Design and Development of Smart Farming Technology for Sweet Charlie Strawberry Using Atmega2560 Microcontroller Board

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Abstract. Rooted in antiquity and grounded upon time-honored traditions, traditional farming is an indispensable pillar supporting sustainable communities across generations. Yet, while lauded for its enduring virtues, it confronts reproach for its labor-intensive methodologies and the challenge of effectively navigating environmental variables, pestilence, and diseases. Strawberry (Fragaria × ananassa), revered as one of the world's most popular fruits, grapples with comparable difficulties aggravated by its innate susceptibility to water. Enter Smart Farming Technology, an automated greenhouse paradigm, poised as a promising solution in ameliorating the manifold obstacles afflicting both traditional agriculture and the cultivation of strawberries. Utilizing advanced techniques such as the sub-irrigation method from Taiwan, the automated greenhouse offers a solution to combat issues related to water sensitivity and water wastage in strawberry cultivation. This study demonstrates the successful integration of sensors, modules, and actuators, resulting in the development of an automated greenhouse system. Every device employed within the greenhouse has passed strict functionality tests, while every sensor has commendable accuracy rates, culminating in a rate of 97.22%. As a testament to the efficacy of Smart Farming Technology, strides have been achieved in urban strawberry cultivation, marked by the growth of strawberries, their larger size, and their resplendent crimson color. With Smart Farming Technology, a substantial advancement in cultivating strawberries within urban environments is made, significantly contributing to modernizing agriculture, promoting sustainability, and precise farming practices.

Keywords: *Smart Farming Technology; Strawberry; Automated Greenhouse; Sub-irrigation method; Quezon City University*

INTRODUCTION

Traditional farming, while fundamental for sustainable communities (Ba et al., 2018), faces criticism for its challenges in managing environmental factors such as sunlight, rain, and wind (Muimba-Kankolongo, 2018), as well as heavy manual labor, which can significantly impact crop yield (Islam, 2021). Cultivating profitable crops like strawberries poses additional challenges, requiring systematic control to avoid production issues (O'Sullivan et al., 2019), especially given the perennial nature of strawberries, which demands specialized expertise (Mubarakah et al., 2023). However, innovative horticultural technologies, like automated strawberry greenhouses, are appearing to address these challenges by facilitating the exchange of knowledge between experienced rural producers and new urban cultivators (Giua et al., 2022).

Furthermore, the QCU Center for Urban Agriculture and Innovation seeks to cultivate Sweet Charlie Strawberries in its greenhouse, exploring innovative urban farming methods. Previous attempts to grow strawberries in pots faced reliability issues due to constraints like limited root space and environmental sensitivity. University agriculturists acknowledge the need for more efficient methods but are wary of potential yield limitations with pot cultivation.

The integration of microcontrollers into greenhouse automation is revolutionizing traditional farming practices by reducing maintenance needs and improving plant growth rates through effective management of ventilation, shading, and irrigation variables (Hansen & Porter, 2006; Каландаров & Murodova, 2024). Furthermore, with the advent of the Internet of Things (IoT), real-time data from sensors is further enhancing farming efficiency (Idoje et al., 2021; Maraveas & Bartzanas, 2021; Khan et al., 2021).

Sub-irrigation technology is essential for irrigating strawberries with high precision, as it regulates water levels beneath the root zone, considering the plant's shallow root systems and susceptibility to drought (Benson et al., 2024). Coexistingly, greenhouse farming, with its precise temperature control, protection, and humidity adjustment, offers an alternative to traditional farming and contributes significantly to modernizing agriculture and promoting sustainability (Muimba-Kankolongo, 2018).

Several studies, including those conducted by Lara et al. (2019), Danita et al. (2018), and Astutik et al. (2019), have investigated monitoring-only systems for greenhouse environments, providing valuable insights into environmental conditions and offering flexibility. This study also involves monitoring environmental parameters, enhanced including control mechanisms for specific environmental variables, thereby endowing the system with intelligence. Through technological advancements and automation, such as intelligent greenhouses, crop production quality and efficiency are improved, facilitating precise farming practices and fostering sustainable agricultural development (Yuan et al., 2022).

This study aims to introduce an automated greenhouse specifically for cultivating strawberries in urban environments. Featuring four plots, each capable of accommodating 18 strawberry plants, the automated greenhouse supports a total of 72 plants. This study recognized the need for the QCU Center for Urban Agriculture and Innovation (QCU CUAI) to enhance urban farming methods, specifically for cultivating sweet charlie strawberries. This aligns with the QCU Research Thrusts and Priorities on contributing to developing a smart and competitive city, particularly on the development of prototype smart urban farming via an integrated use of data analytics, weather, heat, and water sensors.

METHODOLOGY

The study adopted the Prototyping Model, as delineated in Figure 1, for system design and development. Employing descriptive applied research methodology, the researchers synthesized and analyzed data pertaining to the existing smart farming technologies leveraging microcontrollers, sensors, modules, and actuators.

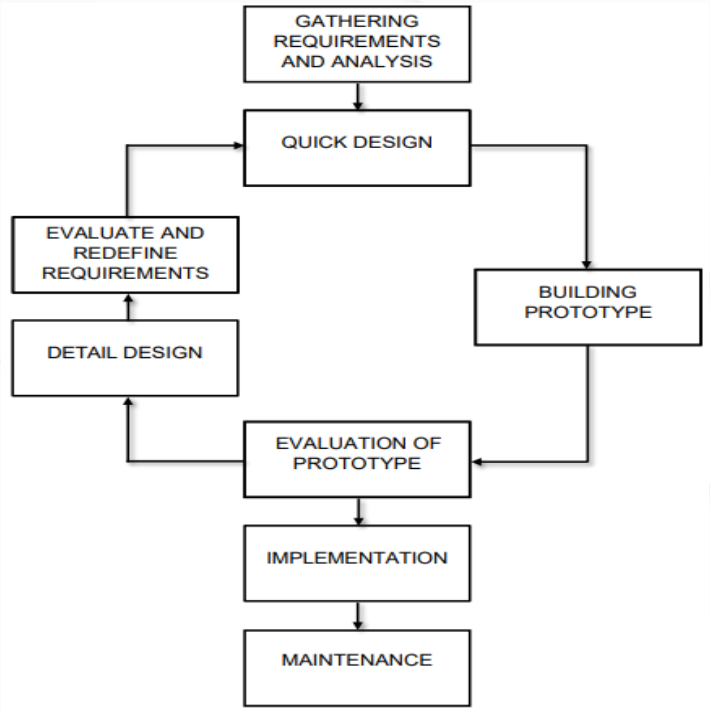


Figure 1: Prototyping Model

A. Requirement Analysis

To develop this study, the researchers engaged in an extensive process of gathering and analyzing relevant information concerning the intricacies and obstacles involved in strawberry cultivation within an urban environment, specifically within the QCU Center for Urban Agriculture and Innovation. This approach involved delving into various aspects such as environmental conditions, resource availability, technological advancements, and agricultural practices adapted to urban settings. By examining these factors, the researchers gained a thorough understanding of the challenges and

opportunities inherent in urban strawberry cultivation, thereby conceptualizing the development of effective solutions.

B. Quick Design

Figure 2 showed the conceptual framework employing the elements of Input, Output, and Process as the directional schema. Environmental parameters like temperature, humidity, light intensity, and soil moisture were monitored and controlled using sensors and actuators connected to an ATmega2560 microcontroller. The system adjusted ambient conditions by operating fans and controlling shade net movement based on sensor readings. Sub-irrigation technology managed soil moisture levels using a water source, pump, and porous pipes. A 220-volt power supply was used, converted to 12 volts for electronic devices. An ESP-01S Wi-Fi module enabled internet connectivity for IoT applications. The connection of each component was further illustrated in Figure 3, depicting the intricate integration of sensors, actuators, and modules.

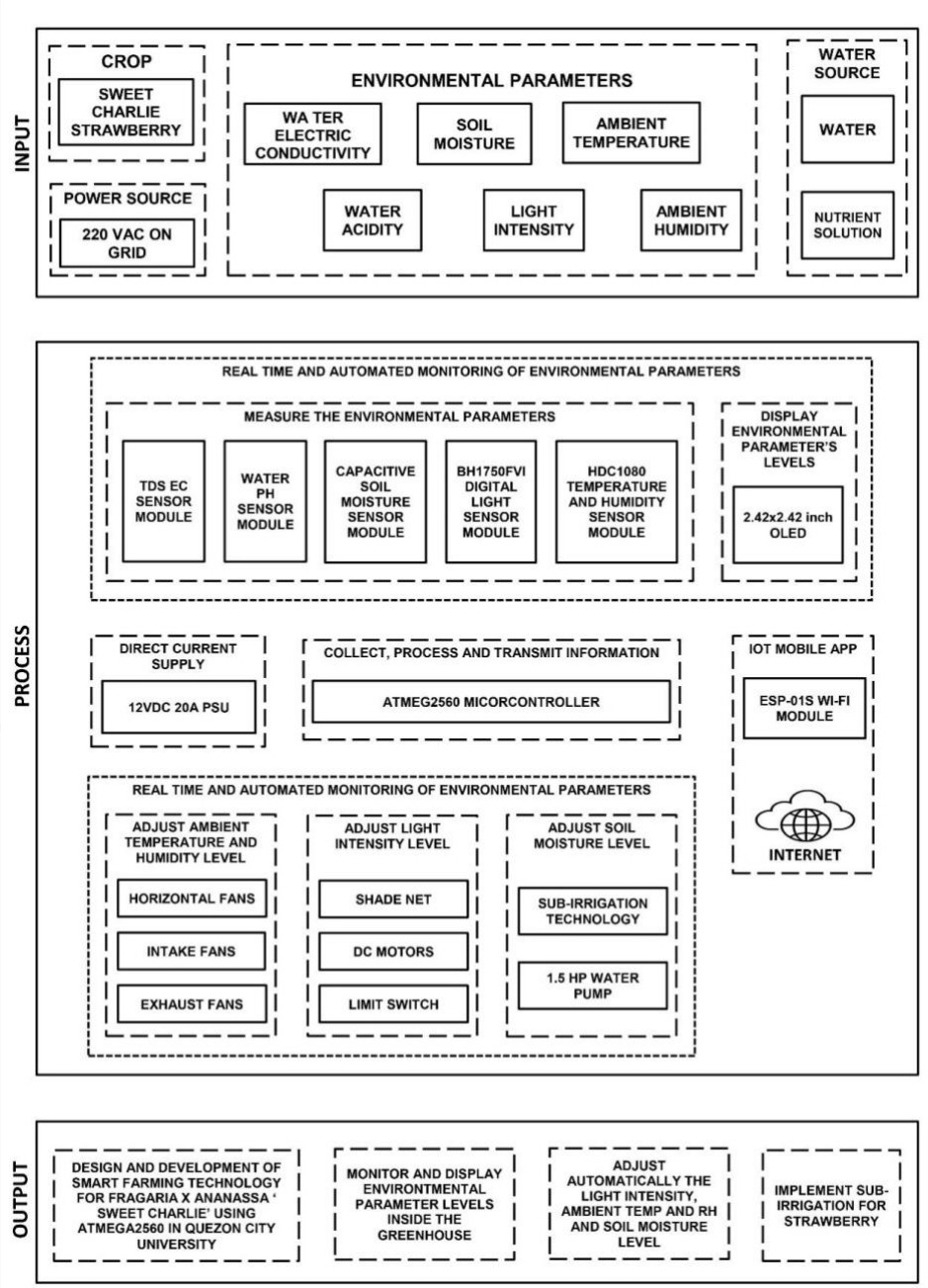


Figure 2: Conceptual Framework– Smart Farming Technology

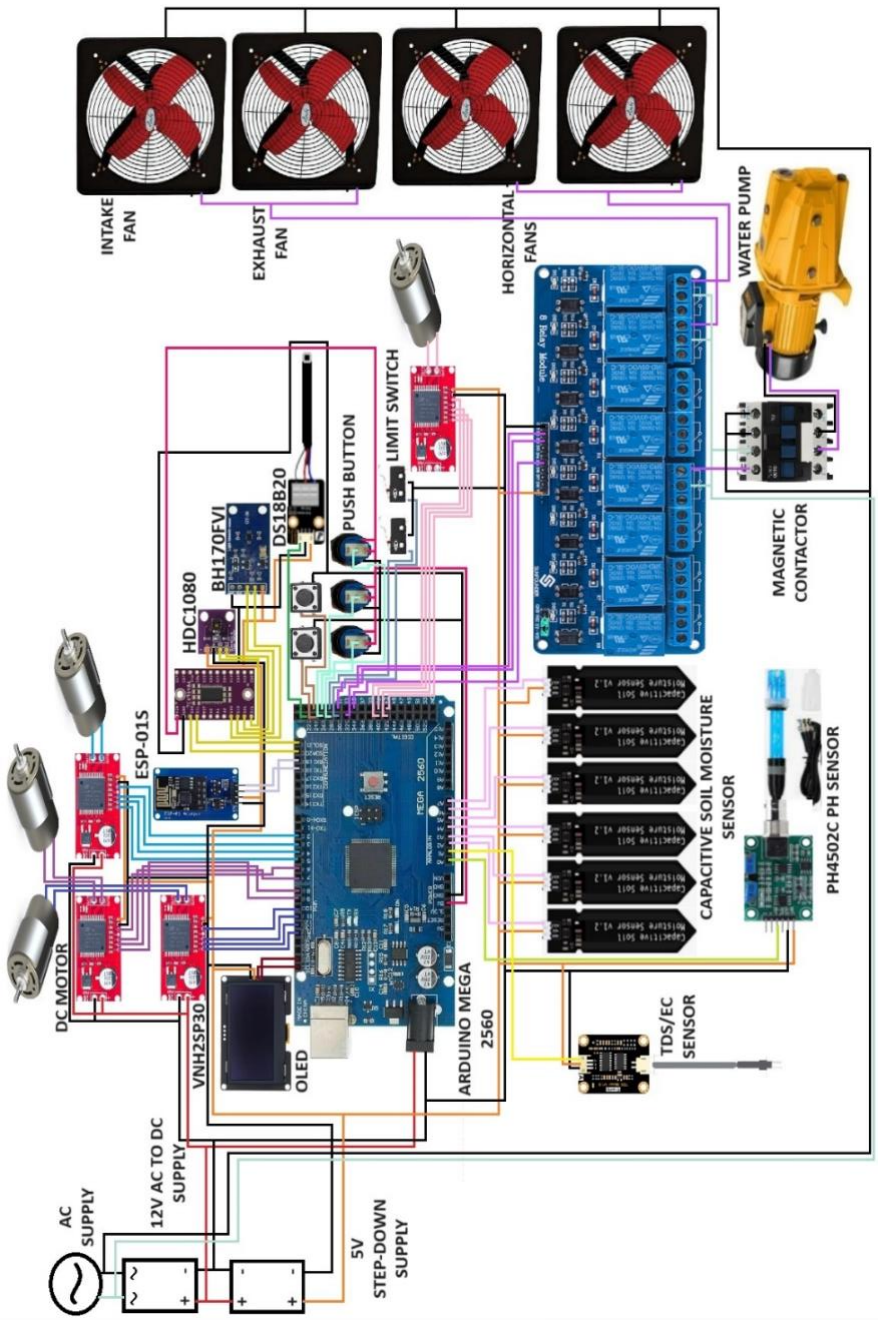


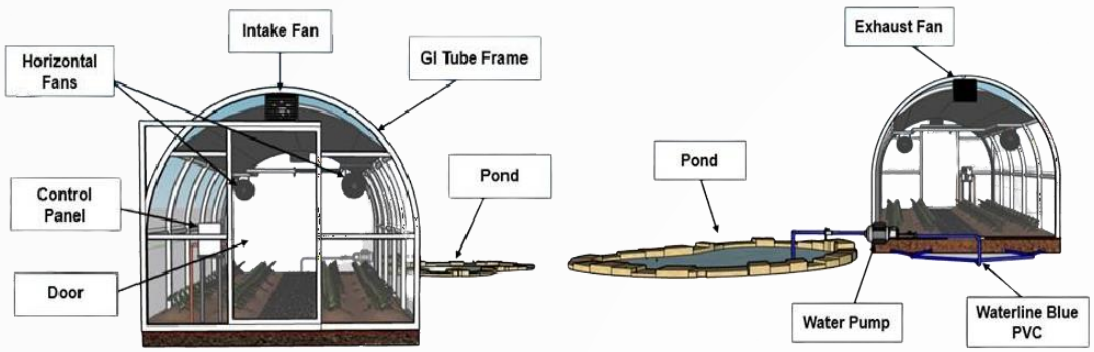
Figure 3: Pictorial Diagram– Smart Farming Technology

C. Building and Evaluation of Prototype

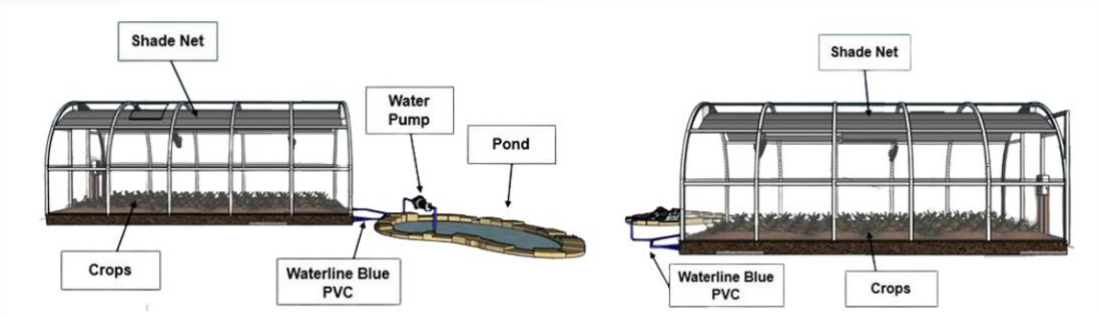
While Figure 4 provides the isometric view of the automated greenhouse, each of the designs shown in Figure 5 adopted the cross-ventilation method, employing four fans for optimal cooling within the greenhouse. This method

guaranteed optimal thermal conditions a remarkable 70% of the time, outperforming conventional approaches. In specific climates, it reduced temperatures by up to 1.5°C and achieved ventilation rates 14 times higher than alternatives (Jiang et al., 2023). Furthermore, appropriate covering materials and shading techniques could be selected and applied in temperate and warm climate regions, particularly where spring and summer solar radiation levels were notably high (Puglisi et al., 2023). Consequently, the utilization of a shade net was also included to regulate the light intensity experienced by the strawberries.

Figure 4: Isometric View of the Greenhouse Structure



(a) **(b)**



(c) **(d)**

Figure 5: Design of Automated Greenhouse with labeled hardware components: a) Front View b) Back View c) Right View d) Left View

Figure 6 further illustrated that the greenhouse automation incorporated advanced sub-irrigation technology to precision-manage watering within its boundaries. This approach was customized to guarantee precise irrigation for sensitive plants, particularly strawberry crops.

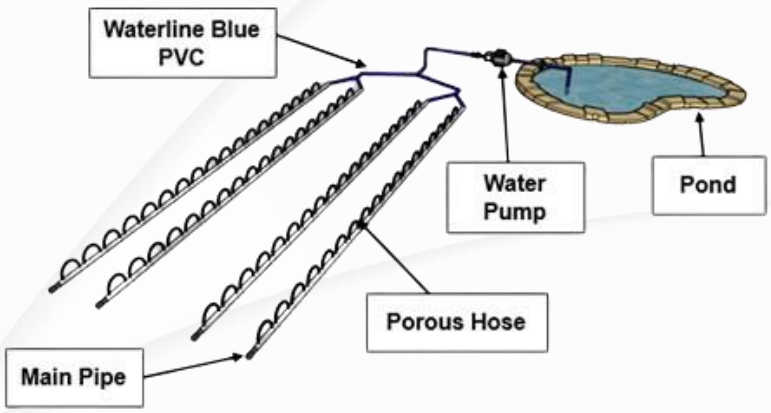


Figure 6: Taiwan – Sub-irrigation Technology

D. Implementation and Testing

The testing phase entailed a comprehensive assessment scrutinizing various system performance aspects. It involved verifying sensors' accuracy and evaluating actuators' responsiveness, particularly for automation processes such as sub-irrigation and environmental control. To enhance the implementation process, urban agricultural experts at QCU-CUAI actively participated, contributing invaluable insights and feedback based on their extensive expertise. Their involvement aimed to ensure that the Smart Farming Technology aligned perfectly with the nuances of urban agriculture, optimizing conditions for Sweet Charlie Strawberry cultivation.

RESULTS

Following the presentation of the completed greenhouse, Figure 7 offers a glimpse into the actual interior. This provides a visual representation of the system's functionality and design.

(a) **(b)**

Figure 7: Actual photo inside the Automated Greenhouse: a) Folded Shade Net b) Expanded Shade Net

Following the completion of the automated greenhouse, the researchers executed a series of tests to evaluate its reliability. The researchers conducted functionality tests (refer to Tables 1 and 2) to provide valuable insights into the system's ability to maintain optimal environmental conditions necessary for the successful growth of Sweet Charlie Strawberries. With the ATmega2560 microcontroller overseeing operations, the effectiveness of various components and sensors in regulating temperature, humidity, light, irrigation, and soil quality was evaluated.

Table 1.
Summary of Completed Functionality Test for Actuators and Modules

TEST TYPE	NO. OF FUNCTIONAL REQUIREMENTS	TEST STEP	REMARKS
Atmega2560 microcontroller	4	4	PASSED
Horizontal Fans	7	7	PASSED
Intake Fan	7	7	PASSED
Exhaust Fan	7	7	PASSED
DC Motor	7	7	PASSED
Limit Switch	4	4	PASSED
Water Pump	7	7	PASSED
Magnetic Contactor	4	4	PASSED
Thermal Overload Relay	2	2	PASSED
ESP-01S Wi-Fi Module	4	4	PASSED
Power Supply 220 ACV Input/12 DCV Output	2	2	PASSED
2.42 x 2.42-inch OLED	7	3	PASSED
Fan Switch	7	4	PASSED
Net Switch	7	4	PASSED
Water Pump Switch	7	4	PASSED

Table 2.
Summary of Completed Functionality Test for Actuators and Modules

SENSOR	POOR	GOOD	SATIS-FACTORY	VERY SATISFACTORY	REMARKS
Capacitive Soil Moisture Sensor				✔	PASSED
DS18B20 Temperature Sensor				✔	PASSED
Analog TDS Sensor				✔	PASSED
pH Sensor				✔	PASSED
BH1750F VI Digital Light Sensor				✔	PASSED
HDC1080 Temperature and Humidity Sensor				✔	PASSED

Furthermore, to evaluate the accuracy and reliability of the sensors used in the greenhouse system, the researchers conducted tests to measure their performance. Table 3 presents the accuracy percentage of each sensor. It unveils their remarkable precision in managing environmental factors. The collective accuracy percentage of 97.22% across all sensors attests to the

dependable nature of the automated greenhouse system. From an objective standpoint, the outcomes reflect the effectiveness of the system in facilitating optimal conditions for crop growth. This is evidenced by the widespread presence of Sweet Charlie crops (refer to Figure 8) and minimized manual intervention. Through efficient management of watering, shading, and temperature control, the system demonstrates its capability to maintain conducive growth environments. Despite occasional challenges such as high light and temperature levels, the general success of crop growth serves as compelling evidence of the efficacy of automated strawberry greenhouse.

Table 3.
Overall Accuracy of the Sensors of Smart Farming Technology

Accuracy Test	Accuracy Percentage
Reading of Digital Light Intensity Sensor	97.44%
Reading of HDC1080 Sensor (Temperature)	95.25%
Reading of HDC1080 Sensor (Relative Humidity)	99.32%
Reading of Capacitive Soil Moisture Sensors v1.2	97.07%
Reading of Liquid pH Sensor	96.57%
Reading of Analog TDS Sensor	97.68%
Reading of Sensors from 7am-10am	97.22%
Reading of Sensors from 10am-12nn	97.42%
Reading of Sensors from 12nn-4pm	96.46%
Reading of Sensors from 4pm-7pm	98%
OVERALL ACCURACY PERCENTAGE	**97.22%**
VERBAL INTERPRETATION	**VERY SATISFACTORY**

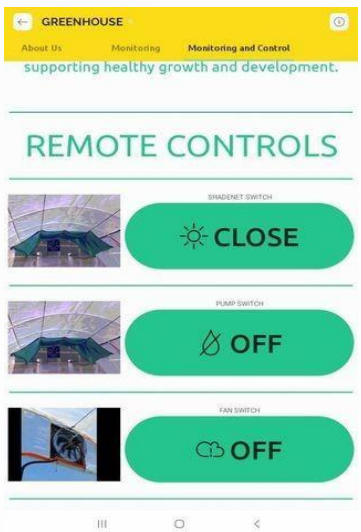
Figure 8: First yield of strawberries inside the Automated Greenhouse

The researchers also conducted portability tests to assess the system's mobility and remote monitoring capabilities. Table 4 shows the successful passage of these tests. The tested devices involve a Mobile Phone, Tablet, Laptop, and a computer. The system also has passed the Operating System encompassing Android, IOS, Windows 11, as well as popular browsers, such as Microsoft Edge, Chrome, and Mozilla Firefox. This assessment not only affirms the ability of the system to operate across a spectrum of devices and platforms but also highlights its accessibility and user-friendliness. Through strict testing involving ten phones, laptops, two tablets, and a computer, the portability of the system was validated. It is a demonstration of the system's capacity to facilitate remote control and real-time monitoring of Sweet Charlie strawberries from any location and at any time. Such functionality empowers users with exceptional convenience and flexibility, irrespective of their device preferences or geographical constraints.

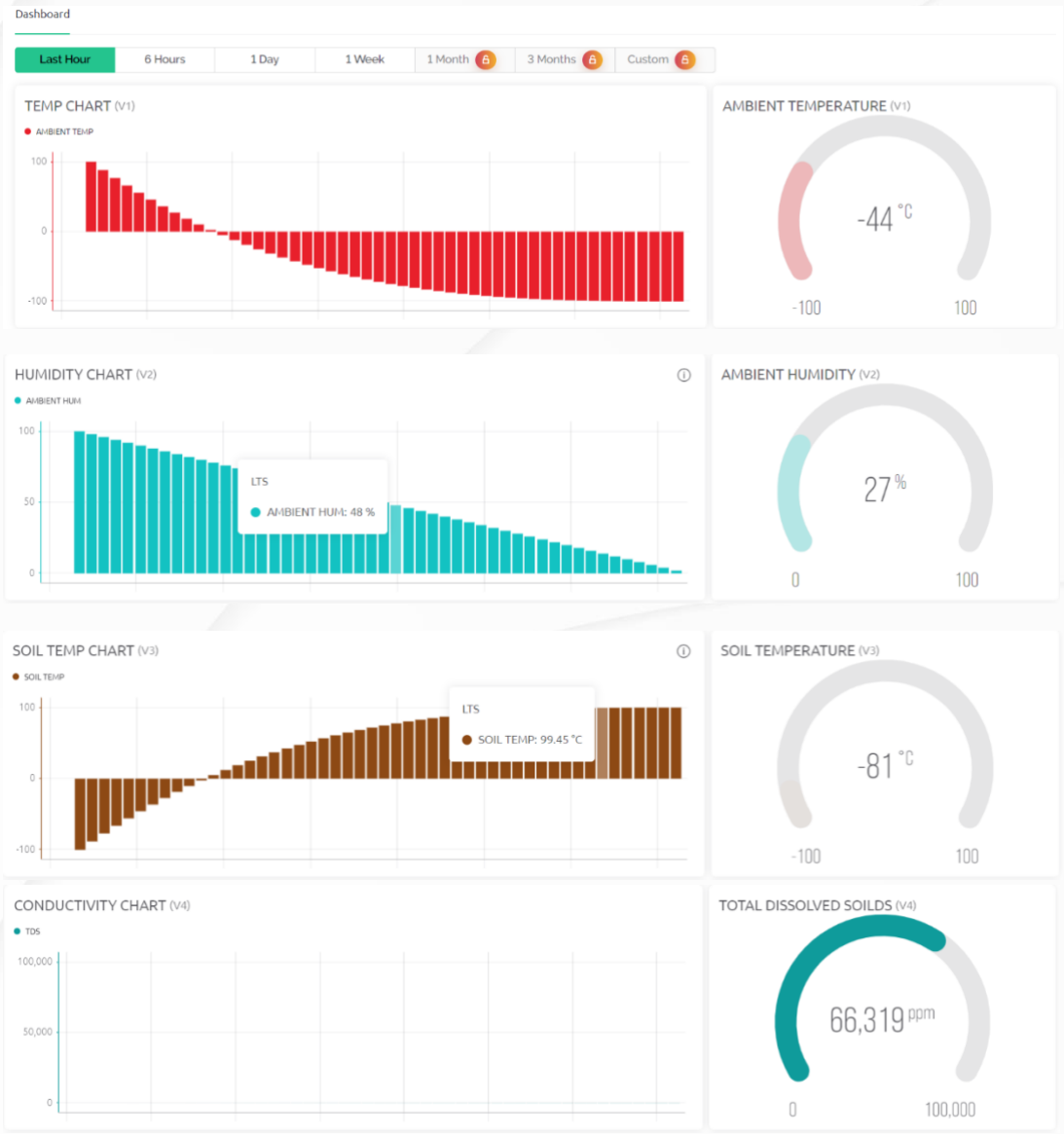
Table 4.
Portability Test

Device	PASSED	PASSED	PASSED	PASSED
	 **Phone**	 **Tablet**	 **Laptop**	 **Computer**
Operating System	PASSED	PASSED	PASSED	
	 **Android**	 **iOS**	 **Windows 11**	
Browser	PASSED	PASSED	PASSED	
	 **Microsoft Edge**	 **Google Chrome**	 **Mozilla Firefox**	

Figure 9 visually illustrates the system's portability. It shows the capacity for remote control and real-time monitoring of Sweet Charlie strawberries from any location and at any time. These tests collectively underscore the reliability of the automated greenhouse system in facilitating efficient and remote-controlled cultivation practices.



(a)



(b)

Figure 9: Smart Farming Technology Monitoring and Control using Blynk Application: a) Remote Controls, tablet interface perspective b) Monitoring of some parameters, laptop interface perspective

DISCUSSION

The result of this study demonstrates that the integration of sensors to monitor and adjust critical parameters, such as nutrient levels, pH, soil moisture, ambient light, temperature, and humidity, assures the maintaining of ideal growing conditions, enhancing crop yield to unprecedented levels. With the greenhouse environment governed by automated systems with accuracy rates— nearly 99% for light intensity, 97.51% for temperature readings, an average of 97% for soil moisture sensors, and an overall rate of 97.22%, this study demonstrates the transformative potential of Smart Farming Technology. Also, by the integration of the Blynk IoT application to have remote accessibility to the amassed data, it shows a capability to allow a remote oversight greenhouse condition, which enables flexibility and systematic management.

It is also important to note that the thorough approach of this study to integrating sensors and automated systems not only enhances crop yield but also lays a foundation for advancing scientific research in agricultural practices. By providing detailed insights into the dynamics of environmental parameters and their impact on crop growth, this study opens avenues for deeper investigation and analysis. Researchers can leverage the data collected and methodologies employed in this study to conduct further experiments, refine existing models, and develop new techniques for optimizing agricultural productivity. Thus, this study not only comes up with practical applications in farming but also enriches the scientific understanding of plant biology and ecosystem dynamics for innovation and progress in agricultural research.

The system could only automatically control the soil moisture, light intensity, ambient temperature, and relative humidity inside the greenhouse. Manual control with the override feature is meant to be a fallback if the automation feature triggers unneeded actions. Moreover, the design can monitor

ambient temperature levels, relative humidity, light intensity, soil moisture, pH, and electric conductivity. The design of the system also includes monitoring and controlling the whole system using the Internet of Things (IoT).

CONCLUSION

From the vast testing and calibration conducted, the outcomes underscore the system's effectiveness in maintaining optimal conditions for the growth of sweet charlie strawberries, exemplified by its flourishing presence. Through precise watering, shading, and temperature management, the automated greenhouse demonstrates its capability to sustain favorable growth environments conducive to plant development.

Based on the greenhouse automation and control system development, recommendations emerge for enhanced performance and user experience. It is advisable to use industrial-grade equipment, select appropriate water pump ratings, and integrate wireless technologies for simplified management. Furthermore, the adoption of machine learning algorithms can continuously optimize system parameters while exploring renewable energy sources can improve sustainability.

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Funding: This research received no outside funding.

Author Contributions: Caranyagan: Project Idea Developing. Validating Ideas. Facilitating Collaborations. Assigning Tasks. Navigating and Solving Team and Project Difficulties. **Destura:** Data Gathering. Technical Writing. Idea Analyzing. Interpreting of Information. Content Curating **Gacias:** Programming. Application Building and Designing. System Developing. **Noche:** Greenhouse Space Layout Planning. Arrangement and Fitting of Devices. Fixture Organizing. **Quimiguing:** Documentation and Report Writing. Information Organizing. Text Editing. Content Curating. **Vicente:** Inspecting Hardware Materials. Verifying devices, equipment, and components.

Advisers: Ligayo: Research Conceptualization and Validating Research Instrument. Interpreting data results and discussions. **Catchillar:** Technical Mentoring and Supervising. Facilitating Collaborations.

Acknowledgments: The researchers extend their heartfelt gratitude to Quezon City University and all faculty members for their support and guidance throughout this study. Special appreciation is also directed towards the QCU Center for Urban Agriculture and Innovation (CUAI), particularly Dr. Romel Sevilla and the dedicated agriculturists. Their expertise and collaboration have been invaluable in advancing this study.

Conflict of Interest: The researchers affirm that no conflicts of interest are associated with this research's publication, providing the integrity and impartiality of the study's findings.

Ethical Statement: All subjects gave their informed consent for inclusion in the study before participating.

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