A FUZZY LOGIC-BASED MOBILE APPLICATION FOR REAL-TIME MONITORING OF MODULAR INDOOR FARMING

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ABSTRACT

To help solve the problems found in traditional farming like the constant monitoring of the plant environment such as the temperature, humidity, and pH level, this study aims to develop a fuzzy logic-based mobile application to monitor and notify users about the plant environment parameters for an indoor aeroponics tower prototype such as temperature, humidity, and pH level. The fuzzy logic was used for overseeing these parameters to determine if they exceeded the set values. The study utilized a waterfall model for the development of the mobile application and a prototype model for the creation of the aeroponics prototype. Tests were conducted to ensure the accuracy of the sensors. These tests were: exposing the sensor to cold and hot areas and testing the pH sensor to different pH buffer solutions. The lettuce, after being placed in the aeroponics prototype for two weeks was shown to purposively selected farmers to determine if the aeroponics prototype is effective. The results showed the effectiveness of the aeroponics prototype as shown by the survey feedback of the farmers. Also, IT experts conducted tests based on the ISO25010 and concluded that the application met excellent standards, the evaluation shows that the system complies with the software quality standards by giving the system a grand mean of 3.49 which is highly acceptable according to the level of acceptability. The questionnaire given to the respondents used a Likert scale which is excellent for capturing the respondents' level of agreement. This study found that the aeroponics system has potential to improve traditional agriculture practices and that fuzzy logic algorithm is highly compatible to aeroponics farming.

Keywords

Aeroponics; fuzzy logic algorithm; indoor

1. INTRODUCTION

The Philippines is one of the countries that relies on agriculture. The current farming method in the country is traditional farming which has been practiced for ages, its main purpose is for the production of staple food supply [1]. This method is the cultivation of plants using just local knowledge and natural processes, with little to no technology used [2].

Unfortunately, some factors affect the traditional farming of the Philippines and one of which is climate change. The Philippines is one of the countries that is heavily affected by climate events, from experiencing strong and destructive typhoons to the progressive increase in temperature [3]. So, a country at risk of climate events would have a significant effect on outdoor agriculture where one harmful flood or drought could wipe out a season's worth of crops [4]. Another problem is the pests that are known to damage the crops and are a common problem in agricultural production. One way that farmers combat pests is through the use of pesticides which are effective in eradicating them, but it is also proven to be harmful to humans [5][6]. The third one is about the increasing growth of the population and decreasing farm size. The Department of Agriculture stressed that population growth control measures are unlikely and the land for farm use cannot be increased [7].

However, as technology advances, modern-day plant growing methods have been taking over the agricultural field. One would be indoor farming, specifically aeroponics. It is the process of growing plants by spraying them with mists or water as they hang in the air supported by cloth or foam. It allows plants to be grown with minimal water and does not need any soil [8]. However, it was found that some of the current existing aeroponics farms do not have monitoring so it is harder to control and find the changes in the plant environment [9].

As a solution, this project aimed to use an indoor farm to allow the plants to be in a controlled environment which would protect them from the effects of the weather and infestations making the farmer use little to no pesticide [10]. Aeroponics specifically is also known to have greater plant productivity which can help in lessening or preventing the food population gap from increasing [11]. As for the space, it only requires a small area for it to be able to produce yields. This type of indoor farming also needs more attention and time to monitor them to be able to achieve successful yields. Thus, this project was also designed to have sensors that would monitor the plant environment and send it to a mobile application for the user to see [12].

2. PROJECT CONTEXT

This study aimed to develop a single-tower aeroponic prototype which consists of IoT monitoring via mobile phone and Arduino's embedded fuzzy logic algorithm. Fuzzy logic produces outputs based on the "degree of truth" and in this study, it is used for decision-making within the aeroponic prototype by assessing the parameter values which are the pH level, temperature, and humidity of the plant environment. It determines the urgency level of the temperature and humidity for the notification system of the monitoring application. The researchers used lettuce (Lactuca Sativa) as the plant to be monitored and grown in a close prototype of the system. The proposed prototype can hold at most four plants (lettuce) which are placed in the holes on the side of a tube where their roots have enough space to grow inside. The tube is placed on top of a bucket that holds the nutrient solution and will pump it to the top spraying the roots of the plants. The design of the prototype is based on the design of vertical farms. The prototype was also designed to be modular. This way, it makes it easy to lay the plants and is much more efficient when packaging and transferring the prototype. The tower is equipped with a temperature and humidity sensor, a pH level sensor, and a proximity sensor that can detect specific parameters and is connected to an Arduino. These sensors can send real-time readings to a mobile application which is used to view the temperature, humidity, pH level, and water level. This study targets indoor farmers, offering a more efficient way to monitor plants with the use of automation. Furthermore, this also serves as a reference for future IoT-related research.

3. STATEMENT OF THE PROBLEM

This study specifically seeks to answer the following problems:

1. How to overcome the limitations encountered in existing aeroponic systems in the constant monitoring of the temperature, humidity, and pH?

2. How effective is the monitoring system for aeroponic farming in terms of notification system and parameters (Temperature, Humidity, pH level)?

3. How effective is the use of fuzzy logic algorithms in real-time decision-making for sending notifications based on the humidity, temperature, and pH level of the aeroponics prototype?

4. OBJECTIVES OF THE STUDY

The main objective of the study is to develop a mobile application monitoring system that uses the fuzzy logic algorithm for an indoor aeroponics farm. Specifically, it aims to:

1. Develop an automated prototype of aeroponic farming that can monitor the parameters needed for a plant to grow.

2. Develop a mobile application that can show the parameters of the plant environment such as the temperature, humidity, and pH level as well as alert the user about its status.

3. Discover the effectiveness of the use of a fuzzy logic algorithm in the growth conditions of the plants in the aeroponic tower prototype

5. SIGNIFICANCE OF THE STUDY

The findings of the study are deemed significant to the following:

Farmers: This system will be beneficial to farmers. The addition of automation and monitoring system in aeroponics allows farmers to use their time and soils efficiently without thinking about the plants that are planted using aeroponics.

Agriculturists: Agriculturists will benefit from this study because the advice they can provide to farmers will increase. Such as their plans, estimates, and specifications for agricultural projects like farms and agribusiness.

Future Researchers: This system will be beneficial to future researchers who are conducting studies on the same topic. This study can serve as a reference and basis for them to accomplish their study.

6. SCOPE AND LIMITATIONS

The goal of the researchers is to develop a mobile application that shows the pH level, temperature, humidity, and water level of the plant environment and notifies the user about the status of the parameters. The researchers will also develop an automated small-scale single aeroponic tower prototype using a PCB for the wirings of the sensors. Further research is required before using it on other types of plants or different environments. Additionally, the researchers used a variant of the C++ programming which the Arduino uses. The embedded fuzzy logic within Arduino was utilized to create a fuzzy logic algorithm for the decision-making process of the system. This study will monitor one aeroponic tower using a Bluetooth module to send data and notifications to the application. The tower will be designed to optimize lettuce growth conditions, with sensors collecting temperature, humidity, and pH data. The focus is solely on monitoring environmental conditions and ensuring optimal tower operation, providing valuable insights for farmers looking to maximize yield.

7. FUZZY LOGIC ALGORITHM IN AEROPONICS FARMING

Fuzzy logic systems are used to control processes and actions. It is a computational method that is based on the degree of truth where the nature of the output depends on certain conditions of the input. Unlike boolean which provides two groups which are 1 and 0, the fuzzy logic can provide more groups such as saying the temperature is warm, very warm, and very cold [13]. To describe the conditional statements in fuzzy logic, if-then rules are frequently used [14]. The study entitled "Design of a Fogponics Farming System based on the Internet of Things and Fuzzy Logic" showed that they were able to successfully implement a fogponics farming system that applied IoT to control their plant environment. They utilized a fuzzy logic-based algorithm that processed the gathered parameters which acted as an actuator to maintain the plant environment. Similarly, A proposed system titled IoT - Based Aeroponic System for Seasonal Plants using Fuzzy Logic that will be able to produce seasonal plants indoors. They used readings from different sensors and IoT to monitor and control the system through the internet. Their study used a fuzzy-logic algorithm to predict the intensity of functions that will be done in the system. The overall result of their system is that they were able to make an easier-to-use and more efficient aeroponics system that can sustain the seasonal plants' growth. This shows that the use of a fuzzy logic algorithm is viable in an aeroponics system [15, 16].

The embedded fuzzy logic library (efll) of Arduino used by the researchers was able to successfully control the quality of normal pH levels and nutritional needs in hydroponic cultivation [17]. The embedded fuzzy logic library (efll) of Arduino was also utilized in the study titled Automated Nutrient Solution Control System using Embedded Fuzzy Logic Controller, wherein the fuzzy logic was successfully used in controlling the pond water valves and water tank valves to regulate the pH and EC level of the nutrient mixture tank [18].

8. CONCEPTUAL FRAMEWORK

The input resources include problems found to come up with the study such as the effect of the weather, pest and pesticides, and population-food ratio to traditional farming as well as the lack of monitoring systems in existing aeroponic farms. It also includes the parameters needed for the plant environment (temperature, humidity, pH level, and water level) and the algorithm used which is the fuzzy logic algorithm. Lastly on the input are the research objectives. For the processes, intensive data gathering was done to gain more knowledge about the topics. The prototype and application were done along with the testing of the systems and sensors to see if they work well in addition to the integration of the fuzzy logic algorithm to the parameters. The final output was then the research title which will be fully evaluated. Evaluation will be done to ensure the system works smoothly and matches the objectives of the study.

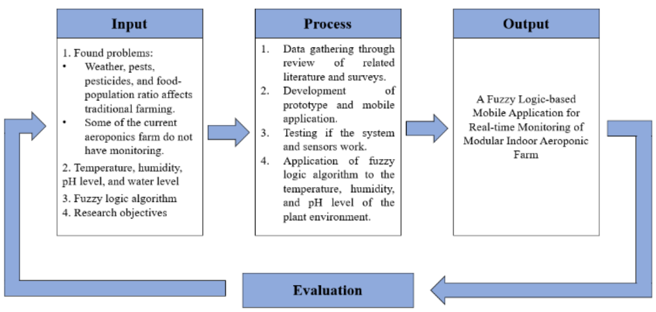

Figure 1 - Conceptual Framework.

9. METHODOLOGY

The techniques and methods used in the development of this study are presented in this chapter.

9. 1 Waterfall Model

In this study, the design of the system mobile application followed the flow of the waterfall model as the software engineer paradigm. The waterfall method depicts the software development process in a sequential linear flow indicating that any phase of the development process can start only when the previous phase is finished. The waterfall model consists of five stages: (1) analyzing the needs of system users, (2) designing the system and software, (3) coding and unit testing, (4) integrating and testing the system, and (5) operating and maintaining the system [19].

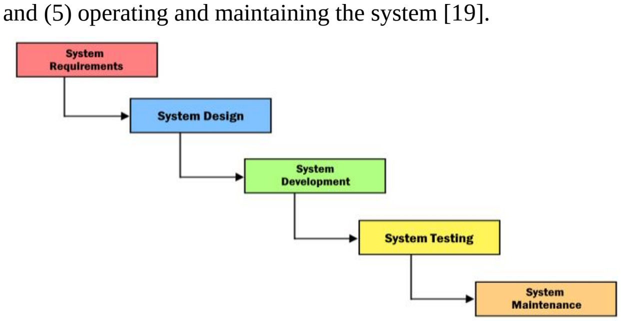

Figure 2 - The Waterfall Methodology.

System Requirements

The researchers attended numerous in-person meetings, as well as online sessions via Google Meet to plan the system's workflow, distribute workloads, and determine the requirements based on what the system and users will need. Research was conducted to review previous works and studies of other researchers to gather ideas, support the decision-making in determining the system's requirements, and define the scope and objectives of the system.

System Design

The next stage is the development of the User Interface. Mockup designs were created using Adobe XD to present to the panelists for further improvements and suggestions. The designers also created a user-friendly design by creating a well-designed layout pattern for farmers or users to easily navigate the app, find content, and complete tasks efficiently even for those who are not technologically inclined. Revisions suggested by the panelists were put into effect wherein the MIT App Inventor 2 was used to complete the system design.

System Development

In the development of the Android-based application, the programmers chose the MIT App Inventor 2 as the primary platform. The MIT App Inventor 2 uses a visual, block-based programming language for creating Android applications. The mobile application was programmed to communicate with Arduino through a wireless connection achieved by using Bluetooth. This allowed the programmers to implement features enabling real-time data updates by receiving the readings from the sensors. The fuzzy logic algorithm is executed on the Arduino microcontroller, while the mobile application is designed to receive and process the data which will be the basis for the notification updates. The programmers used Tinydb, a database component in the MIT App Inventor 2, it saves the data in the flash RAM of the phone, it allows the data to be saved even when the device is turned off and can be accessed when it is turned on, this app allowed the users to access the stored data in a form of logs, which contains the timestamp, temperature, humidity, ph level and water height providing users with the advantage of data retention, accessibility, and historical tracking. The MIT APP has two attributes, tinydb was used for the databases which include saving data and user exit data. Save data saves the current data received while the app is running, the use of exit data saves the data received when the user closes the app. Next are the parameters which are the data being received by the app from the Arduino. The logs class is where the data from the databases are being shown it displays the attributes timestamp, temperature, humidity, pH level, and water height it also has a display function. Lastly, the user class has the attribute view logs the user can access the logs using the app.

System Testing

The programmers conducted a functional testing which focuses on validating the core features of the application such as data collection, fuzzy logic calculations, and optimization algorithms. It also includes checking the application's ability to connect and communicate effectively with the modular indoor farm hardware, ensuring that all functionalities are correctly implemented as per the specification of the study. The programmers checked for potential vulnerabilities and pushed the system to its limits to identify any potential weaknesses or bottlenecks. Measure how the application recovers from failures or high-stress scenarios. After fixing any identified issues, the programmers performed regression testing to ensure that new changes do not introduce new problems. Additionally, usability testing was conducted to assess the user interface (UI) and user experience (UX) of the mobile app. Collecting feedback from potential users helped identify any usability issues and will provide insights for enhancing the overall user-friendliness of the application. The programmers also ensured the protection of sensitive data and the encryption of data transmission through security testing. Furthermore, compatibility testing was conducted to assess the application's functionality across different android devices. Lastly, integration testing was conducted by the programmers to verify its interaction with the modular indoor farm's hardware and sensors. In conclusion, rigorous system testing is imperative to validate the study's project functionality, performance, and usability, ensuring its effectiveness in real-time monitoring of modular indoor farms.

System Maintenance

An evaluation was conducted to compare the planned requirements to the achieved results which enables necessary corrective actions and improvements to be implemented. The contact information about the researchers was included in the application for users to send feedback or concerns. The researchers took into consideration all the feedback and recommendations from the farmers and used them for further improvement of the application.

9.2 PROTOTYPE MODEL

It enables users to be aware of what the system's phases look like such that the System may operate correctly based on what the users require. Through feedback, recommendations, and evaluations, the researchers will be able to continuously understand and improve the product during development [20].

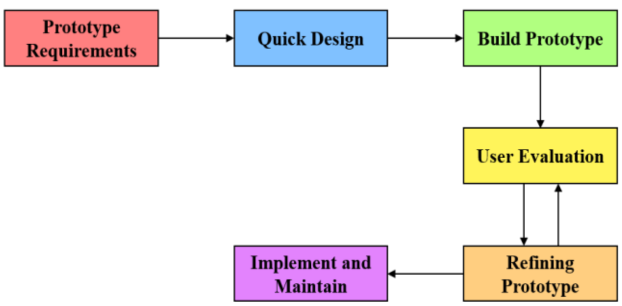

Figure 3 – The Prototype Model

Prototype Requirements

The researchers began by collecting data from various articles and literature during the requirements phase to understand what was needed for the aeroponic prototype. They analyzed the information and developed a plan to address the identified problems. Several iterations of quick designs were created to ensure that the problems would be solved. The prototype consists of 2 segmented towers, a container, various sensors, and a controller box.

Prototype Design

the researchers decided to design a small-scale, singular aeroponic tower to minimize space usage and a small container for the Arduino. The researchers used the draw.io website to create simple design.

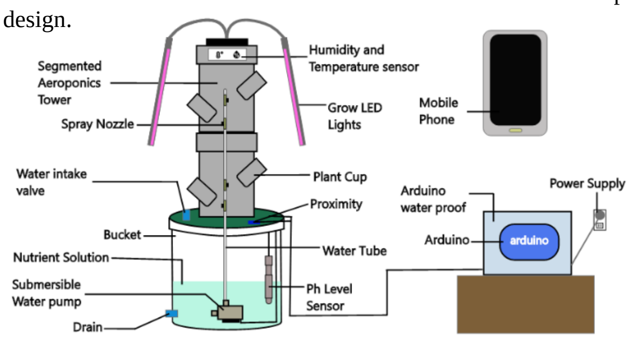

Figure 4 - Model of the Proposed System

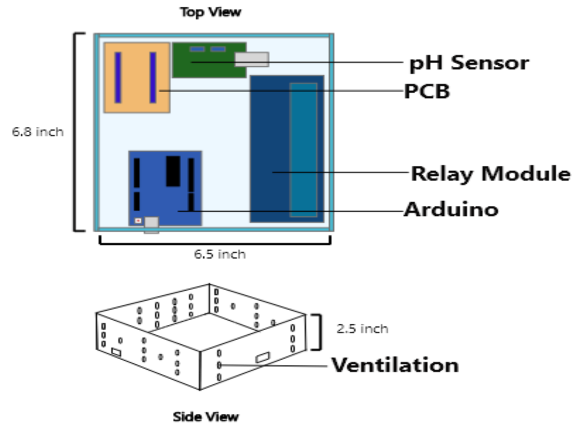

Figure 6 - Design of the Arduino Casing.

Building of Prototype

The prototype consisted of a tube housing four iceberg lettuce plants, each facing different directions and elevations to avoid root overlap and ensure proper spraying. The tube was placed on top of a bucket that held the nutrient solution for the plants. Inside the tube, a submersible water pump was used to pump the solution through a pipe with a mist nozzle that sprayed the solution onto the plants' roots. Any excess solution was collected at the bottom of the bucket. It included sensors which are temperature & humidity, pH level, and proximity sensor connected to the Arduino.

User Evaluation

The researchers presented the prototype they had developed to the panelists and the research adviser. The prototype was designed to solve a problem, and the team had put in a lot of effort to make it as efficient as possible. The evaluation and feedback from the panelists and research adviser proved to be valuable, as it helped the researchers refine their prototypes.

Refining Prototype

The researchers received several suggestions and recommendations, which they used to improve the prototype and make it more effective. The researchers spent several weeks working on the feedback and recommendations, making sure that all the issues and suggestions were addressed. Once accomplished, the researchers showed the improved prototype to the panelists and research adviser and explained the refinements that were made.

Implement and Maintain

The researchers maintained the final product and monitored it to ensure that it fulfilled its purpose. The researchers made sure that the prototype was updated regularly, and that any issues that arose were addressed promptly. The researchers also conducted tests on the prototype to ensure that it was functioning correctly and that it was meeting the requirements of the users.

10. PROPOSED SOLUTION OF THE STUDY

In the development of the system, the researchers mainly utilized the following materials: Bluetooth module, submersible pump, mist nozzle, pH level sensor, temperature and humidity sensor, proximity sensor, grow light LED, and Arduino UNO. The researchers made an aeroponic tower wherein the pH level sensor, temperature and humidity sensor, proximity sensor, grow light LED, and mist nozzle were placed alongside the plant that was used for the testing. Additionally, the sensors and Bluetooth module were connected to the Arduino to serve their functions. The researchers developed an app where the user can monitor the progress or status of the plant. The said app contained information regarding the temperature, humidity, pH level, and water level of the container in real time.

The study titled “Growth and yield performance of lettuce (*Lactuca Sativa L.*) fertilized with varying levels of compost.”, is focused on discovering the growth yield of the lettuce when local organic fertilizers are diversified. The researchers based the growth of lettuce on plant height, width of leaves, length of leaves, and number of leaves [21].

11. DESIGN AND TECHNIQUE

11.1 Research Design

The researchers will use a Quasi-Experimental Research Design. The methods of Quasi-Experimental Research Design utilize variation in the primary independent variable of interest that is not induced by researchers, thus simulating experimental settings wherein the participants are not exposed to treatments randomly [22].

11.2 Fuzzy Logic Algorithm

The researchers used an embedded fuzzy logic library (eFLL). The inputs would be the parameters monitored which are pH level and temperature and humidity of the plant environment. The software design includes fuzzy logic design using MATLAB software. The Mamdani method is the fuzzy method used in this research with 3 variable inputs (temperature, humidity and pH level). Fuzzy logic algorithm is used to accurately measure the degree of level in various parameters such as temperature, humidity, and pH level. By analyzing data based on the degree of membership in different sets, this algorithm can provide precise notifications. This results in more informed and effective decision-making, allowing issues to be identified and addressed in real-time.

The flow of fuzzy logic starts by getting crisp input values which are the parameter values received from the sensors (temperature, humidity, and pH level). The values will be fuzzified which refers to the process where the input variables turn into linguistic variables by classifying them in a fuzzy set. It will be classified as cold, good, or hot for temperature; low, normal, or high for humidity; and acidic, optimal, or alkaline for pH level. The next step would be applying the fuzzy logic rules (conditional statements (if-else)) set to the values. The process is also referred to as inference where it functions in a way that it infers where the value stands based on the fuzzy logic rules that were set. The last step would be defuzzification which calculates a defuzzified value using the centroid method which is the default method in MATLAB Fuzzy Logic Designer software.

$$Deffuzified\ Value = \frac{\Sigma_i\ \mu(x_i) * x_i}{\Sigma_i\ \mu(x_i)}$$

Where:

- i is equal to the fuzzy set.
- xi is the midpoint of the fuzzy set i.
- µ (xi) is the degree of membership of xi.

The result from the equation will be the crisp output which represents the center or average of the fuzzy set.

The fuzzy set for the temperature input variable is divided into: Cold, Optimal, and Hot and the temperature has a membership function that ranges from 0°C-55°C. The fuzzy set for the humidity input variable is divided into: Low, Optimal, and High and the humidity has a membership function that ranges from 50-100. The fuzzy set for the pH Level input variable is divided into: Low, Optimum, and High with the pH Level has a membership function that ranges from 0-14. After fuzzifying the inputs, the researchers had to fuzzify the output variables to model the fuzzy logic inference rules. The output consists of two output variables that were fuzzified.

The equation of the input variables membership function used is as follows:

$$\mu Cold\ Temp(x) = \begin{cases} 1, & \text{if } x \leq 10 \\ \frac{25 - x}{25 - 10}, & \text{if } 10 < x < 25 \\ 0, & \text{if } x \geq 25 \end{cases}$$

$$\mu Good\ Temp(x) = \begin{cases} 0, & \text{if } x \leq 19 \\ \frac{x - 19}{25 - 19}, & \text{if } 19 < x < 25 \\ 1, & \text{if } 25 \leq x \leq 28 \\ \frac{35 - x}{35 - 28}, & \text{if } 28 < x < 35 \\ 0, & \text{if } x \geq 31 \end{cases}$$

$$\mu High\ Temp(x) = \begin{cases} 0, & \text{if } x \leq 28 \\ \frac{x - 28}{35 - 28}, & \text{if } 28 < x < 35 \\ 1, & \text{if } 35 \leq x \leq 55 \end{cases}$$

For cold temperature, if the temperature is below 10 degrees Celsius or above 25 degrees Celsius, the membership is 0 or 1 respectively. For good temperature, the degree of membership is 0 for 19 degrees Celsius or above 35 degrees and 1 for 25 degrees Celsius to 28 degrees Celsius. The degree of membership is calculated using the linear equation of the left rising side of the trapezoidal curve if the value of x is more than 19 but less than 25, where 19 and 25 are the points where the membership function transitions from 0 to 1. For hot temperature, the degree of membership is 0 for 28 degrees and below and 1 for 35 degrees and above. The degree of membership is calculated using the linear equation if the value of x is more than 28 but less than 35, where 28 and 35 are the points where the membership function transitions from 0 to 1.

Table 1 - Membership Function Temperature Variable.

Linguistic Variable	Cold	Optimal	Hot
Temperature	[0,0,10,25]	[19,25,28,35]	[28,35,45,45]

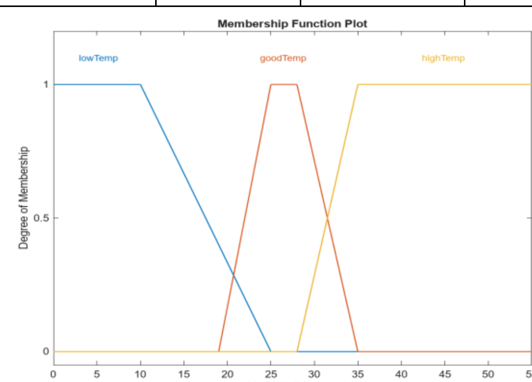

Figure 6 - Temperature Input Membership Functions

$$\mu Low\ Hum(x) = \begin{cases} 1, & \text{if } x \le 55 \\ \dfrac{55 - x}{55 - 65}, & \text{if } 55 < x < 65 \\ 0, & \text{if } x \ge 65 \end{cases}$$

$$\mu Normal\ Hum(x) = \begin{cases} 0, & \text{if } x \le 60 \\ \dfrac{x - 60}{65 - 60}, & \text{if } 60 < x < 65 \\ 1, & \text{if } 65 \le x \le 78 \\ \dfrac{85 - x}{85 - 78}, & \text{if } 78 < x < 85 \\ 0, & \text{if } x \ge 85 \end{cases}$$

$$\mu High\ Hum(x) = \begin{cases} 0, & \text{if } x \le 78 \\ \dfrac{x - 78}{85 - 78}, & \text{if } 78 < x < 85 \\ 1, & \text{if } 85 \le x \le 100 \end{cases}$$

For low humidity, the degree of membership is 0 if the value of x is more than or equal to 65 and if the value of x is less than or equal to 55 then it is 1. The degree of membership is calculated using the linear equation if the value of x is more than 55 but less than 65, where 55 and 65 are the points where the membership function transitions from 1 to 0. For normal humidity, the degree of membership is 0, if the value of x is less than or equal to 60 if the value of x is more than or equal to 85, and if the value of x is within 65 to 78 then it is 1. The degree of membership is calculated using the linear equation of the left rising side of the trapezoidal curve if the value of x is more than 60 but less than 65, where 60 and 65 are the points where the membership function transitions from 0 to 1. If the value of x is more than 78 but less than 85 then the membership degree is calculated using the linear equation of the right falling side of the curve, where 78 and 85 are the points where the membership function transitions from 1 to 0. For the high humidity, the degree of membership is 0, if the value of x is less than or equal to 78. If the value of x is more than or equal to 85 then it is 1. The degree of membership is calculated using the linear equation if the value of x is more than 78 but less than 85, where 78 and 85 are the points where the membership function transitions from 0 to 1.

Table 2 - Membership Function Humidity Variable.

Linguistic Variable	Low	Optimal	High
Humidity	[50,50,55,65]	[60,65,78,8]	[78,85,100,100]

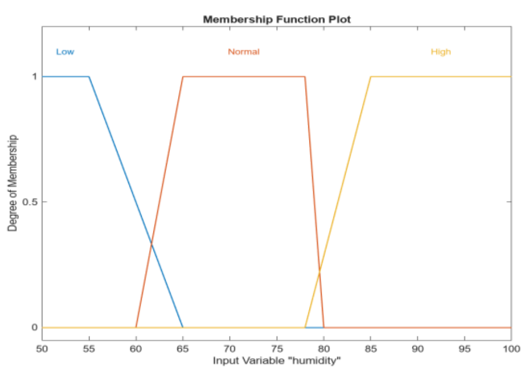

Figure 7 - Humidity Input Membership Functions.

$$\mu Low\ pH(x) = \begin{cases} 1, & \text{if } x \le 4 \\ \dfrac{5.8 - x}{5.8 - 4}, & \text{if } 4 < x < 5.8 \\ 0, & \text{if } x \ge 5.8 \end{cases}$$

$$\mu Optimum\ pH(x) = \begin{cases} 0, & \text{if } x \le 5.5 \\ \dfrac{x - 5.5}{5.8 - 5.5}, & \text{if } 5.5 < x < 5.8 \\ 1, & \text{if } 5.8 \le x \le 6.3 \\ \dfrac{6.6 - x}{6.6 - 6.5}, & \text{if } 6.3 < x < 6.6 \\ 0, & \text{if } x \ge 6.6 \end{cases}$$

$$\mu High\ pH(x) = \begin{cases} 0, & \text{if } x \le 6.6 \\ \dfrac{x - 6.6}{8 - 6.6}, & \text{if } 6.6 < x < 8 \\ 1, & \text{if } 8 \le x \le 14 \end{cases}$$

For low pH, the degree of membership is 0 for x greater than or equal to 5.8 and 1 for x less than or equal to 4. If the value of x is more than 4 but less than 5.8, the degree of membership is calculated using a linear equation where 4 and 5.8 are the points where the membership function transitions from 1 to 0. For optimum pH, the degree of membership is 0 for x less than or equal to 5.5 or if x is more than or equal to 6.6 and 1 for x within the value 5.8 to 6.3. The degree of membership is calculated using the linear equation of the left rising side of the trapezoidal curve if the value of x is more than 5.5 but less than 5.8, where 5.5 and 5.8 are the points where the membership function transitions from 0 to 1. If the value of x is more than 6.3 but less than 6.6 then the membership degree is calculated using the linear equation of the right falling side of the curve, where 6.3 and 6.6 are the points where the membership function transitions from 1 to 0. For high pH, the degree of membership is 0 for x less than or equal to 6.6 and 1 for x more than or equal to 8. The degree of membership is calculated using the linear equation if the value of x is more than 6.6 but less than 8, where 6.6 and 8 are the points where the membership function transitions from 0 to 1.

Table 3. Membership Function pH Level Variable.

Linguistic Variable	Cold	Optimal	Hot
Ph Level	[0, 0, 4, 5.8]	[5.5, 5.8, 6.3, 6.6]	[6.3, 8, 14, 14]

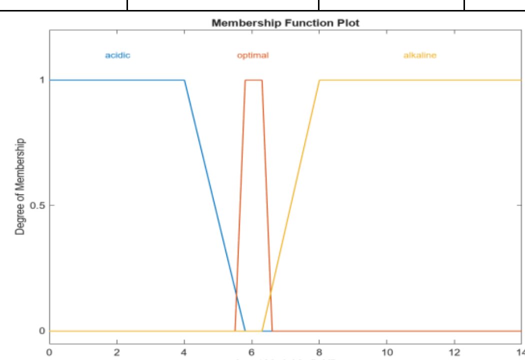

Figure 8 - pH Level Input Membership Functions.

The Fuzzy logic rules are inferred from the linguistic variables and would be the basis for the decision-making of the system. These rules are if-else statements. On the first rule, say if the temperature and humidity are both low then the urgency is high and the pump of the system will be turned on and so on.

Table 4 -Fuzzy Logic Rules

If			*Then*	
#	Temperature	Humidity	Urgency	Pump
1	Low	Low	High	On
2	Low	Normal	Average	Off
3	Low	High	High	Off
4	Good	Low	Average	On
5	Good	Normal	Low	Off
6	Good	High	High	Off
7	High	Low	High	On
8	High	Normal	Average	On
9	High	High	High	On

11.3 System Architecture

The DHT22 sensor is used to detect temperature and humidity, it is connected to the Arduino in the following order: the VCC pin of the sensor is connected to the 5v pin, the GND pin is connected to the ground pin, then, the data pin is connected to digital pin #6. The Gravity Analog pH Sensor is connected to a pH signal conversion board, and the pins of the conversion board are connected to the Arduino. The V+ pin is connected to the 5v pin, then the G pin to the GND pin, and lastly, the Po pin to the A0 pin. For the HC-05 Bluetooth module, its TX pin is connected to the digital pin 2 of Arduino, then when it comes to the RX pin of the module it is connected to digital pin 3 and the VCC pin to the 5v pin of Arduino Uno, also, the GND pin is connected to the GND pin of the Arduino. Furthermore, the 5v pin of the Arduino is connected to the positive pins of a PCB so that the 5v pin is not limited to 2 pins while the GND pin is connected to the minus pin so it won't be limited to 2 pins as well. Finally, the 12v water pump is connected to an 8-channel relay module for the Arduino to relay commands onto it.

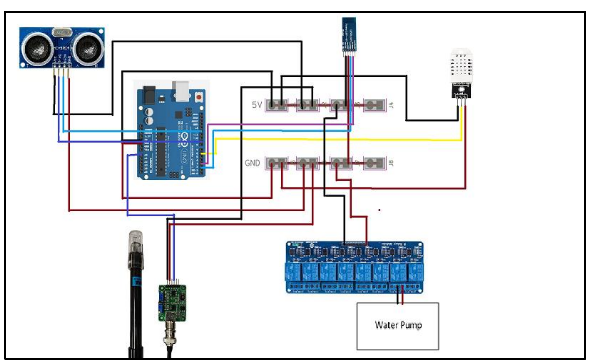

Figure 9 - Schematics of Wirings.

12. REPONDENTS OF THE STUDY

The researchers used the purposive non-probability sampling method. Non-probability sampling method only gets a representative of the whole population for its testing. The way of the non-probability sampling method in picking units is subjective [23]. Specifically, the researchers used purposive sampling which is a type of sampling where the respondents have the characteristics that are relevant to the study [24]. In this case, the researchers purposefully selected four indoor farmers around Apalit, Pampanga, and Santa Rita, Pampanga who are familiar with the aeroponic farm system. The researchers chose Santa Rita, Pampanga because according to the Municipality of Santa Rita, Pampanga [25], Santa Rita is known as one of the best agriculturists and farmers in Pampanga. Additionally, Apalit, Pampanga was also chosen because agriculture is one of its main sources of income as indicated by Apalit Executive Summary [26].

13. INSTRUMENT OF THE STUDY

The researchers gathered the data by giving a written evaluation form to the respondents. An informed consent for every respondent will be produced which will contain the name of the researchers, an email address and contact number, the title, and an overview of the study.

14. ISO/IEC 25010 OR SOFTWARE QUALITY MODEL

The researchers administered a post-survey in the form of a Likert scale questionnaire to evaluate the performance of the proposed system through the selected ISO/IEC 25010 quality standards (functionality, usability, compatibility, performance efficiency, reliability, and portability). The questionnaire was validated by an expert professional to ensure the accuracy of items concerning the study and its proper construction.

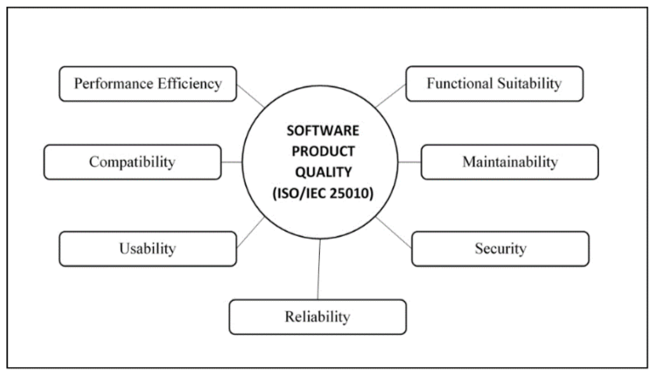

Figure 10 - ISO/IEC 25010 Model.

15. STATISTICAL TREATMENT OF DATA

A Likert scale is a rating scale used to measure opinions, attitudes, or behaviors. It consists of a statement or a question which is followed by four or seven answer statements. The respondents can choose which option is the best that corresponds to how they feel about the statement or question. Likert scales are excellent for capturing respondents' levels of agreement or their thoughts towards the topic in a more detailed manner since they give respondents a variety of viable answers [27].

Table 5 - 4-Point Likert scale presentation.

Rating Scale	Points Value	Mean Range
Excellent	4	3.26 – 4.00
Good	3	2.51 – 3.25
Average	2	1.76 – 2.50
Poor	1	1.00 – 1.75

16. RESULTS AND DISCUSSION

This section exhibits the analysis and interpretation of the study. The researchers performed a purposive sampling method to gather all the survey results. By answering the post-survey questionnaire, the respondents were able to give their insights about the performance of the proposed system;

1. Develop an automated prototype of aeroponic farming that can monitor the parameters needed for a plant to grow.

Following the first objective of the study, the researchers were able to successfully develop an automated aeroponics prototype with a monitoring application to overcome the limitations found in the monitoring of the parameters in current aeroponic farming. The prototype was able to grow 4 lettuce whose parameters were monitored by the mobile application. The researchers then collected and measured data from the planted lettuce and placed them in a table to be able to see the progress and effectiveness. The first measurement started after the germination process before being placed on the prototype gathering the plant characteristics which were the plant height, plant width, and length of the leaves which were all measured in centimeters, then lastly were the number of leaves.

Table 6. Lettuce Growth Before Being Placed in the Aeroponic Tower.

Lettuce	Plant Height (cm)	Plant Width (cm)	Length of Leaves (cm)	Number of Leaves
1	20 cm	10 cm	15 cm	4
2	10 cm	10 cm	10 cm	3
3	15 cm	15 cm	10 cm	3
4	15 cm	15 cm	10 cm	3

Then, the researchers gathered data from the same four lettuce grown on the prototype in a 3-day interval after a week of being planted in the prototype which were also placed in a table. The results show that the lettuce has progressive growth in the plant characteristics.

Table 7. Lettuce Growth Every 3 days.

Date	Lettuce	Plant height (cm)	Plant Width (cm)	Length of Leaves (cm)	Number of Leaves
11-15-23	1	30 cm	35 cm	30 cm	5
	2	20 cm	45 cm	25 cm	3
	3	30 cm	40 cm	35 cm	5
	4	15 cm	40 cm	20 cm	6
11-18-23	1	40 cm	60 cm	40 cm	3
	2	30 cm	80 cm	37 cm	6
	3	40 cm	40 cm	38 cm	8
	4	50 cm	55 cm	52 cm	7
11-21-23	1	20 cm	70 cm	45 cm	4
	2	20 cm	80 cm	50 cm	8
	3	40 cm	60 cm	60 cm	7
	4	50 cm	65 cm	60 cm	6

Farmers were then purposefully chosen to evaluate the characteristics of the grown lettuce to determine if they grew excellently or poorly. The overall weighted average mean computed through Likert scale interpretation was 3.38 which gets the interpretation that the lettuce grown was ‘excellent.

Table 8. Likert Scale Interpretation.

Question	E	G	A	P	A.W.M	Interpretation
1.Plant Width	2	2	0	0	3.5	Excellent
2.Plant Height	0	4	0	0	3.0	Goo
3.Length of Leaves	4	0	0	0	4.0	Excellent
4.Number of Leaves	0	4	0	0	3.0	Goo
Average Weighted Mean	3.38					Excellent

2. Develop a mobile application that can show the parameters of the plant environment such as the temperature, humidity, and pH level as well as alert the user about its status.

Then, to identify the effectiveness of the monitoring application in its notification system and monitoring of parameters, the researchers developed a mobile application through the MIT App Inventor 2. The application was able to connect to the Arduino via Bluetooth and was able to show the real-time readings of the monitored parameters which are the temperature, humidity, pH level, and water level height. It was also able to send a notification that showed which parameter was not optimal and would be saved in the application’s log. The application was evaluated through a post-evaluation survey to IT experts to evaluate the system under the selected software quality characteristics of ISO 25010. The criteria all got the interpretation of ‘excellent’ from the experts aside from the portability of the application to adjust to screen sizes which only achieved ‘average.’

Table 9. Functional suitability of the mobile application

Criteria	IT Expert Mean	Interpretation
1.The mobile app function covers all the specified tasks and user requirements.	4.0	Excellent
2. The system successfully saves data (date and time, temperature, humidity, pH, water level height) in the logs.	3.5	Excellent
Mean for Functionality	3.75	Excellent

Table 10. Performance efficiency of the mobile application

Criteria	It Expert Mean	Interpretation
1.The mobile app provides real-time updates on temperature.	4.0	Excellent
2. The mobile app provides real-time updates on humidity.	4.0	Excellent
3. The mobile app provides real-time updates on pH levels.	4.0	Excellent
4. The mobile app provides real-time updates on water level height.	4.0	Excellent
How would you evaluate the promptness of notifications concerning changes in temperature, humidity, pH level, and water level height?	2.5	Average
Mean for Performance Efficiency	3.7	Excellent

Table 11. Usability and user interface of the mobile application

Criteria	IT Expert Mean	Interpretation
1. The mobile app is easy to navigate and user-friendly.	4.0	Excellent
2. Icons and symbols used in the interface are appropriate and easily understandable.	3.0	Good
Mean for Usability and User Interface	3.5	Excellent

Table 12. Reliability of the mobile application

Criteria	IT Expert Mean	Interpretation
1. The systems Loading time is appropriate.	4.0	Excellent
2. Real-time monitoring data displayed in the application is accurate and reflects the actual conditions of the aeroponics system.	4.0	Excellent
Mean for Reliability	4.0	Excellent

Table 13. Usability and user interface of the mobile application

Criteria	IT Expert Mean	Interpretation
1. The user Interface adapts well to various screen sizes and resolutions.	2.5	Average
Mean or Portability	2.5	Average

Table 14. Result of the evaluation of the mobile application

Criteria	Weighted Mean	Verbal Interpretation
Functional Suitability	3.75	Excellent
Performance Efficiency	3.7	Excellent
Usability	3.5	Excellent
Reliability	4.0	Excellent
Portability	2.5	Average
Grand Mean	3.49	Excellent

3. Discover the effectiveness of the fuzzy logic algorithm to the monitoring of the temperature, humidity, and pH level in the aeroponic prototype.

To see the effectiveness of the fuzzy logic algorithm in the monitoring of the plant environment parameters, tests were first conducted to view its accuracy before using it in growing the lettuce in the aeroponic prototype. Five tests were conducted in the prototype through hot and cold water to test the accuracy of the real-time readings and notifications. The fuzzy logic algorithm performed as intended and was able to detect the urgency level of the parameters following the logic and formula in Chapter III of the study. As for the notification testing, based on the results of the notification testing it was able to successfully control the pump to turn on and off following the fuzzy logic rules set.

Table 15. Results from Notification Testing.

Test	Temperature	Humidity	pH Level	Notification	Fuzzy Logic
1	37.60°C	91.60	10.5	Success	Pump: On
2	30.30°C	75.10	13.7	Success	Pump: On
3	24.70°C	78.80	14.9	Success	Pump: Off
4	26.40°C	55.00	17.2	Success	Pump: On
5	27.80°C	68.30	16.2	Success	Pump: Off
6	28.90°C	80.40	24.4	Success	Pump: Off
7	31.50°C	80.80	24.4	Success	Pump: On
8	31.60°C	80.80	23.3	Success	Pump: On
9	31.60°C	80.80	23.3	Success	Pump: On
10	31.60°C	80.80	24.8	Success	Pump: On

17. CONCLUSION

The automated aeroponics prototype was an effective method for growing lettuce. The survey conducted among the farmers revealed that the lettuce grown in the tower for the given time had positive and excellent results in terms of its growth characteristics. However, it is important to note that continuous monitoring and experimentation are necessary to fully validate the system.

Additionally, the parameters were successfully displayed on the application. The notification testing and fuzzy logic integration were also found to be successful, with the results indicating that the real-time notifications were received immediately and were accurate. Results from post-evaluation with the IT experts mostly rated the quality characteristics of the web application as "Excellent" specifically with the functional suitability, performance efficiency, usability, and reliability of the mobile application after evaluating it. This means that the application covers the tasks well, provides accurate results, has an easy-to-use design, and is reliable in facilitating tasks and maintaining data accuracy.

The pump also successfully followed the given fuzzy logic rules. The algorithm works well with uncertain values such as the readings of the sensors in this study. This may also indicate that the algorithm could be used in a variety of settings and could be expanded. However, the pump was not able to produce enough water for the hose due to its insufficient pressure. This requires further improvement to ensure that the system operates effectively and efficiently. Overall, the aeroponic prototype and mobile application were able to perform their intended functions.

However, further research is required to determine the optimal conditions for lettuce growth in an aeroponic system and to address any issues related to the system's operation and efficiency.

18. RECOMMENDATION

For future studies, the researchers recommended further study and research about other types of plants that can be grown in the aeroponic tower. Aside from being used in notification, it is also highly recommended to try using fuzzy logic for other purposes such as for the optimization of the parameters. Additionally, it is also better to use an SMS (Short Message Service) or a WiFi module for the sending of messages to have a wider range so the farmer can be notified even if not around the tower. Furthermore, the researchers recommend using a humidifier instead of a mist nozzle to ensure the distribution of nutrients to the lettuce. The researchers also recommend integrating the system with smart devices, enabling compatibility with smart devices for better accessibility. Lastly, since the main focus of the researchers in this study is to use fuzzy logic for monitoring the aeroponics tower and the researchers don't have enough knowledge for proper cabling to extend the cables, the researchers didn't risk extending the cable as it might cause a disturbance in the electronics. According to Noakes (2021), one cause of submersible pumps not working properly is due to faulty cabling. Another problem when connecting wires is the phenomenon known as Joule heating; a problem wherein the current causes an increase in temperature in the wires (Joe, et al., 2021). The researchers therefore recommend using a longer cable for the dht22 sensor, pH sensor, and pump instead of buying a short cable and then attaching a different wire to extend it.

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