Article

Implementation of Fuzzy Logic on Internet of Things-Based Greenhouse

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Abstract: This research is an internet of things-based monitoring system using LoRaWAN and the IoT Thingspeak application server. This research is focused on helping farmers, or the agriculture sector focused on Pakcoy. Pakcoy is a plant that can live at an altitude of 500-1200 meters above sea level using the Greenhouse concept; Pakcoy plants can be protected from pests. Nutrients for Pakcoy are sprayed through the leaves, accelerating the provision of nutrients for plants. The Fuzzy Sugeno method is used to control the Greenhouse temperature and Soil Moisture for effective plant development, as well as monitoring the Greenhouse temperature, soil moisture, and pH of the growing media based on the Internet of Things that uses the Long Range 915 Mhz, therefore, the users can find out in real-time the data can be accessed by using Thingspeak and can be used in areas where internet access is difficult.

Keywords: Greenhouse, Long Range 915 Mhz, Internet of Things, soil moisture, Fuzzy Sugeno

1. Introduction

Batu City is located in Malang Regency, East Java Province, precisely at the foot of Mount Bromo, Tengger, and Semeru. In Batu City, there is one hamlet, namely Dusun Brau, a village in Gunungsari Village, Batu City. This hamlet has a unique topography compared to other hamlets. This hamlet is located in a valley in the mountainous area of Batu City, which makes it difficult to access the internet network. Dusun Brau is an agricultural area. One of the plants that can survive is the *pakcoy* plant. Pakcoy plants are usually found in hilly areas and can survive from 500 meters to 1200 meters above sea level.[1] Spraying fertilizer through plant leaves can accelerate the provision of nutrients to plants [2]. One way to protect plants from pests, unstable weather, and high light intensity is to use a greenhouse. [3]. Agricultural management is currently carried out conventionally, such as watering plants and controlling temperature.

The Logic set theory developed to overcome the concept of value between truth and error is fuzzy [4]. Fuzzy inference system is one application of Fuzzy Logic. The Mamdani method, known as the Max-Min method, is applied in the automatic watering process [5]. Long Range (LoRa) is one of the most popular technologies. LoRa technology is very suitable for Internet of Things (IoT) applications that only need to transmit small amounts of data over long distances and low-power and long-range data transmission at a frequency of 915 Mhz and can be applied for agricultural monitoring [6].

One of the problems in agriculture is land management which is still conventional which requires more energy from the farmers. The development of technology from the Internet of Things (IoT) that uses Long Range or LoRa can be used by farmers to monitor soil moisture, soil pH, Greenhouse temperature and provide nutrition to plant leaves on agricultural land even though internet access in their area is still difficult and utilizes Fuzzy Logic in agriculture. Information in sensor data is sent in soil temperature, soil pH level, and greenhouse temperature. The data will be processed by the microcontroller and sent using LoRa [16, 18] to the gateway and then forwarded to the server [17, 19] and Android, which is done in real-time.

Pakcoy is one of the plants used for research. *Pakcoy* is stored in greenhouses which are placed in different locations. The greenhouse system makes it easier for farmers to provide water and fertilizer and easier to monitor soil pH levels and greenhouse temperatures. The location of this research is on Jl. Pisang agung, Unmer Malang Architect building. This research has a goal to help farmers better manage agricultural land to increase good and quality crop yields.

2. Literature Review

The literature review used in this study uses several components in hardware and software. The first Literature Study was Pakcoy, Pakcoy, or *Brassica rapa L* is one of the vegetable plants that are easy to develop in cold or hot weather areas; *pakcoy* vegetables can live at an altitude of 500 meters to a meter above sea level. These vegetables can be planted every year without having to wait for a certain time because these plants can grow and are tolerant of high temperatures, planted in loose soil, abundant organic matter, and irrigation with an acidity degree (pH) of 6 to 7 so that plants can grow optimally [1]. The most widely used planting medium is soil. The characteristics of the soil that can be used as a planting medium without having to make structural improvements are as follows:

1. Soil is brown to blackish brown.
2. When watered, there is no puddle of water for a long time. Easy to destroy when the soil is dry.
3. When wet, it is not sticky and flexible.
4. The soil is not sticky and flexible.
5. Soil pH is between 6-7, depending on the type of plant being planted.
6. There is a good nutrient content for plant development [2].

Furthermore, organic fertilizers are fertilizers made from natural ingredients with good levels and nutrients for plant growth: liquid organic fertilizer or so-called *poc*. In liquid form, not solid, easily soluble in soil, and carry essential elements for plant growth. Plant height can have a significant effect if the concentration of liquid organic fertilizer is given following the predetermined dose [2]. The greenhouse is a plant house; one of the functions of a plant house is to avoid pests and diseases and weather and radiation intensity from the sun. Plant houses for areas with tropical weather are possible in the production and cultivation of plants. Greenhouses can be used in plant cultivation and are an efficient way to provide an environment for plants to approach the optimum conditions for plant growth [7].

The IoT is the concept of where particular objects can transfer data across the network without requiring human-to-human and human-to-device interaction is called the Internet of Things (IoT). Internet Protocol (IP) itself is an identity in the network that can make objects can be controlled. Objects with Internet Protocol (IP) can be connected to the Internet network [8]. A chip that functions as an electronic circuit controller and can store programs is also called a microcontroller. Generally, the microcontroller consists of a Central Processing Unit (CPU), input and output (I/O), and memory. The microcontroller is carried out to run the program [9]. ATMEGA328 is an 8-bit AVR Chip.

Arduino IDE is software that is used for all types of Arduino boards. Integrated Development Environment (IDE) is a special program for a computer to sketch programs for Arduino boards. The programming language used is C. Making a program sketch begins with a sketch, library, object file, binary file and is uploaded to the microcontroller chip via USB cable [9]. Arduino is an open-source control board designed to facilitate electronics and other fields. Arduino Uno has Atmel AVR processor specifications [10]. Arduino Uno uses external power such as an adapter or battery, and power is generated from a computer using a USB cable. Dragino's Shield is one of the Long Range devices created by Dragino. This Shield is used by Arduino boards and uses the SPI protocol. By using this Shield, users can send and receive data over long distances but at a low data rate. In addition, the Shield Dragino is equipped with spread spectrum technology and is immune to interference. Shield Dragino is applied in several fields such as irrigation systems, smart cities, smart metering, etc. This module consists of several frequencies, such as 433MHz, 868MHz, 915MHz, and 920MHz [10].

An acidity measuring instrument is a pH sensor consisting of a probe connected to an electronic device to read and display soil pH values. The soil pH sensor has the following specifications [10]:

1. Sensors can be used on Arduino boards and other Microcontrollers.
2. The linearity of the soil pH data is 0.9962.
3. The required soil depth when measuring is as deep as.

DHT11 can detect temperature and humidity and has an analog data output that can be processed using an existing microcontroller. There are advantages of DHT11, one of which is that reading temperature, humidity, and data is not easy to experience intervention. Measurement of air temperature can be done using DHT11; the value read from DHT11 compared to a digital thermometer is not much different [12]. The humidity sensor functions as a humidity detector and can determine any water content in the soil or around the sensor. Using this sensor is easy by inserting the tip of the sensor probe into the soil, where the humidity level will be measured. This sensor consists of 2 copper plates that function as electrodes to measure soil moisture. The measured capacitance may differ depending on the type of wet soil or dry soil; the sensor in wet soil will have a different capacitance than dry soil. The combination of YL-39 (signal conditioning module) and YL-69 (sensor probe) can measure soil moisture levels. The measured soil moisture is converted to electrical voltage and converted into digital data [13].

Real-Time Clock is a component that can be used as an electronic clock to calculate time starting from the minor scale in seconds to the large scale of years. The time calculation is carried out in real-time by storing time calculation data so that the calculated time is accurate. Real-Time Clock (RTC) allows producing the exact time because it is equipped with a time generator and battery. Real-Time Clock (RTC) has many types depending on usage, and an example is the Realtime Clock (RTC) type DS3231, where the pins used in this module are VCC GND, SDA, and SCL [13].

The L298N motor driver is commonly used to control the motor so that the motor can be controlled through the microcontroller. The motor can rotate, and the motor speed can be adjusted, including the direction of rotation. L298N Motor Driver functions as a current amplifier and voltage to get a sufficient current supply. The L298N driver is a DC motor driver[14]. A DC pump is the same as a DC motor; it's just a different use. DC pumps can move liquids from low-pressure areas to high-pressure areas. The working principle of the DC pump uses a fan as a liquid transfer and a DC motor as a fan, the pressure generated in the pump room when the fan rotates will produce fluid pressure that can suck water and move it. Moreover, Mini Portable AC is an electronic device that has a function as a cooler for a room through the evaporation process

Fuzzy Logic is a set of Logic developed to overcome values between true and false. The Fuzzy Sugeno method is used to support the research carried out. The Fuzzy Sugeno method can be applied to control watering so that the duration of watering follows plant needs [14]. There are three main processes to implement Fuzzy Logic, namely:

1. Changing the input from definite to fuzzy, which is generally attached in the form of a fuzzy set with different membership functions, the process is called fuzzification

2. A reference that explains the relationship between input and output variables will be processed immediately and produce fuzzy; IF-THEN is used to describe the relationship between input and output. This process is called Rule Evaluation

3. Conversion of fuzzy variables into actual data and sent to the controller. This process is called defuzzification

LG01-P is an open-source LoRa Gateway made by Dragino that works with one channel. LG01-P functions to connect LoRa devices with WiFi, Ethernet, 3G, or 4G to connect to the Internet. LG01-P, based on the frequency range, is divided into two frequencies, i.e., 915 MHz and 433 MHz; this value is set from the factory. Lora Gateway is a module that acts as a bridge between one or more nodes to the LoRaWAN server [21]. This module has four frequencies, namely 433MHz, 868MHz, 915MHz, and 920MHz [15]. The user must ensure that the frequency range on the system has the same frequency range as the LG01-P LoRa Gateway. The LG01-P has a link budget of up to 168 dB and can work at low power. ThingSpeak is an open-source website for Internet of Things (IoT) needs and accepts data using the additional HTTP protocol over the Internet. ThingSpeak can be used as data logging and application. ThingSpeak is an open-source website for Internet of Things (IoT) needs and accepts data using the additional HTTP protocol over the Internet. ThingSpeak can be used as data logging and application. ThingSpeak was first launched by ioBridge in 2010, intended as a support service for the Internet of Things (IoT) applications[15]. The ThingSpeak support element contains data, locations, and status. ThingSpeak can be used to analyze, visualize, and act on data from sensors or actuators, such as Arduino.

3. Methodology

A method is a method or series used to solve a problem. The technique used in this research is the Fuzzy Logic Sugeno model for decision-makers for watering plants and controlling greenhouse temperatures. This tool maintains soil moisture and greenhouse temperature and monitors pH, soil moisture, and greenhouse temperature displayed on the *LCD* and the Thingspeak. Architectural model as in Figure 1.

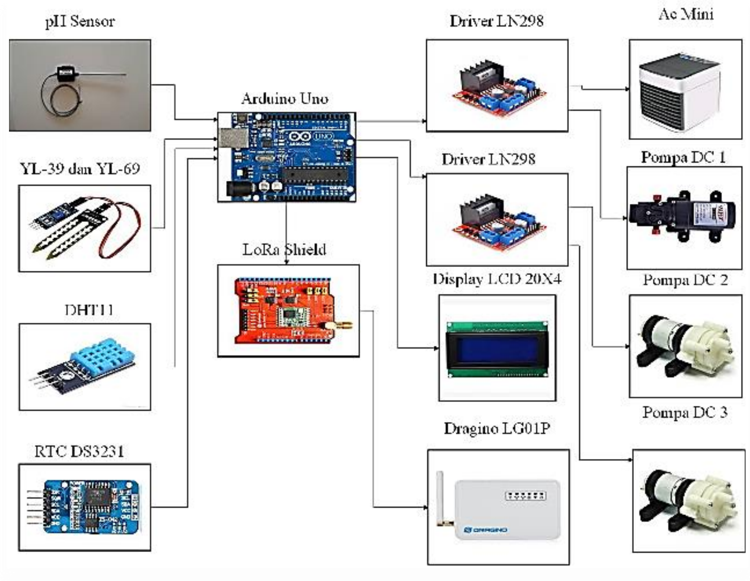

Figure 1. Architectural Model

The block diagram of the designed tool consists of input, process, and output. The data obtained from the sensor will be processed using the Arduino UNO microcontroller; for the automation system, it will be carried out automatically from the data obtained by the sensor, while for monitoring data from the Arduino [20] it will be sent directly using LoRa Shield to the gateway and then forwarded to Thingspeak. Block diagram as in Figure 2.

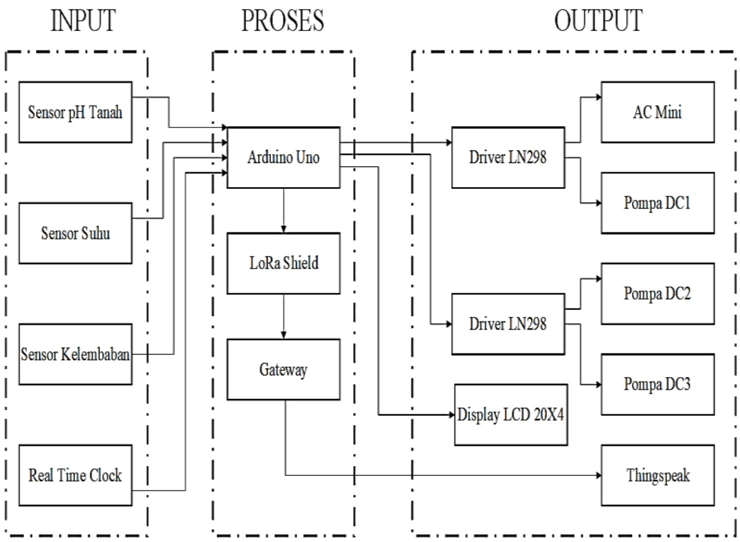

Figure 2. Block Diagram Tool

The system flowchart [Figure 3] that starts from the initialization of the sensors used is continued to the sensor readings. The read data will be displayed on the LCD and sent with LoRa, and the results of the data will be displayed on Thingspeak. The fuzzy Sugeno method produces PWM output for Pump 1 and AC Mini.

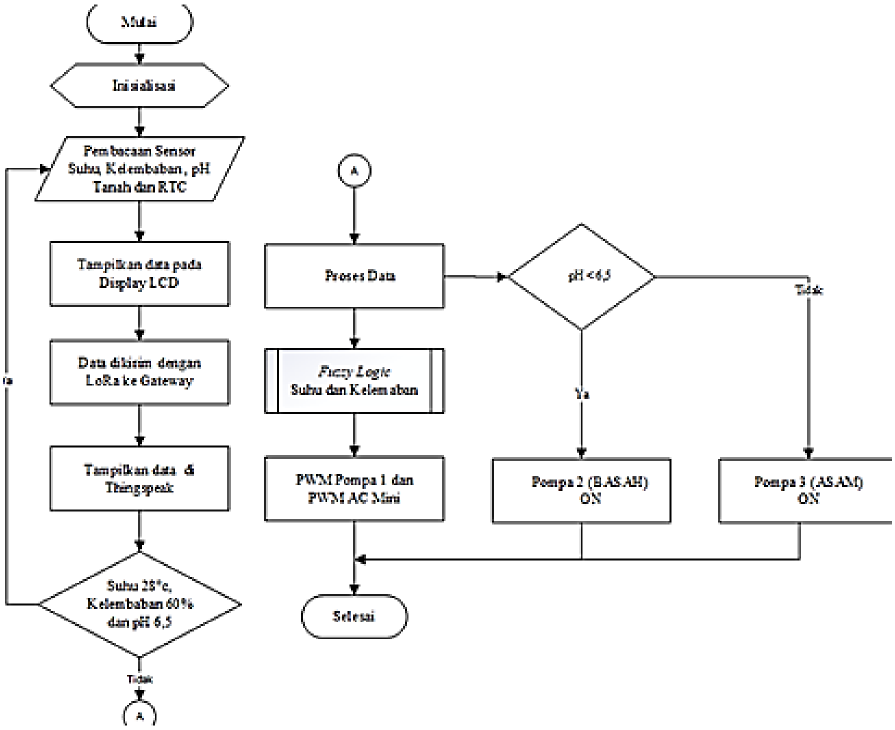

Figure 3. Flowchart system

The voltage line that is channeled to the Arduino and LoRa Shield goes through the Vin Pin. By using step down, which is set at 5Vdc and 2A. This is needed so that the voltage applied to the sensor does not decrease and remains stable. The schematic of the complete tool is as shown in Figure 4.

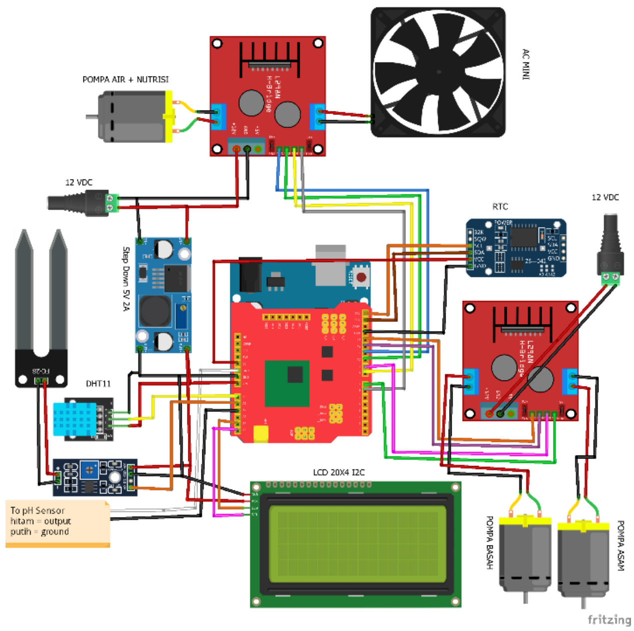

Figure 4. Schematic of the whole tool

4. Result and Discussion

Humidity sensor calibration is needed to see the relationship between the ADC sensor values and standard measuring instruments (3 in 1 soil survey instrument). The value of the reading of a standard measuring instrument has a measurement scale ranging from 1-10 so that it can be compared with the ADC sensor; the scale of the measuring instrument is converted into a percent from where one = 10% to 10 = 100%. The humidity sensor calibration data is shown in Table 1.

Table 1. Soil moisture sensor calibration data

Test	Amount of Water (ml)	ADC Value	Voltage (V)	Measuring Tool Scale
1	0	1023	5	2
2	10	1008	4,92	2
3	20	826	4,16	3
4	30	549	2,62	4
5	40	493	2,32	5
6	50	426	1,77	6
7	60	309	1,41	7
8	70	265	1,24	8
9	80	238	1,15	9
10	90	233	1,12	10
11	100	219	1,09	10

Table 1 shows the relationship between the ADC sensor values, the sensor output voltage, and the standard measuring instrument scale. From these data, Equation 1 is obtained as follows equation 1:

$$Vout=ADC/(Number\ of\ Bits) \times Vin \tag{1}$$

Where Vout: Output Voltage, Vin: Input Voltage, ADC: Read value, and Number of Bits: 1023, furthermore, By comparing the ADC sensor value and the standard measuring instrument scale, the data is processed using a linear regression equation so that the sensor humidity value equation is obtained in the form of a percent (%). The linear regression equation is shown in Figure 5.

From the graphic data in Figure 5, we get the equation between the scale of the measuring instrument and the ADC sensor value as follows equation 2.

$$y= -8,76x+946,09 \tag{2}$$

Furthermore, the following equation is used to obtain the percent scale (%) from the humidity sensor: y: ADC sensor value, x: Standard measuring instrument scale, following equation 3.

$$x= (y-946.09)/(-8.76) \tag{3}$$

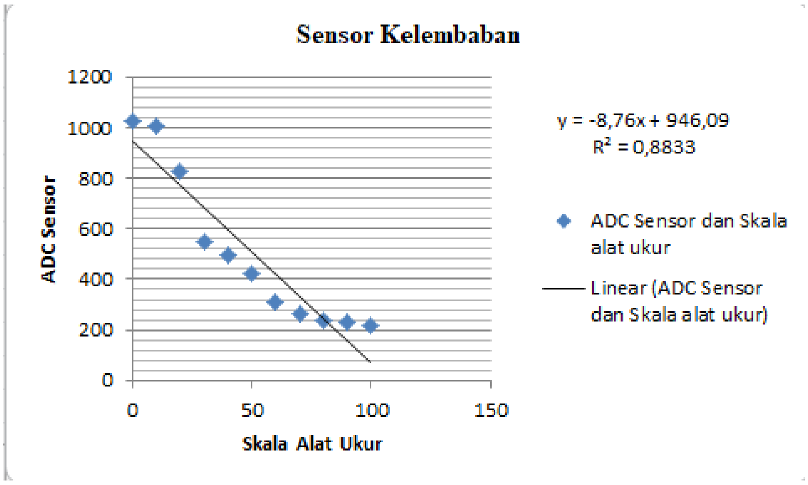

Figure 5. The graph of the linear regression equation of humidity

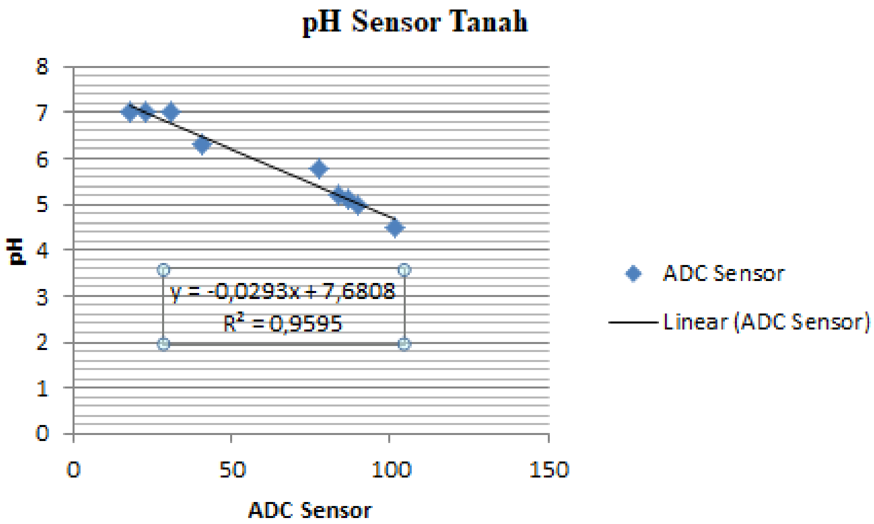

Figure 6. Graph of linear regression equation pH

Table 2. Shows the comparison of the sensor ADC value with the measured pH value from the data processed using a linear regression equation as shown in Figure 6. From the graphic data in table 2, the equation between the ADC sensor and the measured pH value follows equation 4.

$$y= -0.0293x+7.6808 \quad (4)$$

Where y = pH, x = ADC value, and DHT11 . Sensor Comparison, Testing the DHT11 temperature and humidity sensor is done by comparing the sensor readings with the readings on the HTC-2 Thermometer. Temperature testing is carried out during the day and at night. The test data are as in Table 3. To find out the difference and error by using the following equation 5.

$$\text{Difference} = \text{sensor value-reference value} \quad (5)$$

$$\text{Error} = (\text{sensor value-reference value})/(\text{reference value}) \times 100\% \quad (6)$$

Soil pH sensor calibration is carried out to compare the ADC value of the Soil pH sensor and standard measuring instruments to obtain the equation used for the soil pH sensor reference. The calibration data are shown in Table 2.

Table 2. Soil pH sensor calibration data

Acidic Liquid (ml)	pH	Voltage (mV)	ADC	Wet Liquid (ml)	pH	Voltage (mV)	ADC
0	7	94,6	31	0	7	83,1	23
5	6,3	183	41	5	7	65,6	18
10	5,8	331,1	78	-	-	-	-
15	5,2	400	84	-	-	-	-
20	5,1	403,1	87	-	-	-	-
25	5	406,1	90	-	-	-	-
30	4,5	420	100	-	-	-	-

From these data, the average difference at night is 1.3, an error is 5.2%, while the average difference during the day is 1.8, and an error is 6.0%. The comparison graph of the DHT11 AND HTC-2 sensors can be seen in figure 7, and Figure 8 shows a Temperature in 31 Days.

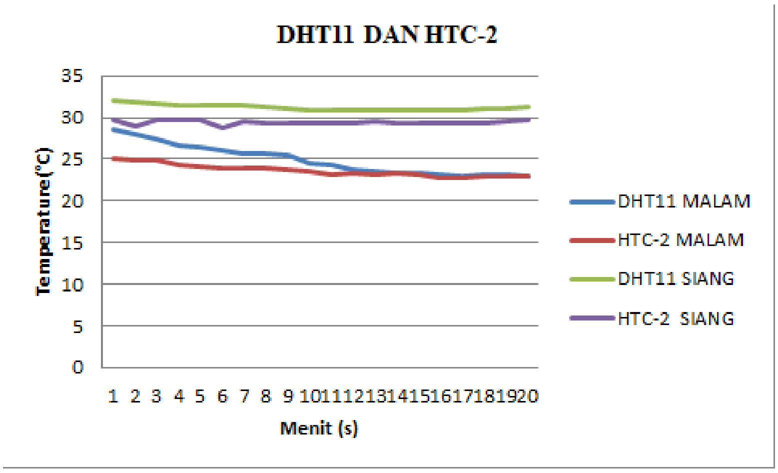

Figure 7. Comparison chart between DHT11 and HTC-2 Temperature sensor

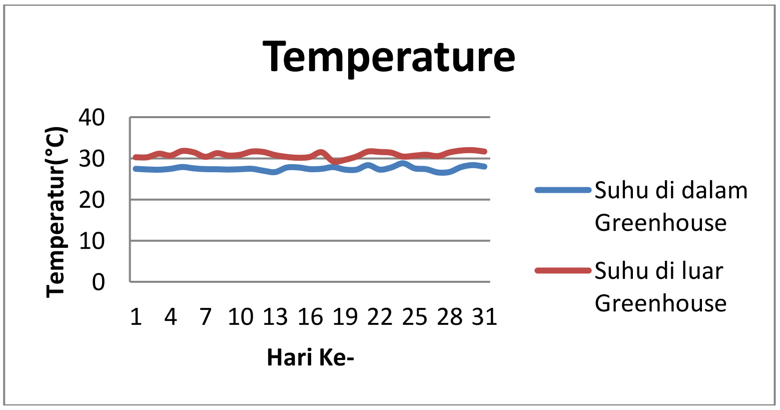

Figure 8. Temperature 31 Days

Table 3. Testing DHT11

Minute	Evening		difference	Error (%)	Midday		difference	Error (%)
	DHT11 (°C)	HTC-2 (°C)			DHT11 (°C)	HTC-2 (°C)		
1	28,6	25	3,6	14,4	32	29,7	2,3	7,7
2	27,9	24,9	3	12,05	31,8	29	2,8	9,7
3	27,4	24,8	2,6	10,5	31,7	29,7	2	6,7
4	26,7	24,4	2,3	9,4	31,4	29,8	1,6	5,4
5	26,5	24,1	2,4	10,0	31,5	29,8	1,7	5,7
6	26,1	24	2,1	8,8	31,5	28,7	2,8	9,8
7	25,7	23,9	1,8	7,5	31,4	29,5	1,9	6,4
8	25,6	24	1,6	6,7	31,3	29,4	1,9	6,5
9	25,4	23,7	1,7	7,2	31,1	29,4	1,7	5,8
10	24,6	23,5	1,1	4,7	30,9	29,3	1,6	5,5
11	24,3	23,2	1,1	4,7	30,9	29,3	1,6	5,5
12	23,7	23,3	0,4	1,7	30,8	29,3	1,5	5,1
13	23,5	23,2	0,3	1,3	30,8	29,5	1,3	4,4
14	23,1	23,3	0,1	0,4	30,9	29,3	1,6	5,5
15	23,3	23,2	0,1	0,4	30,8	29,4	1,4	4,8
16	23,1	22,7	0,4	1,8	30,9	29,4	1,5	5,1
17	22,9	22,7	0,2	0,9	30,9	29,4	1,5	5,1
18	23,1	23	0,1	0,4	31	29,4	1,6	5,4
19	23,2	23	0,2	0,9	31	29,5	1,5	5,1
20	23	22,9	0,1	0,4	31,2	29,7	1,5	5,1
Average difference			**1,3**				**1,8**	
Average error				**5,2**				**6,0**

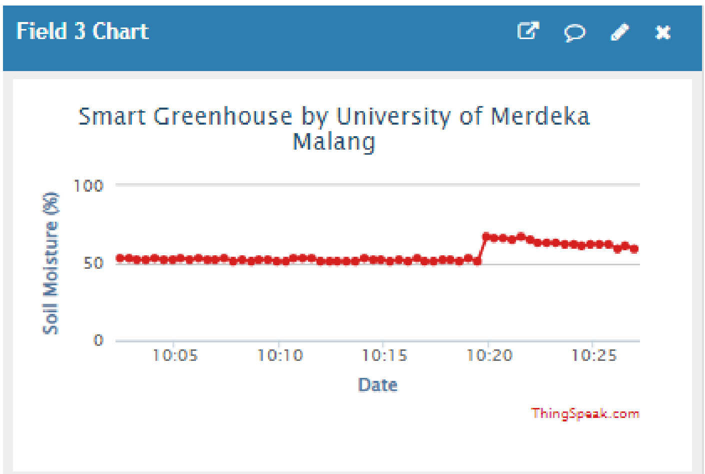

Figure 8. Output on the Thingspeak Application Server

Figure 8 is an example of Sensor data output from Smart Greenhouse Technology with the Thingspeak server application. The data shows real-time observations from the Soil Moisture Sensor (%).

Input and Output testing is carried out on the microcontroller, in this case, the Arduino Mega and the Matlab application, so that the results of the two tests get the difference value from the calculation. The Matlab application is used for testing calculations before the system that has been made is moved to the microcontroller—testing on the Matlab application, as shown in Figure 9.

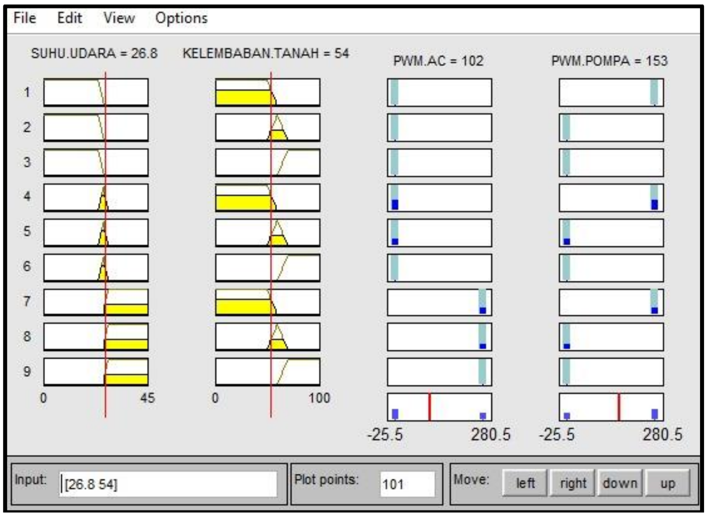

Figure 9. Fuzzy Logic Testing on Matlab Applications

The output is obtained when the temperature is 26.8 °C, and the soil moisture is 54%, 102 for PWM AC, and 153 for PWM Pump. The results of the overall test on the Matlab Application and Arduino Mega Microcontroller are as shown in Table 4.

Table 4. Test results on Matlab and Microcontroller Applications

No	Temperature (°C)	Soil moisture (%)	PWM AC		PWM POMPA		Difference	
			Arduino	Matlab	Arduino	Matlab	AC	Pump
1	20	0	0	0	255	255	0	0
2	21,2	5	0	0	255	255	0	0
3	22,1	10	0	0	255	255	0	0
4	23,5	15	0	0	255	255	0	0
5	24,3	20	0	0	255	255	0	0
6	25,8	25	0	0	255	255	0	0
7	26	30	0	0	255	255	0	0
8	26,1	35	12,75	12,8	255	255	0,05	0
9	26,2	40	22,5	22,5	255	255	0	0
10	26,3	45	38,25	38,3	255	255	0,05	0
11	26,4	50	51	51	255	255	0	0
12	26,5	51	63,75	63,8	229,5	230	0,05	0,5

No	Temperature (°C)	Soil moisture (%)	PWM AC		PWM POMPA		Difference	
			Arduino	Matlab	Arduino	Matlab	AC	Pump
13	26,6	52	76,5	76,5	204	204	0	0
14	26,7	53	89,25	89,2	178,5	179	0,05	0,5
15	26,8	54	102	102	153	153	0	0
16	26,9	55	114,75	115	127,5	128	0,25	0,5
17	27	56	127,5	128	102	102	0,5	0
18	27,1	57	140,25	140	76,5	76,5	0,25	0
19	27,2	58	153	153	51	51	0	0
20	27,3	59	165,75	166	25,5	25,5	0,25	0
21	27,4	60	178,5	178	0	0	0,5	0
22	27,5	61	191,25	191	0	0	0,25	0
23	27,6	62	204	204	0	0	0	0
24	27,7	63	216,75	217	0	0	0,25	0
25	27,8	64	229,5	230	0	0	0,5	0
26	27,9	65	242,25	242	0	0	0,25	0
27	28	66	255	255	0	0	0	0
28	28,1	67	255	255	0	0	0	0
29	28,2	70	255	255	0	0	0	0
30	29,4	75	255	255	0	0	0	0
31	30,7	80	255	255	0	0	0	0
32	31,3	85	255	255	0	0	0	0
33	32,6	90	255	255	0	0	0	0
34	33,2	95	255	255	0	0	0	0
35	34,1	100	255	255	0	0	0	0
					Average difference		0,091	0,043

4. Conclusion and Suggestion

This research is an internet of things-based monitoring system using LoRaWAN and the IoT Thingspeak application server, which can monitor soil pH and soil moisture sensors and temperature in the Greenhouse area. Sensor data has provided feedback on the output to water the plants, providing soil pH fluid automatically. The Fuzzy Sugeno method is used to control the Greenhouse temperature and Soil Moisture for effective plant development and monitor the Greenhouse temperature, soil moisture, and pH of the growing media based on the Internet of Things that uses the Long Range 915 Mhz. penelitian ini masih terus dikembangkan dalam hal kemampuan LoRa pada komunikasi data multi node dalam hal pengaturan pada Quality of Service LoRa Communication. This research is still being developed regarding LoRa capabilities in multi-node data communication to set the Quality of Service LoRa Communication. Finally, the sensor data output from Smart Greenhouse Technology with the Thingspeak server application, which shows real-time observations of the Soil Moisture Sensor (%), has been successfully tested and observed on various digital platforms connected to the Internet.

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