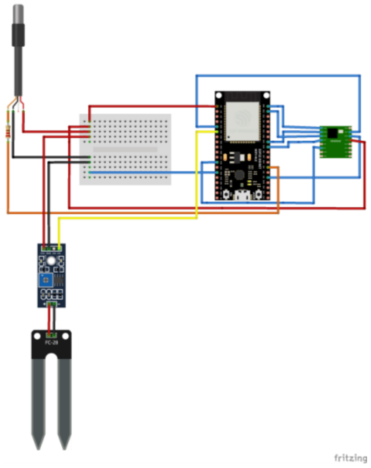

Figure 5 Transmitter Hardware Design

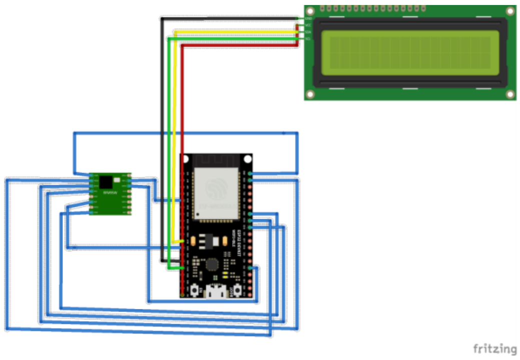

Figure 6 Receiver Hardware Design

System Implementation

Once the above materials are met, the next step is the assembly of the transmitter hardware. From the set of modules above, they will then be assembled into one that forms an integrated tool. The results of the implementation of system device are shown on Figures 7 and 8.

Figure 7 Transmitter System Implementation

From Figure 7, it can be seen tha use of transmitter is by plugging the DS18B20 sensor 2 cm deep and YL 69 cm deep on the ground, then the temperature and humidity data of the soil will be processed by the ESP32 module to then be sent to the receiver with the help of the LoRa RFM95W module.

Figure 8 Receiver System Implementation

Figure 8 showed that the receiver is useful to receive and display the temperature and soil humidity data transmitted by the transmitter and display it on the 16x2 LCD. The transmitter also sends temperature and humidity data through the ESP32 module by first connecting to internet signal in the form of Wi-Fi/hotspot, then it will be read and displayed on the Blynk smartphone application interface.

RESULTS AND DISCUSSION

In this study, the results of the test is aimed to determine the suitability of the tool performance with the design that has been made. The results of the tests were carried out by undergoing the stages of testing monitoring tools, testing LoRa performance for monitoring data transmission, and testing the Blynk IoT Interface. In testing soil temperature and huminity sensors, before being used for monitoring data transmission, the sensors used are first calibrated with conventional measuring instruments using the linear regression method. The results of the estimation of linear regression of temperature sensors with DS18B20 type compared to digital thermometers. As for the soil humidity sensor with the YL-69 type compared to the soil humidity meter. The LoRa test for monitoring data transmission consists of three scenarios, namely testing with variations in Bandwidth (BW), Coding Rate (CR), and Spreading Factor (SF).

For bandwidth testing and coding rate, one constant distance of 15m was used, while for testing the spreading factor, distances of 15m, 20m, 25m, 30m, and 35m were used to determine the ability of LoRa to monitor longer distances in N-Los conditions. The location of the data collection is at the cultivation site of plant seeds KWT Tunas Harapan, Java Gadut RT 02 RW 01 Limau Manis, Pauh District, Padang. This test was carried out by changing the parameters of the LoRa transmission to determine the changes to the Signal Noise ratio (SNR), Receive Signal Strength Indicator (RSSI), and Time on Air (ToA).

Sensor Testing

The results of taking 10 data samples for regression tests from sensors and calibrators are shown in Figure 9 for temperature sensors and Figure 10 for soil moisture sensors.

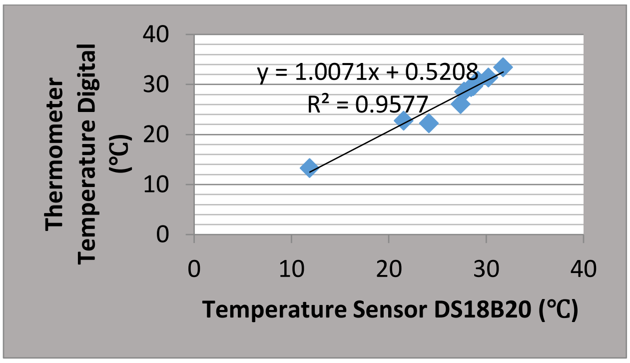

Figure 9 DS18B20 Sensor Regression Results

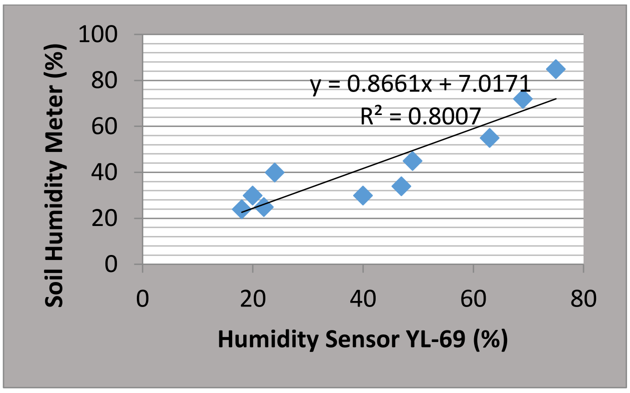

Figure 10 YL-69 Sensor Regression Results

From the graph above, equation 1 which is the result of calibration from the temperature sensor, and equation 2 is the result of calibration from the soil humidity sensor.

$$y = 0.5208 + 1.0071X \quad (1)$$
$$y = 7.0171 + 0.8661X \quad (2)$$

Furthermore, equations 1 and 2 are entered into the program. Thus, the sensor reading approaches the reading of the standard measuring instrument used as a comparison. After the calibration process, then re-measure the sensor used with the calibrator. The results of temperature sensor accuracy measurements are shown in Table 3 and the results of soil Humidity sensor accuracy measurements are shown in Table 4.

Table 3 The accuracy of the temperature sensor

No	DS18B20 (°C)	Termometer Digital (°C)	Accuracy (%)
1	9.69	8.8	89.88
2	27.44	27.8	98.7
3	27.87	28.2	98.83
4	28.44	28.5	99.79
5	30.37	30.2	99.43
6	35	35.5	98.59
7	37.38	37.2	99.52
8	41.13	41.1	99.92
9	43.31	43.2	99.74
10	58.56	58.2	99.38

From Table 3, it can be known that the average accuracy of the temperature sensor that has been compared by the reference tool, namely the digital thermometer after calibration is 98.37%.

Table 4 The accuracy of the soil humidity sensor

No	YL -69 (%)	*Soil Humidity Meter* (%)	Accuracy (%)
1	20	18	88.88
2	36	30	80.00
3	44	40	90.00
4	51	46	89.13
5	57	60	95.00
6	67	65	96.92
7	70	64	90.62
8	70	74	94.56
9	79	80	98.75
10	86	80	92.50

From Table 4, it can be seen that the average accuracy of the soil humidity sensor that has been compared by the reference tool, namely the soil humidity meter after calibration is 91.63%.

Blynk IoT Interface Testing

This test is a reading of measurement data by temperature sensors and soil humidity sensors that can be displayed on the Blynk IoT Interface on smartphone, one of which can be monitored in real time. Sensor data is sent to the *Blynk IoT* using the ESP32 MCU Node over the internet network.

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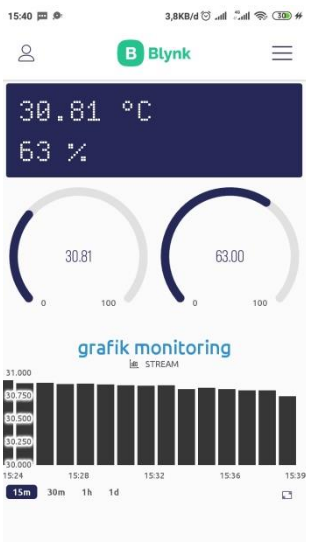

Figure 11 Display of data delivery results on the Blynk IoT Interface

In figure 11, the temperature reading in Celsius and the humidity reading in percentage are visible. It will then be displayed in the form of a widget. Hence, the monitoring data can be accessed remotely and the internet network is used from the smartphone hotspot. In figure 12 the graph displays the results of soil temperature and humidity monitoring data on Interface Blynk IoT.

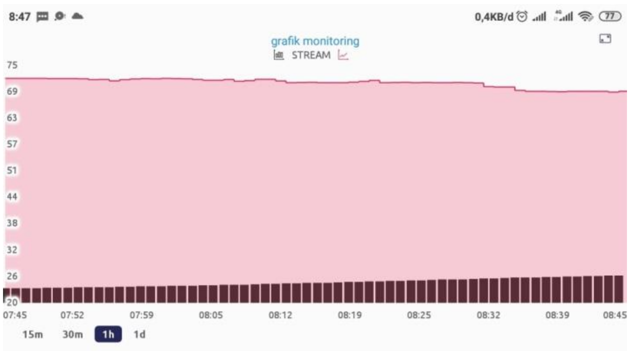

Figure 12 Monitoring Results Graph

From Figure 12, it can be seen that the monitoring system through the application of Blynk IoT successfully displayed and stored the results of temperature and soil humidity data for 1 hour through the form of graphs on the Blynk IOT Interface, where the Wi-Fi/ hotspot signal connected to ESP32 affects the stable monitoring results and real time displayed and stored on Blynk IoT application. Hence, the monitoring tool can acquire data properly.

Lora Performance Testing for Monitoring Data Transmission

The following is the LoRa performance test location for monitoring data transmission located at the cultivation site of plant seeds KWT Tunas Harapan, Java Gadut RT 02 RW 01 Limau Manis, Pauh District, Padang City.

Figure 13 The Test Location can be seen on google earth

The LoRa communication test results obtained consisted of three communication tests, namely testing with variations in BW, CR, and SF. For bandwidth testing and coding rate, one constant distance of 15 meters is used, while spreading factor is used for distance variations of 15m, 20m, 25m, 30m, and 35m to find out the best parameters on LoRa performance for monitoring.

Testing With Bandwidth Variations

This test aims to determine the performance of the LoRa communication system for monitoring data transmission with test parameter SNR, RSSI, and ToA with different bandwidth variations (BW), namely 31.25 kHz, 62.50 kHz, 125 kHz, 250 kHz, and 500 kHz at a distance of 15m between the transmitter and receiver.

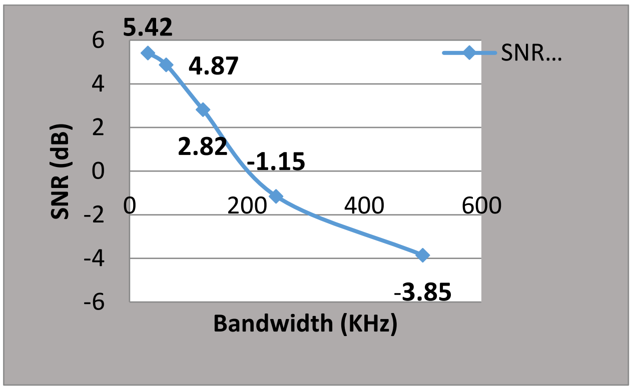

Figure 14 Effect of BW Changes on SNR

The average result of SNR based on the graph on Figure 14 shows that there is a change in SNR from any changes in bandwidth in LoRa communication. Each increase in bandwidth produces an SNR that decreases from BW 31.25 KHz to 500 KHz, with BW 31.25 KHz having the highest SNR result which is 5.42 dB and BW 500 KHz having the lowest SNR result, which is -3.85 dB. From these results, it can be stated that the SNR results obtained is good if the channel used low bandwidth.

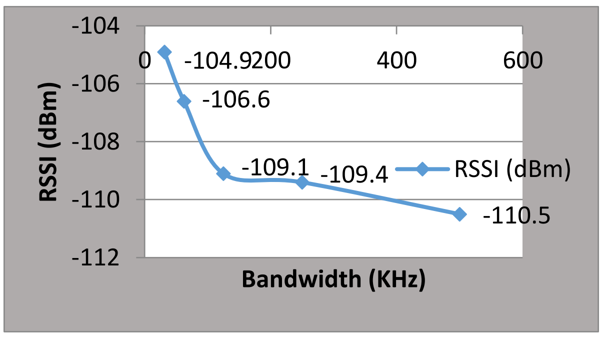

Figure 15 Effect of BW Changes on RSSI

The average RSSI results based on the graph on Figure 15, it shows that there is a change in RSSI from any changes in bandwidth in LoRa communication. Each increase in bandwidth results in a decreasing RSSI from BW 31.25 KHz to 500 KHz with BW 31.25 KHz having the highest RSSI result, which is -104.90 dBm and BW 500 KHz having the lowest RSSI result, which is -110.50 dBm. From these results, it can be stated that the RSSI results obtained is good if a low bandwidth channel is used.

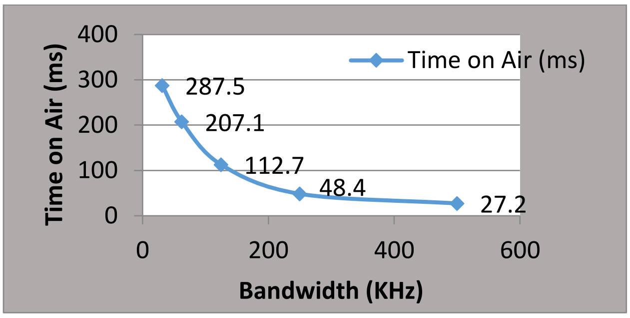

Figure 16 Effect of BW Changes on ToA

The average ToA result based on the graph of Figure 16 can be seen that there is a change in ToA from each change in bandwidth in LoRa communication. Each increase in bandwidth results in ToA that decreases from BW 31.25 kHz to 500 kHz, where BW 31.25 kHz has the highest ToA, which is 287.50 ms, and BW 500 kHz has the highest ToA, which is 27.20 ms. From these results it can be stated that the more bandwidth used, the faster the ToA produced.

From the test of the effect of bandwidth changes on LoRa at a transmission distance of 15m, it showed that any increase in bandwidth used in LoRa communication will decrease the signal quality in LoRa communication, because the greater the bandwidth used, the RSSI value will decrease. In addition, the increase in bandwidth is also prone to interference because the SNR will decrease further when bandwidth is increased. The advantage of using high bandwidth in LoRa communication can be useful to speed up data transmission as evidenced by the ToA value which is faster when bandwidth is increased, with a *wide* bandwidth then data rate will be higher which results in faster data reception process at the receiver.

Testing With Coding Rate Variations

This test aims to determine the performance of LoRa communication system with SNR, RSSI, and ToA parameters with different variations of coding rate , namely 4/5, 4/6, 4/7, 4/8 at a distance of 15m between transmitter and receiver.

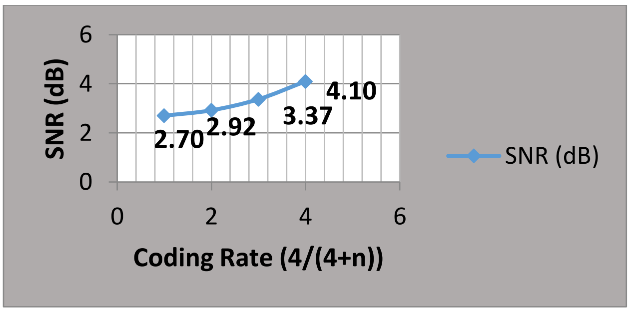

Figure 17 Effect of CR Changes on SNR

The average result of SNR based on the graph in Figure 17 can be seen that there is a change in SNR from each change coding rate in LoRa communication. Each increase in *coding rate* resulted in an increasing SNR from CR 4/5 to CR 4/8, with CR 4/8 having the highest SNR result, which was 4.10 dB and CR 4/5 having the lowest SNR result, which was 2.70 dB. From these results, it can be stated that the SNR results obtained can be said to be good if a high CR is used.

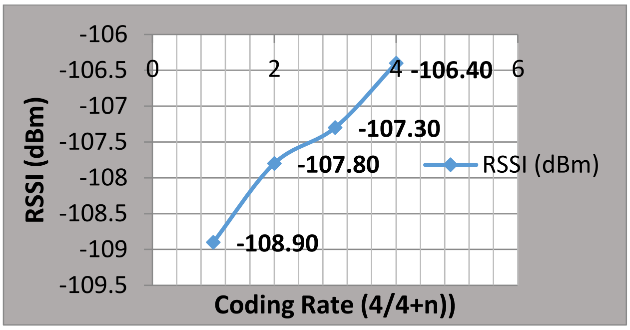

Figure 18 Effect of CR Changes on RSSI

The average RSSI result based on the graph in Figure 18 shows that there is a change in RSSI from any change coding rate in LoRa communication. Each increase in *coding rate* produces an RSSI that increases from CR 4/5 to 4/8 with CR 4/5 having the lowest RSSI result, which is -108.90 dBm and CR 4/8 having the highest RSSI result, which is -106.40 dBm. From these results, it can be stated that the RSSI results obtained can be is good if a high CR is used.

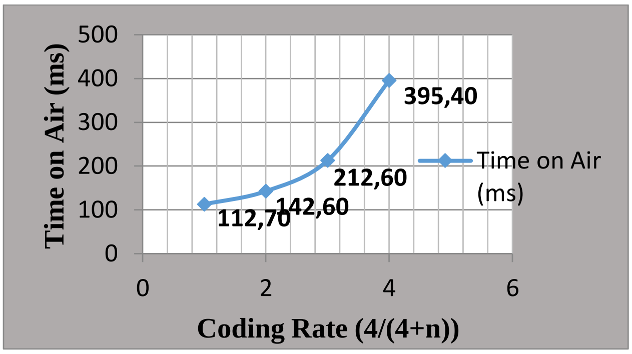

Figure 19 Effect of CR Changes on ToA

ToA based on the graph in Figure 19 shows that there is a ToA change from any changes of coding rate on LoRa communication. Each increase in coding rate resulted in an increased ToA with CR 4/5 having the lowest ToA, which was 112.70 ms and CR 4/8 having the highest ToA, which was 395.40 ms. From these results it can be stated that the higher the Coding Rate used, the higher the ToA produced.

Coding rate (CR) on LoRa is one of the features of LoRa modulation that uses the technique Forward Error Correction (FEC), the FEC implementation is carried out by encoding 4 bits data with redundancy, namely by duplicating the data into 5 bits, 6 bits , 7_759 bits , or 8 bits. The use of FEC makes LoRa signals more resistant to interference due to more duplication of transmitted data thus minimizing missing data or error when transmitted. Based on the tests that have been carried out, the use of CR with high values can improve the quality of SNR and RSSI, but it will result in increased ToA because the higher the CR value

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used, the more data will be duplicated so that the data transmission process will be longer.

Spreading Factor Variation Testing

This test is carried out to test the devices transmitter and receiver for remote transmission, this test also aims to determine the performance of the communication system that has been built. The communication performance parameters tested include SNR and RSSI, and Time on Air. The transmission distances for this test were 15m, 20m, 25m, 30m, and 35m. LoRa technology has several advantages. One is to be able to accommodate long distances with the right settings as well as a supportive environment, such as least interference as well as the types of devices that support LoRa device implementation. The use of LoRa is a distinct advantage in agriculture which requires the transmission of data that is resistant to noise which is widely available in agricultural areas. With diverse spreading factor settings from SF7, SF8, SF9, SF10, SF11, and SF12, it is possible for LoRa to reach a wide area. In this case, the researchers only sampled the SF7, SF9, and SF12 parameters.

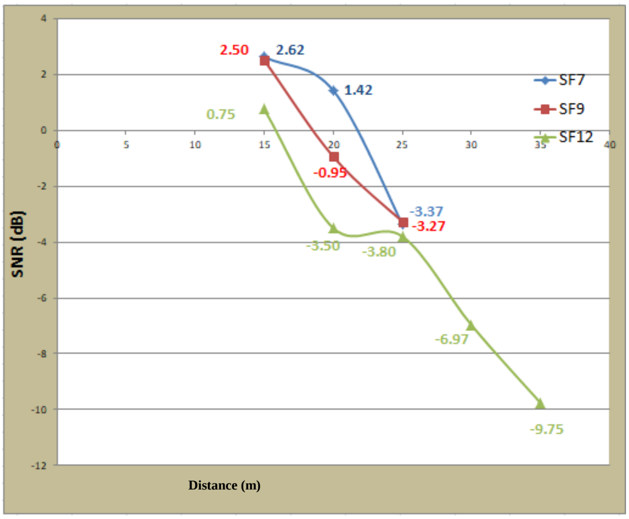

Figure 20 Effect of SF Changes on SNR

Based on the SF test data in the graph in Figure 20 on the 15m distance test, the best average SNR was obtained by the SF7 parameter with a value of 2.62 dB. In the 20m distance test, the best average SNR was obtained by the SF7 parameter with a value of 1.42 dB. In the 20m distance test, the best average SNR was obtained by the SF7 parameter with a value of 1.42 dB. In the 20m distance test, the best average SNR was obtained by the SF7 parameter with a value of 1.42 dB. In the 20m distance test, the best average SNR was obtained by the SF7 parameter with a value of 1.42 dB. To minimize the noise ratio, for a distance of 15m, 20m should be used SF7, for a distance of 25m should be used SF9, and for a distance of 30m and 35m should use SF12.

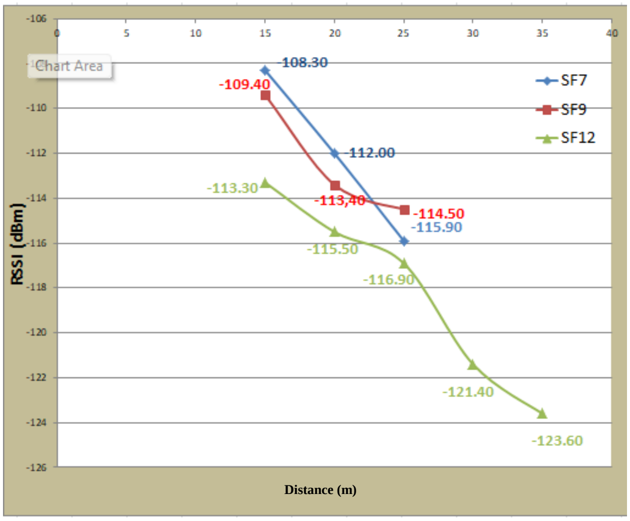

Figure 21 Effect of SF Changes on RSSI

Based on the SF test data in the graph in Figure 21 on the 15m Based on the SF test data in Figure 21 on the 15m distance test, the best average RSSI was obtained by the SF7 parameter with a value of -108.30 dBm. In the test, the best RSSI average 20m distance was obtained by the SF7 parameter with a value of -112.00 dBm. In the test, the best RSSI average 20m distance was obtained by the SF7 parameter with a value of -112.00 dBm. In the test, the best RSSI average 20m distance was obtained by the SF7 parameter with a value of -112.00 dBm. In the test, the best RSSI average 20m distance was obtained by the SF7 parameter with a value of -112.00 dBm. To maximize signal strength, for distances of 15m and 20m SF7 should be used, for distances of 25m SF9 should be used, for distances of 30m and 35m SF12 should be used.

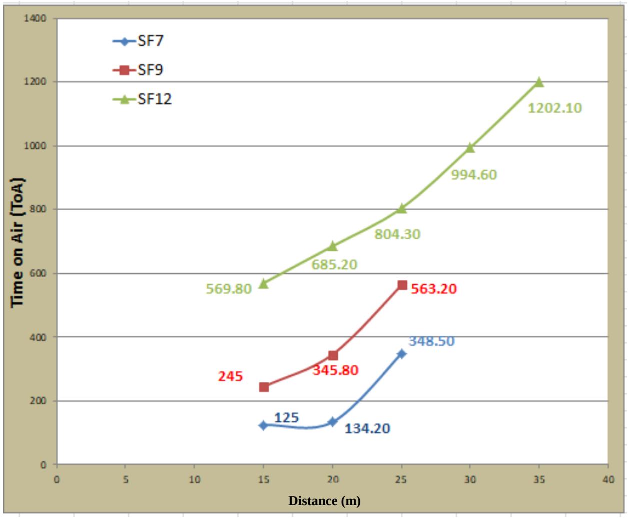

Figure 22 Effect of SF Changes on ToA

Based on the SF test data in the graph in Figure 22, the best ToA average 15m distance test was obtained by SF7 parameter with a value of 125 ms. In the test, the best ToA average 20m distance was obtained by the SF7 parameter with a value of 134.20 ms. In the test, the best ToA average 20m distance was obtained by the SF7 parameter with a value of 134.20 ms. In the test, the best ToA average 20m distance was obtained by the SF7 parameter with a value of 134.20 ms. In the test, the best ToA average 20m distance was obtained by the SF7 parameter with a value of 134.20 ms. To reduce the ToA value at distances of 15m, 20m, and 25, SF7 should be used, while for distances of 30m and 35m, SF12 should be used.

Based on the tests that have been carried out, the greater the SF used from SF 7, SF9, and SF12, the farther the communication range can be achieved. Based on its performance, the further the transmission distance is, the results of SNR and RSSI will be decreased, and the ToA value will increase, which means that the transmission time will be longer.

Table 5 Connection Range LoRa Transmission with Spreading Factor Variation

No.	**Distance (m)**	**Connection**		
		SF7	**SF9**	**SF12**
1	15	Connected	Connected	Connected
2	20	Connected	Connected	Connected
3	25	Connected	Connected	Connected
4	30	-	-	Connected
5	35	-	-	Connected

From Table 5, it can be concluded that the SF value will increase the range of LoRa as seen in SF7 and SF9 that cannot reach the area in the distance of 30m, but SF12 can make communication smoothly up to the distance of 35m.

CONCLUSIONS

The tests of this study revealed that SF12 was the best configuration to reach a distance of 35m compared to the configurations SF7 and SF9 which were only able to reach a distance of 25m. Based on the results of the research, it can be drawn that LoRa technology based on the IoT using the Blynk application can be used as as a temperature and soil humidity monitoring system that is expected to transmit data over long distances, as well as to analyze its communication performance monitoring tool for the farmers to obtain data remotely. While, the data from temperature sensors and soil humidity sensors that have been acquired by the system transmitter were able to acquire data with 91.63% accuracy. Thus, the communication performance testing showed the higher the configuration of SF the wider the LoRa communication range area, but it made the ToA result became longer.

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