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Prototype of Internet of Things-Based Automatic Hydroponic System

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ABSTRACT — The increase in food needs, including vegetables and fruits, corresponds with population growth. However, agricultural land is increasingly declining due to land conversion. This decline can threaten national food security. Utilizing hydroponic systems for plant cultivation is one of the efforts to adapt to land reduction, land degradations, and adverse impacts of global climate change. Unfortunately, hydroponic cultivation requires constant monitoring of plant nutrition. This research aimed to create an automatic hydroponic system that controlled the process of regulating nutrients to save growers time and energy. Through Internet of things (IoT) technology, automatic hydroponic cultivation can monitor plant life, temperature, humidity, water level in reservoirs, total dissolved solids (TDS), and pH of nutrient solutions. In addition, it can visually monitor plants through Android applications. The hydroponic system used for planting was the nutrient film technique, and the plant cultivated was lettuce. The system consisted of TDS sensors to measure TDS, analog pH sensors to measure the pH, the HC-SR04 ultrasonic sensors to measure the water level in the reservoir, DHT11 sensors, ESP32 microcontrollers, and ESP32-CAM to monitor plant growth remotely. Based on system testing results, the average of TDS increased from 600 ppm in the first week to 900 ppm in the fifth week, the average pH was 6.19, and the average water level in the reservoir was 20.89 cm. All test result parameters are at the designed values.

KEYWORDS — Hydroponics, Internet of Things, Total Dissolved Solids, Automatic Control Systems, Nutrient Film Technique.

I. INTRODUCTION

Despite the escalating need for foods due to population growth, the growth of agricultural land does not follow the same pace. The concentration of urban areas in the industrial sector disrupts agriculture in Indonesia by transforming agricultural land into industrial, tourism, and residential lands. Consequently, farmers turns into factory workers and traders; they develop other businesses to fulfill their living needs [1]. One effort to address land reduction is plant cultivation using hydroponic system.

In addition to requiring limited land, hydroponic systems can maintain land quality and anticipate the adverse impacts of global climate change. Consistently, available nutrients allow hydroponic cultivation to increase plant growth up to 50% faster than planting on top of the ground. This method also gives higher results than conventional methods [2].

In order to achieve good food security in the future, where the population is increasing while agricultural land is decreasing, it is hoped that the community can participate in providing food independently by cultivating vegetables and fruits. The community can contribute to providing food independently through hydroponic cultivation. Nonetheless, hydroponic system requires more perseverance and devotion than conventional agriculture. Growers should monitor their plants daily due to their rapid reaction to good and bad nutrients [2]. This monitoring must be conducted manually, which can be time-consuming, prone to errors, and susceptible to rapid undetected changes [3]. These weaknesses can restrict the mobility and flexibility of growers.

An automated hydroponic system enables the community, especially in urban areas, to save time and resources. Plant growth also becomes optimal because nutrients and environmental conditions can be regulated according to the plant needs. In addition, the risk of nutritional errors can be mitigated because it is managed automatically through a programmed system. Waste can also be avoided since the use of water and nutrients are regulated as needed. Automated hydroponic systems will also result in greater production of agricultural products and better quality as the system works stably. It also produces safer plant production as no pesticides are used.

Despite its advantages, the automated hydroponic cultivation is very dependent on modern technology, which may lead to problems in the event of technical damage, network failure, and power outage problem that render the system inoperable. Due to its dependence to the technology, the initial capital for designing this system is quite large.

Thanks to its short harvest period (40 to 45 days), ease of cultivation, and relatively stable selling value, lettuce is among the most cultivated plants in hydroponic system. The economic value of this vegetable is very high, following cabbage, flower cabbage, and broccoli [4].

Previous research on automated hydroponic cultivation has been carried out. A study built a system that monitored pH, total dissolved solids (TDS), air temperature, and water volume and then displayed the data in the form of numbers and graphs on the Online Value of Realtime Data (OVoRD) platform [5]. The system was equipped with an automatic control system for pH and TDS conditions in the solution. Another study built a monitoring system for water level, temperature, air humidity, soil moisture, and pH values in hydroponic plant nutrient solutions which were displayed on the Internet of things (IoT) Message Queuing Telemetry Transport (MQTT) application [6]. This system was equipped with an automatic control system for the pH value of the solution, while the TDS value was measured manually.

A study created an automatic control system to maintain the nutrient concentration value (TDS) which was connected to the database and displayed on the liquid crystal display (LCD) and web dashboard [7]. In this study, pH control was not carried out. Meanwhile, in [8], an IoT-based hydroponic system was created. This system functioned to measure and regulate the provision of nutrients, and the amount of water embedded in the Blynk application. In this study, there was no pH control system, while the provision of AB Mix nutrition was only based on the comparison of the volume of water in the nutrient container, so an accurate TDS value was not obtained. Study [9] compared the benefits of smart farming of Chinese cabbage using IoT-based hydroponic systems with conventional hydroponic farming. The main objectives of this study were to automate environmental monitoring, achieve pH levels, and maintain electrical conductivity equivalent to TDS values through a smartphone and computer interfaces for adjustment of nutrient and acid-base solutions. The results of the study showed an increase in important parameters in plants, namely plant weight, plant height, leaf size/area, and chlorophyll amount. The research emphasizes the ability of IoT technology in improving productivity and quality in hydroponic agriculture.

Prior research developed a hydroponic system of the nutrient film technique (NFT) that could control nutrients (TDS) and pH of the solution and created a system to monitor the temperature and flow speed of the solution in the hydroponic system [10]. This system controlled the nutrients and pH of the solution, but the value of the controlled nutrients remained constant, not following the plant’s age. This system did not control the reservoir’s water level, potentially leading to a decrease in water level due to evaporation, which could reduce the speed of the solution flow in the system. Other research developed an NFT-type hydroponic system that controlled the pH of nutrient solutions and the solution flow using the gravity principle but did not control the TDS in the solution [11]. The advantage of the system is that it can save the consumption of electrical energy by not continuously operating the water pump to drain the nutrient solution. Other research developed an NFT-type hydroponic system that monitored environmental conditions, namely temperature, air humidity, and light intensity; and monitored nutrient solution parameters, namely pH and TDS [12]. However, this system has not been developed to control these parameters. The system was built on an IoT platform that was used as a gateway to send data from sensors via ZigBee communication. Previous research developed an NFT-type hydroponic system that monitored the nutrient solution’s temperature, environmental humidity, pH, and electrical conductivity (EC) [13]. The system used a Node MicroController Unit (NodeMCU) to receive data from sensors and control the pump work, valves, and dispensers. The system did not control pH or EC; the data were monitored through a mobile application (MQTT).

Other research implemented an NFT-type hydroponic system indoor in desert areas with dry climates. The system was cultivated indoors by using an air conditioner (AC) to regulate the temperature of the room, using lamp light instead of sunlight [14]. The system controlled the temperature, pH, EC or TDS, and water level in the reservoir. It also identified the presence or absence of solution flow. In this system, the value of TDS levels remained constant, not regulated according to the plant’s age. The system was not equipped with a camera to monitor the plants. Another research created a web-based smart hydroponic system with IoT in Bireun area [15]. The hydroponic system used was a type of NFT with light, pH, and TDS parameters controlled by a NodeMCU. The system controlled the water pump, nutrient pump, light, and fan as actuators. However, it did not monitor plant growth through cameras.

Prior research planted kale using a hydroponic system that could control the TDS of the solution with an increased value according to the plant’s age [16]. In addition to TDS, the system also controlled the temperature and humidity of the room by using a fan. Data from the sensor was displayed on an LCD and smartphone through the Blynk application with IoT technology. This system did not send notifications when harvest time arrived and there was no system for monitoring plant growth through cameras. Research [17] developed an indoor hydroponic system that could control the temperature, humidity, pH, and TDS of the nutrient solution from the system. The system used a pump as an actuator to control the value of the nutrient solution. Raspberry Pi was utilized to distribute data from sensors to system users. Users could monitor the environmental conditions of the system through a web browser on a smartphone or a laptop. Research [18] developed a hydroponic system using IoT-based sensors to control pH, TDS, and water temperature parameters. The k-nearest neighbor (KNN) algorithm was used to activate the actuator’s work. In this study, the actuator work was improved simultaneously with the previous study by providing a certain interval and time width to achieve ideal nutritional conditions. This system emphasized the values of pH, TDS, and ideal temperature parameters for plants to use. In addition, this system did not conduct plant growth monitoring through cameras. In research [19], two hydroponic systems were developed. These hydroponic systems included the NFT type that circulated nutrient solutions and the hydroponic type that did not circulate the solution, namely the drip irrigation system or fertigation system. The NFT system monitored the temperature of the solution; the temperature and humidity of the environment where the plants were placed; the intensity of light; and the electrical conductivity value of the mixing tank. The system only regulated electrical conductivity and did not control the pH value. The system also used IoT to connect to smartphones, so that it could perform remote monitoring. The paper does not explain applications on smartphones. In prior research, a vertical hydroponic system that could control TDS, pH, temperature, and light intensity was developed [20]. The IoT-based system employed Firebase to store data from sensors via ESP32. The system could automatically and manually adjust the temperature, light intensity, and TDS according to the plant’s age via smartphone.

According to prior studies [5]–[20], not all systems can control the nutritional conditions of TDS and pH in the gutter. Studies [7], [8], [16], and [19] did not regulate the pH conditions of nutrient solutions, while study [11] did not regulate TDS conditions. The study [6] set the TDS manually, while [10] and [14] used constant TDS values throughout the plant life. Studies [7], [10], and [11] detected the presence of water flow in gutters. The advantage of the study [11] is that it uses gravity to deliver water to the gutters so that the water pump does not operate continuously. All systems in previous studies were equipped with a monitoring system both using LCD and through smartphones; only [9] used cameras to capture plant growth so that it could be remotely monitored. However, no study has been conducted to provide notifications at harvest time and develop a system to drain the water in the

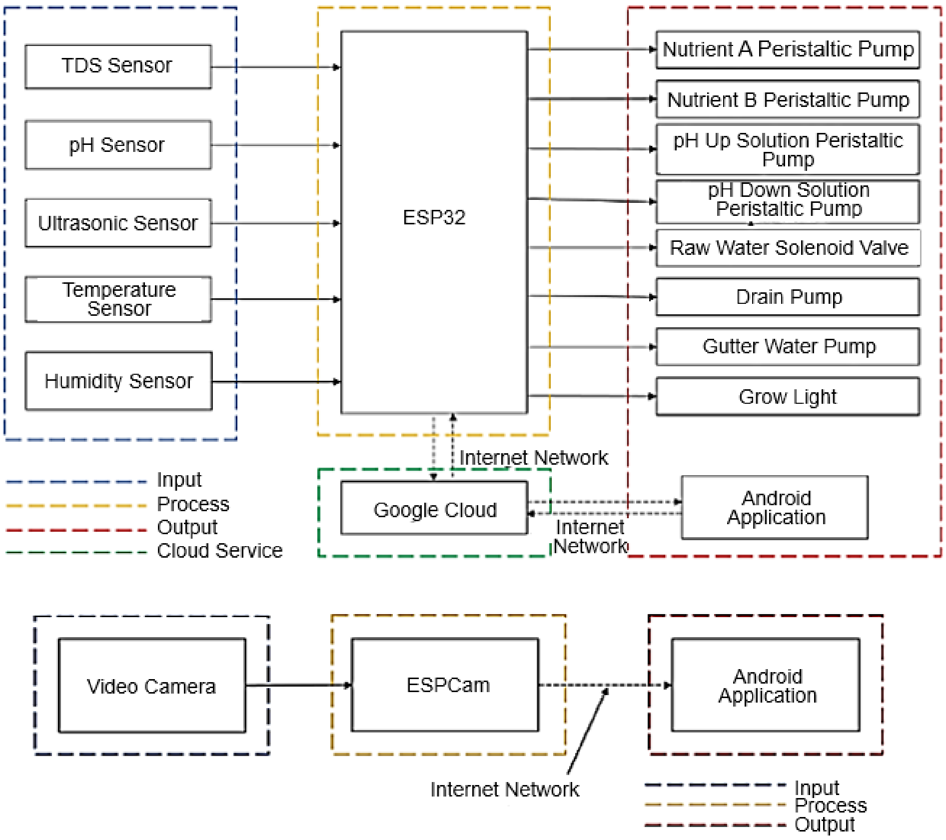

Figure 1. Block diagram of hydroponic system and ESP Cam.

reservoir after harvest. The excellence of this research is attributed to the selection of resources, including the framework used, IoT infrastructure, and Android applications that was independently built. These advantages render this research suitable for extensive development.

The firmware programming in this study used the Espressif IoT Development Framework (ESP-IDF) written in C language, enabling low-level control by providing direct access to the ESP32's hardware and peripherals. ESP-IDF supports a real-time operating system (RTOS) built on FreeRTOS, allowing the creation of multitasking applications where multiple processes (tasks) can run simultaneously. As a comparison, the Arduino IDE can simplify many hardware details to facilitate coding, but it limits control over complex operations. The Arduino IDE also does not provide explicit RTOS support, hence, multitasking is more difficult to set up. In addition, Arduino sketches are designed to run in a single loop.

This study used Google IoT Core as the IoT infrastructure, which is more suitable for large-scale IoT implementations where scalability, security, and performance are priorities. Services like Blynk are better suited for small projects that only require simple dashboards, controls, and real-time data visualization without the need for complicated backend services.

For the reasons mentioned above, this study developed hydroponic cultivation system of NFT type that can automatically control the nutrient conditions in the gutter, namely TDS, pH, water level in the reservoir from the planting period to harvest time, notification when harvesting started, and drain water in the reservoir through the reservoir drainage system when harvest was over [12], [13]. This system employed IoT to monitor TDS, pH, water level, temperature, humidity. In addition, the system employed an ESP Camera for direct observation of plant conditions, allowing for remote visual monitoring on a smartphone [14], [15].

II. SYSTEM DESIGN

A. SYSTEM BLOCK DIAGRAM DESIGN

Figure 1 shows a block diagram of an automated hydroponic control system, which is divided into four parts: input, process, output and cloud services. Input section has four sensors, each of which has an important role in the operation of the automated hydroponic system. The TDS sensor of the DFRobot TDS sensor board measures the number of dissolved particles in a nutrient solution to help regulate the concentration of nutrients needed by plants to support their optimal growth.

The pH sensor with the DFRobot pH sensor board model [16] measured the degree of acidity of a nutrient solution. The TDS and pH sensors from the DFRobot were used in this system as they are prepackaged for water measurements. Furthermore, the sensor module has an isolation circuit to protect the microcontroller from noise, operates with low power, is compatible with the ESP32 microcontroller, and features a compact design. An ultrasonic HC-SR04 sensor was utilized to measure the water level in the reservoir to maintain its stability. This sensor was selected for its extensive measurement range of 2 to 400 cm and an error rate of about 3 mm, rendering it suitable for the size of the water tank in the hydroponic system being developed. The DHT11 temperature and humidity sensor measure the temperature and humidity of the air in the hydroponic cultivation area [17], [18]. This sensor was used due to its operating temperature range of 0 °C to 50 °C and accuracy of ±1 °C, which is suitable for the hydroponic system's room temperature of 26 °C. DHT11 can also measure the air humidity from 20% to 90% and an accuracy of ±1%, which is also suitable with the range of air humidity in the room.

In the process section, ESP32 microcontroller functions as a working controller of the whole system that translates the input from the sensor and generated an output signal to drive the actuator [19], [20]. The ESP32 DevKit was chosen because it has several advantages: it is equipped with built-in Wi-Fi, so that it does not require additional Wi-Fi modules; it has a large number of GPIO pins, making it possible to connect various external sensors and actuators; and it is suitable for applications requiring battery life and wireless communication.

At the output is a peristaltic pump of Nutrient A, functioning to pump Nutrient A into the reservoir, and a peristaltic pump of Nutrient B, functioning to pump Nutrient B into the reservoir. The pH up solution peristaltic pump functioned to pump a solution that can raise the pH of the nutrient solution in the reservoir, the pH down peristaltic pump functions to pump the solution that can lower the pH of the nutrient solution in the reservoir. Peristaltic pumps were chosen because they are commonly used as dosing pumps that can dispense a consistent amount of solution over a measurable time span. In this study, peristaltic pumps were tested for 4 hours. The test results showed that the pump could consistently pump 75 ml of solution every minute. The raw water solenoid valve functioned to open or close the flow of raw water into the reservoir, whilst the drain pump transferred the nutrient solution from inside the reservoir to the discharge upon receiving the harvest order. The gutter water pump had two outputs: to drain the nutrient solution from the reservoir to the plant gutters and to constantly stir the nutrient solution for 24 hours by draining the water in the reservoir. The grow lamp was set with a timer as an artificial light source for hydroponic plants, and an Android application that served as an interface to display information on sensor readings, number of planting days, live-streaming video, and drain commands.

In the live-streaming video system, the input was video from camera which was used to monitor the state or growth of plants in the hydroponic system. This process utilized the ESPCam module that captured video footage and processed that data to be displayed directly in the Android application. The output was an Android application that functioned as an interface to display live streaming video, so that users could see the growth and condition of the plant in real-time.

Cloud services from Google Cloud were used to build the IoT infrastructure on automated hydroponic control systems. Figure 2 shows a diagram of a cloud service block. The ESP32 microcontroller was connected to the cloud of the IoT Core using the MQTT protocol to communicate over the Internet. MQTT used a publish-subscribe communication model, where the ESP32 acted as a publisher to send messages to a specific topic in IoT Core and a subscriber to receive messages from the topic it followed. The Cloud Firestore database service was used to store real-time sensor reading data to be displayed on the Android application. These data were stored in the form of an updated NoSQL document every time the ESP32 sent the sensor readings.

B. SYSTEM AND SOFTWARE DESIGN

The firmware software design in this study used the Espressif IoT Development Framework (ESP-IDF). ESP-IDF is built on FreeRTOS, allowing multiple tasks to run simultaneously. The scheduler can precede a running task to move on to a higher-priority task, ensuring that critical operations are handled on time. Although some variables depend on others, some processes in the program are written in parallel and given priority so that the scheduler can fully execute the determination of running tasks. The system flowchart is shown in Figure 3.

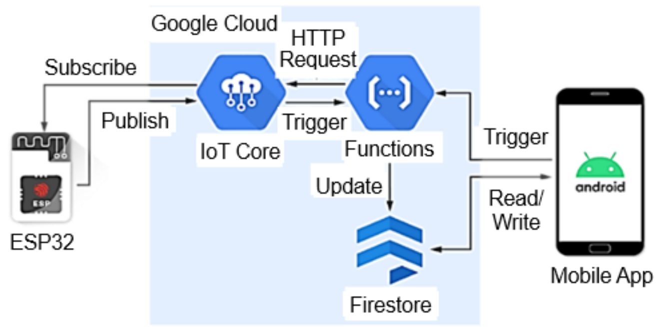

Figure 2. Block diagram of the cloud service.

When the system started operating, the initialization of parameters such as water level, TDS value, pH value, lamp lighting time, and harvest button activation were loaded with preprogrammed default values set as per Table 1.

After initializing the parameters, the hydroponic system automatically waited to be connected to the Internet, then synchronized the internal time on the system with Google's Simple Network Time Protocol (SNTP) server. The parameters of water level, pH value, and lamp time were set to remain consistent throughout the growing period. In contrast, the TDS value fluctuated according to the plant's age, adjusting for the nutrients needed at each stage of its growth. The tolerance for TDS is ±50 ppm, meaning that the TDS value will be considered low if it is less than the TDS initiation value -50 and considered high if it is greater than the TDS initiation value +50.

On the Google Cloud task (part A on the flowchart), the system sent data every 2 s and checked whether there was a harvest order. If the harvest command was not present, the system proceeded to the next task.

The water level task (part B in Figure 3) began with a system reading the water level in the reservoir. When the water level was below 20 cm, the solenoid valve activated, allowing water to fill until the height reached a minimum of 20 cm. Once the reservoir water level reached the target, the gutter water pump would turn on and discharge the nutrient solution to the plant gutters; the nutrient solution would flow to the plant gutters solely if the water level value had attained the target. Once the nutrient solution flowed into the plant gutter, the system would check whether the time was within the range of 6 a.m.–6 p.m. If it was, the grow light would activate and deactivate outside of that time range.

In the TDS task (part C in Figure 3), the system verified whether the reading TDS value was smaller than the target. If the TDS value did not meet the target, the system would automatically activate nutrient pumps A and B to add a nutrient solution for 5 s. The system then paused for 30 s before reactivating the nutrient pump until the TDS value reached the target.

Once the TDS value was suitable, the pH task commenced, and the system checked the pH value. When the pH value was below 5.5, the system responded by activating the pH up pump. This pump would add a solution of potassium hydroxide at a concentration of 10% for 5 s, followed by a 30-second pause before it was reactivated until the target pH value was achieved. Conversely, if the pH value rose above 6.5, the pH down pump was activated to add a 10% phosphoric acid solution for 5

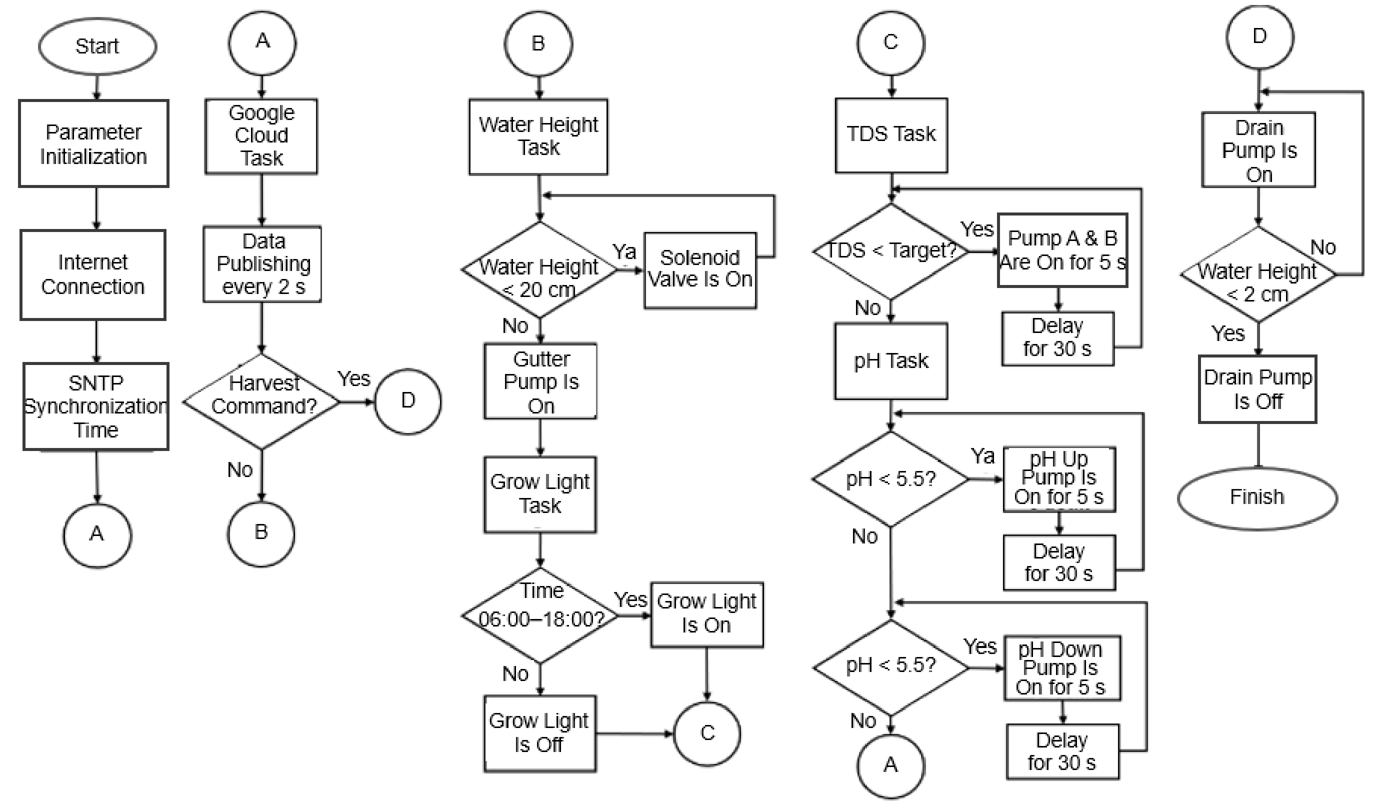

Figure 3. System flowchart.

TABLE I
HYDROPONIC PLANT PARAMETERS

Week	Water Height	TDS	pH	Light Activation Time	Harvest Notification
1	20 cm	600	5.5–6.5	6 a.m.–6 p.m.	Off
2	20 cm	700	5.5–6.5	6 a.m.–6 p.m.	Off
3	20 cm	800	5.5–6.5	6 a.m.–6 p.m.	Off
4	20 cm	900	5.5–6.5	6 a.m.–6 p.m.	Off
5	20 cm	900	5.5–6.5	6 a.m.–6 p.m.	On
6	20 cm	900	5.5–6.5	6 a.m.–6 p.m.	On

seconds, followed by a 30-second pause. After that, the pH down pump was reactivated until the pH of the solution met the target.

The automated hydroponic system was expected to increase the TDS value per 100 ppm in less than 2 min. The AB Mix solution used contained 5 ml A + 5 ml B + 1 l of water to 1,000 ppm, meaning that if the reservoir volume is 38–42 l, every 100 ppm requires 20–21 ml of AB Mix solution. With a peristaltic pump rate of 75 ml/min (1.25 ml/s) and a stirring delay of 30 s, the peristaltic pump pumping time in one cycle is 5 s.

$$120 = \frac{20(t + 30)}{1.25t}$$

$$120 = \frac{16(t + 30)}{t}$$

$$t = \frac{480}{104} \approx 4{,}62s.$$

The determination of the 30 s delay is based on the time required for the solution to mix perfectly, which is obtained through experiments with a gradual increase in the TDS value. The results of the experiment showed that 30 s was the time it took for the solution to reach a stable value.

The TDS and pH sensors used an analog to digital converter (ADC) that was set to take thirty-two readings (NUM_SAMPLES) with a 50 ms delay on each reading (SAMPLE_DELAY), meaning that the sensor took a reading, then waited for 50 ms before taking the next reading. After thirty-two readings (spaced 50 ms each), the program calculated the average of these readings to ensure more accurate results and reduce interference. The total time to collect thirty-two readings or get 1 value is 32 × 50 ms = 1,600 or 1.6 s.

The user had the option to harvest on the 30th planting day (part D on the flow chart). If they opted to harvest, the system activated the drain function on the reservoir, i.e. by activating the drain pump to the minimum or empty water level reading. Subsequently, all information and tasks in the hydroponic system were reset. The system, on the other hand, continued to function if the user declined to harvest.

The research also developed an Android application. The interface on the smartphone screen was created using Android Studio. The Android application displays various information, including the xxth day of planting or the day after planting (DAP); the time of the latest information update in the form of TDS values, pH, temperature, humidity, water level; and a live video display of the live video received from the ESP32-CAM. The Android application was also equipped with a harvest button, this button could not be pressed before the planting day reached 30 days.

III. RESULTS AND DISCUSSION

A. *PROTOTYPE IMPLEMENTATION*

The system testing was carried out indoors with an air conditioning temperature set at 26° C and lamp light instead of sunlight. As seen in Figure 4, the control panel and sensor module consist of ESP32 DecKitC as the main brain of the system, DFRobot TDS Sensor Board for total dissolved solids (TDS) measurement, DFRobot pH Sensor Board for solution pH measurement, DHT11 sensor for monitoring air temperature and humidity, ultrasonic sensor for measuring water height in tanks, and ESP32-CAM for real-time visual monitoring.

The actuator module consisted of two 4-channel relay modules, where each relay was connected to an actuator component as shown in Figure 5. Relay Module 1 consisted of four relays in charge of controlling the operation of Nutrient A, Nutrient B, pH up solution, and pH down solution pumps. Relay Module 2 consisted of four relays that activated the grow light, raw water solenoid valve, drain pump, and gutter water pump. Both modules were integrated into an automated hydroponic system, as shown in Figure 6.

B. TDS SENSOR TESTING

The purpose of this test was to evaluate the hydroponic system's ability to control and maintain the TDS value within the desired range. A graph of the results of the TDS value readings during the period can be seen in Figure 7. This figure shows the trend and stability of the TDS value in the nutrient solution during the test.

From the results of the TDS sensor test, it can be concluded that the results of measuring and controlling the TDS value are in accordance with the target set for each week, as shown in Table 1. The TDS value in the first week was around 600 ppm, increased to 700 ppm in the second week, reached 800 ppm in the third week, and around 900 ppm in the fourth and fifth weeks.

C. PH SENSOR TESTING

The purpose of pH sensor testing was to assess the ability of a hydroponic system to maintain a pH value within the desired value range. Figure 8 shows a graph of the pH values of the measurements over a 36-day test period. Based on test results, the hydroponic system is successful in measuring and controlling the pH value in accordance with the predetermined range, which is between 5.5 to 6.5. The average pH value of the system during the test was 6.19.

D. ULTRASONIC SENSOR TESTING

The purpose of the ultrasonic sensor test was to evaluate the performance of the automated hydroponic system in maintaining the water level in the reservoir at a value of 20 cm to 22 cm [21]. Figure 9 shows a graph of the results of measuring the water height value on a 36-day test. This figure shows the test results where the hydroponic system is functioned well in measuring and controlling water levels in the range of 20 cm to 22 cm with an average water level of 20.89 cm during the test.

E. MONITORING SYSTEM TESTING

The purpose of testing the monitoring system was to assess the ability of the hydroponic system to transmit the results of sensor readings in real-time. The test was carried out by calculating the end-to-end latency or delay, calculating the difference in the transmission time on the microcontroller when sending data and the receiving time in Google Cloud Function when receiving data within a 24-hour period.

The results of the end-to-end latency or delay test showed that the average time required to send data from the ESP32 to IoT Core was 125.33ms with data loss of 0%, as shown in Table II. It shows that the system is able to provide real-time monitoring with a fairly low delay.

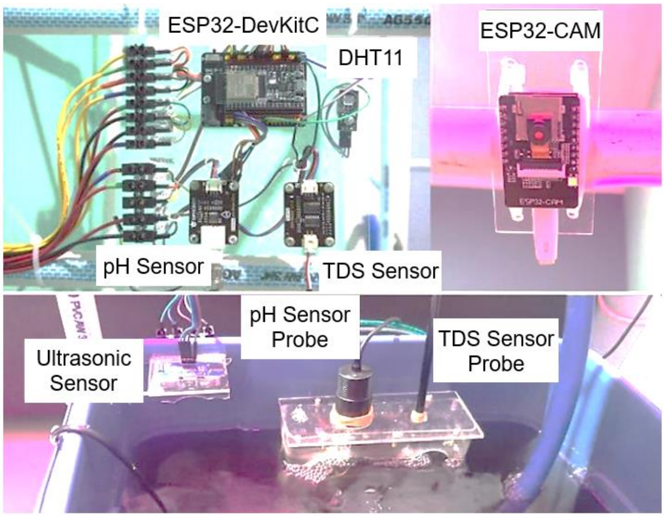

Figure 4. Control panel and sensor module of automatic hydroponic system.

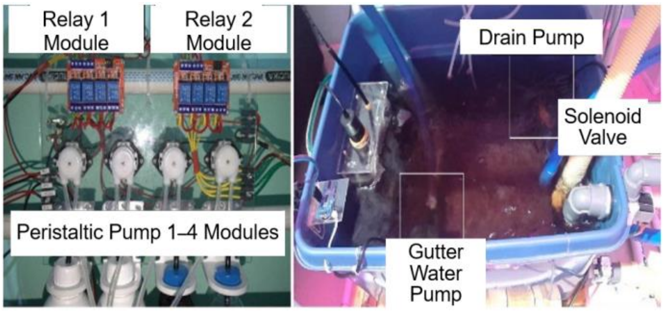

Figure 5. Automatic hydroponic system actuator module.

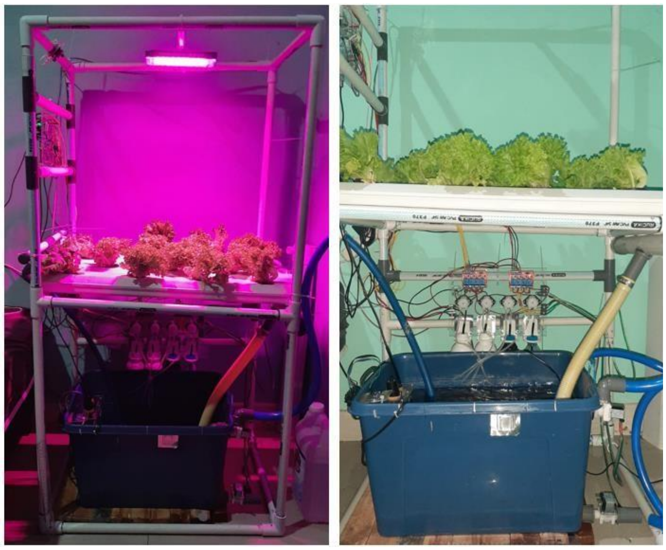

Figure 6. Automatic hydroponic system integrated module.

F. ANDROID APP TESTING AND LIVE STREAMING VIDEO

Testing Android application on automated hydroponic systems aimed to ensure that the application worked properly. The application was designed to provide a display of sensor data such as TDS values, pH, temperature, humidity, and additional information, including the number of days the system had been running and the time of the last update. In addition, the application also allowed users to view live video streams from the hydroponic system. Testing of the Android application and live video streaming was conducted at the study site, using a Wi-Fi network at 100 Mbps every day at 7 a.m. The Android device used was placed at about 5 m from the

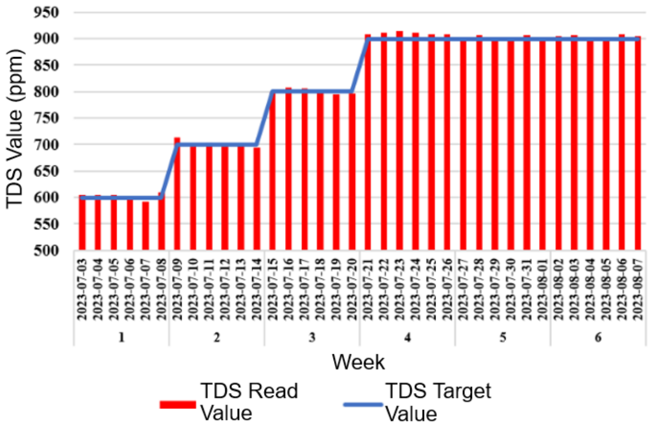

Figure 7. Graph of TDS value test results.

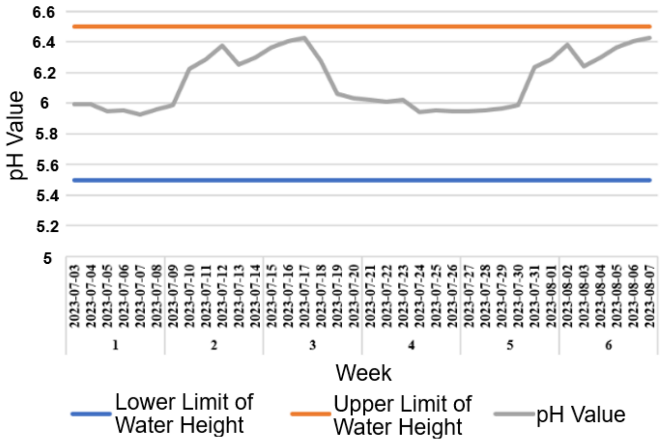

Figure 8. Graph of pH value test results.

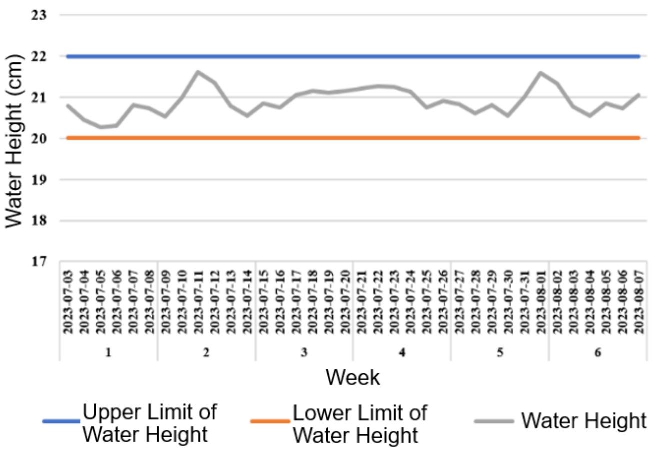

Figure 9. Graph of water height test results.

hydroponic system to test the quality of video transmission under practical conditions. The test results are shown in Figure 10.

The test results showed that the Android application could display sensor data consistently and accurately and was able to transmit live video streams well over the Internet network. The information displayed on the Android application was the number of days or DAP, the time of the last update, TDS value, pH value, air temperature value, air humidity value, water height, and live video stream.

The harvest button was available on the day 30 of DAP, allowing the user to choose to activate the harvest command, which would automatically drive the drain pump to empty the nutrient solution reservoir if needed.

TABLE II
MONITORING SYSTEM TEST RESULTS

GMT+7 (Western Indonesia Time)	Published Telemetry	Received Telemetry	Average of Delay (ms)	Data Loss (%)
12 a.m.– 1 a.m.	1,800	1,800	133.58	0
1 a.m.–2 a.m.	1,800	1,800	127.34	0
2 a.m.–3 a.m.	1,800	1,800	131.94	0
3 a.m.–4 a.m.	1,800	1,800	134.92	0
4 a.m.–5 a.m.	1,800	1,800	129.44	0
5 a.m.–6 a.m.	1,800	1,800	117.37	0
6 a.m.–7 a.m.	1,800	1,800	118.11	0
7 a.m.–8 a.m.	1,800	1,800	121.95	0
8 a.m.–9 a.m.	1,800	1,800	121.50	0
9 a.m.–10 a.m.	1,800	1,800	125.40	0
10 a.m.–11 a.m.	1,800	1,800	122.68	0
11 a.m.–12 p.m.	1,800	1,800	122.14	0
12 p.m. –1 p.m.	1,800	1,800	118.10	0
1 p.m.–2 p.m.	1,800	1,800	132.95	0
2 p.m.–3 p.m.	1,800	1,800	128.48	0
3 p.m.–4 p.m.	1,800	1,800	130.63	0
4 p.m.–5 p.m.	1,800	1,800	135.84	0
5 p.m.–6 p.m.	1,800	1,800	130.45	0
6 p.m.–7 p.m.	1,800	1,800	116.27	0
7 p.m.–8 p.m.	1,800	1,800	117.94	0
8 p.m.–9 p.m.	1,800	1,800	122.35	0
9 p.m.–10 p.m.	1,800	1,800	120.30	0
10 p.m.–11 p.m.	1,800	1,800	124.88	0
11 p.m.–12 a.m.	1,800	1,800	123.40	0
Average delay time			125.33	0

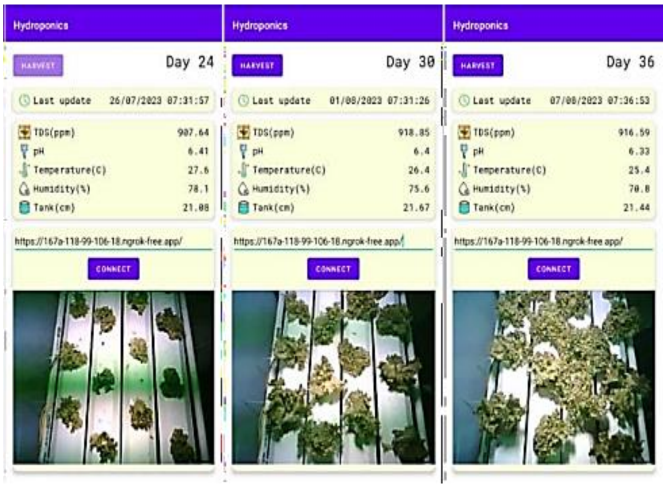

Figure 10. Live streaming video results with ESP32-CAM.

IV. CONCLUSION

Based on the test results, this automated hydroponic system has successfully carried out a real-time monitoring function with a fairly low delay, namely an average end-to-end latency of 125.33 ms with data loss of 0%. This study has also succeeded in carrying out the control function, maintaining the TDS value according to the target for 5 weeks of testing with TDS values from the first week to the fifth week, namely 600, 700, 800, 900, and 900 ppm, respectively. In addition, the system managed to maintain the consistency of the pH value in the range of 5.5–6.5, with an average pH value of 6.19, and maintain the water level according to the target of 20–22 cm, and with an average reading of 20.89 cm. This system was also able to carry out the function of draining the reservoir during harvest. The test results of the Android application and live streaming video showed that the Android application successfully displayed the sensor reading values and the ESP32-CAM could display the video in real-time. By successfully controlling the parameters of the hydroponic system for 36 days, this system could be implemented automatically from the planting period to the harvest.

CONFLICTS OF INTEREST

The authors declare that the article entitled "Prototype of Internet of Things-Based Automatic Hydroponic System" is written free from conflicts of interest.

AUTHORS' CONTRIBUTIONS

Conceptualization, Isyara Khairani; methodology, Isyara Khairani; software, Isyara Khairani; validation, Isyara Khairani and Kiki Prawiroredjo ; formal analysis, Isyara Khairani; investigation, Isyara Khairani and Kiki Prawiroredjo; resources, Isyara Khairani and Kiki Prawiroredjo; data curation, Isyara Khairani; writing—preparation of the original draft, Isyara Khairani ; writing—review and editing, Isyara Khairani and Kiki Prawiroredjo; visualization, Isyara Khairani and Kiki Prawiroredjo; supervision, Kiki Prawiroredjo; project administration, Isyara Khairani and Kiki Prawiroredjo; funding acquisition, Isyara Khairani and Kiki Prawiroredjo.

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