Internet of things implementation and analysis of fuzzy Tsukamoto in prototype irrigation of rice

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ABSTRACT

This research raises the topic of modern technology in the field of rice fields. The problem in this research is determining the fuzzy inference system algorithm for electronic engineering. The prototype was built by Raspberry Pi and python-based to the internet of things. The objective of this research is to design a new model for the rice field monitoring/control system and display every condition based on the internet of things. So that the hypothesis of this research can answer the phenomena that occur in rice fields, including drought problems, maintained plant conditions. The test results showed that irrigation control automatically runs optimally by scheduling, automatic irrigation control of water pH degree value detection analyzed by fuzzy Tsukamoto method at Z=3.5 defuzzification value for low and high irrigation control, and Z value=1.83 for normal irrigation control. Furthermore, the scheduling of spraying liquid fertilizer obtained the results of duration for 60 min in accordance with the needs of fertilizer dose. Lastly, for monitoring data on the website successfully accessed anywhere from the use of hosting servers and domains. Finally, it can be concluded that fuzzy Tsukamoto's algorithm is appropriate to be applied to the modern rice field system.

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1. INTRODUCTION

Rice cultivation is a part of agricultural land that is physically flat, limited by bunds planted with rice and fertilized. For this purpose, sufficient irrigation and fertilization are needed so that rice plant processing can grow well. However, there are several factors that can affect the level of satisfaction of farmers in cultivating rice fields, which until now the yields are still not good. The main cause is lack of water for rice plants during the dry season and during high rainfall which can flood the rice fields so that water exceeds the appropriate dose for rice plants [1].

In addition, water replacement is less effective in using drainage holes at the land boundary [2], the pH level of the water enters acidic and alkaline properties which can cause rice plants to become saturated and die [3], as well as poor fertilizer quality and sometimes not fertilizer application. According to the dose [4]. Currently, the application of technology for rice fields is still being developed, however, according to direct reports from farmers in handling problems in paddy field processing using current technology, it is not yet empowered in terms of quality and quantity [5]–[11].

Then we get a solution that can be implemented into rice cultivation, namely the implementation of the internet of things (IoT) and fuzzy Tsukamoto analysis on the rice field irrigation system prototype. The contribution of this research can be channeled in aspects of the rice fields aimed at the community of rice field managers to take advantage of renewable technology, to universities by combining several disciplines from electrical engineering, computer engineering, agricultural and biosystem engineering and civil engineering, to departments and institutions in terms of cooperation in order to create synergistic rice fields and to farmers who are closely related to controlling irrigation control, monitoring water pH and controlling fertilizer. Automatic control features developed include a tool control feature that can perform irrigation changes based on a predetermined time using water level detection sensors, irrigation changes with the help of water pH value detection tools, spraying liquid fertilizer based on a predetermined time, to display data output into internet-based websites of things. This prototype was built by Raspberry Pi with python programming language, then using Tsukamoto fuzzification method, in order to accommodate nonlinear data so that it is suitable in using linguistic values and conclude the implication results to be simple which is then eased back in defuzzification calculation to determine the output according to the input received. From the quote, this fuzzy logic is focused on creating parameters on the pH value of water that can provide input to perform water change actions that are integrated with water surface level detection.

2. RESEARCH METHOD

Okhaifoh *et al.* [12] offers a solution to monitor water quality to overcome land and water constraints and food security. Water quality is a determining factor in agricultural systems. This research has the objectives of developing a water quality management system based on IoT technology, then combined with a water quality control system based on fuzzy logic [10] and an automatic control system for wireless sensor networks (WSNs) [11]. So, the outcome of this research is to monitor parameters of pH, turbidity, total dissolved solid (TDS), dissolved oxygen and water level, and receive information online anytime and anywhere.

Okhaifoh *et al.* [12] describes water saving in the face of water scarcity that occurs in several cities in the world. The focus of this research is the arrangement of irrigation channels using reflected sound (echo) to provide an indication of water level, automatic control of a water pump engine and installed ultrasonic sensors to send and receive sound waves. The resulting output is a condition where the LED lights up to indicate the water level. Then you can activate the water pump, when the water level conditions are at the minimum level, which is 0.27 meters. Or turn off the water pump, when the water level is at the maximum level, which is 0.05 meters.

Saraf and Gawali [13] describes agricultural conditions in India, which requires the consumption of rainwater every year to increase agricultural productivity. So, this research proposes a plant quality monitoring system such as monitoring soil moisture, monitoring temperature, and humidity using the WSNs method. So that the output of this research is to provide efficient water use by implementing an automatic soil moisture-based irrigation system.

Rasyid *et al.* [14] focused on monitoring temperature and humidity conditions that must be maintained so that it can control the use of water volume wirelessly using the waspmote agriculture sensor node. The function of the waspmote agriculture sensor is to take data from around and use that data as Tsukamoto's fuzzy logic input as a decision maker. The output of this research is that the system can monitor ambient temperature and humidity values.

Mutiara *et al.* [15] describes the results of a researcher visit in Boyolali, Central Java. The findings obtained were changes in extreme weather, poor irrigation systems, changed soil acidity and poor fertilizer management. So, the proposal for this research is to design a mini-rice field prototype that can control the water level, irrigation regulation, detect pH properties, global system for mobile communication (GSM) control as notification and monitoring of liquid fertilizer. The output of this study accurately monitors and controls the mini rice fields in the form of prototypes arranged via short message service (SMS) communication and displayed to a 16x4 liquid crystal display (LCD) screen.

From some of the literature that has been reviewed, this research focuses on the implementation of the IoT and Tsukamoto's fuzzy analysis on the prototype of the rice irrigation system. To make this research successful, the Raspberry Pi as a mini computer [16] is the right answer for the implementation of the internet of things system in the prototype of the rice field irrigation system because it is equipped with Python which is easier to implement [17] and CodeIgniter as a framework for developing applications on the site. web using PHP [18], [19]. So that the concept of IoT which is designed can be implemented well. Some opinions suggest that the concept of the IoT is to integrate several interconnecting devices into an interconnection networking (Internet) so that the concept of wide area network (WAN) is realized without paying attention to the conditions of space and time [20], [21].

2.1. Design

The system designed is intended as a form of automatic control and monitoring of rice fields in the irrigation system, water pH and liquid fertilizer application. So that it can help users to manage their fields more effectively and efficiently. In addition, with the presence of a data viewer through an IoT-based website, it is hoped that it will take part in monitoring Indonesian rice field management activities.

Based on the system description, operational definition and needs analysis, the simulator to be designed is divided into 3 control systems as shown in Figure 1 that are integrated into the Raspberry Pi microprocessor, including; i) irrigation replacement based on timing, ii) water change based on water pH value detection, and iii) liquid fertilizer based on timing.

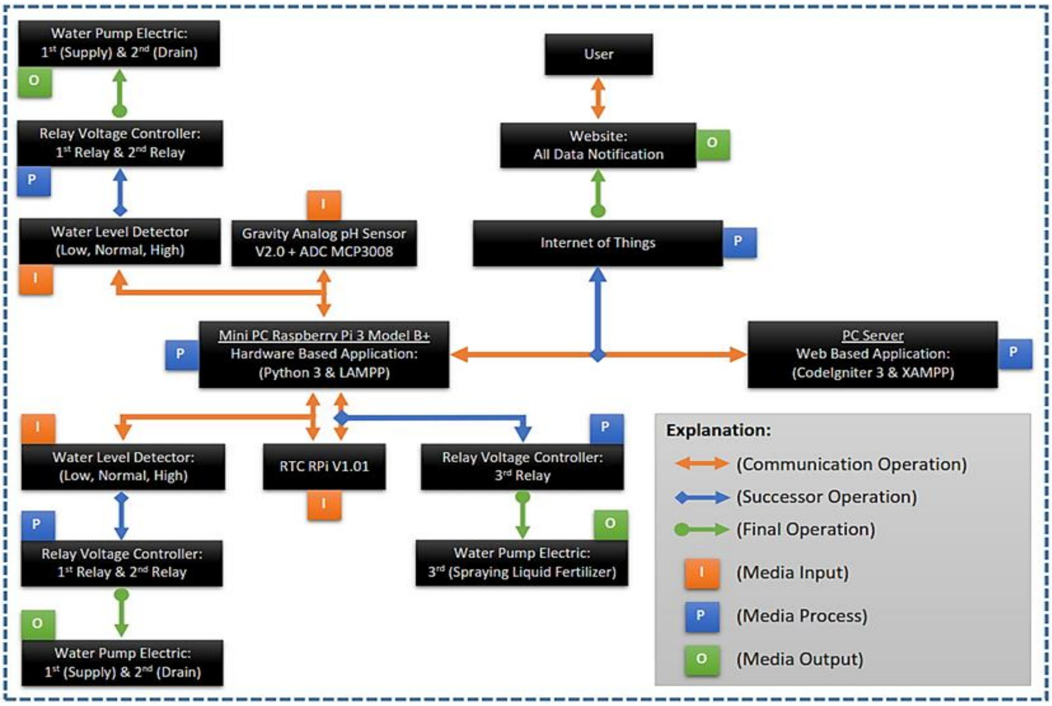

Figure 1. Research proposed block diagram

2.2. Simulator

Figure 2 shows the form of mediator design consisting of several electronic components as well as an integrated module for the implementation of the scope of rice fields. This mediator is a form of innovation that includes the layout of rice fields, irrigation channels, irrigation pumps and liquid fertilizers, liquid fertilizer containers, fertilizer sprayers, detectors, sensors and artificial intelligence devices with prototyping methods. Then obtained the result of mediator size with a length of 87 cm, width of 80 cm and height of 20 cm.

2.3. Fuzzy Tsukamoto

Some opinions [22]–[24] suggest that the Tsukamoto fuzzy inference is one of the irrigation system decision-making methods designed in combination with the MATLAB application to determine the output of Tsukamoto's fuzzy analysis [25], [26]. In Figure 3 is a commonly known fuzzy logic system (FLS). It consists of four basic components: fuzzifier, fuzzy rule base (knowledge base), inference engine and defuzzifier.

Fuzzifier uses membership functions to convert sharp input into fuzzy values. Popular membership functions include triangle, and trapezoid. The fuzzy rule base stores fuzzy rules which have the form: "IF antecedent THEN consequence", where the antecedent and consequence are fuzzy sets. Three main types of fuzzy inference rules and therefore three fuzzy models have been distinguished, namely Mamdani, Sugeno, and Tsukamoto. The inference engine uses different methods to combine fuzzy rules for fuzzy inference [22]–[24]. It can be seen in Figure 4, there are 2 parameters X_1 dan X_1, where $\mu X_1 = \{a_1, b_1, c_1, d_1\}$, $\mu X_2 = \{a_2, b_2, c_2, d_2\}$, $\mu Y = \{a_y, b_y, c_y, d_y\}$ and the fuzzy system consists of two rules, namely [22]–[24], [27]: Rule 1: IF X_1 is a_1 AND X_2 is c_2 THEN Y is a_y and Rule 2: IF X_1 is b_1 AND X_2 is d_2 THEN Y is b_y.

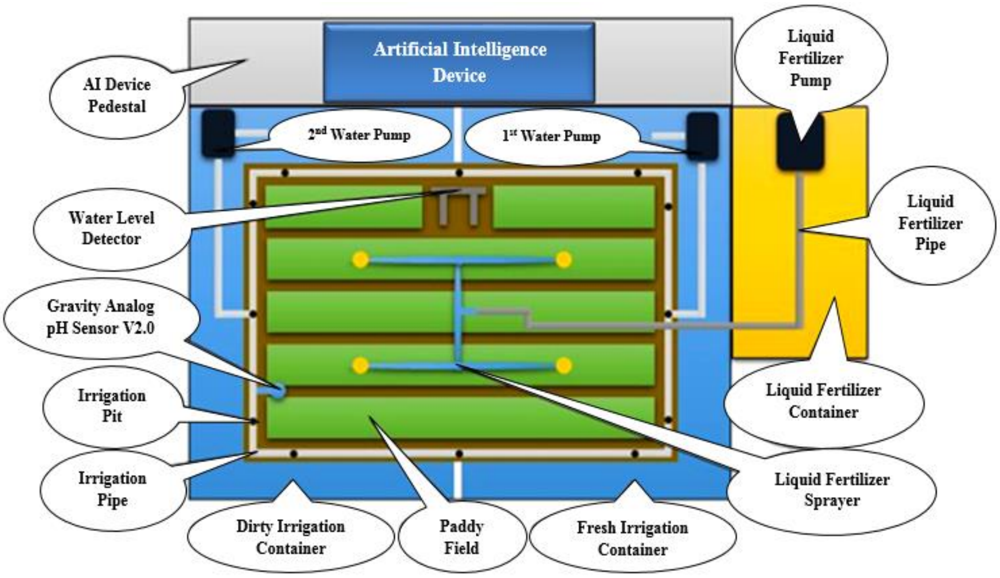

Figure 2. Rice mediator

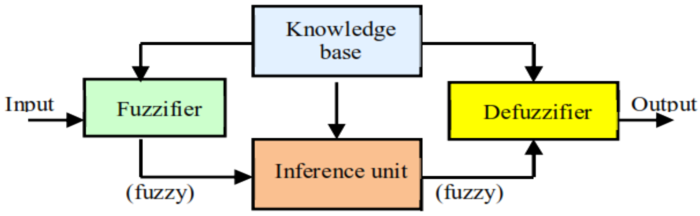

Figure 3. Configuration fuzzy system

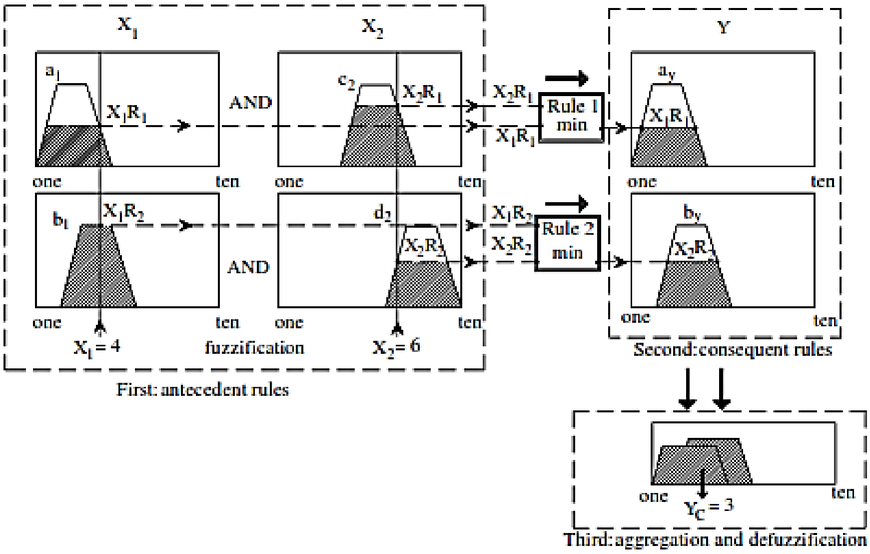

Figure 4. Fuzzy rules firing

Where two input are used $\{X_1 = 4, X_2 = 6\}$. Such two inputs intersect with the antecedents MF of the two rules where two consequent rules are produced $\{R_1\ and\ R_2\}$ based on minimum inter-sections. The consequent rules are aggregated based on maximum intersections where the final crisp value is 3. The aggregated output for R_i rules is given by [22], [25], [26].

- Rule 1 : $\mu R_1 = min[\mu a_1(X_1)\ and\ \mu c_2(X_2)\ ]$
- Rule 2 : $\mu R_1 = min[\mu b_1(X_1)\ and\ \mu d_2(X_2)\ ]$

$$Y : Fuzzification\ [max[R_1, R_2]\ ]$$

The defuzzifier can consist of the following methods: center of gravity or centroid (CoG) including CoA and CoS, altitude method (HM), middle of maxima or mean of maxima (MoM), first of maxima (FoM) in Figure 2. The differences between fuzzy systems are based on the type of fuzzy rules, the inference method and the defuzzifier. An additive fuzzy system or more specifically called SAM featuring Tsukamoto's fuzzy rule, sum-product inference, and CoG defuzzifier were investigated in this study to test the rice paddy system prototype [22]–[24], [27].

Return to the research being done to obtain output of the value and degree of membership, there are main characteristics that require four stages, namely:

a. Fuzzification

The definition of fuzzification is the process of converting non-fuzzy variables (numeric variables) into fuzzy variables (linguistic variables). For the Tsukamoto fuzzification process, either the crisp input or crisp output variables are divided into one or more fuzzy sets. The membership levels that will be used in this study include:

1) Membership function of water surface level input variables

In the input variable the water level is divided into 3 membership groups, namely low, normal, and high. And for the degree of membership used in the form of water level values, namely low (1 cm), normal (3.5 cm), and high (6 cm). Figure 5 shows the membership function of the water level.

2) Membership function of input variable water pH scale

In the input variable the water pH scale is divided into 3 membership groups, namely acidic, normal, and alkaline. And for the degree of membership used in the form of water pH values, namely acidic (0.00 to 4.99 pH), normal (5.00 to 7.99 pH), and alkaline (8.00 to 14.00 pH). Figure 6 shows the membership function of the water pH scale.

3) Membership function of water change output variable

In the water change output variable, it is divided into 4 membership groups, namely water drain pump from normal level, water supply pump from low level, water supply pump from high level and no water pump action. The degree of membership still requires a water level scale (1 to 6 cm). Figure 7 shows the membership function of water change.

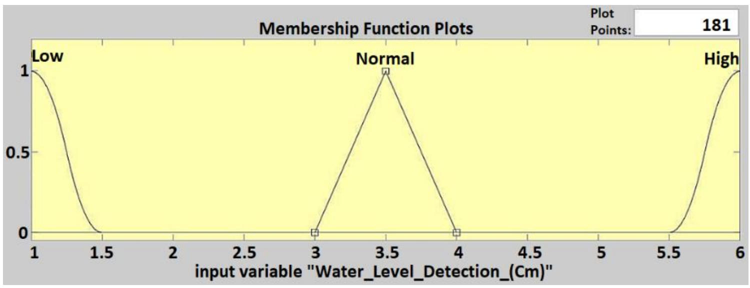

Figure 5. Water level membership function

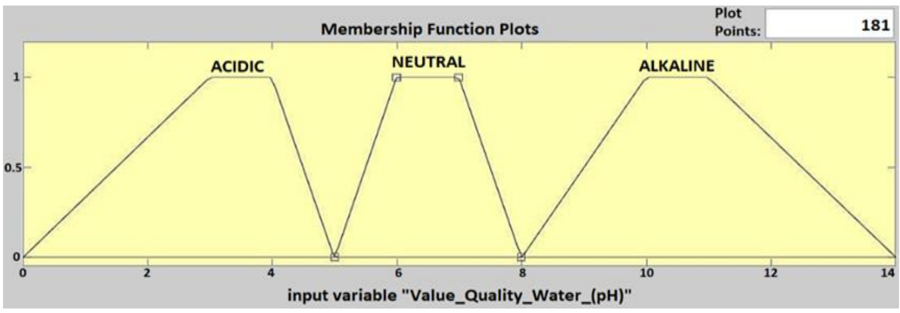

Figure 6. Water pH scale membership function

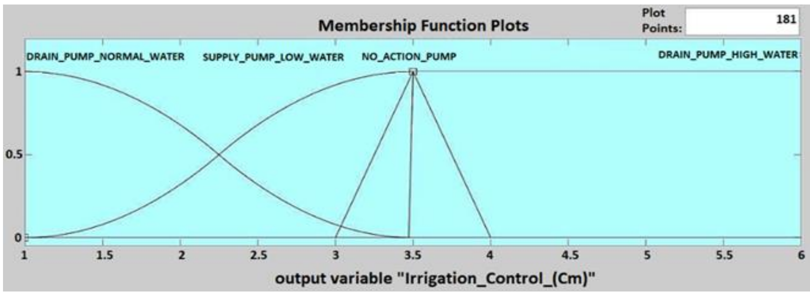

Figure 7. Water change membership function

b. Inference

Inference is an implication which is the process of drawing conclusions from the If-And-Then Rule, in the Tsukamoto method the conclusion uses the MIN-MAX implication function. The rule (rule) in the fuzzy system is from a combination of the set of membership functions for the water surface level, the water pH scale, and the water change. So, if combined there are 3x3=9 which can provide irrigation control results. The following is a Table 1 combinations of fuzzy rules in MATLAB.

Table 1. Combination of fuzzy rules

Water Level Water pH Scale	Low (1 cm)	Normal (3.5 cm)	High (6 cm)
Acid (0.00-4.99 pH)	Irrigation supply control	Irrigation supply control	Irrigation supply control
Neutral (5.00-7.99 pH)	Irrigation supply control	No Action	Irrigation supply control
Base (8.00-14.00 pH)	Irrigation supply control	Irrigation supply control	Irrigation supply control

c. Composition

In the next stage, the system composition will carry out an aggregation process to determine a combination of several outputs from all the formed rules.

d. Defuzzification

The definition of defuzzification is the process of converting fuzzy data into numerical data that can be sent to control equipment. Where the crisp output is obtained by taking the average value that can be done with (1) used in the MathWorks MATLAB application as:

$$Z = \frac{\alpha_1 \times z_1 + \alpha_2 \times z_2 + \alpha_3 \times z_3 \cdots + \alpha_n \times z_n}{\alpha_1 + \alpha_2 + \alpha_3 \cdots + \alpha_n} \quad (1)$$

3. RESULTS AND DISCUSSION

Implementation of the IoT and fuzzy Tsukamoto Analysis in the rice field irrigation system prototype is a set of control and monitoring systems for the rice fields. The design of the tool uses integrated circuit components, relay switches, resistors, diodes, terminal blocks, power supply and the Raspberry Pi 3 Model B+ microprocessor. So that it can instruct detectors, sensors, actuators, indicators and transmit data to the display in the form of a website with the concept of wide area network. Figure 8 shows the rice field simulator designs.

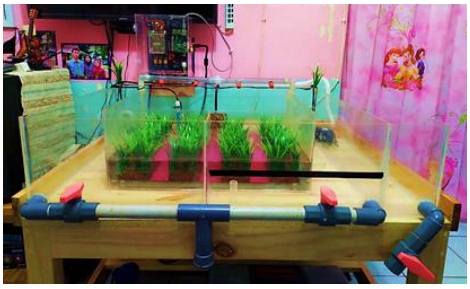

Figure 8. Rice field simulator prototype

3.1. Testing
3.1.1. Timing-based irrigation replacement tests

Timing-based irrigation replacement testing is carried out in a periodic time scheduling integrated with the RTC RPi V1.01 module and water level detector as water level detection. Following is Table 2 of the activation schedule for irrigation replacement. Technically, if when the water drain pump is active, the water level drops until a "low" level detector is detected (low=1 cm), then the water drain pump is turned off and the water supply pump will be active to fill water until a "normal" level detector is detected. (Mid=3.5 cm). In addition, there is a water drain function when the water level exceeds the normal limit. If the water level is detected, the "high" level detector (high=6 cm) will only drain the water until the water pump is turned off again if a "normal" level detector is detected (mid=3.5 cm).

Table 2. Irrigation switch activation schedule

Schedule	(Condition 1) Water Status	Action 1	(Condition 2) Water Status	Action 2	(Condition 3) Water Status
At 00:00	Normal (3.5 cm)	Pump On: drain irrigation	Low (1 cm)	Pump On: Irrigation supply	Back to Normal (3.5 cm)
At 06:00	Normal (3.5 cm)	Pump On: drain irrigation	Low (1 cm)	Pump On: Irrigation supply	Back to Normal (3.5 cm)
At 12:00	Normal (3.5 cm)	Pump On: drain irrigation	Low (1 cm)	Pump On: Irrigation supply	Back to Normal (3.5 cm)
At 18:00	Normal (3.5 cm)	Pump On: drain irrigation	Low (1 cm)	Pump On: Irrigation supply	Back to Normal (3.5 cm)

3.1.2. Irrigation change testing with detection of water pH value

Irrigation replacement testing based on the detection of water pH values uses the Gravity Analog pH Sensor V2.0 which can receive analog signals from water and converted them into digital data using the MCP3008 ADC. The result of the conversion is processed by the Raspberry Pi 3 Model B+ microprocessor so that it can display data [14]. Following is Table 3 of pH sensor calibration settings. In testing the Gravity Analog pH Sensor V2.0 its accuracy can be proven using litmus paper for international standardized universal indicators and has been tested in previous studies [11].

Table 3. pH sensor calibration settings

Calibration (0.00 to 14.00)	
pH Value: 10.00 to 14.00	Very acid
pH Value: 9.00 to 9.99	Middle base
pH Value: 8.00 to 8.99	Low base
pH Value: 7.00 to 7.99	Neutral good
pH Value: 6.00 to 6.99	Neutral enough
pH Value: 5.00 to 5.99	Neutral low
pH Value: 4.00 to 4.99	Low acid
pH Value: 3.00 to 3.99	Middle acid
pH Value: 0.00 to 2.99	Very acid

3.1.3. Timing based fertilizer spray testing

Timing-based fertilizer spray testing is carried out automatically by determining the activation schedule for spraying liquid fertilizer using the RTC RPi V1.01 tool which is processed by the Raspberry Pi Model 3 B+ microprocessor. Table 4 shows the activation schedule for spraying liquid fertilizer. Technically the test is carried out by setting the schedule, hour and time duration to be determined in the python program, then the program will process these settings which are integrated with the RTC RPi V1.01 tool which can give action commands to activate the relay to run the liquid fertilizer pump. The liquid fertilizer that is sucked in by the pump will be forwarded back through the hose and to the nozzle sprayer that is placed on top of the rice plants, so that the liquid fertilizer that is sprayed can be thorough to the rice plants according to the desired schedule. After the time duration reaches 60 seconds, automatic fertilizer spraying is stopped. Figure 9 shows testing the schedule for spraying liquid fertilizer.

Table 4. Schedule activation of spraying liquid fertilizer

Schedule	(Condition 1) Spraying Liquid Fertilizer	Duration	(Condition 2) Spraying Liquid Fertilizer
Wednesday, at 08:00	Active	60 s	OFF
Thursday, at 08:00	Active	60 s	OFF
Friday, at 08:00	Active	60 s	OFF
Saturday, at 08:00	Active	60 s	OFF
Sunday, at 08:00	Active	60 s	OFF

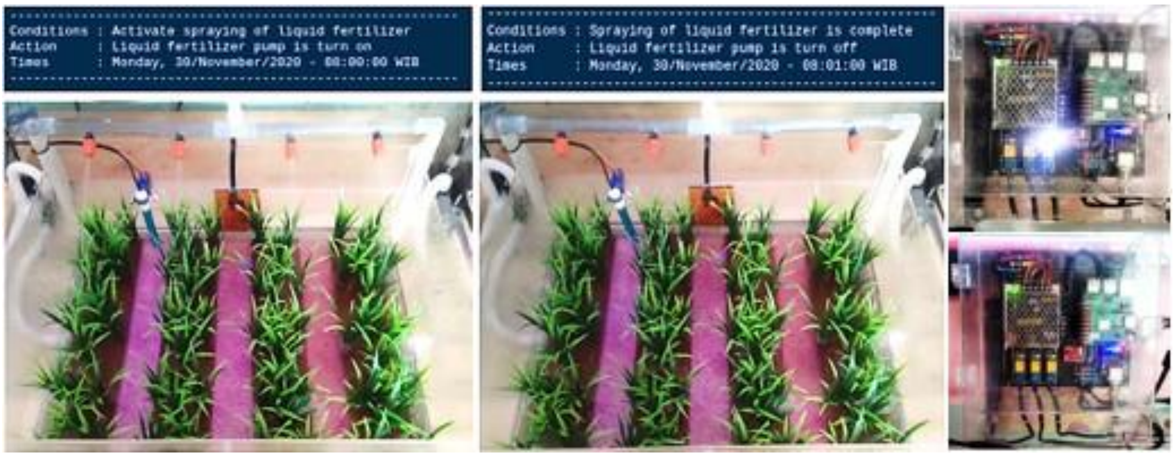

Figure 9. Water level detection test

3.1.4. Testing data viewers based on the internet of things

Internet of things is a concept in which certain objects have the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction [8], [28], [29]. So, from this concept, we get a test of sending data from devices that can be displayed on a website that can be accessed anywhere. Basically, the data that is sent will first be accommodated in the database server, then the data is taken to the website. In the rice field monitoring system displayed on the website after successful login (entry access), there are several features including the sidebar (sidebar), the main menu (main menu) dashboard (homepage), and the table of content (content in the table). Of these several features, it can provide user or manager data security and make it easier to choose the data you want to monitor. The following Figure 10 is viewer control system data

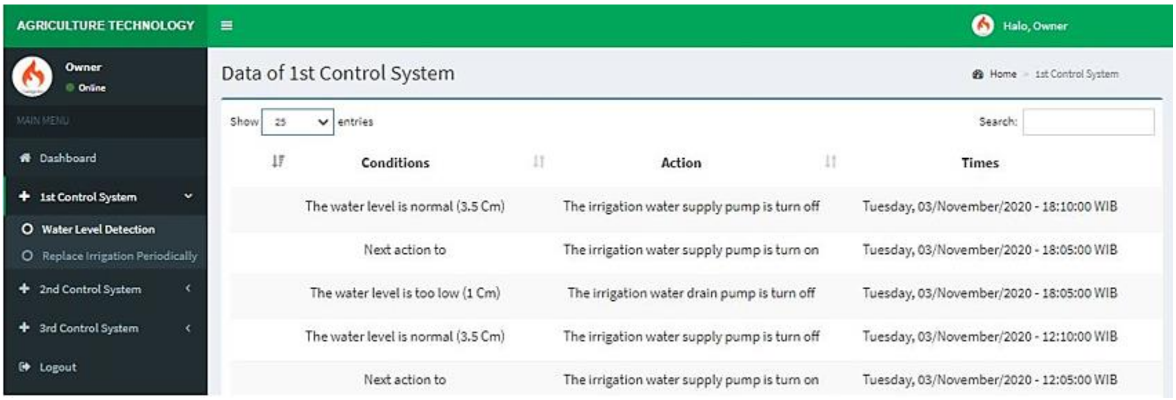

Figure 10. Control system data viewer

3.2. Analysis

The output from MATLAB was then analyzed using data translation in the form of parameter values into fuzzy in the MathWorks MATLAB application guided in the journal [26], so that the Tsukamoto fuzzy method can be analyzed, including: i) in both inputs to provide aggregation of the output of water supply action, where the test results ignore the detection of the pH value of acidic and alkaline water when the water level is 1 cm, because systematically the program designed for irrigation is still supplied back to the normal surface level of 3.5 cm if the water level was detected at the level of 1 cm; ii) in both inputs to provide aggregation of the output of water draining action, where the test results produce the detection of the pH value of acidic and alkaline water and drain the water to a low water level of 1 cm. However, when a normal water pH value is detected, there is no supply pump action or irrigation drain and it can be said that the water level is still normal 3.5 cm; and iii) in the second input to provide aggregation of the output of water draining action, which is where the test results ignore the detection of the pH value of acidic and alkaline water at the water level of 6 cm, because systematically the program designed for irrigation is still drained to a normal surface level if conditions the water is high. So, from the inference results of 9 rules from 3 irrigation control actions, we get several parameters to be defuzzified in (2) to (4):

$$\text{Low} - \text{normal irrigation control} = \frac{1 \text{ x } 2.99 \text{ x } 3.5 + 1 \text{ x } 6.99 \text{ x } 3.5 + 1 \text{ x } 10.99 \text{ x } 3.5}{2.99+6.99+10.99} = \frac{10.465+24.465+38.465}{20.97} = \frac{73.395}{20.97} = 3.5 \quad (2)$$

$$\text{Normal} - \text{low irrigation control} = \frac{3.5 \text{ x } 2.99 \text{ x } 1 + 3.5 \text{ x } 6.99 \text{ x } 3.5 + 3.5 \text{ x } 10.99 \text{ x } 1}{10.465+24.465+38.465} = \frac{10.465+85.6275+38.465}{73.395} = \frac{134.5575}{73.395} = 1.83 \quad (3)$$

$$\text{High irrigation control} - \text{normal} = \frac{6 \text{ x } 2.99 \text{ x } 3.5 + 6 \text{ x } 6.99 \text{ x } 3.5 + 6 \text{ x } 10.99 \text{ x } 3.5}{17.94+41.94+65.94} = \frac{62.79+146.79+230.79}{125.82} = \frac{440.37}{125.82} = 3.5 \quad (4)$$

So, simulator testing and analysis in MATLAB using the Tsukamoto fuzzy method, the defuzzification results for low-normal and high-normal irrigation control obtained a value of Z=3.5, stating that the balance of supply and irrigation drainage reaches a water level at 3.5 cm. And for normal-low irrigation control, the value of Z=1.83 is obtained, stating that the draining of water with an acidic (2.99 pH) or alkaline (10.99 pH) pH reaches a water surface level of 0.83 cm below the detection of 1 cm.

4. CONCLUSION

The conclusions obtained are based on the results of documentation, testing and analysis of the entire system, namely: i) testing the control system for timing-based irrigation changes produces a safe voltage at 5 volts, and successfully states the limit of the water level detected by the water level detector between 1 cm, 3.5 cm, and 6 cm. In addition, the adaptation time set for irrigation changes using the RTC RPi V1.01 can work well with an interval of 6 hours and is integrated with water level detector, electric water pump, and LED light and sound indicators; ii) testing of control systems for irrigation changes based on pH value detection is proven to produce a safe voltage of 2 volts and has an accuracy of ± 0.1 pH by using the Gravity Analog pH Sensor V2.0 and tested with an accuracy difference of ± 0.99 pH using universal indicator litmus paper. With the results of detection of pH values at acid and alkaline levels, it is successful to carry out an irrigation change action that is integrated with a water level detector, electric water pump, and LED light and sound indicators; iii) the control system testing for timing-based fertilizer sprays has also been tested with the time adaptation set using the RTC RPi V1.01 which is integrated with the electric water pump and LED light and sound indicators with a spraying duration of 60 minutes according to the fertilizer dose requirements; iv) testing the monitoring system on the appearance of internet-based data of things can work properly using the concept of WAN where website pages can be accessed anywhere. Data transmission for the three control systems has also succeeded in obtaining an internet protocol address (IP address) interconnection between the Python and SQL systems on the Raspberry Pi 3 Model B+ with the phpMyAdmin and SQL database systems on a personal computer (PC) server on a separate Apache2 server platform; and v) simulator testing and analysis at MATLAB MathWorks with the Tsukamoto fuzzy method, getting optimal water control results from defuzzification calculations for low-normal and high-normal irrigation control obtained a value of Z=3.5, stating that the balance of supply control and irrigation drainage is up to level water level at 3.5 cm. And for normal - low irrigation control, the value of Z=1.83, states that the control of draining water with an acidic (2.99 pH) or alkaline (10.99 pH) pH up to a water surface level point is 0.83 cm below the 1 cm detection point.

Suggestions that can be given are based on the conclusions and from several respondents, including: i) to design a water level detector, you must pay attention to the placement limit of copper in determining the desired water level, as well as the recommended safe voltage limit of only 2-5 volts with a resistor value of only 20-40 KΩ to be placed into the water; ii) in using the real time clock (RTC) tool, it must be adjusted to suit and special configuration on the Raspberry Pi 3 Model B+, so that when the device is turned off, the time will still run after turning it back on. In addition, if the irrigation change is not according to the schedule, upload the program again or check the CMOS battery voltage on the RTC device whether the battery power is still suitable for use; iii) pay attention to the placement of the pH sensor probe not to get too close to the water level detector. Because the copper in the water level detector has a 5 volt electrolyte connected to water, while the pH probe only emits a low voltage of 2 volts and is not equipped with electromotive force (E.M.F) anti-E.M; iv) it is recommended in the future to do the Tsukamoto fuzzy analysis with manual calculations on fuzzification, inference and composition so that the results can be concluded with the analysis in the MathWorks MATLAB application; v) it is suggested in the future to be able to group data in the form of line/bar/pie charts on the website and in this study there is no such function because there is still limited knowledge to explore web programming; vi) in the development of this simulator, the Raspberry Pi controller version 3 still uses, because the 3rd version has a small random access memory (RAM) space and a fairly slow process when running some quite heavy applications. So, it is recommended to use the above version so that the resulting process is more optimal; and vii) the simulator model in rice fields is recommended for real implementation using an irrigation architecture with several holes in the pipe in a square shape, placing 2 water pumps in irrigation and sewage sources, determining the spray point for liquid fertilizer on each row of rice fields, as well as a suitable location and size. to accommodate liquid fertilizer. This research does not discuss real power sources for rice fields. However, as a suggestion from several respondents, in an era of increasingly developing technology, the use of electrical resources can be redeveloped by utilizing solar cells during the dry season or a lightning rod (grounding system) during the rainy season with a power storage (battery backup system).

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