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SMART HYDROCULTURE CONTROL SYSTEM BASED ON IOT AND FUZZY LOGIC

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Abstract. *Limited agricultural land due to increasing development leads to a decline in agricultural production capacity. Therefore, a new solution for modern agriculture is needed to overcome this problem. Technology is useful for modern agriculture, such as the use of IoT for hydroponic farming systems. By using IoT with a smart controlling system, the hydroponic agriculture becomes easier. With the use of IoT in this research, nutrition, pH management, and temperature can be controlled easily. This research also uses fuzzy logic to make the decision making in the control system more efficient and precise. The results of experiments with bok choy and lettuce indicate that the system automatically measures the nutritional value and pH according to the time specified. Then, the system will immediately adjust the value of nutrient content and pH within the specified range. Smart control system shows better plant growth which can be seen from the growth of the leaves' width, length and plant's height.*
Keywords: Hydroponics, IoT, Smart controlling systems, Fuzzy logic, Urban farming

1. **Introduction.** Agriculture is one of important sectors in Indonesia. Along with the growth of the population, the availability of food becomes a necessity that must always be met by the agricultural sector. However, with the current development in Indonesia, a lot of agricultural lands have been converted to non-agricultural areas, such as housing, industrial estates, trade zones and public facilities which will certainly have negative economic, social and environmental impacts. This decrease in agricultural land will obviously cause a decline in agricultural production capacity, thus making the government have to import agricultural products to meet the domestic needs of food.

Agricultural technology is growing rapidly in urban areas. One solution that can be implemented by the community is to develop an agricultural system with limited land availability, commonly called urban farming or urban agriculture. Urban farming or urban agriculture is one of effective solutions for overcoming the decline of agricultural land. Urban agriculture uses areas which are not used in urban areas, such as roofs, balconies, patios, or even walls of buildings. One of agricultural techniques used in urban farming is hydroponics [1].

Hydroponics is one of the most possible options for agriculture even without extensive agricultural land [2]. Etymologically, the term hydroponics comes from Greek. *Hydro* means water and *ponous* means work [3]. Hydroponics is a method of planting without using soil as media [4]; instead, it uses a medium of water mixed with a mineral nutrient solution [5]. The plant roots grow in the nutrient solution [6]. The advantage of hydroponic farming method is that it does not require soil with a large area for agriculture.

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The agriculture can be done in a narrow area by using water. Each hydroponic plant is treated without the use of pesticide. So, the plant is safer to consume. Hydroponics can make plants grow faster because they get all the nutrients they need in proper amounts and proportions [7].

Hydroponic farming method needs special treatment for controlling the water temperature, water level, and acidity (pH) of nutrient solutions. Nutritional solutions for hydroponic systems are aqueous solutions containing inorganic ions, especially from salts which are important elements for plants which are tall [8]. Plants need frequent watering and fertilization [9]. To be able to produce plants that are good in the harvest period, these treatments and regular checks must be done every day. The checks carried out include checking the water content in the installation, the nutrients contained, the dose of the pH, the temperature and humidity of the air, etc., which must meet the specified standards. If one of these elements does not meet the the right dose, the plant will not grow as expected. Therefore, regular checks must be done every day. Due to the need for regular checks, the hydroponic method becomes inefficient because it requires a long time and high costs for maintenance [10]. This also impacts on the selling price of hydroponic plants; the plants become more expensive. While, hydroponic method is a solution to the problem of limited land, it also requires complicated care, making it not efficient for agriculture.

Based on the problem above, this research aims to address this problem by combining hydroponic farming methods with the use of IoT technology for creating a smart controlling system using fuzzy logic which can automatically control all the plant needs. Fuzzy logic is selected for this research because it can perform the control process carried out by humans manually and it is easier to use the analysis model [1]. Fuzzy logic can model very complex nonlinear functions and overcome reasoning data in the form of incorrect estimates. The Internet of Things will connect most objects connected to the Internet [11], transfer data over a network [12], interact with each other and cooperate with other things/objects [13] as well as use it to do things smarter [14]. By using the technology of IoT, every hardware that has a sensor [15], such as pH sensor, EC sensor, and water level sensor, will be able to communicate or send data to the cloud server to be processed and monitored in real time. Each sensor will be connected to Arduino that can automatically control the needs of plants using fuzzy logic. The sensors, such as water level sensor in the installation tank, will work if the water content is reduced. Then, the system will immediately turn on the pump to add water. The EC sensor will work if the nutrient levels in the installation are reduced; then, the system will automatically add nutrients to the installation. The results of processing data from the cloud server will be very useful information for farmers as an evaluation material to continuously improve their agriculture.

The paper is organized as follows. To summarize the current state-of-the-art of research in this field, the related works are explained in Section 2. The proposed method and system design are described in detail in Section 3. While, the results of experiments are discussed in Section 4. Finally, the conclusion of the paper is written in Section 5.

2. **Related Work.** Charumathi et al. [9] designed a smart monitor and control system, especially for people who travel frequently. It is easy to implement the connection of monitoring field and to remote monitoring centres. This system can monitor the environment of hydroponic device through sensors in a real-time and stable way. It also accurately and automatically transmits the data of temperature, humidity, light intensity, water level and pH in real time using Arduino Mega 328 and controls the parameters remotely using IoT technology. The results of the study showed the results of monitoring of the pH

system and the air temperature displayed in a graphical view. Unfortunately, there were no sensors to control the nutritional needs of the plant.

According to [3], the significant decline in agricultural land and the rapid development of hydroponic system technologies, such as Nutrient Film Technique (NFT), have posed great challenges to farmers. The hydroponic system is designed in the form of hydroponic farming management that can monitor water temperature, water level, higher density of nutrient solution and acidity (pH) of nutrient solutions using related sensors connected to microcontroller via website. This system allows users to remotely control and monitor. This research also utilizes solar panels that are converted into electricity as the main source of energy to power all devices.

The hardware used consists of sensors, actuators, microcontrollers, ESP8266, Wi-Fi access points, micro Raspberry Pi and power supplies. Various sensors are installed to detect any changes in the physical or chemical environment. Each of these devices is connected to the network and can be accessed via the web using a browser. Changes in values that occur in the environment will be read by the sensor and will help the farmers improve the effectiveness and efficiency of monitoring and controlling the NFT hydroponic agriculture.

The main result of this study is a system that can help farmers or owners of hydroponic farming systems maintain or create hydroponic farming systems by using hardware modules that are easily found in the market with affordable prices. One of the advantages of this research is that it used solar panels as a source of energy. This system can be implemented on NFT hydroponic agriculture and can optimize plant growth as seen from the table of plant observations.

Paper [5] discusses the use of IoT using an Arduino microcontroller to control and analyze data from all connected devices and sensors. The IoT device used here is useful for monitoring humidity, temperature of nutrient solution, air temperature, pH and Electrical Conductivity (EC) using an android application. In its application, data from the sensors will be combined into one string then converted to JSON. The microcontroller will send the string to the server through MQTT Broker, namely a connectivity protocol for IoT. In the sensor, section begins by reading the temperature and humidity of DHT22 (Temperature and Humidity Sensor). After that, the values will be checked, whether they are in the specified range. If the value is not within the specified range, the system will turn on the water pump (with the relay) to water the system and reduce the temperature. Then, the pH measurement section is done by reading the pH sensor. The data from the sensor will be compared whether it matches the specified range. If the value is not in the range, the solenoid valve will be turned on to release a substance that will reduce the pH value in the nutrient solution or vice versa. The EC value part of the mechanism is carried out similar to the pH process. The EC mechanism will add water when the value is higher than the specified limit and will add nutrients if the value is too low. The evaluation done only ensures that the system can function in automatic or manual mode, and verification that control via the mobile application functions properly.

The primary objective of this research is to implement an Internet of Things for Smart Hydroponic Farming Ecosystem (HFE) that can help new farmers or people who want to have hydroponic farming but do not have time to manage and grow crops. In this study, the system can function properly in automatic or manual mode.

Paper [16] also proposes the use of sensors in a Wireless Sensor Network System by sending data to the cloud and controlling values such as temperature, and light. Sensor technology is intended for accurate mobile control devices. The application control uses the Blynk application where the application can control existing devices through the API provided by Blynk's control. The hardware used is NodeMCU, which is used to implement monitoring modules. DHT11 sensor is a relatively inexpensive sensor to measure temperature and humidity. Soil Moisture Sensor (KG003) is employed to measure soil moisture; Relay Board (5V) to switch AC/DC is used to trigger the AC motor (220V) to operate the valve; Ultrasonic Sensor Module (HC-SR04) includes ultrasonic transmitters, receivers and circuits.

The result of this study is the use of sensor technology intended for automatic control devices via cellphones with the Blynk application. The sensor reading results can be monitored through the Blynk application, and the Blynk application can control to turn on or turn off the attached device.

From some of the research results above, the application of IoT to agriculture can be done well by combining several sensors and hardware accompanied by a good software design. Each sensor device used by several researchers above can be used as a measuring instrument to control some values in plants for researchers to use for analysis. From the research that has been done, the researchers try to summarize and complement the previous research, and add fuzzy logic to obtain the logic of the sensor and hardware to get better results.

3. **Proposed Method.** The system design that will be carried out in this study consists of two parts. The first is hardware design and the second is application design. The focus of this research is to control the pH and EC values in the plant installation to keep the plant always in a stable condition. pH value in plants affects the ability of the plants in absorbing nutrients. Fast changes in pH values will cause stress to the plant. The ideal pH level for plants is between 5.5 and 7. EC value is useful for controlling the amount of nutrients in the installation. If the available nutrients are not sufficient, the plant growth will be hampered.

Hardware design consists of:

- Design of the ESP8266 microcontroller module
- Design of pH Sensor module
- Design of EC Sensor module
- Design of water level sensor modules that are connected to relays and pumps
- Humidity Sensor module design that is connected to servo to open or close the paranet curtain

In designing the application to control each input from the sensor and output to be carried out, the researcher also uses the C language compiled using esp-open-sdk toolchain via the Arduino IDE to write programs on the Arduino Uno microcontroller. Each input from the sensor will be read by Arduino Uno and then fuzzy logic is used to decide what to do. The microcontroller will read each value that will be sent by the sensor to be analyzed and a decision will be made. The microcontroller will connect to the server via an existing Internet connection to store measurement data.

1) The pH sensor: the microcontroller will be programmed to read the pH value continuously. If the pH value is outside the predetermined range, then the system will rule the peristaltic pump to add acid pH or alkaline pH until the pH value is in the desired range.
2) EC sensors: the function of EC sensors is for measuring conductivity values in liquids or measuring nutrient concentrations in hydroponic plants. Similar to the pH sensor, the microcontroller will read the value of the EC sensor measurement results. If the measurement results are outside the specified range, the system will automatically

instruct the peristaltic pump to add nutrients to the installation reservoir until the value matches the desired range.

3) The water level sensor: the microcontroller will read the status of the water level from the sensor. If the sensor sends a value indicating that the water level decreases, the system will automatically instruct the pump to pump water from the water source into the reservoir until the desired water level is reached.
4) The humidity sensor: the microcontroller will receive the results of the existing air temperature reading. If the air temperature is too hot over the specified range, then the system will order the servo to open the paranet curtain installed at the bottom of the installation roof to help reduce the sun ray. If the air temperature is at a normal temperature, the system will order the servo to close the paranet curtain again.

Fuzzy logic control in this system consists of four inputs from the sensor, namely the pH value, EC, water level, and air temperature that will be identified to the fuzzy set [17]. Fuzzy-logic membership functions are designed to produce fast reaction time for the control [18]. The result of fuzzification will determine whether it enters the specified value for each sensor (pH, EC, water level and temperature). The working principle here is that the input value of the sensor will be compared with the range that has been determined. Then, the value will be processed by fuzzy logic control. The output parameters that will be carried out consist of the duration of time (long, medium, fast) [19] to open the tap valve on the pH tube, nutrition, water and to order the servo to open or close the paranet curtain. This old, medium, and fast output value will be converted in seconds.

For example, the pH readings on the fuzzification process plant are input from the pH sensor and the input from the water level in the installation, which is then made into a fuzzy set into a fuzzy membership function. Figure 1 shows the membership function of pH parameter level. The pH value is categorized as follows: very low (0-5), low (4.75-6.25), normal (6-7), high (6.75-8.25), very high (8-10). While, the EC parameter is categorized as follows: very low (0-500), low (400-700), slightly low (600-900), normal (800-1100), high (1000-1200). The membership function of EC parameter is shown by Figure 2. Finally, the the membership function of water level category is shown by Figure 3. The membership function category is decided based on the normal range of pH, EC, and water level for lettuce and bok choy plants [20].

For the pH settings, it is in the form of a defined rule that will be controlled by fuzzy logic control. In this case, the set rules are to turn on the pH Up pump and pH Down pump according to the conditions of the pH value and water level (see Table 1).

Examples of rules that will be applied based on the knowledge base are (Table 1):

- If (the value of pH is very low, and V Water is less), then the value of Valve pH Up on the duration becomes moderate. If the pH condition is very poor and the

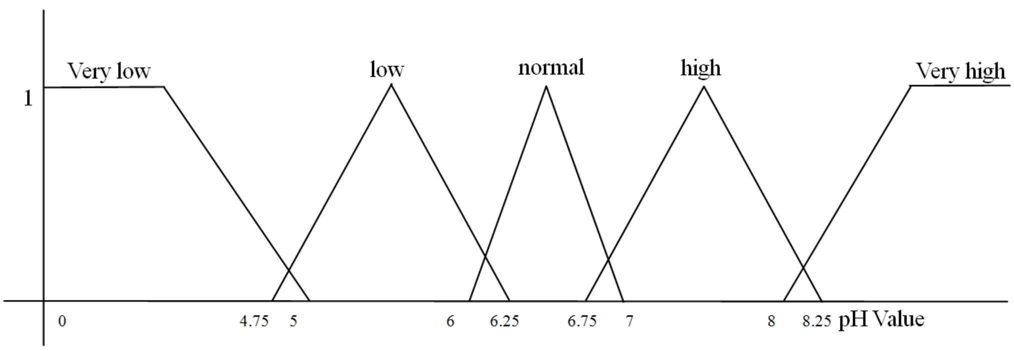


FIGURE 1. The sensor membership function pH

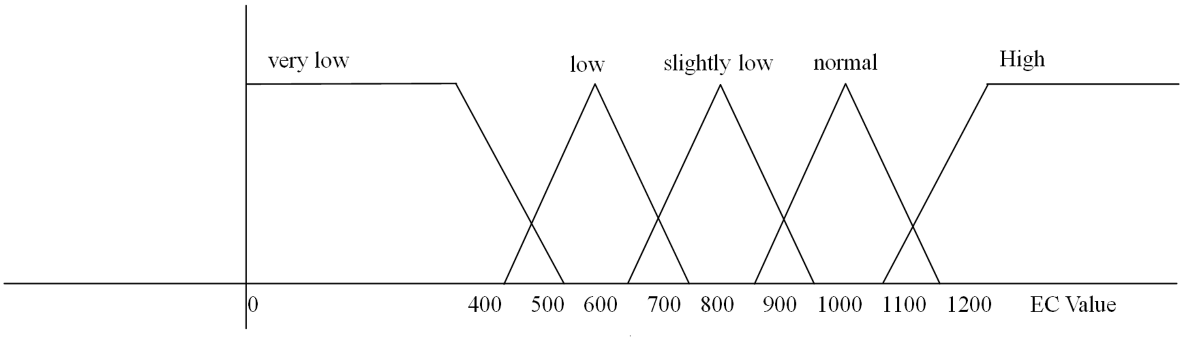


FIGURE 2. The sensor membership function EC

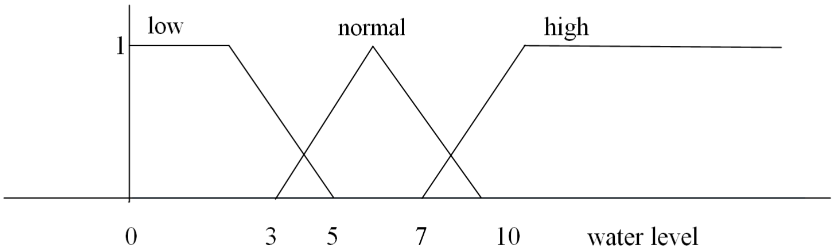


FIGURE 3. Water level sensor membership function

TABLE 1. Knowledge base sensor pH

pH / Water Level	Pump pH Up On		OFF	Pump pH Down On	
	pH Very Low	pH Low	Normal	pH High	pH Very High
Low	Medium	Fast	Stop	Fast	Medium
Normal	Medium	Medium	Stop	Medium	Medium
High	Long	Medium	Stop	Medium	Long

water conditions are lacking, then the pH Up Faucet will be turned on in a medium duration.

- If (the value of pH is very low, and V Water is many), then the value of Valve pH Up becomes On Long duration. If the pH is very lacking and the water conditions are many, then the pH Up tap will be turned on for a long time.
- If (the value pH is high, and V Water is less), then the value of Valve pH Down becomes On Fast duration. If the pH is high and the water conditions are lacking, then the tap will be turned on in a fast duration.

TABLE 2. Knowledge base sensor EC

EC / Water Level	Very Low	Medium	Low	Normal	High
Low	Medium	Fast	Fast	Stop	Stop
Normal	Long	Medium	Fast	Stop	Stop
High	Long	Medium	Medium	Stop	Stop

The examples of rules that will be applied based on the knowledge base are (Table 2):

- If the EC conditions are lacking and there is much water, the TDS pump will be turned on for a long duration.

- If the EC condition is not much and the water level is low, the TDS pump will be turned on in a fast duration.
- If the EC conditions are lacking and the water level is low, the TDS pump will be turned on in a fast duration.

Table 3 shows the output value of the above parameter, the duration of time to open the tap in the duration grouping:

TABLE 3. Output of fuzzy parameters

Parameter Output	**Duration**
Fast	0-3 second
Medium	3-5 second
Long	5-8 second

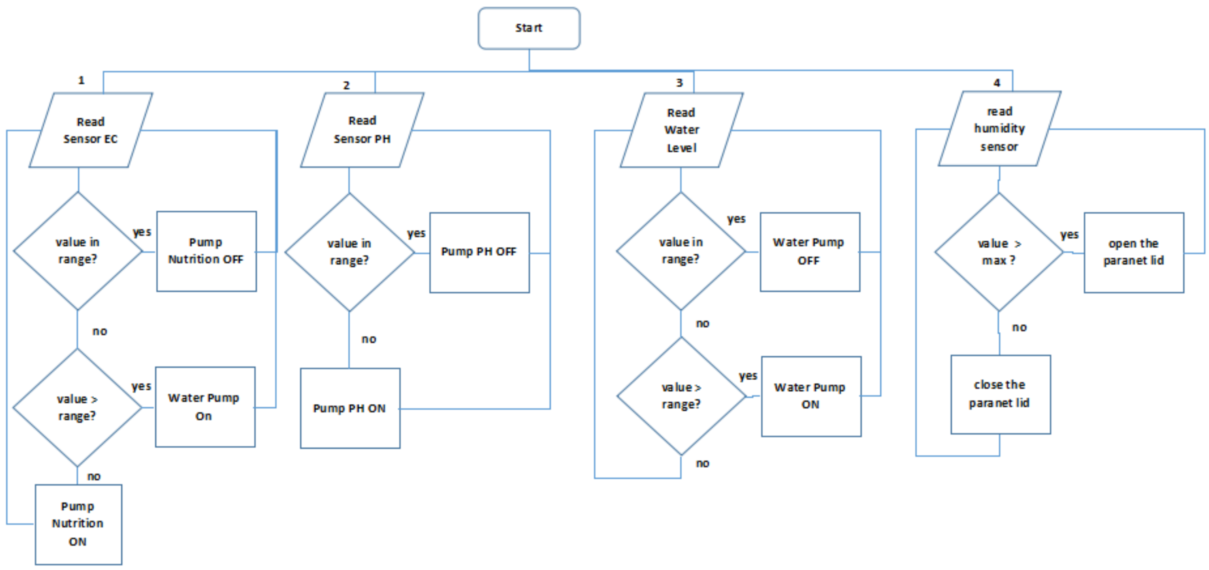


FIGURE 4. Flowchart system

Figure 4 describes the system that will be proposed in this research.

1. The sensor will read the EC value. If the value is in the specified range, then the valve position will be turned off. If the EC value is outside the range, it will be checked whether it exceeds the specified range or not. If it exceeds the specified range, the system will turn on the pump to pump water from the water source to neutralize nutrients so as not to exceed the range. If the EC value is less than the specified range, the system will open the tap valve to drain nutrients at a certain time until the EC value returns in the specified range.
2. The sensor will read the pH value. If the pH value is outside the specified range, then the system will turn on the valve faucet to drain the liquid pH acid/pH base to return the pH value into the range. If the pH value is in range, then the system will close the tap valve.
3. The sensor will read the water level. If the water level is outside the specified range, the system will open the tap valve to drain water from the water source into the installation tank. If the water level is within the specified range, the valve will be closed.
4. The sensor will read the air temperature value. If the air temperature exceeds the maximal temperature, then the system will instruct the servo to open the paranet

curtain to protect the plant from sunlight. If the air temperature is below the specified limit, the system will order the servo to close the paranet curtain.

4. **Result.** The following is a description of the architecture that will be designed for the smart controlling hydroculture system:

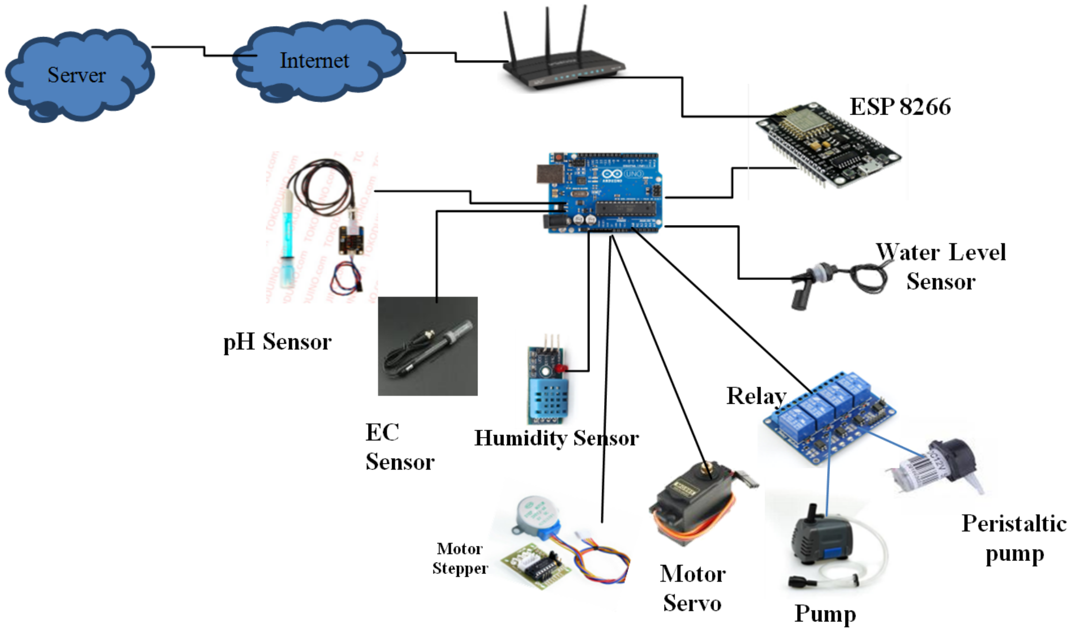


FIGURE 5. System architecture

In Figure 5, the researchers assemble the smart controlling system using Arduino as the microcontroller connected to the sensor and assisted ESP8266 as wifi to send data to the server.

Figure 6 shows the designed smart controlling system which has been successfully created. The tools are arranged in a cork container to make it easier to move and secure

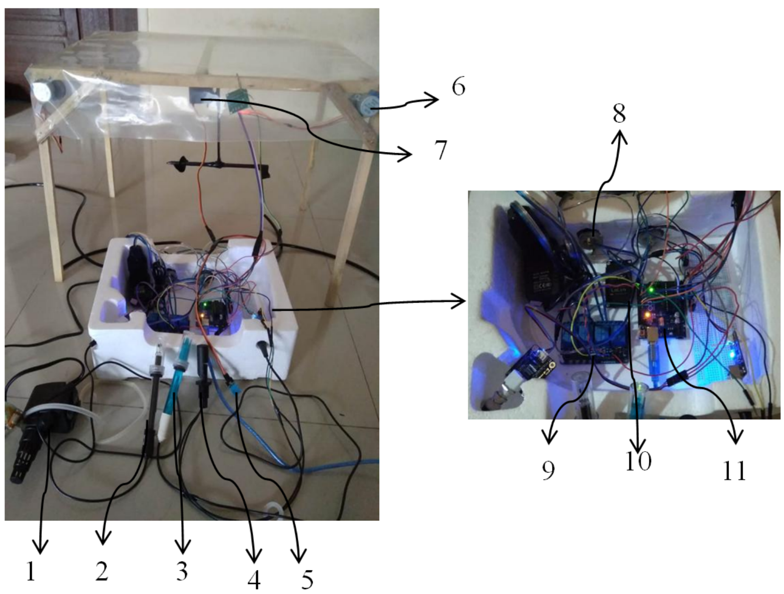


FIGURE 6. The final results of the smart controlling system

from the splashing of water when it is raining. The design consists of several parts, which are:

1) pH sensor used to measure the pH value of the installation if it is in the normal range (see Table 4).

Table 4. Fuzzy logic test on pH sensor

Testing Number	Value Current pH	Set Range pH	Action	Duration (second)	Estimate (second)	Result
1	2	6-7	pH Up ON	8	5-8	valid
2	3.54	6-7	pH Up ON	5.50	5-8	valid
3	5.26	6-7	pH Up ON	4.13	3-5	valid
4	5.8	6-7	pH Up ON	2.79	0-3	valid
5	6.5	6-7	–	0	0	valid
6	7	6-7	–	0	0	valid
7	7.5	6-7	pH Down ON	3.65	3-5	valid
8	8	6-7	pH Down ON	4.5	3-5	valid
9	9.18	6-7	pH Down ON	5.01	5-8	valid
10	10	6-7	pH Down ON	5.50	5-8	valid

2) EC sensor, that is a sensor used to measure the nutritional value of the installation every 3 (three) hours. If the EC condition is below the normal range (800-1000), the system will instruct the relay to turn on the pump according to the duration of fuzzy logic (see Table 5).

Table 5. Fuzzy logic testing on EC sensors

Testing Number	Current Value EC	Set Range EC (ppm)	Action	Duration (second)	Estimate (second)	Result
1	360	800-1000	EC ON	8	5-8	valid
2	410	800-1000	EC ON	7.58	5-8	valid
3	486	800-1000	EC ON	5.68	5-8	valid
4	523	800-1000	EC ON	5.28	5-8	valid
5	508	800-1000	EC ON	5.41	5-8	valid
6	620	800-1000	EC ON	4.98	3-5	valid
7	634	800-1000	EC ON	4.95	3-5	valid
8	670	800-1000	EC ON	4.78	3-5	valid
9	765	800-1000	EC ON	3.26	3-5	valid
10	780	800-1000	EC OFF	2.79	0-3	valid

3) Water level sensor that is designed like a water float, which will automatically check every 1 hour and will turn on the pump when water level in the installation is low.
4) Humidity sensor to measure air temperature in the system installation every 1 hour.
5) Stepper motor to open and close the paranet curtain.
6) Because the pH sensor and EC sensor are not water resistant, the researchers used MG995 servo motor to be used like a robot arm to dip the pH sensor and EC sensor into the installation water when measuring pH and EC.
7) The peristaltic pump used to enter liquid nutrients and pH fluids into plant installations. The duration of the pump when pumping liquid nutrients and liquid pH into

the installation depends on the results of the fuzzy logic output given until the pH value and EC value return to normal conditions.

8) Relay functions as a switch to turn the pumps and peristaltic pumps.
9) ESP8266 functions as a WiFi for Arduino to send measurement data to each sensor and actions taken to the web server. The ESP8266 module can communicate to the web server as long as it is connected to an Internet modem.
10) Arduino Uno functions as a microcontroller that regulates the work of the smart control system.

Result of smart controlling system. After a series of tests carried out both on the sensor and the smart controlling system based on the desired scenario, the researchers conducted experiments applying this smart controlling system directly to the plants. In this experiment, the researchers compared two installations; the first installation was a hydroponic planting which was controlled manually and the second is hydroponic controlled automatically using IoT. In the system controlled manually, measurements and records on nutrition and pH are carried out manually using EC meter and pH meter. If the conditions in the installation require additional water, pH nutrients will be given manually as well. This manual measurement is done every 3 days. The plants planted in these two installations are lettuce and bok choy.

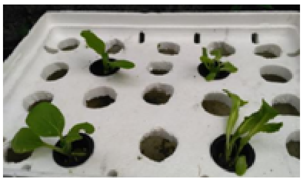
To evaluate the system performance, the researchers measured the plant's height, leaves' length and width on both installations every 3 days. To facilitate the measurement, the researchers only measured the plants' height in 2 pots with the best growth from each installation and measured length of the oldest plant and width of leaves of each installation pot. The results of plant measurements on the two plant installations are shown in graphics to make it easier to compare the increase of plant growth in each installation.

Table 6 presents the comparison between the manual method and the smart controlling system. The results indicate that using the smart controlling systems, the lettuce plants grow better. This can be seen from the growth of wide leaves and plant's height (see Figures 7-12). This result is different from the results of using the traditional method. The lettuce leaves are longer but the leaves are not wider. So, these results indicate that the growth of the lettuce plants is not good. In bok choy plants, the results of smart controlling systems show better width and length of leaves and plant's height. In the manual method, bok choy plants grow slower.

Since only limited amount of sample is available, t-test is conducted to evaluate if there is significant difference between the result of manual method and the proposed smart controller. Table 7 shows the amount of data that resulted from the measurements of the leaves (length, width, and height) using the smart controller and manual method. From each method, 8 sample of leaf and plants are measured. From Table 7, it shows that proposed smart controller produces wider leaf and higher plants. Table 8 below shows us whether there are significant differences between both methods.

According to the result of t-test in Table 8, the value of p at length section is 0.7079. If the value of p is more than 0.05 ($p > 0.05$), then this shows that there are no significant differences in measurement using the manual method and using the smart controller. We also can see that in the width section that p value is 0.0150. This proves that there are significant differences between both methods. The similar thing happens to the height of the plant. The value of the height shows 0.0078, which means that $p < 0.05$. The result shows that the smart controller produces significant growth, that is proven by wider leaf and higher plants. Table 8 also shows the value of mean and 95% confidence interval. For evample, the value of the means in the length section is 0.575. This value shows

TABLE 6. Comparison of plant growth

Traditional Method	Week	Smart Control
	**I**	
	**II**	
	**III**	
	**IV**	

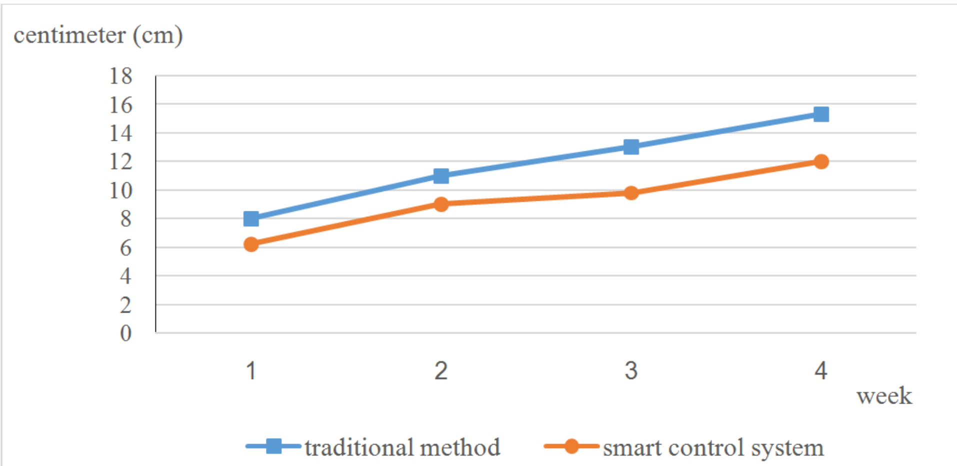


FIGURE 7. Comparison between the length of lettuce's leaves

the difference between the leaf length growth $8.988 - 8.413 = 0.575$ and the difference is -2.650 until 3.800 (95% confidence interval of this difference).

With the manual method, the plant checking is conducted every three days to check the value of the nutritional content and pH of the plant installation. If the measurement results are not within the specified range, they will be added manually until the nutritional value and pH of the plant are within the specified range. Manual measurement is not

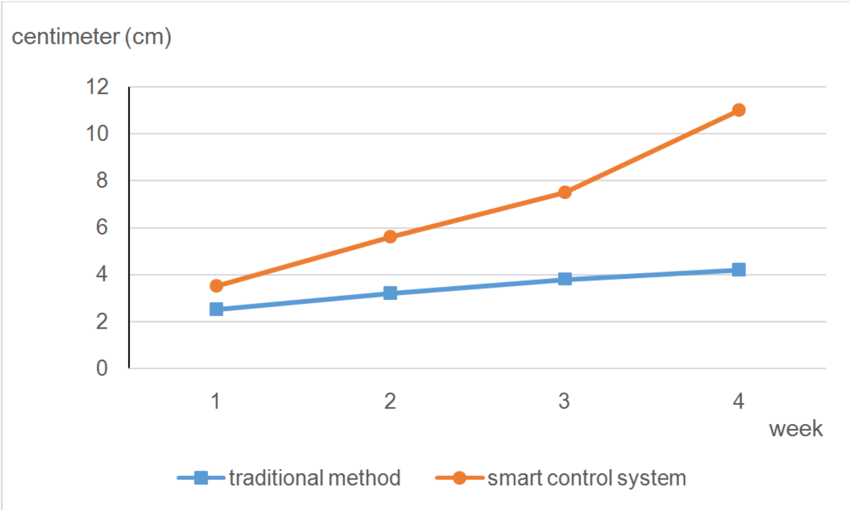


FIGURE 8. Comparison between the width of lettuce's leaves

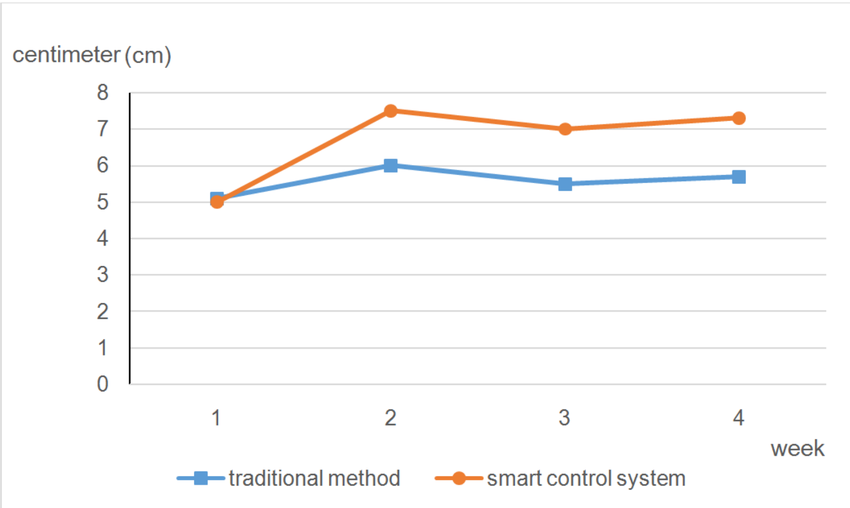


FIGURE 9. Comparison between the height of lettuce's leaves

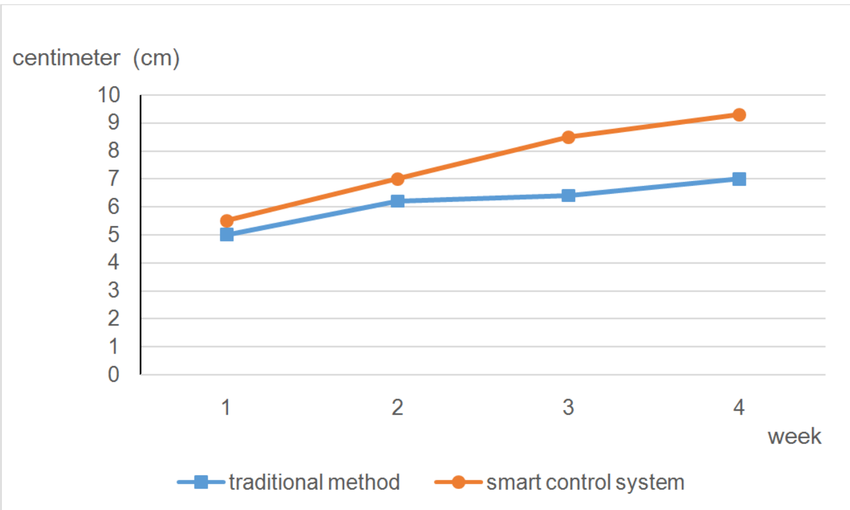


FIGURE 10. Comparison between the length of bok choy's leaves

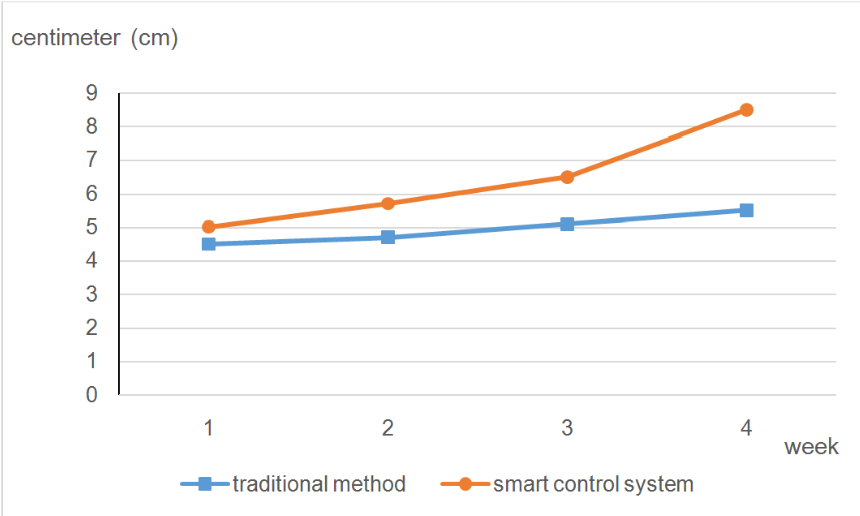


FIGURE 11. Comparison between the width of bok choy's leaves

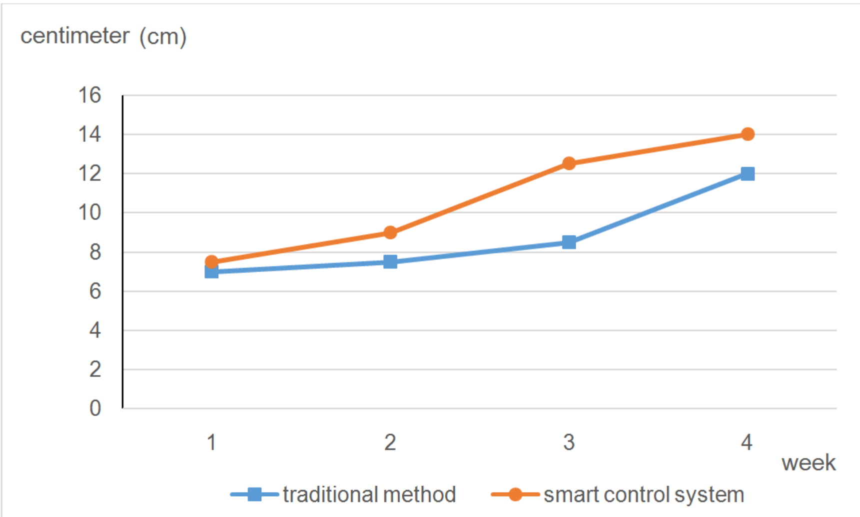


FIGURE 12. Comparison between the height of bok choy's leaves

TABLE 7. T-test group statistic

Group	*Leaf Length*		Leaf width		Plant height	
	Manual	*Smart controller*	Manual	*Smart controller*	Manual	*Smart controller*
Mean	8.988	8.413	4.188	6.663	7.163	8.725
SD	3.690	2.115	0.992	2.322	2.263	3.025
SEM	1.304	0.748	0.351	0.821	0.800	1.069
N	8	8	8	8	8	8

efficient because they have to be checked every three days and there also other factors that will obstruct or hinder us. This manual method also does not guarantee that the value of nutrients and pH in the installation are within the desired range because in a short time there are many factors that can change the value suddenly like the weather factor. As for the smart controlling system, the system will automatically measure the

Table 8. Independent sample t-test

Independent samples test	p Value	Mean	95% confidence interval of this difference		t	df	Standard error of difference
			lower	Upper			
Leaf Length	0.7079	0.575	−2.650	3.800	0.3824	14	1.504
Leaf width	0.0150	−2.475	−4.390	−0.560	2.7725	14	0.893
Height plan	0.0078	−1.563	−2.564	−0.561	3.6904	7	0.423

value of the nutrient content and pH according to the time specified. Then, the system will adjust the value of the nutrient content and pH to always be within the desired range.

5. **Conclusions.** Using a smart controlling system will help farmers treat hydroponic plants, because there is no need to check the plants any time. The smart controlling system will automatically help control the pH, EC, water requirements of plants so that the nutritional content and pH of the plant are within the desired normal condition so that plant growth can be optimal. Besides nutritional factors and pH, plant growth is also influenced by weather factors. For example, rain will hamper plant growth because photosynthesis is not optimal. The experiment result shows the smart controller produces significant growth in terms of leaf width and plants height.

It is recommended that future research should use ultraviolet lamps so that photosynthesis can still occur during cloudy weather or at night (in dark conditions) to further accelerate the growth of plants.

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