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Smart agriculture for optimizing photosynthesis using internet of things and fuzzy logic

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ABSTRACT

Photosynthesis is a process that plants need. Plant growth requires sunlight to carry out photosynthesis. At night photosynthesis cannot be carried out by plants. This research proposes an internet of things (IoT) model that can work intelligently to maximize photosynthesis and plant growth using fuzzy logic. The plants used in this research are mustard plants because mustard plants are plants that have broad leaves and require more photosynthesis. The outputs of this proposed model are the activation of light emitting diodes (LED) lights and automatic watering based on input sensors such as soil moisture, temperature, and light intensity which are processed with fuzzy logic. The results show that the use of the IoT model that has been proposed can provide faster and better growth of mustard plants compared with mustard plants without an IoT system and fuzzy logic. This result is also strengthened by comparing the t-test between the two groups, with a significant 95% confidence level. The proposed model in this research is also compared with similar research models carried out previously. This research resulted in a plant height difference of 30.43% higher than the previous research. So, it can conclude that the proposed model can accelerate the growth of mustard plants.

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1. INTRODUCTION

The agriculture sector is a critical sector considering the primary food needs of vegetables which have a total requirement of 7.12% of the real needs of the Indonesian population in 2018 [1]. Vegetables rank fourth after fast food, cigarettes, and rice [1]. Based on data from the Central Statistics Agency of Indonesia, the Indonesian population only consumes 43% of the recommended vegetables. It is necessary to increase fruit and vegetable production if the Indonesian people have to eat vegetables and fruit as recommended. One of the problems of the lack of vegetable consumption in the communities is that vegetable production has not been maximized, so current production cannot meet the needs of vegetables in the communities. Economic factors also affect people's purchasing power of vegetables. Poor people buy and consume fewer vegetables [2], agriculture is also the primary source of income for some people [3], [4]. There is a need for innovation to overcome less than optimal vegetable production problems, resulting in less vegetable consumption than recommended.

To overcome the lack of productivity in agriculture, this research proposed internet of things (IoT) and fuzzy logic models to maximize growth and crops in agriculture by using several input sensors such as temperature sensors, light intensity sensors, and soil moisture sensors. The output of the proposed IoT model is an automatic plant watering system that adjusts soil moisture conditions. This plant watering system aims to ensure plants always get water according to their needs. In addition to the automatic plant watering system, the output of the proposed IoT model is to activate light emitting diodes (LED) lights with the light intensity that can adjust automatically based on conditions of sunlight intensity around the environment. The function of starting LED light is that plants always get even light even though the background is dark to maximize photosynthesis time and make faster growth. The maximum photosynthesis process can maximize plant growth [5]. The light intensity affects photosynthesis to determine the proteins needed for photosynthesis [6], [7]. It is proven by research that has been done by [8] about the effect of interactions in plants on the influence of light. The research results conducted by [8] found that plants that receive low sunlight have a lower rate of photosynthesis. This research proposed IoT because IoT allows traditional agriculture to become technology-based agriculture to provide timely and cost-effective processing [9], [10]. Such as [11], who proposes an IoT model to maximize water consumption in irrigation systems. Other research on IoT was also conducted by [12] who built a system that can detect the availability of intravenous fluids in patients being treated in real-time. Zende *et al.* [12] proposed an effective system for monitoring patient infusion fluids for saving costs. The literature review conducted by [13] explains that IoT can perform real-time growth monitoring, predict and control agriculture. This research also proposes the use of fuzzy logic because fuzzy logic has a better approach in decision-making [14]. Fuzzy logic is straightforward to implement in IoT applications [14], such as research [15] which proposes a data acquisition system using fuzzy logic. The results of the Haddin *et al.* [15] show that the applied fuzzy can reduce errors in measurement. In [16], fuzzy applied to the controller can reduce the vibration of the flexible joint manipulator and increase the accuracy of tracking the robot’s trajectory.

Several kinds of researches have been conducted to increase agricultural products, such as [14] which proposed a smart watering system with multiple input sensors such as soil moisture sensor, light intensity sensor, humidity, and temperature sensor. The data obtained from the sensor input is processed using Sugeno fuzzy inference. The data that has been processed makes a schedule for watering plants and recommendations for what plants are suitable for planting. The IoT model proposed by Munir *et al.* [14] used a Wi-Fi module for connectivity between IoT devices and the data exchange process. This research has some similarities with [14] such as input variables and Wi-Fi modules for communication. This research has differences from [14] on the fuzzy rules, fuzzy inference, and output variables. In the study [14], used two fuzzy inference rules, the fuzzy inference used is Sugeno, and the output is a water pump for watering the plants. In comparison, this research uses 24 fuzzy inference rules, the fuzzy inference used is Tsukamoto. The outcome is watering the plants and activating the LED light to replace sunlight to photosynthesize even though the environment is dark.

Krishnan *et al.* [17] proposed an automatic watering system to save water in watering crops on the farm. The proposed system has several input sensors such as soil moisture, temperature, and rain. The data obtained from the sensor input is processed using fuzzy logic on the Arduino Uno microcontroller, which is connected to the global system for mobile communications (GSM) module. This GSM module sends the data processing results from the microcontroller to the user’s cellphone in a short message service (SMS). An IoT system built and applied in agriculture results in water savings of up to 10%. The research differences of [17] are input variables, fuzzy rules, fuzzy inference, and connectivity used. The research [17] used a soil moisture sensor, temperature sensor, and rain sensor. For the rule, 27 rules were used, Mamdani fuzzy inference and GSM module were used for data transmission. While in this research used different input sensors such as soil moisture sensors, temperature sensors, and light intensity sensors. There are 24 rules used, and the fuzzy inference used is Tsukamoto’s fuzzy inference for data transmission in this research using the Wi-Fi module. In [18] proposed smart irrigation using unified sensor pole (USP) as a decision-maker for irrigation systems in agriculture, the input sensors used include temperature sensors, humidity sensors, and soil moisture sensors. The decision-making is based on the USP algorithm. Data that has been processed with the USP is sent via Wi-Fi connectivity. The test was carried out on spinach plants. The test results obtained that the proposed system can produce up to 67% water savings compared to traditional methods, but the paper does not explain the growth effect on spinach plants. Compared to [18], this research has the same type of soil temperature and humidity sensors but has differences in decision-making algorithms. Nawandar and Satpute [18] used USP in the decision-making algorithm. This research uses fuzzy logic with Tsukamoto’s fuzzy inference and has an output of a watering system and an output in the form of LED lights to illuminate the plants.

In another work, Alipio *et al.* [19] proposed smart farming using IoT and Bayesian networks to make better lettuce growth in hydroponic systems than in conventional hydroponic systems. The input sensors used consist of several sensors such as pH level sensors, electrical conductivity (EC) sensors, relative humidity (RH) sensors, light intensity (LI) sensors, and water temperature (WT) sensors. All sensors are connected to the Raspberry Pi microcontroller while the output activates the light bulb, humidifier, and water pump. The research [19] has a different number of input and output variables made, in research [19], decision-making algorithm using Bayesian network, while this research used fuzzy logic in the decision-making process. Besides increasing agricultural productivity, several kinds of research also suggest resilience in agriculture, such as [20] who proposed IoT systems integrated with computer vision into smart agriculture to help farmers solve crop problems such as infection or disease. Another research conducted [21] on resilience in agriculture to crop damage caused by animals. The system built can adjust soil moisture according to plant needs. Sensor input from Navulur *et al.* [21] uses soil moisture, pH, sound, and water level sensors. The outputs are water pumps for the irrigation system and sound to stop animals from damaging the farm. Focus Chandana *et al.* [20], and Navulur *et al.* [21] are different from the model proposed in this research but have the same goal of accelerating production in agriculture and providing defense in agriculture.

The contribution of this research is to propose an IoT model that can be applied to agriculture by improving the IoT model in previous researches to accelerate plant growth and increase agricultural productivity. This research uses a different light intensity sensor from the IoT model in previous studies, namely the Max440099 ambient light sensor. This research also uses only one microcontroller with the ESP8266 type, a simple microcontroller module integrated with the Wi-Fi module. This research also uses a different fuzzy inference system from previous research, namely Tsukamoto fuzzy inference with rules that have been adapted to the needs of the plant. In addition, this research also has a dimmer module output connected to an LED lamp to illuminate the plant with a light intensity that adapts to the plant's needs and adjusts the intensity of sunlight to the environment around the plant. Thus, the plant will always get light for the needs of photosynthesis so that the plant can photosynthesize in a dark or cloudy environment. By applying the IoT model proposed in this research, it is possible to maximize photosynthesis time resulting in taller plants, broader leaves, and faster growth. The proposed model of IoT in this research can also maximize productivity in agriculture. This article is divided into several sections. The first section explains the problem, proposed model, relations with previous research, and research contributions. The second section is the research method that describes the technique used in this research. The third section is the results and discussion, and this section explains the findings of this research. The last section is the conclusion that explains the conclusions of the research results.

2. RESEARCH METHOD

2.1. Proposed model

This research proposed an IoT model by utilizing several input sensors processed on a microcontroller using fuzzy logic. The proposed IoT model produces a fuzzy logic output that controls the dimmer module to activate the LED and the relay to activate the pump automatically. Figure 1 is the proposed model of the IoT system that has been built. Figure 1 shows all of the proposed smart agriculture model that has been built by utilizing three sensors input, namely a temperature and humidity sensor with DHT11 type, a light intensity sensor with a Max4999 ambient light type, and a soil moisture sensor. An ESP8266 microcontroller processes the data obtained from the input sensor, which has applied fuzzy logic. The resulting output is an automatic watering system using a water pump connected to the relay module and activating LED lights attached to the dimmer module. LED lights are used to help plants in the process of photosynthesis when the light intensity is reduced. The input data from sensors processed on the microcontroller are sent via the internet to the Blynk server using the hypertext transfer protocol (HTTP) protocol provided by the Blynk library. Application monitoring and control can be done using a smartphone via the Blynk application.

The proposed model has two modes, namely automatic mode, and manual mode. In automatic mode, the data obtained from the input sensors are processed on the microcontroller with fuzzy logic. The output produced in automatic mode determines when the water pump will turn on and how long the water pump is on for watering the plants. In plant growth, regular watering is required, if this watering is ignored, it will be fatal to the plants [22], so in automatic mode, this is given automatic watering process. In addition to activating the water pump for watering, in automatic mode, it also has an output that determines when the LED lights will turn on and how bright the LED lights are. The input data from the input sensors are sent via the internet with the HTTP protocol and monitored via a smartphone using the Blynk application. In manual mode, it has the same function as automatic mode. Still, manual mode users can activate the water pump and LED lights manually via a smartphone to water the plants and illuminate the plants manually via a smartphone controller.

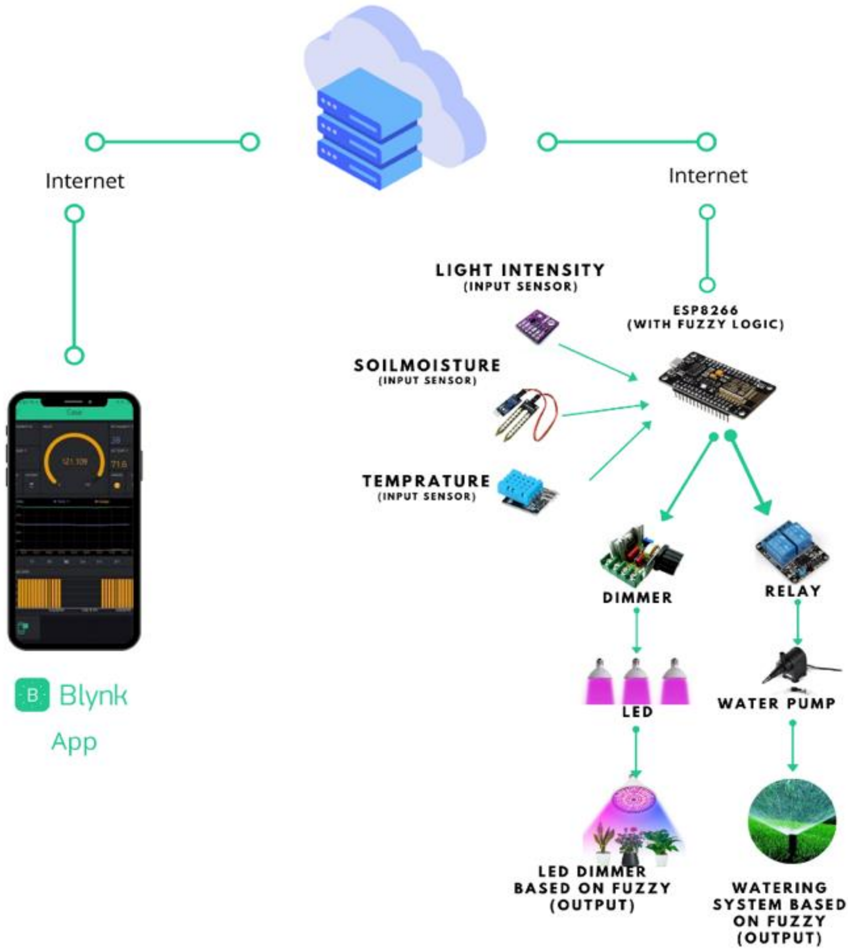


Figure 1. Proposed model of smart agriculture

2.2. IoT hardware model

IoT systems are built using multiple input, process, and output hardware. The details of the hardware model for the IoT system that has been made are shown in Figure 2. Figure 2 shows the proposed IoT hardware model that has been built. Several input sensors are used, including a temperature sensor used to read the temperature around the plant. This light sensor can read how much light intensity is around the plant, and the soil moisture sensor is used to read soil moisture. The microcontroller used to process data from the input sensor is a microcontroller with the ESP8266 type, which already has a Wi-Fi module. In addition to input hardware and microcontrollers, there is also output hardware such as a dimmer module. This dimmer module is connected to an LED light that will light up at an intensity that adjusts automatically with reduced sunlight. In addition to LEDs, the proposed hardware model also uses a water pump connected to a relay module. This relay module functions to activate and deactivate the water pump automatically. Power used from some sensors is taken from the power generated by the controller, and the controller uses the power generated from the adapter. The details of the hardware used are described in Table 1.

2.3. Fuzzy logic model

Figure 3 is a fuzzy logic block diagram. The proposed fuzzy in this research has three input variables, light intensity, soil moisture, and temperature. In the fuzzy logic controller, the fuzzy process starts from fuzzification, followed by fuzzy inference by providing a rule base of 24 rules and Tsukamoto inference. The last process is defuzzification to determine the action of LEDs and water pumps.

2.3.1. Fuzzification

In the proposed IoT model, there are three input variables and two output variables. The input variables in the proposed IoT model include temperature, light intensity, and soil moisture, while the output variables in the proposed IoT model include LED output and water pump output. In this fuzzification process, the membership function of each input variable and the output variable is determined. In the temperature input variable, there are five input values, namely cold (CD), cool (CL), normal (N), warm (W), hot (H) to describe the temperature around the plant, and the input temperature function shown in Figure 4.

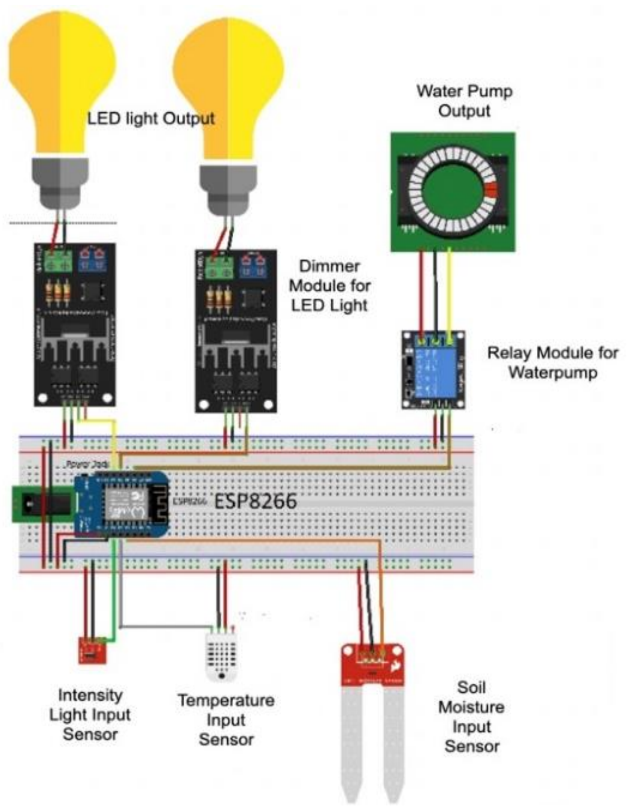


Figure 2. Proposed model of IoT hardware for smart agriculture

Table 1. IoT hardware specification of the proposed model

Name	Type	Qty
Soil moisture sensor	Soil moisture hygrometer detection humidity sensor module 3.3-5 V	1
Temperature sensor	DHT 11	1
Light intensity sensor	max44009 ambient light for Arduino	1
Microcontroller	ESP 8266	2
Dimmer module	Modul light dimmer 220 V 16 A	1
Relay module	Relay 4 channel	1
Water pump	Water pump DC 12 V, flow rate 240 L/H	1
Adaptor	Adaptor type c model B 4B	1
LED light	LED spectrum 220 V	4

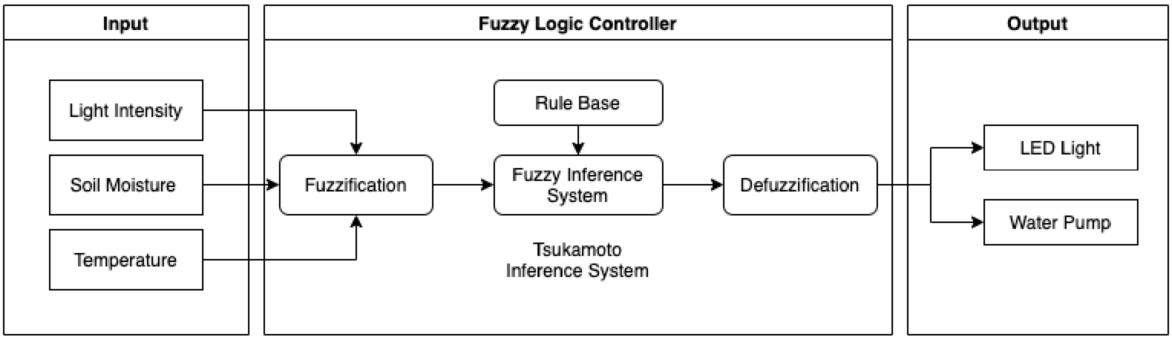


Figure 3. Block diagram fuzzy logic

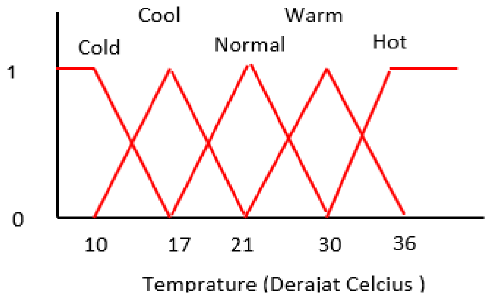


Figure 4. Fuzzy membership function of the temperature input variable

In the light intensity membership function, there are four linguistic values, namely the light (L), medium (M), dim (D) and dark (DK) values, to describe the light intensity around the plant. The membership function of light intensity is shown in Figure 5. The membership function of soil moisture has three linguistic values, namely dry (D), medium (M) and wet (W). This value describes the condition of the soil around the plant. The following is the membership function of the soil moisture input shown in Figure 6. In the variable output, there are two outputs, namely LED and water pump. Membership function output LED has three linguistic values, namely low light (L), medium light (ML) and bright light (B). The LED output value represents the intensity of the LED output. The following is the membership function of the LED output shown in Figure 7. For the water pump membership function has four linguistic values, on for while (OFW), turned on medium (ToM), rather on long time (ROLT), turned on long time (TOLT). The fuzzy membership function of the water pump output variable describes the length of time the pump releases water to water plants. The pump uses four outputs of linguistic values to work according to soil conditions to adjust to plant needs. The output value of the water pump is shown in Figure 8. The number of membership functions for input and output variables is chosen so that each input value has a different treatment. The system will adapt to changing environmental conditions and plant needs with the appropriate model and membership functions.

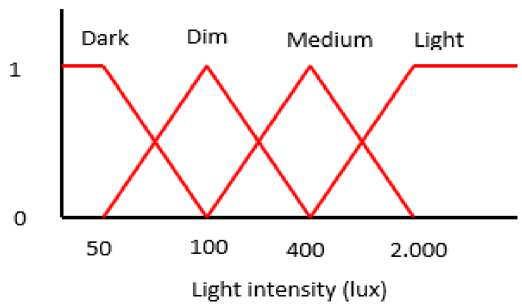


Figure 5. Fuzzy membership function of the light intensity input variable

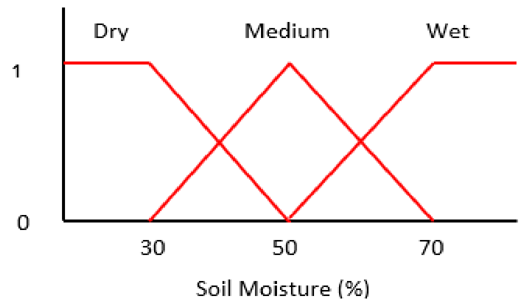


Figure 6. Fuzzy membership function of the soil moisture input variable

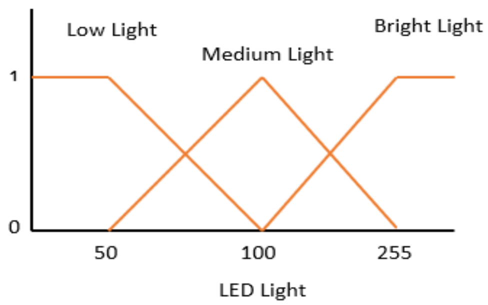


Figure 7. Fuzzy membership function of the LED light output variable

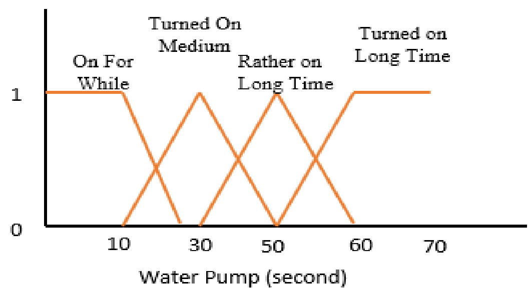


Figure 8. Fuzzy membership function of the water pump output variable

2.3.2. Knowledge base and fuzzy inference

In the proposed model, several rules are used to determine under what conditions the LEDs should be lit and at how intensity the LEDs are required, and when to turn on the pump and perform watering. The fuzzy rules are made taking into account the characteristics of the mustard plant, which require 30% soil moisture [23], the intensity of 105-210 µmol [24] and the temperature is about 14-30 degrees Celsius [25]. Concerning the characteristics needed by mustard plants, they are made into two groups of rules regulating the light intensity and automatic watering to grow well. Photosynthesis can be optimal by maintaining the characteristics or needs of mustard to accelerate the harvest period. There are two groups of rules used in this system. The first rule is made to control the LED lights, for the second rule, namely the rules used for watering plants automatically, with sensor input, namely soil moisture, and light intensity. Fuzzy rules inference of LED shown in Table 2 and fuzzy rules inference of watering system as shown in Table 3.

Table 2. Fuzzy inference rules of LED

Temperature	Light Intensity			
	Light	Medium	Dim	Dark
Cold	Low Light	Medium Light	Bright Light	Bright Light
Cool	Low Light	Low Light	Bright Light	Bright Light
Normal	-	Low Light	Medium Light	Bright Light
Warm	-	Low Light	Medium Light	Bright Light
Hot	-	Low Light	Low Light	Bright Light

Table 3. Fuzzy inference rules of watering system

Soil Moisture	Light Intensity			
	Light	Medium	Dim	Dark
Wet	On for a while	-	-	-
Medium	Turned on Medium	On for a while	-	-
Dry	Turned on Long Time	Turned on Long Time	Rather on Long Time	On Medium

2.3.3. Defuzzification

The defuzzification process in Tsukamoto converts the fuzzy set values into crips values after getting the a predicate. After looking for the z value, defuzzification is done by dividing the sigma a predicate times z by the sigma a predicate [26]. Here's Tsukamoto defuzzification formula.

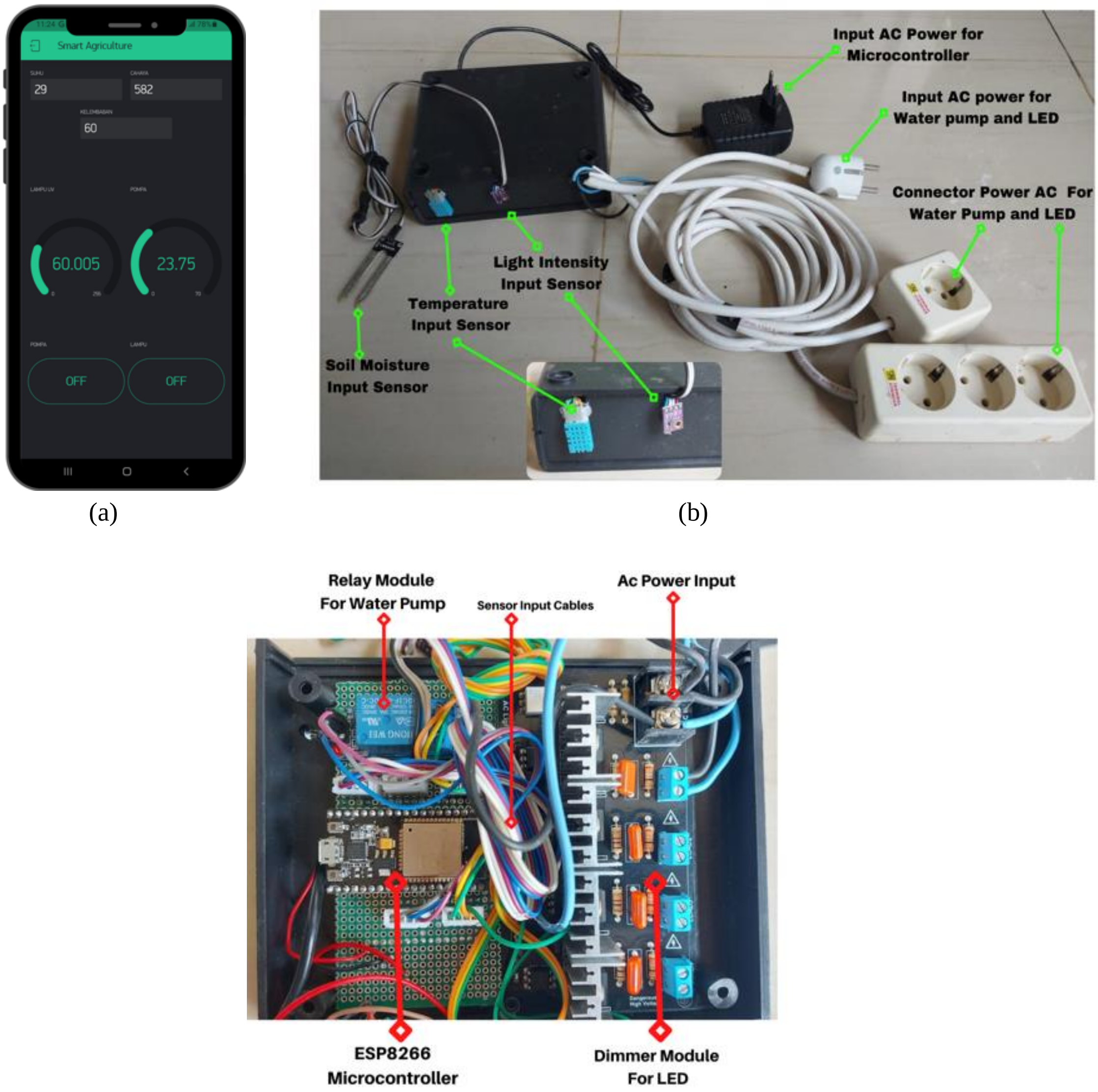
$$Ztotal = \frac{\sum_{1}^{i=n} apredikat * Zi}{\sum a\ predikat} \tag{1}$$

Search for z value can be searched using the membership function formula according to the output in the rule. In contrast, α predicate can be searched by performing a slice between the results of the membership function that has been calculated at the beginning of the fuzzification. The slice is carried out by the rules that have been established in the knowledge base. Here is the formula for finding the α predicate:

$$a\ predicate = \mu[rule1] \cap \mu[rule2]. \tag{2}$$

2.4. IoT configuration

Figure 9 shows the results of the IoT model that has been built. There are two systems created. The first system is a mobile monitoring system as shown in Figure 9(a) that monitors IoT devices using the Blynk platform. This monitoring system uses the Blynk application and the server provided by Blynk. The second system is an IoT device that can perform automatic watering and LED light control to keep the plants according to their needs as shown in Figures 9(b) and 9(c). This pumping and lighting management is controlled using a microcontroller embedded with fuzzy logic as shown in Figure 9(c) so that the system can work smartly. In sending data to the server that the microcontroller has processed, it is done using the hypertext transfer protocol (HTTP) protocol with the library's help from the Blynk platform. This IoT system can also continue to work on watering plants and activating LEDs without using the internet because the internet is used to send data to servers and monitor data via smartphones. In contrast to research [14], [17] an IoT system with a watering system output, this research is a watering system and automatic lighting for the photosynthesis process. This architecture also uses an ESP8266 type microcontroller which includes a Wi-Fi module, so there is no need for an additional Wi-Fi module such as [14], [17].



(a) (b)

(c)

Figure 9. The IoT configuration, (a) monitoring applications mobile app-based, (b) IoT hardware, and (c) IoT hardware configuration

3. RESULTS AND DISCUSSION

3.1. Validation model of fuzzy logic

Validation determines whether the fuzzy embedded in the system follows the rules and fuzzy inferences designed previously. The input of soil moisture, temperature, and light intensity obtained in the IoT system has been recorded in the comparison stage. Then the fuzzy output generated from the IoT system is also recorded. For comparison, the input value obtained from the sensor is calculated into a membership function. The results of each membership function are entered into formula (2) to resulted in α predicate. The following process is defuzzification with Tsukamoto inference by finding the average value of α predicate using formula (1). The result of procedure (1) is called Z total. The result of the manual calculation of total Z is a fuzzy output which is then compared with the output value of the IoT system. From the results of the comparison ten times, the same results are obtained between the output of the IoT system with manual calculations so that the fuzzy system embedded in the IoT system is valid.

3.2. Experiment preparation

Before experimenting, several things need to be prepared. This research used mustard plants, so 60 mustard seedlings were prepared as sample observations in this research. This research uses mustard plants because the mustard plant is a type of broadleaf vegetable that carries out photosynthesis well. The seeding process often referred to as a nursery, is carried out within 14 days before being transferred to a larger land planting area. Seeding is carried out on soil media. The seeds are spread on the land for 14 days until they grow and are transferred to a larger land. The minimum number of sources is 60 seeds, where 30 seedlings are sampled using the IoT system and 30 seed samples that did not use the IoT system, so that there is a difference between the two sample groups. The initial condition of plants before IoT implementation (14 days planting) can be seen in Figure 10.

Figure 10 shows the initial condition before IoT implementation after the 14th day of seeding. Figure 11 shows the initial height of the plant on the 14th day. On the 14th day of planting, the mustard plants had the same average height between those using the IoT system and those without IoT. The mustard plant on the 14th day has a height of 7 cm and leaves as many as three leaves. On the 14th day, the plants wilted because the plants had just been transferred from the seeding medium to a larger land planting. In Figure 10, the planting is divided into an area with an IoT system and an area without an IoT. The land that using IoT systems is planted with more than 30 mustard plants, and land that did not use IoT is also produced with more than 30 mustard plants. Both fields were grown with the same number of mustard plants and the same size and planting time to compare their growth with those using IoT systems or those not using IoT systems. At the time of implementation, the system requires electrical power and the internet. Still, the system can also run without using the internet because fuzzy is embedded in the device so that the function of the internet is only sending data from the device. The IoT hardware is placed next to the land area, and the LED light on the tool is hung in the middle of the land. Soil moisture sensors are placed on the ground plane to detect soil moisture. The hose connected to the pump is placed in the ground area. On the blue hose, a water sprinkler has been given with a 360^{o} distribution direction so that the entire land gets water distribution.

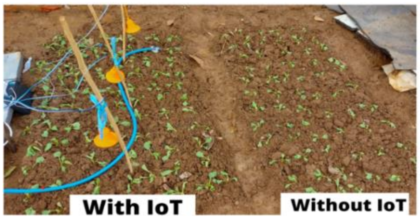


Figure 10. The initial condition before IoT implementation (14 days planting)

Figure 11. The initial height of the plant in 14 days

3.3. Experiment results

The results of the IoT system experiment started on the 14th day after seeding until harvest time. The comparison of the plant's growth on day 19th day can be seen in Figure 12. Figure 12 shows the experimental results after the 19th day of planting. The difference between planting with an IoT system and planting without IoT use the system begins to appear. Using an IoT system, after 19th days reaches the height of the plants 11.5 cm, the width of the leaves is up to 4 cm. At the same time, those that do not use the IoT system have a height of up to 8 cm and a leaf width of 3 cm. In the implementation that has been carried out for 19th days, it can be seen the difference between those who use the IoT system and those that do not use the IoT system. Those who use IoT systems grow taller and wider. Plants that use the IoT system grow faster because of the need for adequate sunlight and an automatic watering system that keeps the soil in line with the mustard plant's needs. In Figure 13 can be seen growth comparisons on the 30th day. On the 30th day of planting, the IoT system's growth had a plant height of 29 cm and a leaf width of 10 cm. At the same time, plants that do not use IoT have a height of 21 cm and a width of 8 cm. The growth of the two plants has a difference of 8 cm in height and 2 cm in width. To measure the difference between the two groups of mustard plants, one growth data from each mustard plant is measured in height and width, which uses an IoT system and does not use an IoT system. Plant height and leaf width were used as a reference to measure the growth of mustard plants. This refers to a similar study conducted by [27], where the measurement of the growth of the mustard plant is seen from the height of the mustard plant. The measurement of the height of the mustard plant was also carried out so that result of this research could compare the performance with similar researches. The comparison of the mustard plant that uses an IoT system and that does not use an IoT can be seen in Figures 14 and 15.

In Figure 14, we can see that the mustard plant has the same height from 0 days to the 14th day. On the 14th day, the IoT system has been implemented in the experimental field. From the 19th day to the 30th day, you can see the difference in the height of mustard plants that use the IoT system and mustard plants that do not use the IoT system. Mustard plants that use the IoT system have a higher plant height growth than mustard plants that do not use the IoT system from the 19th day to the 30th day. On the 30th day, the mustard plants that use the IoT system have a height of up to 29 cm, while the mustard plants that do not use the IoT system have only 21 cm. Figure 15 is a comparison graph of the growth of mustard plants using the IoT system and without the IoT system seen from the width of the mustard leaf. Figure 15 shows that on the 0 days to 14th day, the leaf width of the mustard plant has the same width because the IoT system has not been implemented in the experimental field. On the 14th day, the IoT system has been implemented in the experimental area. Just like the height of the mustard plant, the leaf width of the mustard plant also has a different leaf width from the 19th to the 30th day. Mustard plants that use the IoT system have broader leaf growth than mustard plants that do not use the IoT system from the 19th day to the 30th day. On the 30th day, the width of mustard leaves using the IoT system reaches 10 cm, and mustard plants that do not use the IoT system only have 8 cm. Figures 14 and 15 show that mustard plants that use the IoT system can grow taller and broader than mustard plants that do not use the IoT system.

Figure 12. Comparison of plant growth after 19 days

Figure 13. comparison plant growth after 30 days

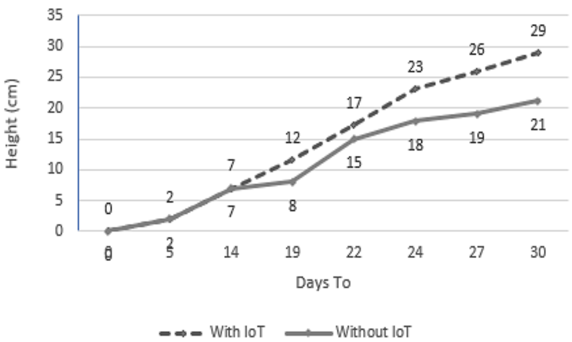


Figure 14. The comparison of mustard plant height with IoT and without IoT during 30 days of planting

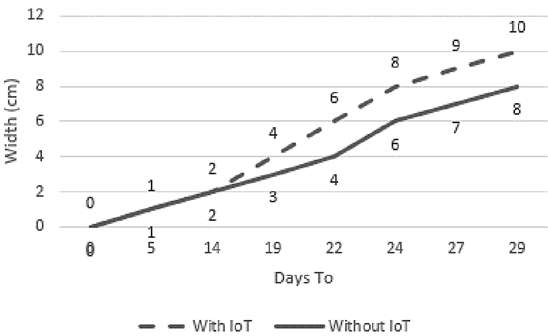


Figure 15. The comparison of mustard leaf width with IoT and without IoT for 30 days planted

Table 4 compares the growth of mustard plants using the IoT system and without the IoT system. The experimental results show that the height of the mustard plant that uses the IoT system is 8 cm higher, the leaf width is 2 cm wider, and the harvest time is six days faster than the mustard plant that does not use the IoT system. This proves that the IoT model built can provide higher plant growth, broader leaves, and faster harvest times.

In this research, mustard plants were used because mustard plants are broad-leaved plants that require photosynthesis. In mustard plants, this IoT system model can accelerate growth which can be seen from the height, leaf width, and harvest period. However, this IoT system model can also be applied to other plants or vegetables with broadleaf characteristics and require water for growth, such as lettuce and bok choy.

Table 4. The comparison of planting growth with IoT systems and without IoT systems

Item	Comparison		Difference
	With IoT	Without IoT	
Height (cm)	29	21	8
Leaf width (cm)	10	8	2
Harvest Time (days)	30	35	5

3.4. Performance evaluation model

An independent T-test was conducted to see whether the two groups of plants had significant differences. Both groups used the IoT system and plants that did not use the IoT system. the sample took the test sample from plant data on the 30th day. The number of samples tested from each group was 30 mustard plants. The total sample used for the T-test was 60 mustard plants. To find out whether the two groups had a significant difference in plant height, a standardized test was carried out with the following hypothesis: i) if the sig value (2-tailed)<0.05, then there is a significant difference in growth between the group a mustard plant with IoT system and the growth of the mustard without IoT system group and ii) if the sig value (2-tailed) >0.05, then there is not a significant difference in growth between the group a mustard plant with IoT and the growth of the mustard without IoT system group.

Independent T-test testing is carried out with the help of SPSS software. From the tests that have been carried out using the SPSS application, the results of the independent testing are: Table 5 is a data description of experimental results. In Table 5, we can see that the number of samples from mustard plants that use the IoT system is 30 mustard plants, with a mean value of 26.58, a standard deviation of 1.72, standard error of 0.31. At the same time, the sample of mustard plants that do not use the IoT system has a total sample of 30 mustard plants with a mean value of 19.10, a standard deviation of 0.91, and a mean standard error of 0.16. Table 6 is the results of the independent T-Test, the results of calculations using SPSS software show sig. (2-tailed)<0.05, which following the hypothesis that the growth results between the two groups have a significant difference with a 95% confidence level.

Table 5. The data description of experimental results

Sample	N	Mean	Std. Deviation	Std. Error Mean
With IoT	30	26.58	1.72	0.31
Without IoT	30	19.10	0.91	0.16

Table 6. The T-Test result of the experiment

				95% confidence interval of difference	
	t	df	Sig. (2-tailed)	Lower	Upper
With IoT	20.97	58	0.00	6.76	8.19
Without IoT	20.97	44.22	0.00	6.76	8.19

Figures 14 and 15 show that mustard plants that use the IoT system and fuzzy logic have higher growth and have broader leaves than mustard plants that do not use them during their growth. However, if you want to implement this system, a large amount of funds is required at the beginning to build the infrastructure and system. Still, the significant investment upfront will lead to faster agricultural yields at harvest time. For example, this research requires a fee of IDR 300,000 for the IoT devices mentioned in Table 1. At the cost of IDR 300,000, issued at the beginning of the IoT implementation, resulted in 60 mustard plants with five days faster harvest time, higher plant height, and broader leaves. Indeed, the initial costs look pretty significant, but these costs are investment costs that are only incurred at the beginning. At the beginning of the harvest, farmers also feel at a loss when using this system, but if farmers consistently use the IoT system, this will benefit long-term. This system is also suitable for greenhouse farming. If you want to use it outdoors, you need a protection system so that IoT devices are not exposed to rain.

The limitation of the proposed model is the type of sensor that cannot operate 24/7. It takes regular checks and sensors on the IoT system to ensure the system is running correctly. In addition, it requires a reasonably significant investment cost at the beginning to apply this system to an extensive farm. In addition, not all areas that are dominated by agriculture already have a stable internet provider. Good internet infrastructure is also required to implement this entire IoT system model. This IoT system can indeed accelerate the growth of broadleaf plants, but in the experiment that has been carried out, pest attacks on vegetables were still seen. This system has limitations for pest management, and further work is needed by integrating it with a pest management system.

Table 7 shows the comparison of the proposed model with another related research. The [27] proposed the IoT system built with fuzzy Sugeno produced 23 cm height of mustard plants, while the experimental results of the proposed model in this research produced a mustard plant height of up to 30 cm. From Table 7, we can see that the proposed model has a plant height difference of 7 cm or equivalent to 30.4% higher than the research results [27]. This research is compared with research [28], which researched the system's effects of monitoring photosynthesis using field programmable gate array (FPGA). Millan-Almaraz *et al.* [28] used a light sensor to detect light intensity. In addition, Millan-Almaraz *et al.* [28] also used high pressure sodium lamp (HPSL) lamps to illuminate plants to keep photosynthetic at night. However, the HPSL lights used are manually turned on from 9 am to 9 pm. Millan-Almaraz *et al.* [28] resulted in a system that can perform real-time monitoring with visual graphics, instant value measurement, and longtime data logging.

Table 7. The comparison of the proposed model with another related research

Model	The height of mustard plant (cm)	Difference (cm)	Difference (%)
IOT for Hydroponic [27]	23	7	30.43
Proposed Model	30		

Mat *et al.* [29] has also resulted in IoT systems that can be applied to agriculture. The system built is used to automate the irrigation system in agriculture with the help of sensors for light, soil moisture, and temperature. Experiments were carried out on mushroom plants. The experimental results showed that mushrooms using the IoT system were 0.3 cm thicker and 5 grams heavier than mushrooms grown with conventional methods. Mat *et al.* [29] focused on the automation of agricultural and irrigation systems. Khoa *et al.* [30] also researched IoT in agriculture to make automation in watering systems, besides research [30] had the aim of the proposed system can provide saving cost. The input sensors used are temperature, soil moisture, rain, and water level sensors. The controller used is the ATmega type combined with the ESP8266. The IoT systems built [30] resulted in savings cost up to 30%. This research was also done to propose a model of an IoT system that can automate and monitor agriculture. Unlike the research [28], which offered a system that can monitor photosynthesis, this research is proposed to monitor photosynthesis. This research proposed a system built to maximize photosynthesis time by activating the LED automatically. Besides that, compared with research studies [29], [30] resulted in automatic irrigation systems and water consumption savings. This research also proposed a system that can perform irrigation automatically based on soil moisture needed by plants. However, this research has the advantage of being able to accelerate plant growth. The method used is by applying fuzzy logic to LEDs so that plants can still photosynthesize even though the sun is cloudy.

This research resulted in an IoT system that can maximize photosynthesis time with the help of LEDs. So that it accelerates plant growth as evidenced by the quality of plant growth seen from the plant height and leaf width, which is higher and broader than planting without using the IoT system as shown in Figures 14 and 15. Table 4 also explains the differences between plants using IoT systems and plants that do not use IoT systems. Table 4 shows some differences in plant height, leaf width, and harvest time. From the research that has been done, it is found that we can use LED lights to replace sunlight so that plants can photosynthesize even though the sunlight has decreased. With the maximum photosynthetic time with the use of LEDs, automatic watering, a fuzzy model that suits the needs of the plants, and the use of suitable sensors can accelerate plant growth. That way, vegetable production will be faster and maximized to meet the needs of vegetables and solve the problems described in the introduction section.

4. CONCLUSION

This research resulted in an IoT model that can be applied to conventional agriculture to maximize photosynthesis time. The proposed IoT model has input sensors such as soil moisture, light intensity, and temperature. The data obtained from the sensor input is processed by a microcontroller that has embedded fuzzy logic. The output generated from the proposed model is the activation of LED lights and watering plants. The resulting output can adjust to the needs of the plants. The proposed model uses the Blynk application server and the Blynk platform to monitor the farm. Experimental testing of the IoT system was carried out on mustard plants and compared with mustard plants that did not use the IoT system. The experiments' results showed that the growth of mustard plants using the IoT system had a higher growth of mustard plant height and wider leaf width than growing mustard plants that did not use the IoT system. Planting systems that use IoT have a mustard height 7 cm higher than plants that do not use an IoT system and have a mustard width 2 cm wider than the width of a plant without using an IoT system. The test was also strengthened by using an independent T-test and had a significant difference in growth between plants using the IoT system and plants not using the IoT with a 95% confidence level. In addition, the results of this research were also compared with the results of previous studies and had a higher difference in growth, which was 30.43% higher than the previous research. This IoT system is expected to be applied in agriculture to help agriculture accelerate plant growth, especially in vegetables, accelerate harvests, increase agricultural yields, and meet the needs of vegetables, especially in Indonesia. This system is suitable for agricultural greenhouses with a roof so that the electronic system in IoT is not easily damaged. However, the system built still has weaknesses. The weakness in this system lies in the input sensor device, where problems such as not being able to read the state of the environment after several weeks of use. This system can accelerate the growth of mustard plants, but pests can still be seen on mustard plants. In further works, it is hoped that research can be carried out on using more durable sensors to avoid problems when using the system for a long time. The plan can also be expanded by adding automatic pest control and fertilization for crops to run fully automated.

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