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Simultaneous Hydroponic Nutrient Control Automation System Based on Internet of Things

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***Abstract*— Hydroponic is one of the solutions of gardening methods using water as a nutrition medium. Usually, maintaining hydroponic plant quality and water nutrients are done manually and require human efforts, such as the degree of acidity or wetness (pH), TDS (Total Dissolved Solids), and nutrient temperature. With the Internet of Things technology, we can automate hydroponic control by measuring the nutrients' TDS, pH, and temperature values and controlling water nutrition by pump nutrition needs for hydroponic plants. This research uses the NFT (Nutrient Film Technique) for the hydroponic system and uses lettuce as the nutrition parameter. The lettuce parameters are pH, TDS, and Water Temperature equal to the sensor we used in the proposed IoT system. The condition has 27 classifications, and we use this classification as a reference in decision-making, using the K-Nearest Neighbor (KNN) algorithm to activate the actuator. We improve the simultaneous actuator from previous research with specified intervals and duration to achieve ideal nutritional conditions. The other improvement is that we collect more data and more testing times. The accuracy was 91.2%, with k = 3. From the evaluation results, the accuracy of KNN is quite high and has an advantage, which has better accuracy than the other algorithms and can activate actuator simultaneously. We conclude that the hydroponic nutrient automation system using the Internet of Things method is ready for real planting use with this improvement.**

***Keywords*— Hydroponic; Internet of Things; K-Nearest Neighbor.**

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I. Introduction

Hydroponic is a planting method without using soil. “Hydro” in Greek means water, and “Ponos” means work. So that in hydroponic, nutrients need to be given to plants, which is mineral water enriched by nutrients [1]. There are several methods in hydroponic, which are circulating methods such as Nutrient Film Technique (NFT) and Deep Flow Technique (DFT), a non-circulating method such as Root Dipping Technique, Floating Technique, dan Capillary Action Technique [2].

The NFT hydroponic system is a cultivated plants method where plant roots grow in a shallow and circulating layer of hydroponic nutrients to get enough water, nutrients, and oxygen. Plants grow with plant roots submerged in water containing a nutrient solution circulated continuously by a pump [3]. The root area in the nutrient solution can develop and grow in a shallow nutrient solution so that the top of the plant roots are on the surface between the nutrient solution and the net pot. This part of the roots in the air allows oxygen to be met and sufficient for average growth [4]. In hydroponic, enriched water relates to acidity or pH value because it could impact nutrient absorption and affect plants' quality of fertility and growth[5]. Besides the pH value, it is also necessary to monitor and control the Total Dissolved Solids (TDS) value and water temperature where in general, monitoring and controlling these values is done manually, such as adding a pH up or down to increase or decrease the pH value and adding A and B nutrients to increase the TDS value. TDS in nutrients indicates the level of nutrient concentration. This value is strongly influenced by what is dissolved in the nutrient content [6]. Units of parts per million (ppm) represent the TDS value[7]. In a hydroponic system, the ppm value of the TDS sensor needs to be maintained under the parameters of the plants. Increasing the ppm level is necessary to dissolve macro and micronutrients [8].

All nutrients cannot be useful to plants if they cannot be absorbed easily. The main factor in determining a plant's ability to absorb nutrients is the relative acidity or pH of the water or solution. pH stands for “power of Hydrogen”; is measured on a scale of 1-14 and represents the concentration of hydrogen ions in solution [9]. Generally, the pH value determines whether a water is acidic or basic. pH is acid when the value of pH is below 5.5, pH is normal when the value is between 5 and 7, and pH is base when the value is more than 6.5[10]. Some nutrients may not be available to plants if the pH of the solution is not between the values of 5.5 to 6.5 on a scale of 1-14[11]. By utilizing the Internet of Things, monitoring and controlling nutrition can be done remotely to increase the effectiveness of resources where people can measure, detect, and control the nutritional components in detail and real-time [12].

Internet of Things (IoT) is a concept where "things" or objects (can be heterogeneous devices or sensors), which are connected and can collect and share data [13]. On the other hand, IoT can also be defined as a small network of low-power, low-cost, ubiquitous electronic devices wherein sensing data and communicating information occurs without direct human intervention [14]. IoT architecture divides into various layers of supporting technologies, which describe the relationship between technologies and the relationship between scalability, modularity, and configuration in their development [15][16].

Previous research [17] created an Internet of Things (IoT)-based hydroponic system by designing a PCB microcontroller connected to light sensors, air temperature, humidity, water temperature, water level, and water level relays turn on the water pump and lights. The system could send data from the sensor via a WiFi network. Then it could be displayed on the smartphone screen via a web browser. That system still uses an internal WiFi network, not the Internet. While the relay controlling is still done manually by pressing on/off button on the system.

The use of IoT to monitor nutrients can be done in the various method of hydroponic, such as the automatic hydroponic system that uses sprinkles as irrigation method or known as drip method. This research uses Arduino Mega 2560, DHT11 sensor (temperature and humidity), RTC, pH sensor, EC meter, and light sensor as tools [18]. Nutrient control in other hydroponic systems was carried out by Adidrana et al. [19] in his research, applying IoT to monitor and control the nutritional value of the NFT hydroponic system

Based on the explanation above, this study could make a nutrient automation system that uses IoT to simultaneously turn on the nutrient control pump actuators based on kNN classification. These nutrient control pump actuators could supply pH up, pH down, nutrient A, nutrient B, and cooling solutions.

II. Materials and Method

This research is divided into two main stages: hardware manufacturing and software development. Hardware manufacturing is the manufacture of NFT hydroponic systems and nutrition control systems. Software developing comprises a starting from sending data to the ThingSpeak web service and applying the water nutrient condition classification using kNN to order the pump actuator.

A. System Architecture

1) Sensor Module: This module consists of sensors, the first sensor is pH sensor, the pH sensor can measure nutrition acid or base degree by measuring the potential difference that occurs on the pH meter probe after being immersed in the measured nutrition [20]. It takes a constant water temperature to measure the pH value because it depends on temperature very much [21]. The second sensor is the TDS sensor; the TDS sensor is an analog TDS sensor that can be used on Arduino. This sensor supports input voltages between 3.3-5V with the resulting analog voltage output ranging from 0 – 2.3V and has three pins, ATA, VCC, and GND, to communicate with the controller [7]. The third sensor is DS18B20 (water temperature). The DS18B20 temperature sensor is a temperature sensor that has a digital output [22]. DS18B20 has a reasonably high level of accuracy, which is 0.5°C in a temperature range of -10°C to +85°C[23]. These sensors connect to the Arduino Leonardo as a microcontroller to collect data and then use the ESP8266-01 to connect to the Internet wirelessly and send server data to the ThingSpeak data storage service.

2) Server Classification: It is a server for classifying data from the ThingSpeak service and giving commands to the actuator module according to the calculated classification using k-Nearest Neighbor.

3) Actuator Module: The Actuator Module consists of a NodeMCU as a microcontroller and integrated WiFi, so there is no need for an additional WiFi chipset[24]. The NodeMCU has a System on Chip (SoC) architecture that allows communication via GPIO to connect to the Internet and transmit data over the Internet, making it perfect for IoT connections [25]. The actuator module also consists of relays as actuators and pumps placed in each control solution reservoir. pH UP is used for increasing pH levels, pH down to decrease pH levels, Nutrient A and B to increase the TDS levels of nutrients, and a pump that could flow water to the filter to reduce TDS levels.

B. Ideal Nutritional Conditions

The data in this study were taken from the pH sensor, TDS sensor, and water temperature sensor to see changes in their values. Then the data could be given a threshold value according to the parameters of the lettuce plant needs in Table I [26][27].

TABLE I
LETTUCE IDEAL CONDITIONS

Lettuce Ideal Conditions	Min	Max
TDS	560	840
pH	5.5	6.5
Temp. Nutrition	24	26

C. Classification of Nutrient Conditions

The classification of nutrient conditions is calculated based on the number of sensors used. This study uses three sensors, and then the sensor data could be adjusted to the parameters in Table I, where each sensor could have three possibilities, 3^3 = 27 conditions, and the actuator action are listed in Table II.

TABLE II
CLASSIFICATION OF NUTRIENT CONDITIONS

Label	Condition	Actuator Action	Label	Condition	Actuator Action
1	Normal	Idle	**15**	high pH, high TDS, low water temperature	pH down pump ON, TDS down pump ON
2	Normal pH, normal TDS, high water temperature	water cooler ON	**16**	high pH, low TDS, normal water temperature	pH down pump ON, AB nutrition pump ON
3	Normal pH, normal TDS, low water temperature	water cooler OFF	**17**	high pH, low TDS, high water temperature	pH down pump ON, water cooler ON
4	Normal pH, high TDS, normal water temperature	TDS down pump ON	**18**	high pH, low TDS, low water temperature	pH down pump ON, AB nutrition pump ON
5	Normal pH, high TDS, high water temperature	TDS down pump ON, water cooler ON	**19**	Low pH, normal TDS, normal water temperature	pH up pump ON
6	Normal pH, high TDS, low water temperature	TDS down pump ON	**20**	low pH, normal TDS, high water temperature	pH up pump ON, water cooler ON
7	Normal pH, low TDS, normal water temperature	AB nutrition pump ON	**21**	low pH, normal TDS, low water temperature	pH up pump ON
8	Normal pH, low TDS, high water temperature	AB nutrition pump ON,water cooler ON	**22**	low pH, high TDS, normal water temperature	pH up pump ON, TDS down pump ON
9	Normal pH, low TDS, low water temperature	AB nutrition pump ON	**23**	low pH, high TDS, high water temperature	pH up pump ON, TDS down pump ON, water cooler ON
10	High pH, normal TDS, normal water temperature	pH down pump ON	**24**	low pH, high TDS, low water temperature	pH up pump ON, TDS down pump ON
11	high pH, normal TDS, high water temperature	pH down pump ON, water cooler ON	**25**	low pH, low TDS, normal water temperature	pH up pump ON, AB nutrition pump ON
12	high pH, normal TDS, low water temperature	pH down pump ON	**26**	low pH, low TDS, high water temperature	pH up pump ON, AB nutrition pump ON, water cooler ON
13	high pH, high TDS, normal water temperature	pH down pump ON, TDS down pump ON	**27**	low pH, low TDS, low water temperature	pH up pump ON, AB nutrition pump ON
14	high pH, high TDS, high water temperature	pH down pump ON, TDS down pump ON, water cooler ON			

These 27 conditions could be used as a reference table for the dataset. We improved sensor data collection to 5470 sensor data is about 20% from our previous research[28]. We use this data as the dataset for KNN classification (Table III). To get the optimal value of k for the K-Nearest Neighbor, the dataset was trained by testing the k = 1 to k = n. In Figure 1, the highest accuracy result is at k = 3 and decreases until k = 9. From this test, the research discussion could use the value of k = 3.

TABLE III
LABELED DATASET EXAMPLE

pH	ppm	Water temp	label
5.80	722	27	2
6.17	970.22	27.05	5
6.02	363	27	8
6.92	684	27.14	11
7.88	935.23	27.05	14

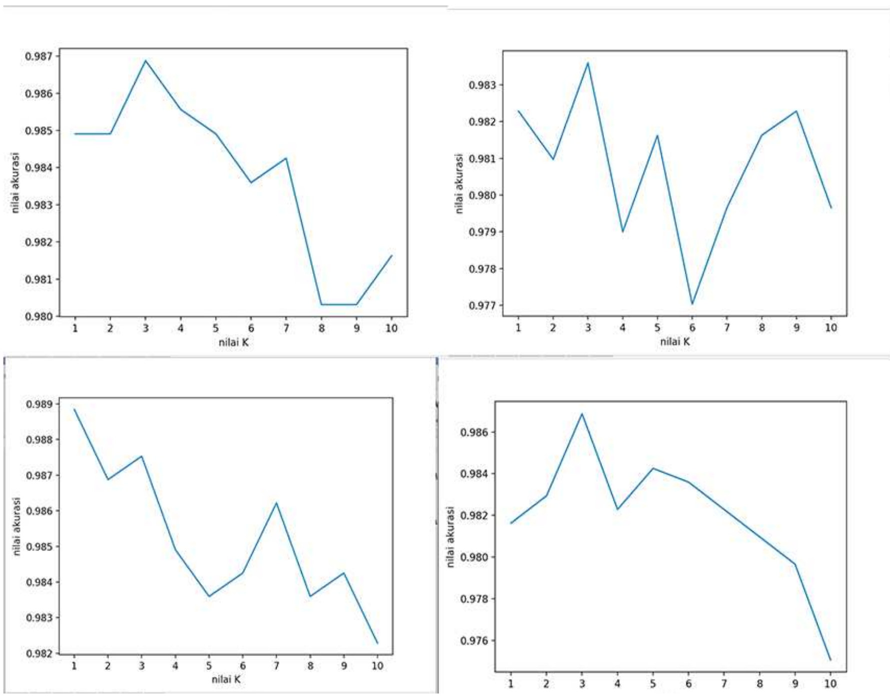

Fig. 1 K Value Testing Result

III. Results and Discussion

A. Sensor and Actuator Module Creation

The sensor module consists of Arduino Leonardo acting as Microcontroller, Breadboard for connecting sensor, pH Sensor, TDS Sensor, DHT11 Sensor, DS1B820, Ultrasonic Sensor HC-SR04, ESP8266. Figure 2 is a schematic connection between Arduino, sensors, and ESP8266.

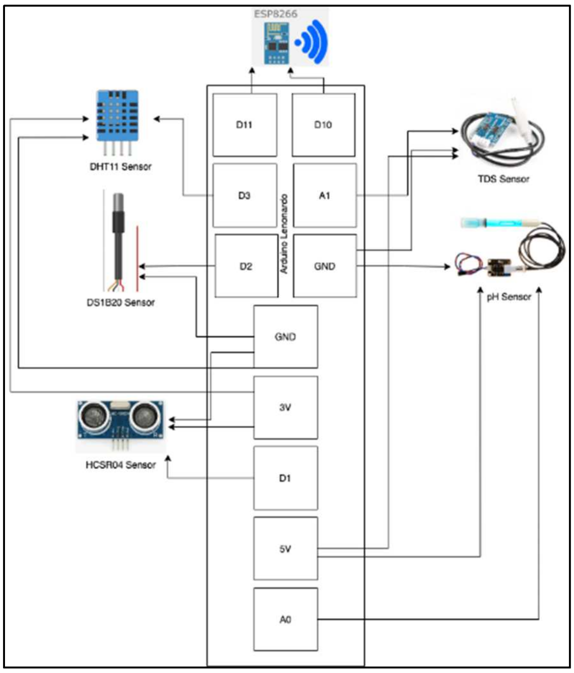

Fig. 2 Sensor Module

There are three sensors with digital pins, which are DHT11 Sensor, DS1B20 Sensor, and HSR04 Sensor connected to D1, D2, D3, GND and given a voltage of 3.3v. Another two analog sensors, TDS and pH sensors connect to A0, A1, and 5v voltage and ground. These sensor data could connect to the Internet via ESP8266 as a wireless communication medium and connected to pins D10 and D11, which are connected serially and are given a voltage of 5v and ground.

The actuator module uses NodeMCU as a microcontroller and uses a breadboard Power Supply, 5 pcs Submersible Pumps, 8 Channel Relays. Figure 3 shows that the Relay Pin is connected to 5 digital pins from nodeMCU to send commands to pump 1 to pump 5.

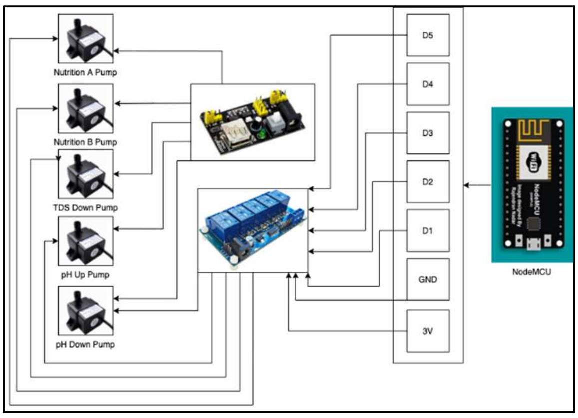

Fig. 3 Actuator Module

The relay uses 3.3v voltage and GND from nodeMCU while the pump use 5v and GND from the breadboard power supply. Sensor modules and actuator modules have been assembled and placed into boxes (Figure 4).

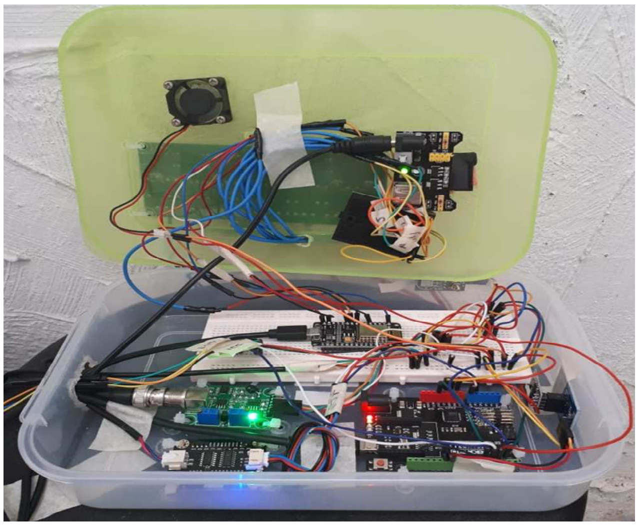

Fig. 4 Assembled sensor and actuator module

The sensor module and actuator module could be assembled in a single box. However, the sensors from the sensor module could be assembled in the water nutrition tank. The pump from actuator module could be assembled in each nutrition tank such as TDS down a tank, TDS up a tank, pH Up tank, pH down a tank.

Fig. 5 Assembled with NFT System

B. Classification Testing and Actuator Response

It is necessary to calculate the water discharge flowed by each pump before testing the classification and response of the actuator, to get the duration of the actuator. The obtained duration of the actuators is shown in Table IV.

TABLE IV
ACTUATOR DURATION

Actuator	Duration
pH Up Pump	1 second
pH Down Pump	1 second
Nutrition A Pump	4 seconds
Nutrition B Pump	4 seconds
TDS Down Pump	20 Minutes

Here is an example of the classification and response of the actuator in system testing.

1) Idle Conditions: There is no command for the actuator in this condition because the nutrient condition is read under normal conditions. See Figure 6.

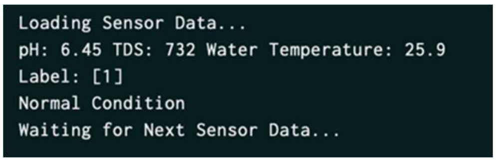

Fig. 6 Idle Condition

2) Actuator Conditions Respond to Nutrient Classification: This condition is classified as normal pH conditions, low TDS, and high temperature. So, the solution is to turn on the nutrient pump A, nutrient B, and water cooler, as seen in Figure 7.

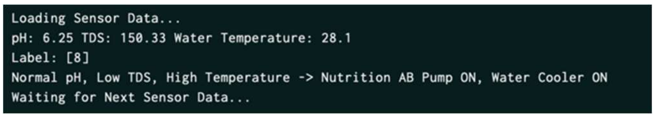

Fig. 7 Classification and Solutions for Nutrients

The actuator response is seen in Figure 8.

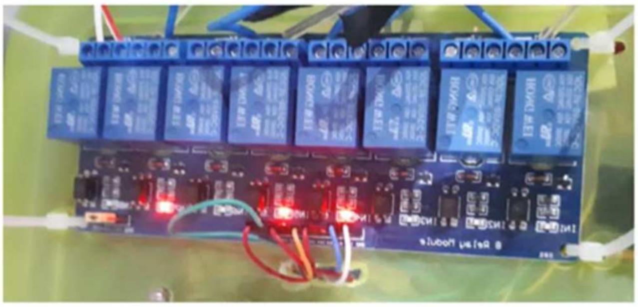

Fig. 8. The actuator response: nutrient A pump on, nutrient B pump on, and water cooler on.

3) Classification Accuracy: Equation 1 is used to calculate the classification accuracy of the K-Nearest Neighbor classification. The test was carried out 57 times, where there were five errors, those are the 12th, 18th, 22nd, 54th, and 56th tests, obtained an accuracy of 91.2%.

$$Accuracy = \frac{True\ Classification}{Classification\ Total} x\ 100\% \qquad (1)$$

TABLE V
CLASSIFICATION TEST

Test	pH	TDS	Water temp	Label	True Label
1	6.0	780	25	1	1
2	6.67	580	28.31	2	2
3	5.55	678	23	3	3
4	6.13	878	25.2	4	4
5	5.77	978	29.2	5	5
6	6.12	890	22.3	6	6
7	6.01	444	24.6	7	7
8	5.92	444	31.4	8	8
9	5.88	423	23.5	9	9
10	7.42	781	24.8	10	10
11	7.42	781	311	11	11
12	7.12	762	23.4	11	12
13	8.66	943	24.1	13	13
14	7.47	894	27.2	14	14
15	7.34	897	21.2	15	15
16	7.82	123	24.5	16	16
17	7.82	324	27.8	17	17
18	9.08	233	21.2	16	18
19	5	600	25.7	19	19
20	5	688	31	20	20
21	4.67	589	23.5	21	21
22	4.78	930	25	23	22
23	4.88	904	28	23	23
24	4	890	23.9	24	24
25	4	170	24.9	25	25
26	4.2	500	28.9	26	26
27	3	150	23	27	27
28	6.23	150.33	28.1	8	8
29	6.18	953.14	27.69	5	5
30	6.17	898.66	27.6	5	5
31	6.32	892.03	27.44	5	5
32	6.33	819.56	27.38	2	2
33	6.45	788.1	27.31	2	2
34	6.34	779.45	27.19	2	2
35	6.34	724.21	22.75	3	3
36	6.41	771.21	24.1	1	1
37	6.39	771.07	24.5	1	1
38	6.32	744.99	24.81	1	1
39	6.44	736.66	25.94	1	1
40	6.43	736	25.9	1	1
41	6.45	732	25.9	1	1
42	6.40	732	25.82	1	1
43	6.35	724.92	25.89	1	1
44	6.42	741.8	25.90	1	1
45	6.33	749.23	25.98	1	1
46	6.37	743.65	25.88	1	1
47	6.74	727.72	26.06	11	11
48	6.60	759.00	26.38	11	11
49	6.67	714.94	27.94	11	11
50	7.06	632.87	26.13	11	11
51	7.15	631.01	27.13	11	11
52	8.45	663.89	26.88	11	11
53	8.90	674.00	27.00	11	11
54	8.63	660.59	26.94	17	11
55	8.51	677.97	27.00	11	11
56	8.71	700.46	26.88	10	11
57	8.54	666.47	26.88	11	11
True Classification					**52**

In previous research [28], we compared the Internet of Things system using K-Nearest Neighbor with previous research which uses Deep Neural Network and Fuzzy Logic[29], [30]. The fuzzy logic method has the highest accuracy because it uses a closed-loop process. However, it has a weakness because the closed-loop process could execute the next task if the first task is completed. So, there is only one actuator possible to start at that time. Meanwhile, in K-Nearest Neighbor has higher accuracy than DNN. It can turn on and off multiple actuators simultaneously or step-by-step according to the actuator duration from Table IV.

IV. Conclusion

This research is an improvement from previous research. We conclude that the hydroponic nutrient automation system using the Internet of things method could work well based on the test results. Start with monitoring the sensor data and classify using K-Nearest Neighbor until the actuators can receive commands to simultaneously turn on the pump or water cooler at different intervals and specific durations. The accuracy is 91.2%, with k = 3. The K-Nearest Neighbor has an advantage compared to previous research using DNN and Fuzzy Logic, which have better accuracy than DNN and can activate actuator simultaneously.

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