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IoT-based monitoring system for hydroponics

Abstract. *A hydroponic system is a method to grow plants using water. Hence, the quality of plant water must be at an optimal level to ensure the plants grow well. This project proposed Internet of Things (IoT) technology to monitor plant water quality. In this project, the NodeMCU ESP32 microcontroller is used to control the entire hydroponic system, while the Total Dissolves Solid (TDS) sensor and ultrasonic sensor (HCSR04) were used to measure the plant water quality (water concentration and water level inside the reservoir). The Cayenne myDevices App acts as a platform for mobile monitoring. The measured data from both sensors will be sent to NodeMCU ESP32 by using Wi-Fi connectivity, before being sent to Cayenne myDevices App to be displayed on mobile devices. The water concentration and the water level inside the reservoir are the elements that were monitored in this project, and this project focuses on mustard green cultivation. The results of several experiments that have been carried out show that the proposed hydroponic cultivation monitoring system-based IoT technology successfully displays the water quality of mustard green through display on mobile devices using the Cayenne myDevices App. Users will also be notified when the distance between the ultrasonic sensor and the water level inside the reservoir is more than 10 cm, and the reading of water concentration is lower than 840 ppm. Overall, the monitoring system developed in this project is proven to be able to effectively monitor the water quality of mustard green plants.*

Streszczenie. *System hydroponiczny to metoda uprawy roślin przy użyciu wody. Dlatego jakość wody roślinnej musi być na optymalnym poziomie, aby rośliny dobrze rosły. W ramach tego projektu zaproponowano technologię Internetu rzeczy (IoT) do monitorowania jakości wody w roślinach. W tym projekcie mikrokontroler NodeMCU ESP32 służy do sterowania całym systemem hydroponicznym, natomiast czujnik Total Dissolves Solid (TDS) oraz czujnik ultradźwiękowy (HCSR04) zostały wykorzystane do pomiaru jakości wody roślinnej (stężenia wody i poziomu wody w zbiorniku). Aplikacja Cayenne myDevices działa jako platforma do mobilnego monitorowania. Zmierzone dane z obu czujników zostaną przesłane do NodeMCU ESP32 za pomocą połączenia Wi-Fi, zanim zostaną przesłane do aplikacji Cayenne myDevices w celu wyświetlenia na urządzeniach mobilnych. Stężenie wody i poziom wody w zbiorniku to elementy, które były monitorowane w tym projekcie, który koncentruje się na uprawie gorczycy. Wyniki kilku przeprowadzonych eksperymentów pokazują, że proponowany system monitorowania upraw hydroponicznych oparty na technologii IoT z powodzeniem wyświetla jakość wody musztardowej zieleni poprzez wyświetlanie na urządzeniach mobilnych za pomocą aplikacji Cayenne myDevices. Użytkownicy zostaną również powiadomieni, gdy odległość czujnika ultradźwiękowego od poziomu wody w zbiorniku przekroczy 10 cm, a odczyt stężenia wody będzie niższy niż 840 ppm. Ogólnie rzecz biorąc, udowodniono, że system monitorowania opracowany w ramach tego projektu jest w stanie skutecznie monitorować jakość wody gorczycy zielonej. (***System monitorowania oparty na IoT dla hydroponiki**)

Keywords: Hydroponics, IoT, NodeMCU, Mustard Green
Słowa kluczowe: Hydroponika, IoT, NodeMCU, Mustard Green

Introduction

A. *Agriculture in Malaysia*

The agricultural sector is one of the main contributors to the economy of a country, apart from the service sector and the manufacturing sector. In Malaysia, the agricultural sector is reported to have contributed as much as 7.1% (MYR 101.5 billion) to the country's Gross Domestic Product (GDP) in 2019. As shown in Figure 1, vegetables are among the second largest contributors to the agricultural sector (25.9%), after oil palm (37.7%) [1]. However, extreme climate change and the worsening food supply crisis around the world are still a real concern for the world's population [2]. Agricultural activities should be stimulated to ensure a sufficient food supply. Recently, it can be seen that the application of the latest technology in the agricultural sector has successfully boosted agricultural activities in Malaysia [3]. This modern farming method is proven to be successful in advancing the agricultural sector in Malaysia [4].

B. *Hydroponic System*

The hydroponic system is one of the methods often used in agricultural activities. Hydroponics is a soil-free plant cultivation method and has become the fastest-growing and fastest-growing second-generation crop production system in the agricultural industry [5]. Hydroponics is a method of growing plants in a nutrient solution with or without the use of an inert medium such as gravel, vermiculite, stone wool, peat moss, saw dust, coir dust, coconut coir, and other similar materials. The phrase hydroponics comes from the Greek words "hydro", which means water, and "ponos", which means labor, and literally means "water power". In the early 1930s, Professor William Gericke coined the word "hydroponics" to describe the growth of plants with their roots floating in water containing mineral fertilizers [5].

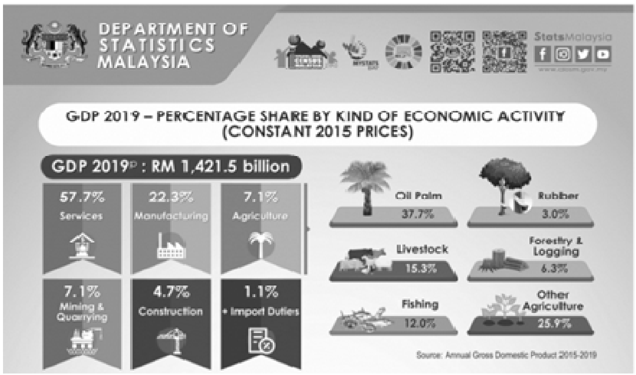

Fig.1. Malaysia Gross Domestic Product (GDP) 2019 [1]

Plants grown using the hydroponic method were also found to grow faster compared to plants grown using soil since nutrients were given directly to the plant's roots [6]. Besides, the quantity and quality of crops for the hydroponic system are more stable for the amount of crop production than compared to the soil cultivation method. The soil cultivation method is unstable and leads to pest or soil-borne pathogens [7]. Conventional cultivation (using soil) is also reported to leave many adverse effects on the environment, including soil pollution, water pollution, and air degradation [7].

C. Techniques in Hydroponic

Basically, there were several techniques in hydroponics; aeroponics, wick, ebb and flow, drip, deep water, and Nutrient Film Technique (NFT) [8]. This project focuses only on the hydroponic cultivation method using the NFT. NFT for hydroponics (shown in Figure 2) was first developed by Dr. Alen Cooper in England in the mid-1960s.

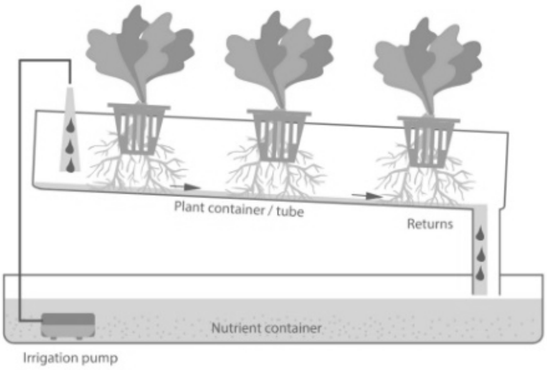

Fig.2. NFT for hydroponics

Dr. Alen Cooper introduced NFT to solve the limitations of the ebb and flow approach (another technique used for cultivation using the hydroponic method). By using NFT, water or fertilizer solution will circulate throughout the system and be delivered to the growth tray by a water pump (without a timer) [9]. The NFT system is slightly tilted, allowing nutrient fluid to flow through the roots and into the reservoir. Plants grow in channels or tubes, with their roots suspended in a hydroponic solution. Many leafy vegetables can be produced easily when using the NFT, among them are salad and mustard green plants. However, the main drawback when using NFT is the plant roots will be susceptible to fungal infection due to continuous immersion in water or nutrients.

D. Important Aspect in Maintaining Plant Quality in Hydroponics

(i) pH and Electrical Conductivity (EC)

Plant nutrients used in hydroponics are often inorganic or ionic in nature and soluble in water. Therefore, a combination of several chemicals should be used to ensure plant growth. For optimal plant performance, the pH value and EC value of the fertilizer solution must be appropriate [5]. Table 1 shows the optimum range of EC and pH values for several types of hydroponic plants.

(ii) Water level

Table 1. The optimum range of pH and EC for hydroponic crops

Crops	EC (dSm^{-1})	pH
Asparagus	1.4 to 1.8	6.0 to 6.8
Basil	1.0 to 1.6	5.5 to 6.0
Bean	2.0 to 4.0	6.0
Broccoli	2.8 to 3.5	6.0 to 6.8
Cabbage	2.5 to 3.0	6.5 to 7.0
Celery	1.8 to 2.4	6.5
Cucumber	1.7 to 2.0	5.0 to 5.5
Lettuce	1.2 to 1.8	6.0 to 7.0
Pak Choi	1.5 to 2.0	7.0
Spinach	1.8 to 2.3	6.0 to 7.0
Tomato	2.0 to 4.0	6.0 to 6.5

A reservoir will be used in the hydroponic system to hold nutrient water. All nutrients and pH neutralizers will be mixed into the reservoir water. The size of the reservoir is determined by the number of plants. The bigger the reservoir, the more plants there are. Although the premise in hydroponics is flowing water, the water level in the reservoir may decrease due to solar evaporation [10]. That is why the water level must be monitored regularly to ensure that plants receive sufficient nutrients [11].

E. Monitoring System for Hydroponics

Several hydroponic monitoring systems have been reported been developed in several studies [12], [13], [14]. Helmy et al. (2016) [12] developed a hydroponic monitoring system using the Nutrient Film Technique (NFT). The system was developed to monitor pH values, temperature, and water level. Helmy et al. (2016) used a website as a monitoring platform and Arduino UNO as a microcontroller. However, the size of the monitoring system developed by Helmy et al. (2016) is considered large cause of the use of GSM/GPRS as a Wi-Fi module.

In 2017, P. Sihombing et al. [13] built an automatic hydroponic system. The hydroponic system developed by P. Sihombing et al. (2017) used Arduino UNO as a microcontroller, and the system is based on Android. Compared to the project developed by Helmy et al. (2016) in [12], the monitoring system by P. Sihombing et al. (2017) only focused on monitoring water temperature and water level [13]. The platform used to monitor water temperature and the water level is Thingspeak; which is a website-based platform. However, no discussion of pH water or water concentration was presented in the study.

Apart from Helmy et al. (2016) [12], and P. Sihombing et al. (2017) [13], Usman et al. (2018) [14] also reported having developed a hydroponic monitoring system. The hydroponic monitoring system by Usman et al. (2018) used the flow technique. This project focuses on air level, pH, temperature, and humidity values. Raspberry Pi 3 is used as a microcontroller, while Sugino fuzzy logic is used as a method to automatically control the pump.

Recently, it can be seen the trend of applying Internet of Things (IoT) technology for the purpose of monitoring a system has started to get high demand. Not limited to plant monitoring, IoT has also been reported to be used in smart transport and mobility systems, smart buildings, smart buildings, smart manufacturing, and many more [15].

F. Mustard Green in Hydroponic

Figure 3 shows mustard green that is commonly grown using the hydroponic method. Mustard greens are very easy to grow and are among the favorite vegetables of many. Mustard green usually takes only 4 to 6 weeks to grow, starting from seed nursery to harvest [16]. This shows that, if properly managed, a hydroponic greenhouse has the potential to produce a dozen or more crops of mustard greens each year.

Fig.3. Mustard green in hydroponics

The quality of mustard green is determined by the pH value of the water and the nutrient content in the water (TDS, measured in parts per million (ppm) or Electrical

Conductivity (EC)) [17]. Table 2 lists the recommended pH values and nutrient content values in water (TDS) for the cultivation of mustard green using the hydroponic method [17].

Table 2. pH and EC/ppm range for mustard green

pH	TDS
6.0 to 7.5	1.2 to 2.4 (EC) / 840 to 1680 (ppm)

Methodology

The project development can be divided into two stages. The first stage is aiming to monitor the Total Dissolves Solid (TDS) and water level. Meanwhile, the second stage is to analyze the accuracy of TDS. Figure 4 and Figure 5 illustrate the flowchart of these two stages.

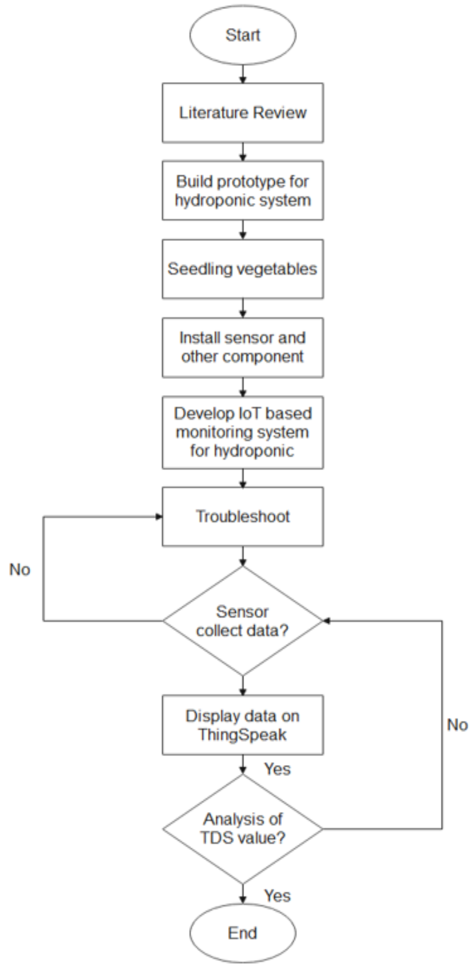

Fig.4. Project flowchart (stage 1)

The development of this project began with a literature review (refer to Figure 4). In the literature review, research on past projects related to hydroponic monitoring systems, including the components used, was reviewed. The main focus of this procedure is to study the methods in hydroponics, the types of sensors used, and the types of analysis performed in past studies.

The next procedure is to build a prototype for the proposed hydroponic monitoring system. Once the prototype is ready, mustard green seedlings will be sown in pots, and sensors and other components will be attached to the prototype. Next, the connection between the microcontroller and the sensors will be done. By doing this, TDS data and water level data are ready to be collected and displayed on the Cayenne myDevices website and applications.

Once the monitoring system has been developed, the next procedure is to identify and solve problems found in the system, including the components used. The sensor's ability to detect and subsequently collect data will also be tested during this procedure. If the sensor fails to detect data, the troubleshooting process will be performed until the data is successfully detected by the sensor. The data successfully detected by the sensor will be displayed through the Cayenne myDevices application. Next, the collected data will go to the next stage (stage 2) to go through the analysis process.

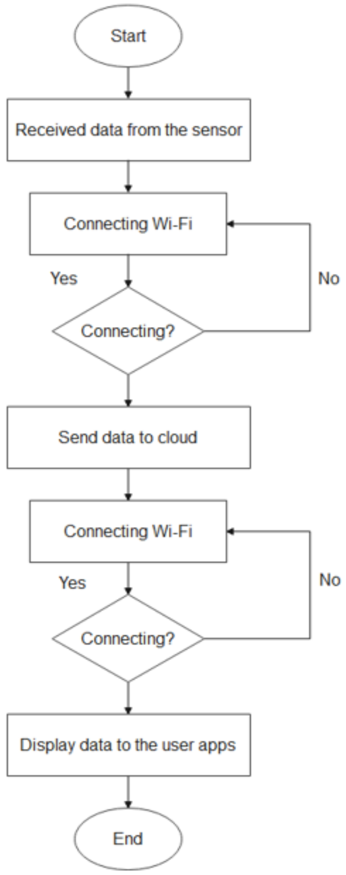

Fig.5. Project flowchart (stage 2)

Figure 5 is the second stage of project development. In this second stage, the data that has been detected by the sensor will be sent to the cloud via a Wi-Fi platform. If the Wi-Fi connection is successful, the data value detected by the sensor will be displayed on the Cayenne myDevices application.

A. Monitoring System

The main focus of this project is on its monitoring system. In this project, a monitoring system will be used to help users monitor the water pH, water concentration, and water level of the hydroponic plants. Figure 6 shows the block diagram of this project.

Based on Figure 6, the TDS value of the water in the reservoir will be monitored using a TDS sensor. Meanwhile, an ultrasonic sensor (HC-SR04) will be used to detect the water level in the reservoir. This ultrasonic sensor uses echoes to detect air. Data collection from all these sensors will be done using the NodeMCU ESP32 microcontroller. For monitoring purposes, reading data is also available on the Cayenne myDevices website and the Cayenne myDevices mobile app.

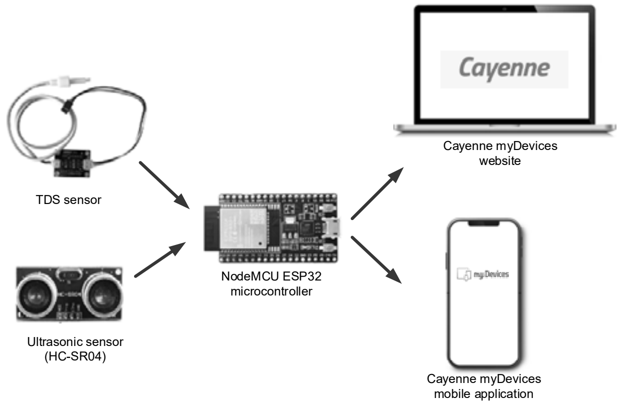

Fig.6. Project block diagram

B. TDS Accuracy

The objective of this project is to measure the accuracy of the TDS value based on the volume of fertilizer A and fertilizer B for 5 liters of water. Figure 7 shows the experimental setup. The reservoir is used to store nutrient water for the hydroponic system.

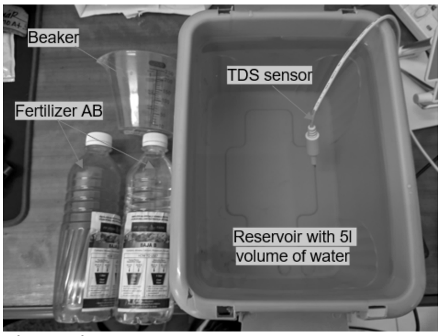

Fig.7. Experimental setup

Figure 8 shows the TDS meter and TDS sensor used. In this project, these two components are used to determine the accuracy of data reading between the two.

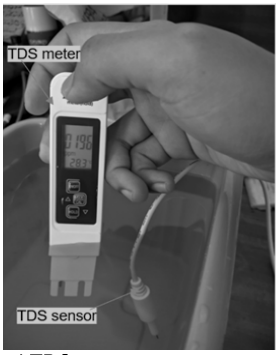

Fig.8. TDS meter and TDS sensor

The accuracy of the TDS data measured using both the TDS sensor and TDS meter can be determined using Equation (1).

(1)

$$Accuracy\ error\% = \frac{|Approximate\ value - Exact\ value|}{|Exact\ value|} x100$$

Table 3 shows the TDS data obtained from the TDS meter and TDS sensor, based on the volume of fertilizer A and fertilizer B. As seen in Table 3, the TDS value increases as the volume of fertilizer A and fertilizer B increases.

From Table 3, it can be seen that the average accuracy error between the TDS meter and the TDS sensor is about ±7.98%. The accuracy between the TDS meter and the TDS sensor shown in Table 3 is calculated based on Equation (1). Figure 10 shows a comparison data plot for reading TDS values using TDS meters and TDS sensors.

Figure 9 shows fertilizer A and fertilizer B which are added 5ml each to get 10ml.

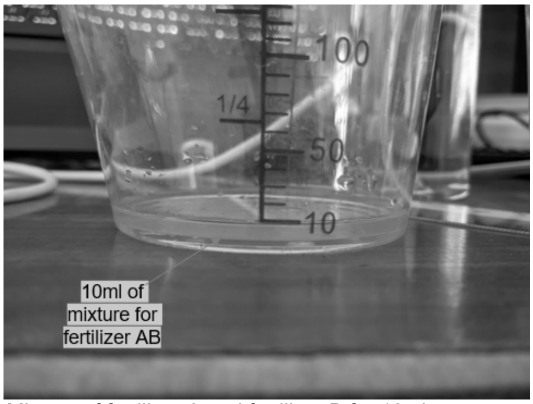

Fig.9. Mixture of fertilizer A and fertilizer B for 10ml

Based on the graph in Figure 10, the volume of TDS value (ppm) for the TDS meter and TDS sensor is directly proportional to the volume of fertilizer A and fertilizer B. Although the two data plots have little difference in terms of reading values, however, both plots are still in the same stream. It can be concluded that 1ppm TDS volume value is equivalent to 74.843ml of AB solution.

Table 3. Collected data of TDS using TDS meter and TDS sensor

No.	Volume of fertilizer (ml)		Volume of water (ml)	Digital meter	Analog sensor	Accuracy (%)
	A	B		TDS value (ppm)		
1	0	0	5000	59	61	3.39
2	5	5	5000	122	154	26.23
3	10	10	5000	196	226	15.31
4	15	15	5000	282	306	8.51
5	20	20	5000	348	356	2.30
6	25	25	5000	366	441	20.49
7	30	30	5000	483	516	6.83
8	35	35	5000	552	603	9.24
9	40	40	5000	618	675	9.22
10	45	45	5000	694	761	9.65
11	50	50	5000	769	857	11.44
12	55	55	5000	862	933	8.24
13	60	60	5000	943	987	4.67
14	65	65	5000	1031	1048	1.65
15	70	70	5000	1128	1117	0.98
16	75	75	5000	1223	1144	6.46
17	80	80	5000	1381	1298	6.01
18	85	85	5000	1472	1356	7.88
19	90	90	5000	1497	1421	5.08
20	95	95	5000	1525	1487	2.49
21	100	100	5000	1587	1563	1.51
Average of accuracy (%)						**7.98**

Results, Analysis, and Discussion

A. The Development of a Monitoring System

A hydroponic monitoring system using Internet of Things (IoT) technology has been developed in this project to help users, especially farmers monitor their crops through mobile phones. By using the monitoring system that has been developed, users can monitor TDS values and water level values in the reservoir anywhere. The developed monitoring system can display the current TDS reading detected by the sensor and the previous TDS reading for reference. By using this developed monitoring system, users do not need to go to the crop area every time to check the condition of the nutrient solution used for their hydroponic system.

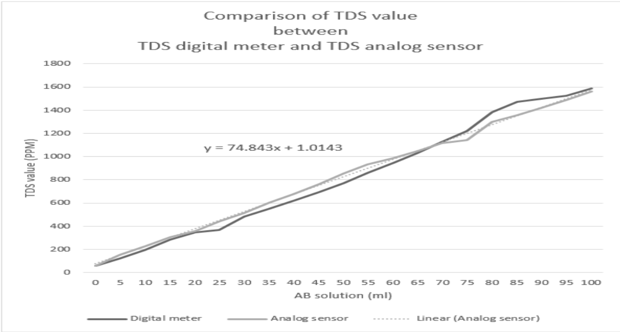

Fig.10. Comparison between TDS reading for TDS meter and TDS sensor

Cayenne myDevices has two platforms, a website, and a mobile application. In this project, the developed IoT-based hydroponic monitoring system first needs to be configured with the Cayenne myDevices website. Figure 11 shows the web dashboard interface for the monitoring system. As shown in Figure 11, the dashboard displays the real-time data value for TDS and water level. The Cayenne myDevices web is synchronized with the Cayenne myDevices app for smartphones. Every widget declaration in the Cayenne myDevices web dashboard will appear on the Cayenne myDevices mobile application. Figure 12 shows the GUI for the Cayenne myDevices application.

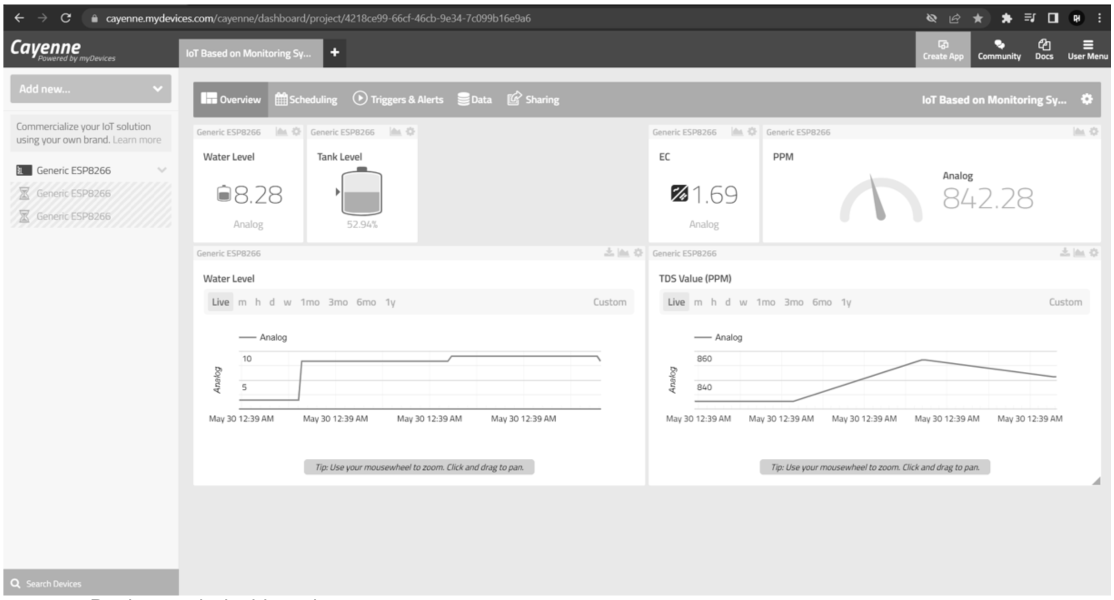

Fig.11. Cayenne myDevices web dashboard

Fig.12. Cayenne myDevices application

Figure 13 shows the Cayenne myDevices mobile application interface.

The widgets that have been set in the Cayenne myDevices web dashboard will appear in the mobile application. For the TDS value in ppm units, a gauge has been used as an indicator. Meanwhile, a reservoir icon was used to show the water level in the reservoir. In order to ensure that the air is nutritious and the water level in the reservoir is always within the set range, notification alerts have been added to the monitoring system.

Cayenne myDevices is also equipped with the additional function of notification alerts in the trigger section (see Figure 14).

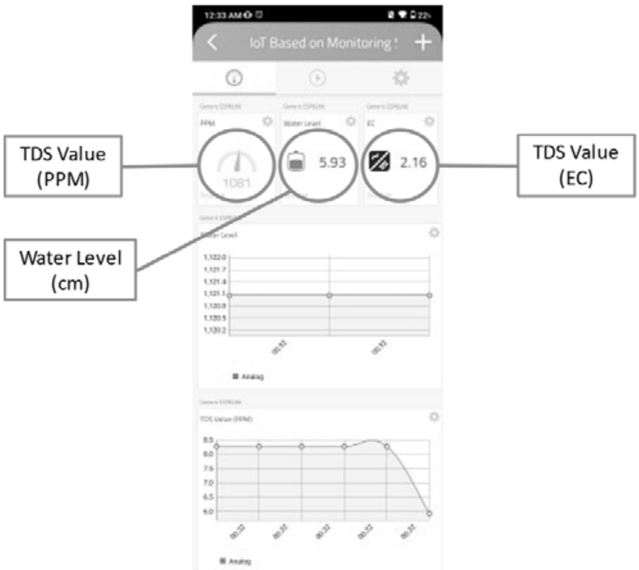

Fig.13. Cayenne myDevices mobile application interface

The user will also be notified via email notification if the TDS value is less than the range that has been set (range 840 to 1680 ppm). For the case of water level, every time the ultrasonic sensor (HCSR04) detects a distance of more than 10cm, a notification to the user will be sent by email.

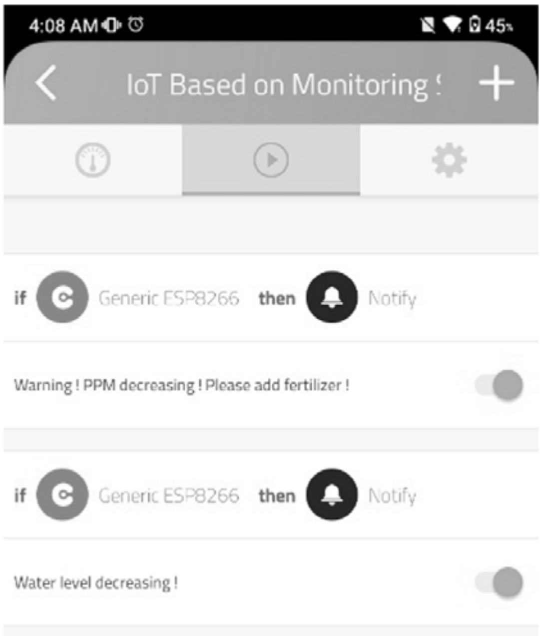

Fig.14. Notifications alert on trigger section

Conclusion

A monitoring system based on IoT technology for hydroponic plants has been successfully developed. Based on the results of the experiments that have been carried out, the results of the experiments are as expected. Throughout the experiment, 20 TDS data were collected and observed using TDS sensors and TDS meters. From the experiment, the accuracy obtained for the TDS value is about ±7.98%. Subsequently, the accuracy of the TDS value was tested and observed 20 times using different fertilizer A and fertilizer B solution values. As a result, 1 ml of fertilizer solution A and 1 ml of fertilizer solution B gave a TDS value reading of approximately 74.843ppm. With this data, the user can determine how much fertilizer A and fertilizer B solutions are needed to stabilize the TDS value of the water used for this hydroponic system. This system focuses on mustard greens, for which the required standard range for TDS is between 840 to 1680 ppm, while the required standard range for pH is between 6 to 7.5. Any plant that uses the same TDS and pH range as this mustard green vegetable can also use this system without any modifications.

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