Hydroponics Farm Monitoring Using Data Fusion and Fuzzy Logic Algorithm

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***Abstract*—This study was made to develop a hydroponics farm monitoring that focuses on the four critical factors in a hydroponics farming namely, the potential of hydrogen (pH), water level, water temperature and Electrical Conductivity (EC) using data fusion and fuzzy logic algorithm. The prototype can automatically control the four critical factors inside the nutrient tank. A cloud-based logging system was in place to store sensor data readings for future reference and visual alarm. Also, the SMS notification system comes handy if access to the cloud platform is not possible. Simulation using MATLAB and Simulink was used together with a prototype demonstration and evaluation form used by a team of evaluators to evaluate the prototype. The results revealed that the prototype model garnered a superior rating from the group of evaluators.**

***Index Terms*—data fusion, electrical conductivity, fussy logic, pH, prototype**

I. Introduction

The current world population as of October 2018 is 7.7 billion, according to the most recent United Nations estimates elaborated by worldometers.info. At present, the average population is estimated to increase by 83 million people per year. The latest world population estimation indicated to reach up to 10 billion people in the year 2055 and 11 billion by the year 2088 [1]. The Philippines population is expected to grow to 107.19 million at the end of 2018, according to the Commission on Population [2]. As conveyed by the PopCom executive director, the population will grow by 1.8 million at the end of 2018, increasing at a rate of 1.69 percent. The Philippines is an agricultural country with a land area of 30 million hectares, 47% of which is agricultural land [3]. In the Philippines, prime agricultural lands are located around the main urban and high population density areas [4].

The rapid increase in global populace positively affects the availability of food supply [5]. With this, sustainable development for food security with soilless is very much necessary, especially to those overpopulated countries. A recent study conducted by Science and Education for Agriculture and Development suggest that despite performing well in the year 1960's and 1970's, Philippine agriculture went down in the succeeding years. Sector growth slowed, and public investments for agriculture went down, and at the turn of the century, Philippine agriculture was no longer counted as a significant contributor to the country's aggregate economic growth [6]. This leaden performance in productivity growth noted as a significant restraint in the sector's development. The introduction of information technology in agriculture also hopes to entice younger Filipinos to get into agriculture by showing them how the old practice of farming makes use of innovative technologies. Technological developments today make the combination of science is prevalent, including in Computer Science and Agriculture to make both of science need each other [7].

At the Pennsylvania State University, Applied Research Laboratory, a general-purpose fuzzy-logic architecture has been developed that provides for control of sensing resources [8]. Fuzzy Logic has previously been used in studies an example is the study by that is entitled, "Mapping the Soil Texture in the Heihe River Basin Based on Fuzzy Logic and Data Fusion" [9]. A study conducted by entitled "Recognition of weeds with Image Processing and Their Use with Fuzzy Logic for Precision Farming" used fuzzy logic in their methods [10]. The main objective of the study is to develop a methodology for processing digital images taken from cornfields in order to determine a weed map. Another study is from [11]. The objective of their research was to develop a system for controlling the pH value of the nutrient solution used in potted flower cultivation.

This research aims to develop an algorithm that monitors the environment of a hydroponic farm through data fusion in a real-time and stable way, and then, automatically transmit the data in real-time.

Specifically, this research focuses on the following objectives:

1. To design a hydroponics farm system can be monitored by fuzzy logic
2. To design an algorithm to incorporate fuzzy logic in monitoring the hydroponics farm system.
3. To determine if fuzzy logic and data fusion are best suited for the monitoring of the overall health of a hydroponics farm.

II. Methods

The study uses prototyping model development method in which a prototype was built, tested, and then

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reworked as necessary until the acceptable prototype finally achieved. The study aims to develop an algorithm that monitors the environment of a hydroponic farm through data fusion as shown in Fig. 1 and fuzzy logic algorithm as shown in Fig. 2 in real-time. It shall determine the values of the four critical factors and evaluate if the values are within the ideal range. A Fuzzy Inference System can calculate the amount of nutrient needed if nutrient deficiencies are detected. A dosing pattern using fuzzy logic was developed and formulated to help the system provides the correct amount of nutrient so that it will not compromise all the other critical factors and avoid overdosing the nutrients. A cloud-based logging system was in place to store sensor data readings for future reference and visual alarm. SMS notification system comes handy if access to IoT platform is not possible. Using the Arduino MEGA 2560 designed for more advanced projects with 54 digital I/O pins, 16 analog inputs and a bigger space for algorithms, the incorporation of fuzzy logic, data fusion and hydroponics was made possible.

A. The Setup Used in the Study

The setup of the study will be composed of a clean water reservoir, water pumps, an air pump, nutrient pumps, a controlled water reservoir, sensors, wastewater reservoir, and a fuzzy controller.

Clean Water Reservoir. The clean water reservoir shall serve as storage for the clean, unused water. It is where the clean water in the controlled water reservoir comes.

Controlled Water Reservoir. The controlled water reservoir shall serve as the central system where the monitoring and controlling of the critical variables shall take place; it is to have four sensors, one for each of the variables to be monitored.

pH Meter Pro Analog Sensor. An Analog pH Meter with an industrial real-time online electrode, specially designed for Arduino controllers. This industrial pH electrode comes from a delicate glass membrane with low impedance. Used in a variety of pH dimensions with quick response and outstanding thermal stability.

Analog EC Sensor. Specially designed for Arduino controllers to measure water conductivity. The conductivity of water is an essential indicator in the magnitude of water quality. It reflects the level of electrolytes that are present in the water.

DS18B20 Temperature Sensor. A waterproof Arduino temperature sensor. It is handy when need to measure something far away or in wet conditions

Ultrasonic Sensor. A water level recognition sensor. The sensor measures the water level by emitting sound waves at a frequency too high for humans to hear to determine the water level. This sensor is similar to how radar measures the time it takes a radio wave to return after hitting an object.

Fuzzy Controller. The fuzzy controller shall be the device that administers fuzzy logic on the data collected from the sensors. Monitor nutrient levels and calculate nutrient dosing amount. Fuzzy Logic is an algorithm or control system which uses the “degree of truth” from the inputs and generates outputs depending from the rate of the inputs rather than the usual “true and false” or 1 and 0 [12]. It primarily gives foundations for approximate reasoning using imprecise and inaccurate decisions and allows using linguistic variables. Fuzzy Logic is an addition to the traditional Boolean logic, using linguistic variables that express logical values intermediate between FALSE and TRUE, describing with exceptional efficiency in the uncertainty principle in the real world. Fuzzy Systems are real-world applications that utilize Fuzzy Logic in its decisions making by linguistic variables and terms [13].

The drive of data fusion is to yield better-quality information or approximation of the system from a set of an independent data source. In this study, several sensors were utilized to ensure the perfect health of the hydroponics system. These sensors are the hardware components that can capture different types of signals at a rapid rate. The quality of data is one of the major concerns for many applications using sensors. The data quality may drop due to various reasons including the existence of missing and incorrect values also known as noisy values that are brought about by factors such as interference. Drop in data quality may seriously give impact to the performance of the systems. The use of data fusion algorithm could ensure the accuracy of data and could correctly identify the action [14]. Table I shows the processes that compose the data fusion levels, the levels are as follows: 1) Processing of Raw Data, 2) Determine characteristics and Patterns, 3) Making Decisions using Fuzzy Logic.

B. Simulation of Changes in Solution

Initially, the hydroponics system shall be set up on a state wherein all the critical factors are all within the standard ranges. Over time, pH, temperature and electrical conductivity and the water level of the system will be changed to simulate the fluctuations of a real hydroponics system. It is important to note that the researcher shall opt not to use plants and necessary nutrient media in the simulation run as these factors may change without the use of both plants and nutrient media. It is important to note that the researcher has opted to use household items such as vinegar [15] and table salt for the simulations as these are only simulations of real-world situations [16].

C. Dosing Pattern

The output membership function that will map the sensor readings on how much is the dose needed to normalize the water in the nutrient tank as shown in Fig. 3. Dose1 can dispense approximately 3.3ml (depending on the sensor reading) of nutrient solution to normalize the water inside the nutrient tank. While Dose2 can dispense 12.885 ml of nutrient solution to normalize the water inside the nutrient tank and Dose3 can dispense 22.5 ml of nutrient solution to normalize the water inside the nutrient tank.

D. Prototype Evaluation

To evaluate the system, six (6) members of the evaluator's team of which two (2) IT professionals, two

(2) hydroponic grower and, two (2) hydroponic experts. They were invited to evaluate the prototype model. The evaluation of the model focuses on the functionality, performance, robustness, workmanship and overall rating of the prototype. Furthermore, simulation using MATLAB and Simulink to evaluate the effectiveness of the nutrient dosing and hydroponics health monitoring of the prototype.

E. Results

A simulation using MATLAB and Simulink to evaluate the effectiveness of the nutrient dosing and hydroponics health monitoring of the prototype. The primary objective of this dosing pattern simulation is to monitor how the dosing Fuzzy Inference System (FIS) behaves and respond to the data generated by the sensor. The scope block in the simulation of Fig. 4, will create a graph that will display the behavior of the data produced by the FIS in response to the sensor readings. The results of the simulations showed that the Fuzzy Inference System responds appropriately to control the level of the nutrients inside the nutrient tank. Fig. 5, shows the results of the simulation of Electrical Conductivity dosing pattern. It exhibits that the dosing is inversely proportional to the sensor data. If the sensor reading is at a low level, then the dosing needs to be high. Likewise, if the sensor reading is at a high level, then the dosing needs to be low. Fig. 6 shows the results of the simulation of Potential of Hydrogen dosing pattern. It exhibits that the dosing is directly proportional to the amount of Potential of Hydrogen level inside the nutrient water tank. If the value of the pH inside the tank is at a low level, then the amount of dosing required would be low. Likewise, if the value of the pH inside the tank is at a high level, then the amount of dosing needed would be high. Results on both simulations show a very promising result regarding the dosing of the hydroponics farm using fuzzy logic and sensor data fusion.

Series of simulations and tests were conducted to expose the prototype to real-world situations. The objective of the simulations is to evaluate the effectiveness of the monitoring and maintaining the culture media in keeping the perfect health of the hydroponics nutrient tank. Fig. 7 simulates the monitoring of pH level. Fig. 8 simulates the monitoring of EC level. Fig. 9, simulates the monitoring of the water level. Fig. 10 simulates the monitoring of the water temperature. Results on the series of simulations showed a very promising result regarding the monitoring and maintaining the perfect health of the hydroponics farm using fuzzy logic and sensor data fusion.

Table II shows the findings on the evaluation given by the team of evaluators using the prototype demonstration and evaluation form. It measures the parameters desired in this study were a grade of ***A-*** obtained a rating of 90 to less than 93, a grade of ***A*** obtained a rating of 93 to less than 96, and ***A+*** obtained a rating of greater than 96. The result revealed that regarding functionality the prototype model met the deliverables required. It is superior regarding performance with a rating of 93.8. Regarding robustness, the prototype is operational with very minimal adjustments. It showed quality workmanship with a below superior rating. Overall, the prototype model garnered a superior rating of 94.2 as rated by the team of evaluators.

F. Formula and Equation

A dosing formula is formulated to be able to maintain and obtain a stable water condition regarding the electrical conductivity and potential hydrogen inside the nutrient tank:
DTS = dosing time in seconds
VS = volume of stabilization
FR = flow rate of dosing pump
WV = volume of water inside the nutrient tank
Pn = Membership function parameters

$$DTS = \frac{VS}{FR}\ (WV) \quad (1)$$

$$P3 = \frac{DTS}{6} + 2 \quad (2)$$

$$P2 = \frac{P_3+P_1}{2} \quad (3)$$

$$P4 = P_3 - 4 \quad (4)$$

$$P6 = P_3 + \frac{DTS}{3} \quad (5)$$

$$P5 = \frac{P_6+P_4}{2} \quad (6)$$

$$P7 = P_6 - 4 \quad (7)$$

$$P9 = P_6 + \frac{DTS}{2} - 2 \quad (8)$$

$$P8 = \frac{P7+P9}{2} \quad (9)$$

G. Figures and Table

Three levels of the data fusion algorithm to ensure the quality of input data to the fuzzy logic algorithm.

TABLE I. DATA FUSION LEVELS

LEVEL	GOAL	APPLICATION
1	Processing of Raw Data	Digital Filters and Adaptive Smoothing
2	Determine characteristics and Patterns	Pattern Recognition and Fuzzy Theory
3	Making Decisions	Expert System or Fuzzy AI

The summary of the evaluation ratings given by the evaluators in rating the prototype is shown in Table II.

TABLE II. SUMMARY EVALUATION RATING OF THE PROTOTYPE

Attribute	**Grade**	**Remarks**
Functionality	A (95.6)	Superior
Performance	A (93.8)	Superior
Robustness	A- (91.8)	Below Superior
Workmanship	A- (92.0)	Below Superior
Overall	A (94.2)	Superior

Fig. 1 shows an overview of the data fusion procedure used mainly in this study where data made available by the sensors and undergo a synergistic combination.

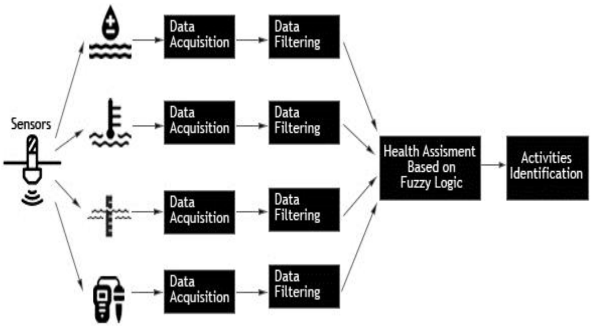

Figure 1. Overview of sensor data fusion process.

Fig. 2 shows the overall state of the environment as the fuzzy rules implemented into the combinations of data provided by the various sensors.

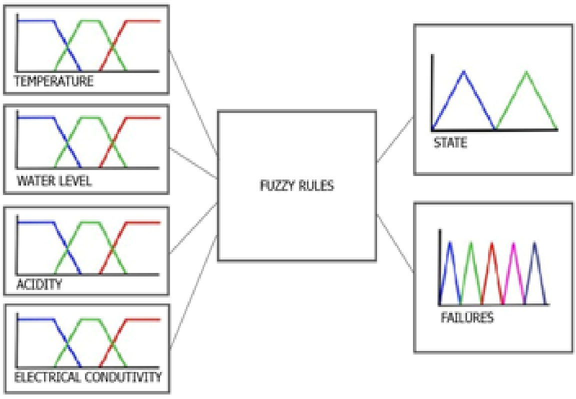

Figure 2. Fuzzy logic and data fusion algorithm structure

Fig. 3 shows the membership function of the dosing pattern. Basing from this fuzzy logic membership function the prototype can identify the amount of nutrient to be injected into the nutrient tank.

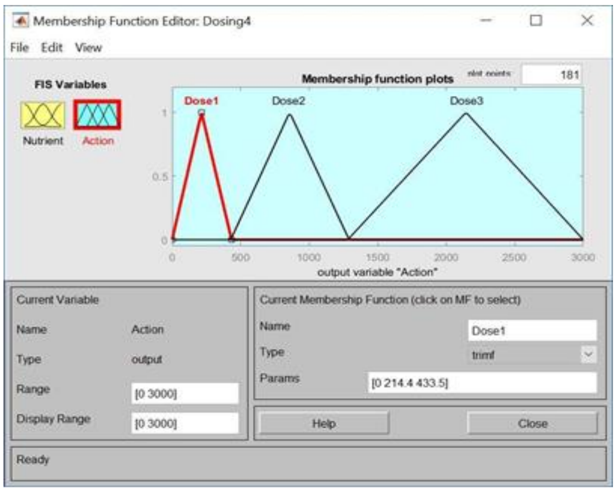

Figure 3. Nutrient dosing pattern

Fig. 4 shows the simulation of the automated dosing mechanism of the hydroponics system using a fuzzy logic algorithm. The simulation has three components 1) Random block which is a number generator that generates random numbers that act as a sensor, 2) Fuzzy Inference System used in the development of the prototype, and 3) Scope block that will display a graph of the results.

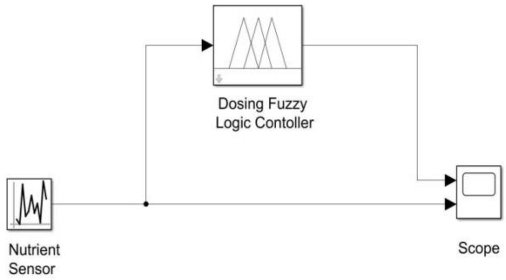

Figure 4. Dosing pattern simulation

Fig. 5 shows the results of the dosing pattern simulation. Divided into two layers; the top layer exhibits the approximate amount of nutrient to be injected into the nutrient tank. The bottom layer presents the sensor reading of the electrical conductivity level inside the nutrient tank

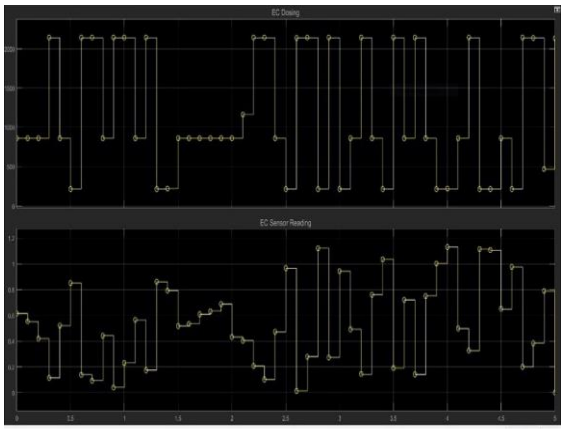

Figure 5. EC dosing pattern simulation result

Fig. 6 shows the results of the dosing pattern simulation. Divided into two layers; the top layer exhibits the approximate amount of nutrient to be injected into the nutrient tank. The bottom layer presents the sensor reading of the potential of hydrogen level inside the nutrient tank

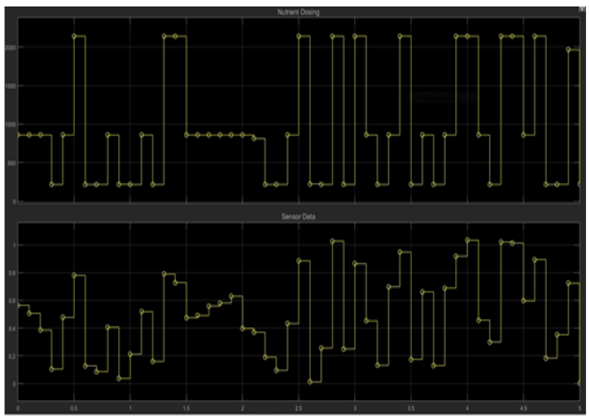

Figure 6. PH dosing pattern simulation result

Fig. 7, Simulation compose of a scope block to display the results. The Drain block represents the mechanism to release water from the nutrient tank while the Dose block represents the dosing mechanism for adding vinegar into the nutrient tank.

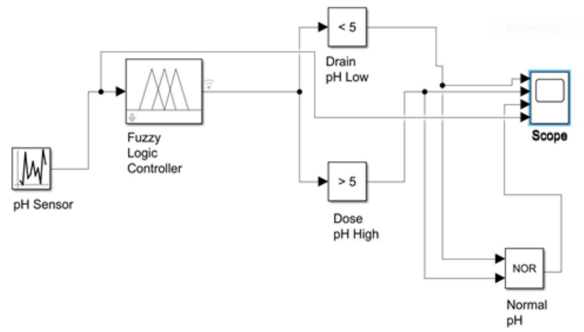

Figure 7. Potential of hydrogen level monitoring

Fig. 8, Simulation compose of a scope block to display the results. The Drain block represents the mechanism to release water from the nutrient tank while the Dose block represents the dosing mechanism for adding a salt-water solution into the nutrient tank.

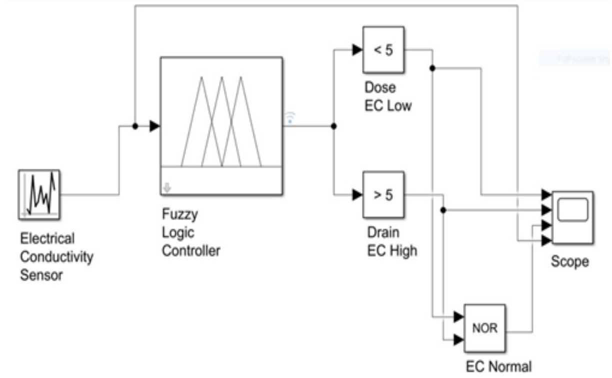

Figure 8. Electrical conductivity monitoring simulation

Fig. 9, Simulation compose of a scope block to display the results. The Drain block represents the mechanism to release water from the nutrient tank while the Add block represents the mechanism for adding water into the nutrient tank.

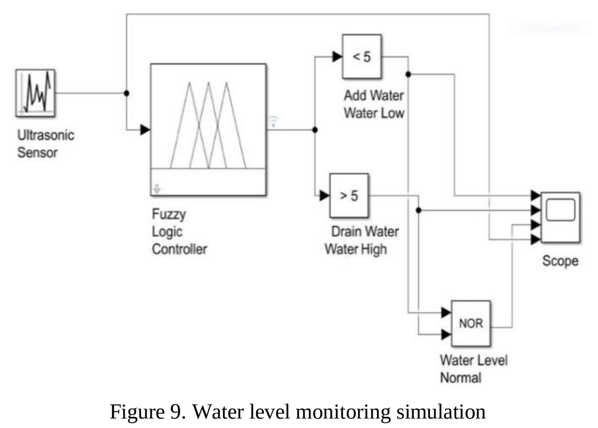

Figure 9. Water level monitoring simulation

Fig. 10, Simulation compose of a scope block to display the results. The Heater block represents the mechanism to heat the water from the nutrient tank while the Cooler block represents the mechanism for cooling down the water in the nutrient tank.

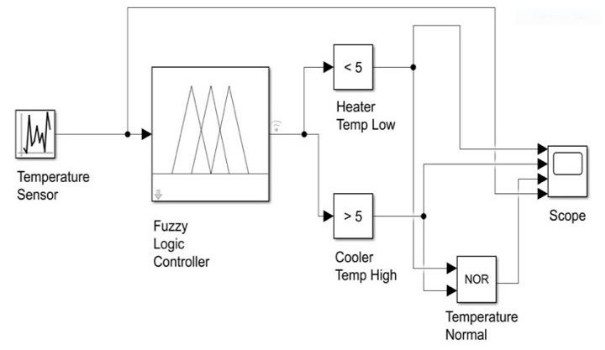

Figure 10. Temperature monitoring simulation

In the simulation of Fig. 11, a random block generator was used to generate numbers as sensor data. In the simulation, a scope block was used to display the results. The Drain block represents the mechanism to release water from the nutrient tank while the Add block represents the mechanism for adding water into the nutrient tank.

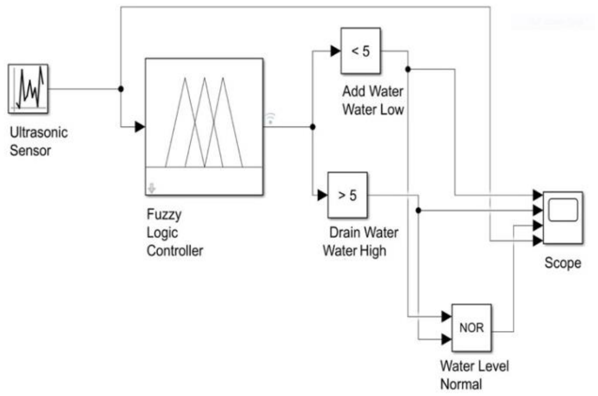

Figure 11. Water level monitoring simulation

III. Conclusions

The researcher has used data fusion and fuzzy logic algorithm to develop a hydroponics monitoring system. The prototype undergoes and survives situations that simulate the different stresses in a hydroponics farm. The researcher has chosen the four critical factors in a hydroponics farm, namely, Potential of Hydrogen (pH), water level, water temperature and electrical conductivity (EC). The prototype was made to adjust any detected abnormality in the system. Different simulations made to test these factors. The design of the system is to detect changes in the water temperature. The system automatically cools down or heats the water inside the nutrient tank; in the same manner, if the system detects any deviance from the Potential of Hydrogen, the system triggers the addition of vinegar (if pH is too high) or the drainage of the nutrient solution (if pH is too low).

Additionally, if the electrical conductivity of the water in the nutrient tank is read to be below or above normal, the prototype triggers the addition of water-salt solution (if the EC is too low) or the drainage of the nutrient water (if the EC is too high). All these tests are made not compromising any of the critical factors. It is also important to note that the researcher has opted to use household items such as vinegar and table salt for the simulations as these are only simulations of real-world situations. Also, the prototype also can compute the amount of nutrient dosing that is required to adjust the values of any abnormality in the nutrient tank.

Moreover, the use of MATLAB and Simulink for the designs of Fuzzy Inference Systems and simulations used in this study. Embedded Fuzzy Logic Library developed by Robotic Research Group also used in programming.

The prototype was also evaluated and has garnered the following scores from the evaluators; 95.6 for functionality, 93.8 for performance, 91.8 for robustness, 92.0 for workmanship and 94.2 for the overall performance. These numbers entail that regarding functionality, the prototype model has effectively met the deliverables required, it is superior regarding performance, it can function as expected with very minimal adjustments, and it showed quality workmanship. Overall, the prototype model garnered a superior rating.

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