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Automated Solar-Powered Aeroponics Structure for Plant Cultivation and Monitoring

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***Abstract* - Global food security is at risk due to climate change and outdated agricultural technology. The application of readily available technology and input management increased the food supply by 10 to 30 percent, raising a need for alternative farming practices. Furthermore, this study designed, developed, tested, and evaluated an automated, solar-powered aeroponics structure for plant cultivation and monitoring. A research and development approach was used, adapting the iterative model with its four phases: design (planning the prototype), development (creating program logic and assembling components), testing (functionality testing), and evaluation (assessing strengths and weaknesses of the prototype), creating a manageable and flexible workflow, allowing the researchers to incorporate changes based on ongoing feedback. The researchers constructed a prototype with three (3) main components: a growing chamber, a control panel, and a water reservoir. This system was programmed to read and transmit sensor data to the cloud for monitoring. Testing confirmed the functionality of all parts, and evaluation revealed the prototype to be both user-friendly and adaptable to user preferences. In conclusion, the aeroponics structure's high ratings in functionality, acceptability, and adaptability demonstrate a well-performing and user-friendly prototype. This aeroponics system offers a promising and efficient way to advance agricultural practices through its high adaptability to a wide range of conditions. Farmers will be able to modify the aeroponics structure to grow a variety of crops, including vegetables, as it advances. Moreover, the system requires less manual labor due to its automated features, making it an efficient and convenient agricultural innovation.**

Keywords: agricultural innovation, sustainability, sensor-based crop monitoring, IoT-based agriculture, smart farming.

I. INTRODUCTION

The agricultural sector in the Philippines started to grow in the 1960s and 1970s, however, it also showed inconsistencies throughout the following years. As a result, the sector only produced 9% of the country's gross domestic product [1]. One main reason for this phenomenon was low agricultural productivity; hence, based on a study by the World Bank [2], a critical role for the government is to invest in research and development. While agriculture plays a significant role in the economic development of all nations by ensuring food security and bringing in money for exports [3], the Philippines has failed to maximize its potential. In a study by Ozor and Urama[4], the application of readily available technology and input management increased food supply by between 10 to 30 percent, raising a need for alternative farming practices.

Additionally, the study by Gomiero et al.[5], stated that the decrease in soil fertility was brought on by the low adoption of sustainable agricultural practices is one of the obstacles to raising agricultural productivity. The problem of ensuring food security is complicated and difficult to solve because it cannot be described or limited by a single factor, such as income, location, education level, or demography [6]. The global agri-food industry is constantly evolving and restructuring in an effort to satisfy the constantly shifting dietary needs and preferences of consumers worldwide. One of the main issues facing this sector is trying to balance product costs against other factors like demand, safety, quality, and variety [7]. The Philippines needs to find a solution to satisfy public demands while adapting to the decrease in soil fertility. In this context, aeroponic systems, a cultivation method designed to enhance production and minimize resource usage, present an alternative approach [8].

In Aeroponics, a revolutionary method of suspending plants in the air without soil or any other medium [9], offers a compelling solution for the future of agriculture. By eliminating theneed for soil, it thrives in limited spaces, making it ideal for urban vertical farms and reducing the environmental impact of food transportation [10]. Furthermore, aeroponically grown plants often exhibit enhanced vegetative growth compared to traditional methods, with even extended growth cycles for certain crops [11].

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According to Butler and Oebker [12], soil-less plant cultivation is the practice of growing plants in substrate culture or water culture without the use of soil. Numerous socio-economic advantages are made possible by the technique, such as the capacity to address the growing global food challenges, environmental modifications for the purpose of mitigating malnutrition, management, and effective use of natural resources. Additionally, the soil-less method can supply an uninterrupted, year-round supply of fresh, clean, and hygienic vegetables [13]. The system allows for multiple plant harvesting with maximum output while requiring the least amount of input. The idea behind soilless culture is to provide a novel way to guarantee the long-term viability of high-quality, economically viable food sources [14].

Previous studies extensively focused on the execution of an automated aeroponic cultivation system for green leaf plants in which it controlled the parameters of humidity, temperature, and irrigation time by utilizing a mist spray of nutrients under the roots of a specified plant [15]. In another study [16], a microSD memory holds the data that the system provides, and an Internet web server and Bluetooth can access it in real time. Another feature that was integrated in Aeroponics systems is data analytics. Based on a study by Garzón [17], to optimize their aeroponic systems and increase yields, farmers can use data analytics to analyze large amounts of data on plant growth, weather patterns, and nutrient levels in order to accurately predict the ideal conditions for plant growth. However, other systems have shown flaws and inconsistencies with the creation of their automated systems, such as Sihombing et al. [18], who recently built a hydroponic greenhouse system with success. However, this system's drawback is that it can only measure the temperature and water level of the nutrient solution. In another study, Belhekar et al. [19] and Jaimes et al. [20], established a system that measures water level, pH, electrical conductivity, temperature, and relative humidity. Farmers received alerts about the imbalance of nutrients in the system after the data was uploaded to a database. The system's only function is to monitor the hydroponic environment. Consequently, the farmer must control events because the system lacks the presence of actuators.

In line with this, previous systems only focused on monitoring the temperature and water level of a specified plant. However, it may cause an insufficiency of the data to provide adequate nutrients required for plant growth. Early studies also utilize the data of a plant to receive alerts and, afterward, conduct manual action to manage the system. In this context, this study will design and develop an automated solar- powered aeroponics structure for cultivation and monitoring. Moreover, the system will determine the temperature, humidity, light intensity, pH level, and water level to maintain the required parameters for optimal growth of a plant [21]. Additionally, in the Philippines, there is a lack of innovative technology that improves agricultural productivity by harnessing fewer ingredients, consumption of fertilizers and nutrients, irrigation of water, and having the entire growth process in a confined and regulated environment [22].

Specifically, this study aimed to (1) design an automated solar-powered aeroponics structure for plant cultivation and monitoring; (2) develop a program logic for the prototype; (3) test the functionality of the system in terms of the parameters pH level, humidity, temperature, and light intensity; and (4) evaluate the level of acceptability and adaptability of the automated aeroponics system. This project contributes to the achievement of the United Nations (UN) Sustainable Development (SDG) Goal 12 (Responsible Consumption and Production) and Goal 2 (Zero Hunger) by developing a system that facilitates capacity building in science and technology within developing nations. This system serves as a catalyst for their transition towards environmentally sustainable production and consumption patterns. In addressing Zero Hunger, Rivera et al.'s study[23] shows that aeroponic systems in urban areas have the potential to improve local food security by providing year-round accessibility, availability, and stability of supply of wholesome, fresh foods that could lessen or eliminate reliance on imports and have competitive environmental performance. The aeroponics system optimizes growth conditions and nutrient delivery, producing more food in a limited area [24]. Furthermore, by requiring significantly less water and nutrients compared to conventional soil- based farming, aeroponics structure can mitigate water scarcity issues and reduce environmental impact [25]. Through the implementation of vertical farming, farmers can readily optimize resources and tailor interventions based on real-time environmental data. Future advancements including automation, AI-powered decision support, and even integration with robotics, hold immense promise for further revolutionizing agriculture [26].

II. MATERIALS AND METHODS

2.1 Materials

The electrical components used in the study were ESP32 microcontroller, 1 LCD screen, 1 temperature and humidity sensor, 1 pH level sensor, 1 photoresistor, water level sensor, relays, case fan, 220V water pump, inverter, solar panel, charge controller, and 12V battery. This aeroponics structure utilized one (1) large storage box with (72.3 x 52 x 44) cm and a small- sized container with (44 x 13 x 31) cm dimensions. The smaller-sized container was used as a plant support structure with the spray nozzles attached underneath. Two (2)

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spray nozzles were used and connected through the pipes to the water pump inside the water reservoir.

2.2 Research Design

The Research and Development (R&D) design consisted of four (4) phases: design, development, testing, and evaluation, each corresponding to the study objectives. The design phase included planning for the electrical components, structural materials, and layout of the automated solar-powered aeroponics structure. The development phase was for the program logic for the prototype, which was the software component of the system that would control the sensors, water pump, ventilation, and monitoring system. This phase also included the prototype assembly. The testing phase involved the functionality testing of the system in terms of its software and hardware components. The researchers utilized a checklist in ensuring that all the software and hardware components were working as expected and met the requirements. Lastly, the evaluation phase included surveying the level of acceptability with potential users or field experts. The calculated results were used to assess the strengths and weaknesses of the automated solar-powered aeroponics structure.

2.3 Procedure

2.3.1 Prototype Modelling

The researchers have improved the most recent designs by adding a photo resistor for detecting light intensity, an automated fan for temperature regulation, and a cover for the main structure, providing an indoor enclosure and protection. The main structure was approximately (72.3 x 52 x 44) cm, containing a smaller structure for the growing chamber that was approximately (44 x 13 x 31) cm. The control panel,all the electronic devices for system operation and communication module, were installed closest to the growing chamber, including the sensors for monitoring the temperature, humidity, and light intensity. The pH level and water level sensors were then placed inside the main structure near the growing chamber. The LCD screen was installed on the exterior of the main container. A separate container was used for the water reservoir, with a hose secured between the container and the main structure for water circulation. The case fan was installed to the main structure and is connected to the microcontroller. The components used for the power source, namely, the charge controller, battery, and the inverter was placed in a separate compartment attached to the main structure. This was to keep the components less bulky and out of reach when the prototype is turned on. The Solar panel was positioned outside the structure, connected to the charge controller.

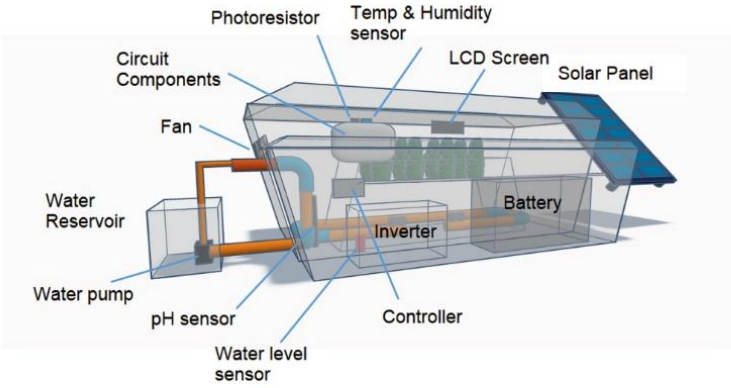

Figure 1: Prototype Design

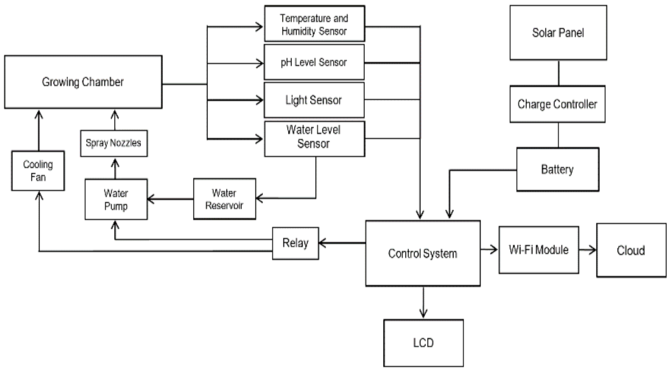

Figure 2: Diagram of Components

2.3.2 Prototype Programming and Coding

The commands and data collection protocol to be executed were written in C-environment using the Arduino IDE platform. The process of integrating the components required to produce the proposed system for the Automated Solar-Powered Aeroponics Structure follows these steps:

2.3.2.1 Initialization

Involved incorporating necessary libraries like Wire.h and LiquidCrystal_I2C.h, defining variables for various components, and setting calibration values for each sensor. Incorporating sensor calibration into this process ensures the reliability and accuracy of the sensor values and the sensor readings are aligned with the actual conditions being measured. This approach was undertaken to ensure that the system follows a structured program flow and easy-to-maintain code where the data are collected, processed, and displayed coherently.

2.3.2.2 Sensor Calibration

Before initiating the main loop, this step ensured accurate readings by calibrating sensors before the main loop. This involved placing sensors in a known environment, adjusting

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calibration values, and updating variables accordingly. The optimal values used for the pH level ranges from 6.5 as the lowest and 7.5 as the highest. Optimal values were also established for the other sensors as a basis for the monitoring system. The temperature ranges from 20 °C to 34 °C, humidity from 50% to 70%, and light intensity from 50% to 100% or moderate to high intensity.

2.3.2.3 Setup Function

The function began from initializing serial communication to facilitate debugging processes configuring the LCD, displaying an introductory message, setting up sensor power pins, and establishing IoT connectivity for remote monitoring.

2.3.2.4 Main Loop

In this phase, each sensor (light sensor, water level sensor, temperature and humidity sensor, and pH level sensor) was read, processed, and displayed on the LCD for 5 seconds. For IoT Integration, the system implemented a function to send sensor data to an IoT platform via API endpoints and enable receiving commands from the IoT platform to control the display of information on the LCD. Commands from the IoT platform include a water pump scheduler, which facilitates the on and off schedule for.

2.3.2.5 Sensor Functions

In enhancing modularity and readability, separate functions were created for each sensor reading and processing task. Sensor-specific code was included within each function, further aiding in maintaining and troubleshooting individual sensor functionalities. The data for each sensor was sent over to the IoT platform. The following action was notified when the data was less than or exceeded the optimal value range. For the temperature regulation function, the fan would be triggered on when the recorded temperature value exceeded 34°C and would trigger off when the value was less than 34°C. For the pH level regulation, the water pump was turned on if the values were less than or exceeded the optimal range of 6.5-7.5 pH level.

2.3.2.6 Display Function

The system established a specific function to manage the LCD. Within this function, delays were incorporated before clearing the display during data- printing processes. Furthermore, the IoT platform used, Arduino Cloud, features a display interface presenting trend graphs for each sensor being monitored in real- time along with alerts for notifying out-of-range sensor readings. The IoT integration in the proposed system allows remote monitoring and control for enhanced system usability.

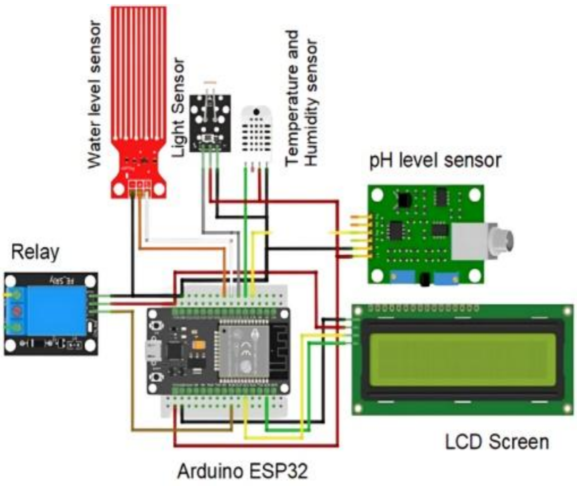

Figure 3: Circuit Diagram

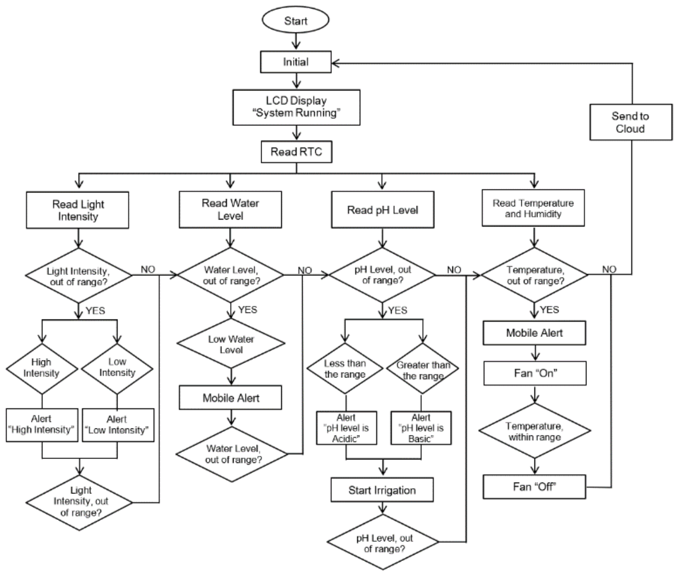

Figure 4: System Flow of the Prototype

2.3.3 Prototype Testing

The performance of the various components was assessed by the researchers using a checklist that covers both hardware and software aspects. The hardware checklist consists of the cooling fan, water pump, nozzles, solar panel, inverter, battery, and the components in the circuit, including the sensors for the pH level, temperature and humidity, light, and water level. The functionality of the electrical components was determined by their light indicators. The water pump and cooling fan were also tested according to their programmed triggers through the sensors. This includes altering environmental conditions for each sensor and adjusting the set values. The software checklist consists of the system readings

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and the display of variables on the IoT platform and the notification functions for the out-of-range values.

2.3.4 Prototype Evaluation

Evaluating the prototype involves measuring the acceptability and adaptability among experts in the field through a survey questionnaire. The results were analyzed and interpreted to identify the strengths and weaknesses of the prototype and to suggest possible improvements.

2.3.4.1 Respondents and Sampling Technique

For this study, the respondents were selected through a purposive sampling technique. This non- probability sampling technique was used to select respondents who meet specific criteria relevant to the research objectives [27]. The selection process was guided by the following criteria: a) participants must hold a degree in a field relevant to the study, such as electronics and communications engineering; b) they should possess a minimum of three years of professional experience; and c) they must be located within the province of South Cotabato. This approach ensures that the respondents meet the qualifications necessary for the prototype evaluation.

2.3.4.2 Prototype Evaluation

The study used a 5-point Likert scale survey questionnaire, which consists of two (2) sections with 17 questions in total. The first section rates the level of acceptability of the prototype, which includes the simplicity of the prototype in terms of usage, the prototype design, and the overall experience of the user. The second section assesses the level of adaptability of the prototype in different conditions, the ease of adjusting features, and the prototype's portability. To ensure the questionnaire's validity, a pilot test was conducted. Cronbach's alpha coefficient was calculated for each section to assess internal consistency, a measure of reliability.

2.4 Data Analysis

The data collected from the acceptability and adaptability levels questionnaire was subjected to thorough statistical analysis to determine whether it is an efficient operating system that is acceptable to professionals in that field. The weighted mean from the survey will be calculated to evaluate its acceptance and adaptability among field experts. To draw significant conclusions, the findings were analyzed using a table of interpretation adapted from another study [28]. These results will not only confirm that the system works as planned but also ensure it is in line with user expectations and industry norms, leading to successful adoption and usability.

Table 1: Interpretation for Levels of Acceptability and Adaptability

Rating	Range	Descriptor	Interpretation
5	4.50 - 5.00	Strongly Agree	Highly Acceptable
4	3.50 - 4.49	Agree	Acceptable
3	2.50 - 3.49	Neutral	Fair
2	1.50 - 2.49	Disagree	Not Acceptable
1	1.00 - 1.49	Strongly Disagree	Highly Not Acceptable

2.5 Ethical Consideration

In developing an automated solar-powered aeroponics system for plant cultivation and monitoring, ethical considerations were applied. To conduct this study, the researchers were able to obtain approval from the principal. Subsequently, a comprehensive letter of consent was created, outlining the study objectives, respondent roles, and potential risks. This letter also provided instructions and a statement affirming the privacy and confidentiality of the data, anonymity, respondent rights, and autonomy. As part of the process, the study focused on minimizing environmental impact through sustainable practices while upholding ethical standards in plant handling and taking measures to minimize environmental impact by integrating sustainable practices.

III. RESULTS AND DISCUSSIONS

This section of the study presents and discusses the results of the conducted evaluation and testing of the aeroponics system prototype.

3.1 Development of the Prototype

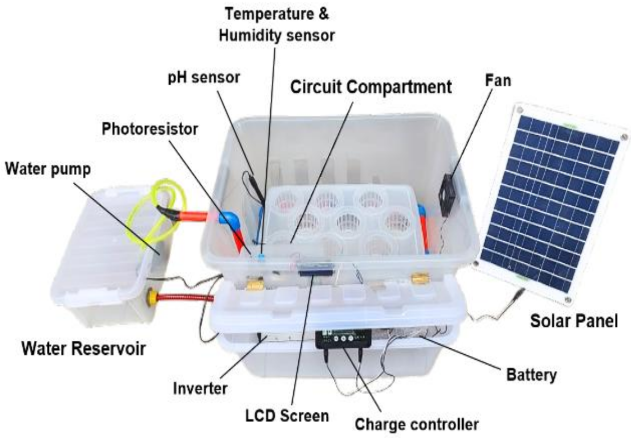

Figure 5: Prototype Modelling

The researchers added a light sensor, a fan to control temperature, and a cover for protection. The main structure was about (72.3 x 52 x 44) cm, housing a smaller growing chamber. The control panel, with all the electronic devices, was close to the growing area, while sensors monitor temperature, humidity, and light inside. pH and water level

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sensors were also nearby. An LCD screen was outside. A separate container held the water, connected to the main structure for circulation. The case fan and power components were kept separate for efficiency and safety. A solar panel outside powered the system.

```
#include "thingProperties.h"

#include <Wire.h>
#include <LiquidCrystal_I2C.h>
int lcdColumns = 16;
int lcdRows = 2;
LiquidCrystal_I2C lcd(0x27, lcdColumns, lcdRows);

#include "DHT.h"
#define DHTPIN 25
#define DHTTYPE DHT11
DHT dht(DHTPIN, DHTTYPE);

#define POWER_PIN  33
#define WATER_LEVEL 32
#define WATER_MIN 0
#define WATER_MAX 1800

#define pump 4
#define fan  19

int value = 0; // variable to store the sensor value
int level = 0; // variable to store the water level

float calibration_value = 14.4; // CALIBRATE PH SENSOR HERE
int phval = 0;
unsigned long int avgval;
int buffer_arr[10], temp;

void setup() {

  Serial.begin(9600);
  delay(1500);
```

Figure 6: Prototype Programming and Coding

The program logic was written in C-environment using the Arduino IDE platform, focusing on accurate sensor readings and user interaction. The sensors were calibrated to ensure reliable data collection within specific parameters (pH, temperature, humidity, light). The main operation involves a continuous loop that reads the sensors every 5 seconds, and the readings are then displayed on the LCD screen. The system integrates Arduino Cloud, an IoT platform that allows users to monitor the data graphically and receive alerts for out-of-range readings remotely. The platform also enables some adjustments to the program, such as the water pump schedule and the management of information displayed on the LCD screen. The system utilizes modular programming, which separates the functions for each sensor, improving readability and simplifying maintenance. The design is user-friendly since the operation includes automated controls based on the sensor readings.

3.2 Program Logic

The system will start when turned on and display the LCD introductory message signifying the system is running. The system will then read the real- time clock and proceed to the sensor readings. The system will initially read the light sensor, when the value is out of the optimal range (50% to 100% or moderate to high intensity), the system will send an alert. The system will then read the water level in the water reservoir; if the water level is below the set level, it will send an alert. Then the system will read the pH level in the water; if the pH level is out of range, it will send an alert and start running the irrigation system to regulate the pH level in the water until it is within the established range (6.5 to 7.5). Then, the temperature and humidity are read. If the temperature is out of range, then it will send an alert and automatically activate the fan to regulate the temperature until it is within the established range (20 °C to 34 °C). If all conditions are regulated, all the data from the sensors will then be sent to the Arduino Cloud, where it will be presented in a graphical format.

3.3 Functionality Test

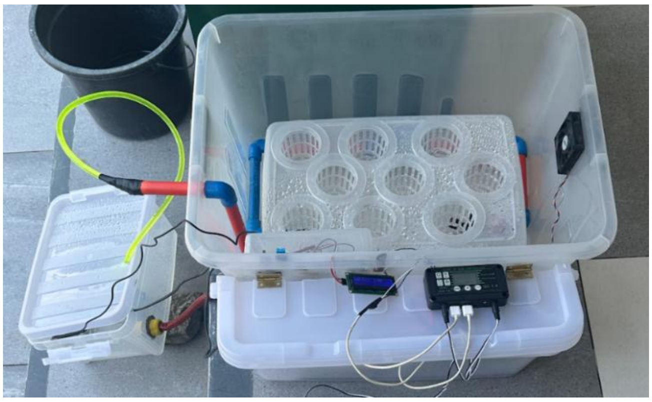

Figure 7: Prototype Testing

After establishing the physical structure and software mechanisms, the researchers conducted a prototype testing to ensure the quality and efficiency of its working conditions. The prototype was set-up and was evaluated by engineers that have rated the performance of the prototype in terms of its different components. After which, the researchers were able to determine the state of the system and the elements that needed to be improved.

Table 2: Checklist for Component functionality

Components	FUNCTIONAL	
	YES	NO
12V Relay	✓	
Case Fan	✓	
220V Water Pump	✓	
Solar Panel	✓	
Charge Controller	✓	
12V Battery	✓	
Inverter	✓	
Spray Nozzle 1	✓	
Spray Nozzle 2	✓	
ESP 32 Microcontroller	✓	
Temperature and Humidity Sensor	✓	
pH Level Sensor	✓	
Photoresistor	✓	
Water Level Sensor	✓	

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Table 2 shows the operational status of all sensors, including the ESP32 microcontroller, responsible for collecting vital data (pH, water level, light intensity, temperature) and controlling other sensors based on its programming. Verifying the operational status of these sensors and electrical components is critical, as they directly execute actions based on the collected data and ESP32 programming, ensuring proper system function.

Table 3: The functionality of the Sensor modules, power supply, and Wi-Fi module in its offline stage and activation

NODE	Initial		Condition	Final	
	Indicator	OUT PUT		Indicator	OUT PUT
Temperature Sensor	Gray	Off	Turned On	Red	On
pH Sensor	Gray	Off	Turned On	Red	On
Light Sensor	Gray	Off	Turned On	Red	On
Water Level Sensor	Gray	Off	Turned On	Red	On
LCD Screen	Gray	Off	Turned On	White	On
Water Pump	Gray	Off	Turned On	Red and Green	On
Cooling Fan	Gray	Off	Turned On	Red and Green	On
Inverter	Gray	Off	Turned On	Green	On
Charge Controller	Screen Display Blank	Off	Turned On	Screen Display Active	On

The functionality of the Sensor modules, power supply, and Wi-Fi module in its offline stage and system when turned on were evaluated. Initial outputs, working conditions, and final outputs exhibited functioning mechanisms.

Table 4: The functionality of the Water Pump and Wi-Fi module

NODE	Initial		Condition	Final	
	Indicator	OUT PUT		Indicator	OUTP UT
Temperature Sensor	Red	On	Steady	Red	On
pH Sensor	Red	On	Steady	Red	On
Light Sensor	Red	On	Steady	Red	On
Water Level Sensor	Red	On	Steady	Red	On
LCD Screen	White	On	Steady	White	On
Water Pump	Red and Green	On	Turned Off	Gray	Off
Cooling Fan	Red and Green	On	Steady	Red and Green	On
Inverter	Green	On	Steady	Green	On
Charge Controller	Screen Display Active	On	Steady	Screen Display Active	On

The water pump and Wi-Fi module displayed initial outputs of “ON” status. Most conditions displayed steady results aside from the water pump. However, all final outcomes displayed the same output as the initial outputs.

Table 5: The functionality of the Sensor modules and Water Pump simultaneous activation

NODE	Initial		Condition	Final	
	Indicator	OUT PUT		Indicator	OUT PUT
Temperature Sensor	Red	On	Turned Off	Red	On
pH Sensor	Red	On	Turned Off	Red	On
Light Sensor	Red	On	Turned Off	Red	On
Water Level Sensor	Red	On	Turned Off	Red	On
LCD Screen	White	On	Turned Off	White	On
Water Pump	Gray	On	Steady	Gray	Off
Cooling Fan	Red and Green	On	Steady	Red and Green	On
Inverter	Green	On	Steady	Green	On
Charge Controller	Screen Display Active	On	Steady	Screen Display Active	On

In this trial, the initial output stage demonstrated 1 “OFF” status as well as having 4 working conditions with the addition of the water pump. However, all final outputs displayed operative outcomes.

3.4 Levels of Acceptability and Adaptability

The questionnaire used in evaluating the acceptability and adaptability of the prototype was pilot tested in ensuring the internal validity of the questionnaire. The level of acceptability questionnaire yielded a Cronbach's alpha of 0.64, which can be interpreted as reliable. The level of adaptability questionnaire, however, demonstrated stronger reliability with Cronbach’s alpha of 0.70.

Table 6: Level of Acceptability of the Prototype

Indicator	M	SD	Interpretation
Understanding the functionality of the prototype was easy.	4.2	0.45	Acceptable
I am satisfied with the performance of the prototype.	4.00	0.00	Acceptable
I am likely to recommend this prototype to others.	4.00	0.71	Acceptable
The prototype was intuitive and easy to use.	4.00	0.00	Acceptable
The prototype design/layout is intricate and well-thought out.	4.00	0.00	Acceptable
The wire management of the prototype is satisfactory.	3.8	0.45	Acceptable
The features of the prototype are relevant to its purpose.	4.00	0.00	Acceptable
The different parts of the prototype are easy to navigate.	3.8	0.45	Acceptable
Overall, I am satisfied with the prototype.	3.8	0.45	Acceptable
Overall Weighted Mean	3.96	-	Acceptable

The results in table 6 show that the prototype is acceptable among the respondents. Overall, respondents agreed that understanding the functionality of the prototype was easy (M=4.2, SD=0.45). A high mean score of 4.2 indicates that the prototype design is easy to use and aligns

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with the study of Lucero et al. [15] who emphasized the importance of clear functionalities which suggests that the prototype will be accessible to a wide range of users. While the wire management of the prototype was generally deemed acceptable by the respondents, there was slightly less agreement regarding their satisfaction with it (M=3.8, SD=0.45). This suggests that there may be room for improvement in wire management to enhance overall user satisfaction. The study [15] underscores the importance of addressing various aspects or prototype design to ensure user satisfaction and usability.

Similarly, participants agreed that navigating the different parts of the prototype was easy (M=3.8, SD=0.45), but they expressed overall satisfaction with the prototype (M=3.8, SD=0.45). Another study [16] contributes to understanding prototype navigation by providing insights into data storage and accessibility. Its emphasis on creating strong data management infrastructure likely influenced the perceptions on the prototype's navigational ease. By ensuring access to data and information, the prototype becomes more user-friendly and accessible which contributes to positive user experiences.

The overall weighted mean of 3.96 indicates acceptability for the prototype, suggesting promising potential for its adoption. This is consistent with the study of Al-Naamani [22] which underscores the relevance and applicability of innovative agricultural technologies in addressing agricultural issues. The acceptability of the prototype suggests that it offers a solution to the challenges identified by Al-Naamani [22], such as the need for increased efficiency and sustainability in agricultural practices.

Table 7: Level of Adaptability of the Prototype

Indicator	M	SD	Interpretation
The prototype can easily be adjusted to fit different user needs.	4.2	0.45	Acceptable
It is easy to add new features or functions to the prototype.	3.6	0.55	Acceptable
Users can change settings or how the prototype works without trouble.	4.00	0.00	Acceptable
The prototype can keep up with the new trends or technology changes.	3.8	0.45	Acceptable
Users can make the prototype fit different places or conditions.	3.8	0.45	Acceptable
Putting together or taking apart the prototype is simple and doesn't need special tools.	4.00	0.00	Acceptable
The prototype's materials are strong and can handle different kinds of weather.	4.00	0.00	Acceptable
Storing, moving, and using the prototype in different places is easy.	4.00	0.00	Acceptable
Overall Weighted Mean	3.93	-	Acceptable

The results in Table 7 demonstrate the favorable reception of the prototype's adaptability among respondents. Overall, respondents agreed that the prototype can easily be adjusted to fit different user needs (M=4.2, SD=0.45). This suggests a strong agreement among respondents that the prototype possesses the flexibility to be easily adjusted to accommodate different user needs. This is supported by the study of Ritter et al.[11] that discusses the extended growth cycles and enhanced vegetative growth associated with aeroponically grown plants. This highlights the adaptability of aeroponic cultivation methods, which are likely to contribute to the acceptance of the prototype among the respondents.

Although the agreement was slightly lower, respondents still generally accepted that it is easy to add new features or functions to the prototype (M=3.6, SD=0.55). This result suggests that there may be some room for improvements in terms of the prototype's adaptability to incorporate new functionalities and may indicate potential opportunities for integrating advanced functionalities into the prototype to further enhance its adaptability and user satisfaction. This is consistent with the study of Garzón [17], which suggests that advancements in data-driven approaches can enhance the adaptability of agricultural technologies.

The overall weighted mean of 3.93 indicates that the prototype is acceptable, suggesting promising prospects for adoption. This is consistent with the study of Golan and Kohli [1], who provide insights into the challenges faced by the agricultural sector in the Philippines. By understanding the context of low agricultural productivity, it becomes evident that innovative solutions like the prototype are crucial for improving agricultural outcomes. Therefore, the acceptability of the prototype among respondents indicates its potential to contribute to overcoming productivity limitations in the agricultural sector.

IV. CONCLUSION

The accomplished aim of the process of design, development, testing, and evaluation of the prototype yielded the following results: The prototype for a solar- powered aeroponics system for plant cultivation was successfully designed, developed, tested, and evaluated. In terms of structure, it measured (72.3 x 52 x 44) cm and included a growing chamber that was approximately (44 x 13 x 31) cm. The system is written in a C-environment in Arduino IDE for coding and data reading. The program uses code functions for sensor calibration, variable creation, and value adjustments. Functionality tests were conducted, demonstrating a functional system operation. The prototype's acceptability and adaptability were evaluated, with a strong agreement (M=3.96) indicating its user- friendliness and ability to adapt

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to various possibilities. This implied that the prototype design was deemed user-friendly and had clearly defined functionality. While the prototype's adaptability was at a great level, with an overall mean of 3.93, it showed that the prototype is workable and had the ability to adapt to different possibilities. The level of acceptability accumulated throughout the process of evaluating the system denotes a strong agreement (M=3.96). This indicated that respondents clearly concur that the prototype has a high level of flexibility to adjust based on the user's various requirements. Moreover, Strong agreement is shown by the amount of acceptance that has been acquired during the system evaluation process (M=4.2S, D=0.45). This implies that the prototype design is deemed user-friendly and has clearly defined functionality.

V. RECOMMENDATIONS

Based on the results of the study, the researchers have several recommendations to further enhance the prototype. The prototype acceptance score (M=3.96) indicates a user-friendly design. Given the high acceptance rating, (1) the researchers suggest applying the system to existing greenhouse management systems to optimize data collection and leverage existing automated features. Additionally, as the sensors in the system are fully functional in reading various parameters, long-term testing with actual plant growth is recommended. However, due to its limited capacity, (2) a new design should be developed to house multiple plants and accommodate taller crops. This design should also prioritize ease of assembly, maintenance, and repair. (3) To improve prototype versatility the researchers recommend integrating additional sensors to provide more data for closely monitoring plant health, such as nutrient levels, CO_2 concentration, and even potential plant diseases. Moreover, (4) the researchers recommend granting users more control over parameters, scheduling, and automated operations to enhance the system's adaptability to individual needs and preferences.

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