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IoT-Based Hydroponic Plant Monitoring and Control System to Maintain Plant Fertility

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***Abstract*—Abstract Hydroponics is a method of cultivating plants by utilizing a small amount of land without using soil media. Hydroponic cultivation is still done conventionally in monitoring and controlling nutrients and pH of the air. Hydroponics is already with Internet of Things (IoT) technology in the cultivation process. The research aims to use IoT technology by developing control devices and monitoring hydroponic plants remotely, to make it easier for cultivators to control and monitor plant color, temperature, nutrients and the pH value of hydroponic plant water. Control and monitoring can be done through a smartphone application. The data from testing the condition of hydroponic plants obtained an average error of 1.8% for air temperature, 4.8% for water pH, 6.6% for plant color and 7% for water nutrients. Hydroponic plants with the TCS3200 sensor get a monitoring opportunity of 53.3%. Testing of tool control related to nutritional improvement has been carried out using the fuzzy Mamdani method with an increase in the probability of 88.75% for adding nutritional value and 0% for decreasing nutritional value. Tool control for improving the pH value of hydroponic plant water has been successfully carried out.**

Keywords—Component*: *Hydroponics; Fuzzy Mamdani; Water PH; Water Nutrition; IoT

I. Introduction

Population growth is always increasing. Agricultural land has been converted into land for housing development. This situation has an impact on the process of increasing agricultural production [1].

The progress of the times has created a method of farming that can produce quality agricultural products without having to have a large area of land. The farming activity is cultivation using the hydroponic method [2]. Hydroponics is agricultural cultivation land that is used to grow crops without using soil media but using water media in its application [3].

Hydroponic cultivation can be carried out in the yard of the house as a producer of fresh vegetable ingredients and can be produced as an ingredient of selling value [4]. Cultivation using the hydroponic method can produce quality plants that are free of pesticides and do not depend on the harvest season [5]. Types of vegetable crops that can be cultivated such as mustard pak-coy, lettuce, and spinach. Cultivation with the hydroponic method is different from the usual farming method, so it is necessary to understand in advance to be able to use it.

The hydroponic method requires skills in the cultivation process, because it is necessary to monitor nutrition and pH on hydroponic devices [5]. Beginner cultivators still use conventional methods to monitor and control hydroponic devices [6]. The conventional monitoring process creates problems for cultivators who do not have free time to be able to monitor hydroponic plants.

Technological developments are growing rapidly until the term Internet of Things (IoT) appears [7]. IoT technology allows activities carried out by humans to be controlled through the internet network [8]. The hydroponic method can be juxtaposed with IoT technology for cultivators to monitor and control hydroponic systems anywhere [9]. The application of IoT in hydroponics can be added with a method to support tool performance, one of which is the fuzzy logic method [10].

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Research conducted in Ref [11] mentioned that there is research that proves that plants that do not get the value of nutrient solution concentration and pH levels are good or appropriate will result in a decrease in plant quality in terms of plant height, length and height plant leaf width, as well as plant weight and productivity.

Based on the existing problems, a system will be developed that utilizes Internet of Things (IoT) technology that can help cultivators monitor hydroponic plants via smartphones. The system will have several features such as a hydroponic plant monitoring feature based on temperature, color, pH levels and the concentration value of the hydroponic plant nutrient solution. The control feature for improving pH and nutrient levels is carried out with the help of a mini water pump that is regulated by a relay. The control feature for users can be done through a mobile application to determine the minimum and maximum limits for pH levels and nutrient solution concentrations (ppm). The function of improving the concentration of hydroponic water nutrient solutions is carried out using the Mamdani fuzzy logic method as a support in the mini water pump control process.

II. Research Methodology

A. *Hardware Design*

1) *Schematic Diagram*

The material used in this research is in the form of hardware components that have been described in the schematic diagram. The following is a schematic diagram for this research.

Schematic diagram is an electronic circuit that describes a circuit using symbols that are connected by lines that describe the relationship of the cable components to the sensors used in the circuit [12]. it can be said that a schematic diagram is a diagram that represents every component contained in a system.

2) *Flowchart Diagram*

A flowchart can be defined as a chart that shows the overall workflow of the system, which explains the steps of the procedures in the system and shows what the system does [13]. In short, a flow chart is a diagram that describes how the system works by dividing it into each process that occurs in the system itself. The following is a flowchart of how the system works from this research.

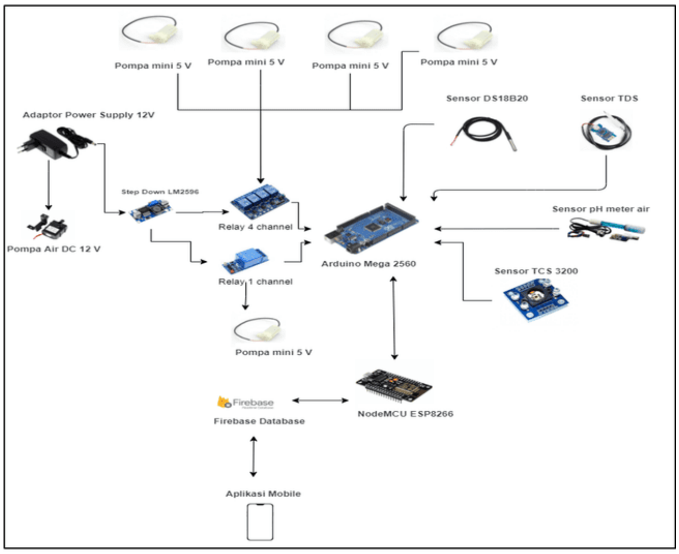

Figure 1. Schematic Diagram

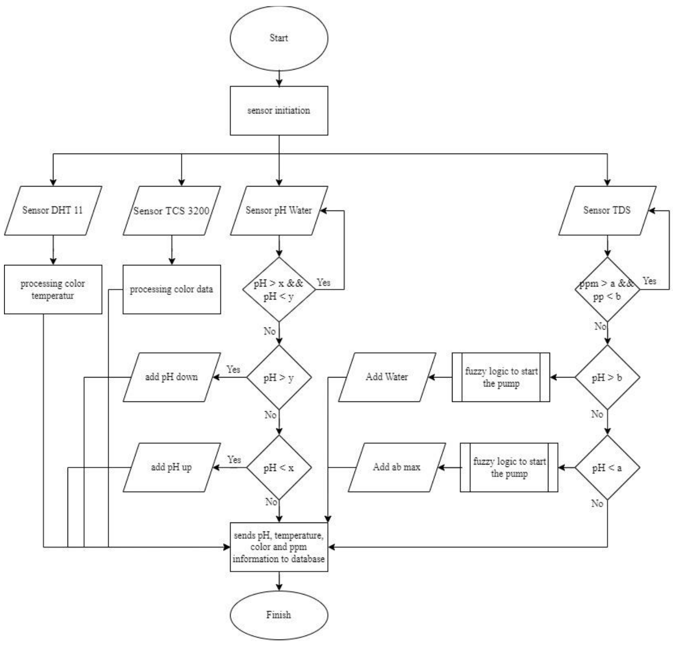

Figure 2. Flowchart Diagram

B. *Software Design*

1) *Software Planning*

Software design contains about display interface to be developed for mobile applications. The apps are for Indonesian users, so that the apps is in Indonesian.

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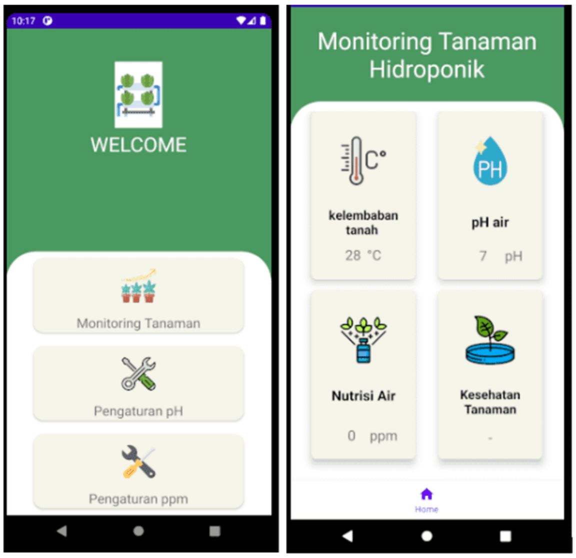
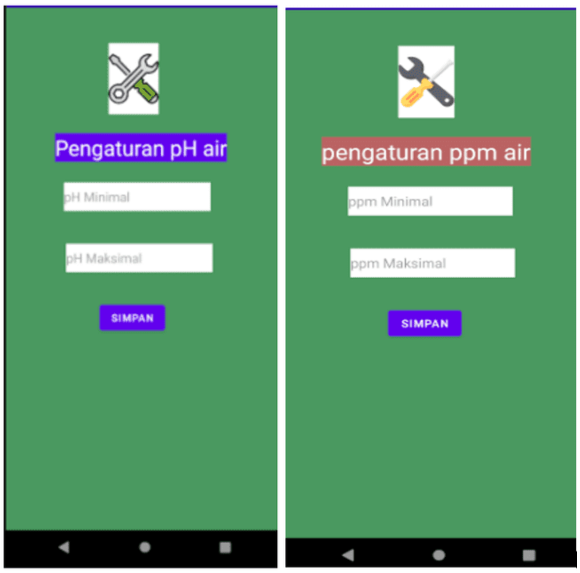
Figure 3 (a) shows the main page interface design which contains a monitoring menu, a pH setting menu and a ppm setting menu.



A B

Figure 3. (a). Main Page Display, (b). Monitoring Page Display

Figure 3 (b) shows the design of a monitoring page interface that functions to monitor the condition of sensors related to hydroponic plants such as sensors for plant color, temperature, nutrition, and water pH.



(A) (B)

Figure 4. (a) PH Settings Page Display, (b) PPM Settings Page Display

Figure 4 (a) shows the design of the interface for the pH setting page that allows users to input values related to the minimum and maximum limits for an automation tool for improving water pH quality. Figure 4 (b) shows the design of the ppm (nutrition) setting page interface that allows users to input values related to setting the minimum and maximum limits for automation tools for improving water quality ppm.

C. Methods

1) Fuzzy Logic

Fuzzy logic is a method that can map an input space into an output space. Fuzzy logic has real values in the range 0 to 1. Rule-based decision-making process that aims to solve the problem of uncertainty, where the system is designed to control one output from several irrelevant input devices [14]. In the theory of fuzzy systems in general there are four stages, namely the fuzzification stage, the rule composition formation stage, the inference stage and the defuzzification stage.

III. Results and Discussion

A. Design Results and Tool Description

The results of the monitoring and control system design for hydroponic plants have gone through several stages, namely the manufacture and assembly of boxes with the laying of hardware that has been done and also the manufacture of mobile application software. The results of the hardware design can be seen in Figure 5.

Figure 5. Hardware Implementation

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B. Hardware Test Results

1) Test Results of Water Temperature and Nutrition

Testing the value of temperature and water nutrients is carried out by comparing the values obtained by the nutrition sensor in ppm (parts per million) and water temperature in units (°C) with a nutrient checker and standard water temperature in the main water tank for hydroponic plants.

The test result data is processed to find out the percentage of errors obtained. The error percentage has the following equation :

$$\% \text{ error} = \left| \frac{\text{original value - measure value}}{\text{original value}} \right| \text{ X } 100\%$$

Table 1. Nutrition Test Results

No	Time	Tds Water	Sensors Tds Water	Percentage Error tds (%)
1	14:05:00	1120	1211	8.10%
2	14:06:00	1100	1186	7.80%
3	14:07:00	1085	1193	9.90%
4	14:08:00	1114	1180	5.90%
5	14:09:00	1102	1174	6.50%
6	14:10:00	1123	1198	6.60%
8	14:12:00	1095	1181	7.80%
9	14:13:00	1104	1194	8.10%
10	14:14:00	1090	1179	8.10%
Average				**7.64%**

Table 2. Water Temperature Result

No	Time	Water temperature	Sensors Water temperature	Percentage Error temperature (%)
1	14:05:00	31	31,6	1.90%
2	14:06:00	30,9	31,6	2.20%
3	14:07:00	31	31,7	2.20%
4	14:08:00	31	31,5	2%
5	14:09:00	31,1	31,6	1.60%
6	14:10:00	31,1	31,5	1.20%
8	14:12:00	31,1	31,6	1.60%
9	14:13:00	31,1	31,7	1.90%
10	14:14:00	31	31,8	2.50%
Average				**1.86%**

The percentage of error obtained from testing the tds tool is 7.64% (Table 1) and the water temperature tool is 1.8% (Table 2).

2) Water PH Test Results

Water pH meter testing is done by comparing the values obtained by the water pH meter sensor with standard water pH tools.

Table 3. Water pH Test Result

No	Time	pH Water	Sensors pH Water	Percentage Error (%)
1	14:45:00	6.7	6.5	3%
2	14:46:00	6.7	6.9	3%
3	14:47:00	6.7	6.4	4.4%
4	14:48:00	6.8	6.5	4.4%
5	14:49:00	6.8	6.2	8.8%
6	14:50:00	6.7	6.7	0%
7	14:51:00	6.8	6.5	4.4%
8	14:52:00	7.0	6.5	7.1%
9	14:53:00	6.9	6.6	4.4%
10	14:54:00	6.9	6.7	2.9%
Average				**4%**

The results from Table 3 shows the percentage of error obtained from testing the pH of the water at 4,8%.

3) Water PH Test Results

The plant health test is carried out with the TCS3200 sensor where the sensor can change the color obtained into a converted frequency signal. The colors owned by the photodiode are composed of the basic colors RGB (Red, Green, Blue).

Table 4. Color Sensor Test

No	Object	Range	Frequency [R,G,B]	Result
1	Red	2 cm	[82,280,214]	Red
2	Red	6 cm	[265,711,546]	Red
3	Red	10 cm	[562,1020,844]	Red
4	Green	2 cm	[185,124,143]	Green
5	Green	6 cm	[672,477,562]	Green
6	Green	10 cm	[891,791,787]	Blue
7	Blue	2 cm	[234,187,88]	Blue
8	Blue	6 cm	[651,540,278]	Blue
9	Blue	10 cm	[1000,989,596]	Blue
Average				90%

The results from Table 4 show that the percentage of error obtained from testing the color sensor of the tcs3200 tool is 90%.

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4) Test Results of Automatic Mini Water Pump

Testing the mini automatic water pump to find out the addition and decrease in the nutritional value of water or the pH meter of the water in the main water tank. From Table 4 the amount of solution or liquid delivered by the mini water pump is quite stable because the increase in the amount of solution or liquid delivered every second has the same multiple for the value of the solution given to the main water tank.

Table 5. Solution Conduction Test Results Based on Time

No	Water Pump	Time (ml/s)	Total water
1	Pump a	1 s	10 ml
2	Pump a	3 s	30 ml
3	Pump b	1 s	10 ml
4	Pump b	3 s	30 ml
5	Pump pH down	1 s	10 ml
6	Pump pH down	3 s	30 ml
7	Pump pH up	1 s	10 ml
8	Pump pH up	3 s	30 ml
9	Pump neutral	1 s	10 ml
10	Pump neutral	3 s	30 ml

5) Nutrient Value Test Results of Automatic Mini Water Pump

In testing the nutritional value of hydroponics, an experiment was conducted to find out how much influence the automatic water pump control had in distributing the solution either to increase or decrease the nutritional value of hydroponic plant water. The solution used is ABmix as an increase in the nutritional value of water and fresh water as a decrease in the nutritional value of hydroponic plant water.

The results from Table 5 show that the increase in the nutritional value caused by the ABmix solution delivered by the mini pump showed quite good results because the average increase of 10 ml of ABmix solution in 1 second could increase the nutritional value of water by ± 67. Inversely proportional to with the results obtained during the process of decreasing nutritional value, which shows a very small reduction in nutritional value of ± 5.3 where the mini water pump has delivered total fresh water to the main water tank as much as ± 810 ml/ 27 seconds.

6) Test Results PH Value of Automatic Mini Water Pump

In testing the pH of water in hydroponics, an experiment was carried out to find out how much influence the automatic water pump control had in distributing the solution either to increase or decrease the pH value of hydroponic plant water. The solution used is "PH UP" as an increase in the pH value of the water and "PH DOWN" as a decrease in the pH value of hydroponic plant water.

Table 6. Results of Automatic Water Pump Testing on Plant Nutrient Control Values

No	Before Treatment Sensor TDS	Pump Time (delay/second)	Treatment Nutrition (ABmix/water)	After treatment Sensor TDS	Conclusion
1	155	1 : 240 s	ABmix a and b 10ml	214	59
2	214	1 : 240 s	ABmix a and b 10ml	283	69
3	283	1 : 240 s	ABmix a and b 10ml	345	62
4	345	1 : 240 s	ABmix a and b 10ml	410	65
5	410	1 : 240 s	ABmix a and b 10ml	487	77
6	1011	3 : 240 s	water 30 ml	1010	1
7	1010	3 : 240 s	water 30 ml	1010	0
8	1010	10 : 240 s	water 100 ml	1001	9
9	1001	5 : 240 s	water 50 ml	997	4
10	997	10 : 240 s	water 100 ml	990	7
Average decrease nutrition			Average increase nutrition		
Sensor TDS= ± 4,2 / 52 ml (water)			Sensor TDS= ± 67 / 10 ml (AB Mix)		

The results from Table 6 show the process of decreasing and increasing the pH value of the main water tank carried out by an automatic water pump. From Table 6, the value of decreasing and increasing the pH of the water showed stable results, both from the water pH sensor tool in reading the pH value, as well as from the water pH meter used as a comparison. The average calculation result for decreasing the pH value with the "PH Down" solution is ± 0.3 / 10 ml and the average calculation result for increasing the pH value with the "pH UP" solution is ± 0.5 / 10 ml.

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INTEK Jurnal Penelitian
Vol. 9, No. 1, pp. 33-41, April 2022

Table 7. Automatic Water Pump Test Results on PH Value of Plant Water

No	Before Treatment	Pump pH (delay/second)	Treatment (pH Up / pH Down)	After treatment	Conclusion
	Sensor PH			Sensor PH	
1	6.4	2 : 600 s	Ph up (20 ml)	7.5	1.1
2	7.5	1 : 600 s	pH up (10ml)	8.1	0.6
3	8.1	1 : 600 s	pH up (10ml)	8.5	0.4
4	8.5	1 : 600 s	pH up (10ml)	8.9	0.4
5	8.9	1 : 600 s	pH up (10ml)	9.2	0.3
6	9.2	2 : 600 s	pH down (20ml)	8.7	0.5
7	8.7	2 : 600 s	pH down (20ml)	8.2	0.5
8	8.2	2 : 600 s	pH down (20ml)	7.6	0.6
9	7.6	1 : 600 s	pH down (10ml)	7.4	0.2
10	7.4	1 : 600 s	pH down (10ml)	7.2	0.2
Average decrease pH			Average increase pH		
Sensor pH = ± 0,3 / 10 ml (pH Down)			Sensor pH = ± 0,5 / 10 ml(pH UP)		

7) Test Results of Water Nutrient Automation with Fuzzy Method

In testing to adjust the desired water nutritional value, the Mamdani fuzzy logic method is used. The fuzzy function here is to map the existing input values as parameters, where in this case the parameters used are the tds value and water temperature from the sensor that has been built. In addition to the 2 inputs that are used as parameters, of course there are also outputs that will be produced, namely, to determine how long the mini pump will function either to increase or decrease the value of the desired water nutrients.

Table 8. Testing the Fuzzy Method on Automatic Mini Water Pumps for Water Nutrition

No	Time	Min	Max	Temperature	Nutrition	Activity sensor	Fuzzy
1	23:38:37	750	1000	30.81	215	Pump Nutrition Up 3.5 s	Pump Up 3.5
2	23:40:52	750	1000	30.75	392	Pump Nutrition Up 3.5 s	Pump Up 3.5
3	23:43:07	750	1000	30.75	589	Pump Nutrition Up 3.18 s	Pump Up 3.48
4	23:45:13	750	1000	30.75	778	Pump Off	Pump Off

The results from Table 7 can be seen that the output of the tools and systems made with the fuzzy method process when compared to the MATLAB application shows the same results in the process of setting the pump on and the pump off.

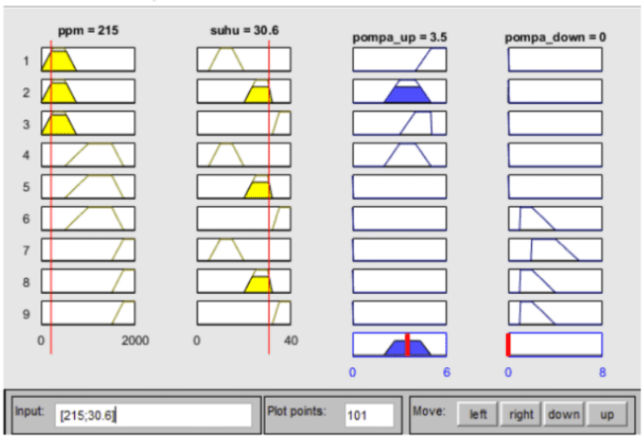

Figure 6. Fuzzy Calculations for PPM 215 and Temperature 30.6

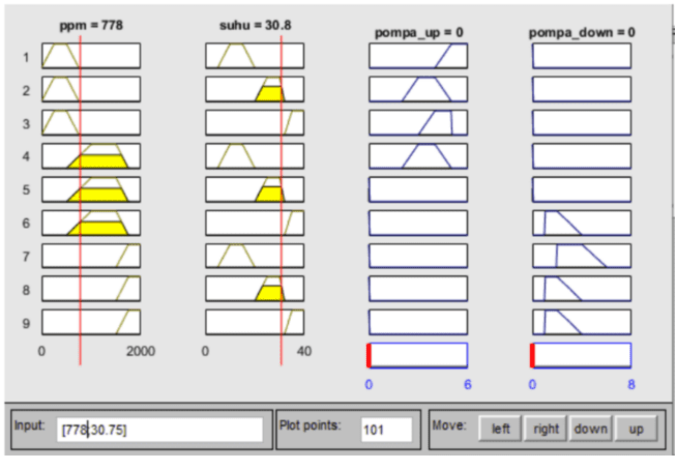

Figure 7. Fuzzy Calculation for PPM 778 and Temperature 30.8

Figure 6 and Figure 7 the results of checking the input and output values of the experiments that have been carried out as shown in Table 8.

8) Water PH Automation Test Results

The automation process to reduce the pH value of water does not use the fuzzy method, because the parameter that determines the pH meter value only has one variable. Therefore, automation is carried out with a simple method of turning on and off the water pH meter regulating pump.

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The firebase database has data on the lower limit of the pH value = 6, and the upper limit of = 7. So, the pH range of the water in the main tank must be between 6 to 7 pH. When the initial sensor reading was taken, the pH showed that it was at a value of 7.40 pH, so it was necessary to lower the pH where the pump was running automatically for 1 second to add a pH Down solution as a lowering of the pH value. This will continue until the position of the pH value is in the range of 6 to 7.

9) Plant Condition Monitoring Test Results

The process of monitoring plant conditions through the TCS3200 sensor is carried out by placing the sensor at a certain distance to get the RGB frequency value. RGB frequency becomes a parameter of the sensor to be able to determine the condition of the plant through the color of the plant.

Table 9. Results of Plant Condition Monitoring Tests

No	Object	Range	Sensor	Frequency [RGB]	observation	condition
1	Pak-coy	2 cm	Detection	[162,186,204]	Detection	Yes
2	Pak-coy	6 cm	Detection	[452,509,519]	Detection	Yes
3	Pak-coy	10 cm	Not Detection	[619,676,580]	Detection	No
4	Lettuce	2 cm	Detection	[140,155,182]	Detection	Yes
5	Lettuce	6 cm	Not Detection	[296,369,366]	Detection	No
6	Lettuce	10 cm	Not Detection	[511,651,590]	Detection	No
7	Spinach	2 cm	Detection	[198,207,232]	Detection	Yes
8	Spinach	6 cm	Detection	[442,462,471]	Detection	Yes
9	Spinach	10 cm	Not Detection	[673,698,643]	Detection	no
	Probability of success					55.55%
	Average Error					44.45%

The test results from monitoring the condition of hydroponic plants based on the frequency of RGB color indicate that from 9 experiments on 3 types of plants with different distances for each type of plant, the average success rate of 55.55% and an average error rate of 44.45%. It can be seen in Table 8 that the results of the appropriate sensor readings at a certain distance are precisely at the sensor readings at 2 and 6 cm. This can happen because the sensor will be more accurate if the object is close, so the closer the sensor is, the more accurate the detection will be [4].

C. Software Test Results

1) Hydroponic Plant Monitoring

Monitoring of hydroponic plants can be done through a mobile application that has been created. The application can display the value of temperature, nutrition, pH, and plant health in real time.

2) Setting Water Nutrient Values for Hydroponic Plants

The mobile application provides a feature for users to determine the desired water nutritional value of hydroponic plants. The nutritional value setting page on the mobile application has two entries where the user can fill in the input field according to the directions already in the application.

3) Setting the PH Value of Plant Water for Hydroponic Plants

The mobile application provides a feature for users to determine the desired water pH value from hydroponic plants. The pH value setting page on the mobile application has two entries where the user can fill in the input field according to the instructions that are already in the application.

D. Hydroponic Plant Growth Test Results

The results of testing the growth of hydroponic plants that have been cultivated, were observed on the development and growth of plants with parameters of height and number of leaves of hydroponic plants. Observations of plant height were measured uniformly from the surface of the rockwool planting medium and observations of the number of leaves were carried out on fully formed leaves. Initial observations were made when the plants were 7, 14, 21 and 28 DAP.

1) Plant Height Test Results

The test will be carried out at a predetermined time, namely in the first week to the fourth week after planting. Plant height testing will be carried out using a measuring tool with a centimeter (cm) scale.

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Table 10. Hydroponic Plant Height Test Results

Days After Planting (HST)	plant height		
	Pak-coy	Lettuce	Spinach
7	11.2	13.3	16.4
14	14.4	17.6	22.1
21	18.7	20.3	30.7
28	20.4	25.8	36.1

The results of the test on plant height as shown in Table 9 show that growth occurs every time the monitoring is carried out. The plant height growth of each plant on pak-coy, lettuce, and spinach was 20.4, 25.8, and 36.1 cm, respectively. This shows that there is development in the cultivated plants.

2) Plant Leaf Test Results

The test will be carried out at a predetermined time, namely in the first week to the fourth week after planting. Tests on plant leaves will be carried out using direct observations for leaf color and leaf number of hydroponic plants.

The results of tests on the number and color of plant leaves as shown in Table 10 show that growth and changes occur every time the monitoring is carried out. The growth of the number of leaves at the last monitoring was 28 DAP for pak-coy, lettuce, and spinach, respectively, were 13, 15, and 38 leaves. The general plant color for pak-coy, lettuce, and spinach is green. In the monitoring carried out, there are wilted leaves so they are not included in the calculation of the number of plant leaves.

Table 11. Result of Color Test and Number of Leaves of Hydroponic Plants

Days After Planting (HST)	plant leaves					
	Total			Color		
	Pak-coy	Lettuce	Spinach	Pak-coy	Lettuce	Spinach
7	7	7	12	Green	Green	Green
14	9	8	20	Green	Green	Green
21	11	13	27	Green (one withered)	Green (one withered)	Green (two withered)
28	13	15	35	Green	Green (one withered)	Green (two withered)

IV. Conclusion.

1. A device designed to maintain and maintain water fertility in hydroponic plants using sensors of color, temperature, pH and hydroponic water nutrients. NodeMCU serves to send data from reading sensors to the firebase database. The mobile application will retrieve data from the firebase database to display information about hydroponic plants from temperature, color, pH, and water nutrients to hydroponics to users.
2. The fuzzy Mamdani method is used to automate the improvement of hydroponic plant water nutrients by using water temperature parameters and water nutritional values. Sensor readings that produce values for temperature and water nutrients will be processed on the Arduino Mega board for further fuzzification, which will display an output that can set the mini water pump to turn on automatically as needed.
3. The mobile application can run as intended to display information about plant color, nutrition, temperature, and pH. The feature to determine the minimum and maximum limits for both the pH value and the nutritional value has been running successfully.
4. The feature of decreasing the nutritional value of water in hydroponic plants is still not optimal because when the experiment was carried out, the results that were expected to significantly reduce the nutritional value of water had not been achieved. This can happen, one of which is because the ABmix solution used is too concentrated so that when fresh water is added to dissolve the ABmix solution in the main bath, the ABmix solution is still difficult to dissolve, resulting in the expected decrease not being maximized.
5. The system for regulating the nutritional value of hydroponic plants using an automatic water pump controlled by the fuzzy mamdani method obtained an average error value for 4 trials for increasing the nutritional value of 11.25% and 0% for decreasing the nutritional value of hydroponic water.

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6. Monitoring features related to plant conditions are carried out with the TCS3200 sensor by testing the cultivated hydroponic plants, namely pak-coy, lettuce, and spinach with each parameter used being 2, 4, 6, 8, and 10 cm. The probability of success obtained from this test is 53.3%, and the distance that produces the appropriate value is in the range of 2 to 4 cm.

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