Turkish Online Journal of Qualitative Inquiry (TOJQI)
Volume 12, Issue 6, June 2021:593-609

Research Article

IoT-based Automated Greenhouse with Monitoring and Control using MQTT Protocol

Jackılyn B. Baccay[1], Clarıssa P. Vıcente[2], Marıbel T. Bravo[3]

Abstract

The study was conducted to find ways to automate greenhouse irrigation and controlling the environment. The microcontroller was programmed in such a way that controls the ventilator fan and electromechanical gate valve based on the following conditions: (1) through web-based, the user can manually turn on/off using any internet-connected device (2) a pre-determined time of schedule as determined by the personnel, and (3) when a pre-determined temperature for the ventilator fan and soil moisture content of crops is obtained. The data collected by the sensor node was saved in the external drive in .csv format to serve as backup. The data was sent via the Message Queue Telemetry Transport Protocol for graphical presentation via the Wi-Fi module. The respondents consisted of PSAU Project staff/laborers, Agriculture experts, IT experts, and Students. In terms of functionality, dependability, usability, and connectivity, the designed system is satisfactory. As a result, the end-users were convinced that the built system could be used and customized in their projects and areas of responsibility.

CCS Concepts

Hardware → Hardware, communication hardware, interfaces and storage, Sensor devices, and platforms

Keywords: *Automated Greenhouse, IoT-based, Sensors and Actuators, Microcontroller, Web-based Application*

[1] Pampanga State Agricultural University, jackilyn_baccay@psau.edu.ph
[2] Baliuag University, clarissavicente@baliuagu.edu.ph
[3] Pampanga State Agricultural University, maribel_bravo@psau.edu.ph

Introduction

The advent of technology in the 21st century has continued to rise to make a difference in all fields, such as in the sector of education, business, and agriculture. Computers are being utilized in the field of information technology to store, retrieve, transmit and manipulate data towards achieving efficiency. One of today's technology trends is the Internet of Things (IoT), an interconnection of physical devices which are embedded with electronic software, sensors, actuators that make data transfer possible [1]. The agricultural sector is one of the benefactors of integration from the IT industry in the pursuit of change towards efficiency and success. It interacts with several other industries to provide basic subsistence among the entire population of a certain country.

Agriculture is indisputable as an important aspect of any sovereign nation's economy. Since early civilization, it has been considered one of the principal jobs of man, and the traditional way of farming can still be seen today [2]. In this aspect, agriculture is the primary source of food, income, and employment for the rural population. However, according to an article published by Business World [3], the Philippines has been identified as one of the country's most at risk from environmental change, as well as the fifth most affected by changing climatic patterns in recent years. El Niño climate cycles, which are characterized by reduced rainfall and greater temperatures, have become a more common occurrence in recent years, posing a threat to crop harvests. Climate change's effects on ecosystems are already severe and broad, and ensuring food security in the face of climate change is one of humanity's most difficult issues [4]. As a result, developing climate-smart technologies that are available and accessible to farmers is vital and urgent in order to integrate resilience into agricultural production systems [5].

The Alternative Low-Input Agriculture System (ALIAS) Research and Development Center at Pampanga State Agricultural University (PSAU) is one of several R&D programs under the university's Research, Extension and Training Office that promotes organic and sustainable food production systems through farm/field demonstrations and piloting. The ALIAS R&D center conducts research and development, extension and training, linkage and promotional efforts, and other activities to support the PSAU research agenda, which focuses on food security and production to meet the demands of an ever-growing population. The facility is supported by a number of organizations. Growing diverse crops that require regulated watering or irrigation is one of ALIAS's research undertakings. Crop characteristics such as variety, development stage, plant population, and growing season all influence water requirements [6]. The majority of research personnel's responsibilities include monitoring greenhouse environmental conditions and maintaining the water content of soils where laboratory crops are grown.

Currently, there is no existing computerized and automation system in managing the greenhouse in PSAU ALIAS. In this manner, one of the tedious activities of ALIAS is directing the water supply of their yields, recording and retrieval of important information, and monitoring and control of environmental conditions inside the greenhouse. In this light, the proponents has developed an automated greenhouse for PSAU ALIAS R&D Center that aims to control the appropriate environmental condition and amount of water provided by the water irrigation facility depending upon the water necessity of the crop inside the greenhouse. The proposed study utilized the Internet of Things (IoT) and Message Queue Telemetry Transport (MQTT) protocol for the monitoring and control features while the automation processes were done using microcontrollers and Raspberry pi.

1.1 Objective of the Study

The study's major goal was to create an IoT-based Automated Greenhouse for PSAU ALIAS R&D Center with monitoring and control utilizing the MQTT protocol.

Specifically, the proponents proposed to achieve the following:

1. to design an IoT-based Automated Greenhouse for ALIAS R&D Center equipped with automatic irrigation and monitoring and controlling of climatic condition;

2. to develop the system with components capable of:

a. recording and gathering relevant data for ALIAS greenhouse;

b. automatically saves data log for backup;

c. displaying on the screen real-time data from greenhouse characteristics such as soil moisture, temperature, and relative humidity;

d. allowing remote monitoring of temperature, heat index, relative humidity, and soil moisture;

e. providing a user interface to allow the user to modify the irrigation and ventilation processes; and

3. to test and evaluate the system for applicability by IT experts and End users using ISO 25010 standard.

Review of Related Literature and Studies

2.1 Agricultural Related Research

The study entitled "Progress Report on Energy Conservation for Greenhouse Research" tended to the prescribed procedures and the manners in which Mediterranean yield producers can decrease the different reasons for pressure exerted by atmosphere conditions in the development of harvests during the pervasive warm season. The investigation adopted the utilization of technology essential in the training and education of crop producers. The study is among the many existing research and developmental undertakings directed by a few research facilities and extension services of the nations in the Mediterranean [7].

The Pampanga State Agricultural University Alternative Low Input Agriculture System facility pays attention to researches involving organic crops such as lettuce, tomato, eggplant, pepper, and okra. The current investigation focused on automating the data acquisition, recording, watering, and ventilating activities of personnel in the PSAU Greenhouse.

Humid regions have unpredictable rainfall, which presents distinctive technical issues. Still, water system research has not been given priority in humid regions, and it is in the dry areas where most irrigation innovation has been advanced.

Research information, especially for greenhouses, ought to be made accessible to farmers and agriculturists. In any case, a few studies in the field of agriculture had communicated the inadequate or constrained inquires in the said field of study. The office of PSAU ALIAS R&D Center, through this study, can possibly add to the research endeavor which is considered noteworthy in agriculture.

2.2 Greenhouse and Irrigation System

Elaydi [8] described the usage of a modern-day water system in greenhouses in the Gaza Strip, where water was delivered drip by drip to the root zone of the plants, maximizing the use of available water. Farmers in Gaza are currently adopting drip irrigation with manual control. This procedure consumes more water in certain cases, and aberrant irrigation results in dry harvests in others. Water deficiency can cause fruit to mature more slowly and be lower in weight. This problem can be handled by installing an automatic drip irrigation system that only water crops when they need it.

On the other hand, Eaton & Perez [9] conducted an experiment in an open field that aims to obtain the highest fruit productions using an irrigating method with high frequency. The said experiments acquired comparative responses pertaining to high fruit productions in relevance to proper irrigation. Too frequent watering diminished vegetative growth and yield in the experiments on tomato and pepper. The vegetative development reached, and the positive response to high irrigation frequencies should be related.

Also, Buttaroa et al. [10] mentioned that the crucial factor for acceptable outcomes is selecting suitable water potential set-points in accordance with the season of cultivation. The factors such as the progressive effects of precise and appropriate water stress on the quality of fruits ought to be given utmost consideration.

Water management and practices in greenhouses are a significant factor in crop yield. Researchers in the field of utilizing greenhouses in countries with water shortage had been emphasized in various researches. The management of crop watering in greenhouses is significant to efficient crop growth. Also, the increased recurrence of watering resulted in lowering crop harvest and inefficient water consumption in greenhouses. This exploration is anchored on efficient water utilization through watering just when soil dampness had set off the requirement for a water system. Additional expense in the establishment of automated greenhouses may require a large amount of money; however, it aimed to lead towards more efficient water consumption and better yield production.

2.3 Greenhouse vegetable production

Montero et al. [11] pointed out that one of the strategies is cultivating vegetables and plants in greenhouses, avoiding the need for the conditions on the outdoor climate. The other solution is cultivating plants in more than one location with variances in harvesting periods, supporting a non-stop and efficient supply to markets all throughout the year.

It is now a reality to produce crops in greenhouses throughout the world. The level of complexity and technology is dependent on the climate situations in the local region and the socio-economic atmosphere [12].

The demand for a year-round supply among consumers of quality agricultural products had increased. It thereby triggered the need for efficient production offered by the greenhouse industry. The production of agricultural products through greenhouses is a growing industry throughout the world. It is concluded by research undertakings that greenhouse crop production will soon take a major part in the unpredictable climatic environment as a means for crop intensification leading to production optimization through water-use efficiency in an environment experiencing scarcity in water. It will also provide better control of agricultural product quality and its safety.

2.4 Asteraceae Crops

Baudoin et al. [13] stated that in recent decades, producing vegetables in a protected environment like a greenhouse is a progressing agricultural sector in most Mediterranean countries. Both the areas of cultivation and production have consistently increased. Asteraceae crops are one of the largest plant families. These crops include lettuce, mustard, pechay, and the like.

Asteraceae and Solanaceous crops, particularly lettuce, mustard, pechay, herbs, tomato, pepper, and eggplant, are those that are currently planted in PSAU ALIAS R&D Center greenhouses. Such kind of crops is significant to be part of agricultural research. The studies both in China and the Mediterranean, as mentioned above, had accounted for the massive consumption of Asteraceae and Solanaceous crops.

2.5 Integration of IoT and MQTT Technologies for Sustainable Agriculture

By bringing new technological elements, the Internet of Things is expected to help advance the farming and agricultural industries. Ray [14] offered a complete evaluation of IoT adoption for innovative agricultural applications in his analytical report. According to the report, an IoT-based agricultural framework offers the benefit of a full-fledged integration of agriculture with IoT. Meanwhile, Tzounis et al. [15] examined how rising food demand, both in terms of quantity and quality, has increased the need for agricultural intensification and industrialization. The "Internet of Things" (IoT) is an extremely encouraging collection of technology that is capable of providing a wide range of solutions for agricultural modernization. The most widely used protocols for IoT and Machine to Machine (M2M) settings, such as MQTT, CoAP, and LWM2M, are all based on the Transmission Control Protocol/Internet Protocol (TCP/IP) protocol suite at the moment.

The above statements are presented to illustrate the various application of IoT and MQTT technology in different areas. The researchers has considered the usability and popularity of this technology as an advantage to create an automated greenhouse that will ease the work of PSAU ALIAS personnel and have a better crop yield. This project would somehow provide solutions or lessen the burden of farmers in dealing with environmental change.

2.6 Automated Greenhouse System with Different Sensors

Greenhouses are a complicated system. Any significant changes in one environment parameter, such as the plant development cycle, can have a negative impact on another environment parameter. As a result, continual monitoring and adjustment of these environmental variables will ensure the highest possible harvest output. Temperature, humidity, and water flow rate are the three most prevalent variables in crop production that most growers pay attention to. A greenhouse, according to Vu [16] in his paper "Automated Wireless Greenhouse Management System," allows growers to cultivate plants in regions where the climate would normally be unsuitable for plant growth. Crop yields are unaffected by geographic location or season. The greenhouse also serves as a shelter for the plants, shielding them from the elements, insects, and diseases. It allows the plants to grow in perfect conditions, enhancing their growth potential. Crop management quality, where a good administration scheme is defined by the quality of the data gathered from the greenhouse climate, has a significant impact on yield quality and efficiency.

It was also the goal of the present study on the automated greenhouse to contribute to the body of knowledge of agricultural research by providing potential stored data to other researchers. Accessibility of stored data is one of the thrusts of the locale, PSAU ALIAS R&D Center. This is towards the availability of greenhouse research here in the Philippines, which is already being conducted in other countries such as India, China, and the Mediterranean regions.

2.7 ISO 25010

The ISO 25010 software standard is a global standard that aids in the development of a sound foundation for software evaluation. This standard is widely adopted to encompass a wide range of models and metrics. It is separated into six sub-key traits and attribute. One of the key goals is to use the formulation and evaluation of quality requirements to influence the development of software products. Both computer systems and software products can benefit from the model.

Research Desıgn And Methodology

3.1 Research Methodology

The IoT-based Automated Greenhouse was developed using Descriptive, Experimental, and Agile Modeling. The descriptive method was chosen because it accurately depicts the nature of the situation at the time of the investigation [17]. The descriptive research process entails more than just data collection and tabulation. It involves a component of interpreting the meaning of what is shown. Furthermore, the research is exploratory in character because experiments were undertaken to test various sensors and data gathering devices in order to define the automated greenhouse's feedback mechanism. Electromechanical devices such as gate valves and relays were also put to the test in order to create a water dispensing control system. A suitable microcontroller module was found, and a program was created to act as a bridge between the sensors and electromechanical devices and mobile devices or personal computers.

3.2 Respondents of the Study

The following respondents were chosen using purposive sampling to evaluate the system: Agriculture experts, Project staff (laborer), Agriculture students, IT experts and students.

There are five PSAU Project staff who operate the activities (such as irrigation) in the different nurseries, five Agriculture experts who conducted their research and projects at the

ALIAS greenhouses, and ten BS Agriculture fourth year students major in crop science who are currently enrolled in PSAU. The five project staff were laborers in different PSAU projects such as ALIAS, Nursery and Horticulture, Bamboo Production, and Mushroom Production. The Agriculture experts were faculty members from the College of Agriculture Systems and Technology (CASTech). On the other hand, IT experts are experienced practitioners in the field of Information Technology. Five professionals evaluated the framework to test its level of consistency as indicated by the ISO 25010 quality item attributes. These experts were knowledgeable and had a profound experience in their respective fields, which include hardware and software development. The ten IT students were also identified as respondents to evaluate the system.

3.3 Research Locale

The study was conducted at the PSAU Alternative Low-Input Agriculture System (ALIAS) Research and Development (R&D) Center. The ALIAS R&D center undertakes activities including research and development, extension and training, linkaging and promotional activities, etc. The PSAU ALIAS greenhouses are designed with a manual drip irrigation system and are being operated by ALIAS personnel.

3.4 Research Instruments

The research instruments used in the study were enumerated below.

a. Data Gathering

Interviews were conducted with the ALIAS director, farmers, and agriculture professors. The researchers also completed a number of online activities related to system programming and automation, including watching video classes and reading relevant publications and journals. End-user interviews were also conducted to collect their feedback and perspectives on the system. There was also some canvassing for hardware resources, such as visiting hardware-buying websites on the internet. Finally, the researchers created a questionnaire to see how people reacted to the completed project in comparison to the hypothesis under consideration. In terms of functionality, usability, dependability, and connection, the software evaluation tool was based on the ISO 25010 quality standard.

b. Statistical Treatment of Data

To make data collection and tabulation easier, computerized software was deployed. The study's results and findings were calculated using the frequency percentage and weighted mean. A frequency count was performed to determine the number of responses. The weighted mean is identical to the arithmetic mean (the most common type of average), except that some data points contribute more than others to the final mean.

$$x = \sum fx/n$$

where:

x = arithmetic mean; n = total frequency; and

f = frequency; x = responses

On a scale of one to five, with five being the highest and one being the lowest, the rating was done. The researchers used a Likert scale based on the following criteria: system functionality, reliability, usability, connectivity, and user interface (for IT experts), as well as the ability to monitor and control, conserve water and electricity, be efficient in plant growth, reduce workload, and apply to any type of crop (for Agriculture experts and project staff).

Table 1. Rating scale used

Range	Rating	Verbal Interpretation
between 4.51 and 5.00	5	Strongly Agree
between 3.51 and 4.50	4	Agree
between 2.51 and 3.50	3	Slightly Disagree
between 1.51 and 2.50	2	Disagree
between 1.00 and 1.50	1	Strongly Disagree

c. Evaluation Criteria

The developed system was tested by the selected IT experts and the end-users. The main research instrument used in the study was the questionnaire developed based on the ISO 25010 quality standard. The ratings and technical comments, and suggestions from the experts were used to further enhance and refine the developed system.

3.5 System Development Methodology

Agile Modeling was used because of its flexibility compared to conventional modeling methods making it suitable for a fast-changing environment. The Agile Model shown in Figure 1 illustrates how the researchers arrived at the final output of the IoT-based Automated Greenhouse for PSAU-ALIAS.

The phases start from Project Initiation as part of the Requirement Analysis, followed by System Design, Implementation, Acceptance, and ended by Deployment, when the project achieved an acceptable level of agreement from the users. Each phase worked with testing such as unit, integration, and acceptance to make sure that the software product meets the required specifications. The following are the details of each phase.

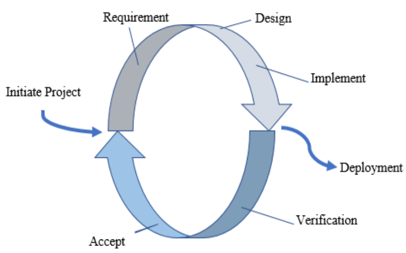

Figure 1. Agile Model

a. Requirements

The first phase involved gathering requirements where the researchers had to gather detailed information on expectations of the users of the system output. The researchers has conducted observations and interviews with the ALIAS personnel and Agriculture faculty members.

b. System Design

The second phase involved the preliminary layout of the specification of the proposed system based on the information gathered during the first phase. The system design also involved understanding and detailing the complete hardware and software setup for the product under development.

c. Implementation

In this phase, all the hardware such as microcontroller and sensors were already installed and developed based on the design. All the wirings needed to interconnect the components of the system on the breadboard were installed. The coding for the device that governs the overall performance of the system was set up. This phase took much time because errors and unexpected problems occurred during the configuration.

d. Verification

In this phase, the developed IoT-based Automated Greenhouse was verified to ensure that the sensors could collect and send data to the microcontrollers and server.

e. Acceptance

In this phase, the target users evaluated the primary output, noting its strengths and weaknesses and retaining what was required in the system, and discarding those that were not necessary. The completed prototype was tested and validated by the selected IT experts, Agriculture experts, and project staff.

f. Deployment

After the project underwent testing, it was deployed, and user acceptance testing was also done based on the locale's expectations. The developed system was demonstrated to the users as evidence for the project completion.

3.6 Hardware Design

The proposed IoT-based Automated Greenhouse consists of 5V DC Power Supply, Channel Relay, MQTT, Wemos D1 mini microcontroller, temperature and humidity sensor, soil moisture sensor, solenoid gate valve, water pump, and raspberry pi. The hardware design started with the configuration of the MQTT protocol to allow the device to communicate with each other. The soil moisture sensor and DHT22 sensor that was connected with Wemos D1 mini microcontroller were interfaced, and the connection of each component was tested to ensure that they were working properly. The microcontroller was connected wirelessly to the router where the Raspberry pi server was also connected. It sent soil moisture, temperature and humidity, and heat index data to the server. The system and the database reside inside the raspberry pi. The database holds the collected data by the sensors. The electromechanical devices were used to automate irrigation and ventilation. A channel relay module, controlled by Wemos D1 mini, is connected to the solenoid valve, ventilator fan, and a power supply release 5V direct current. The raspberry pi sends the message via ESP866 using MQTT protocol to give the signal to the solenoid valve and ventilation fan.

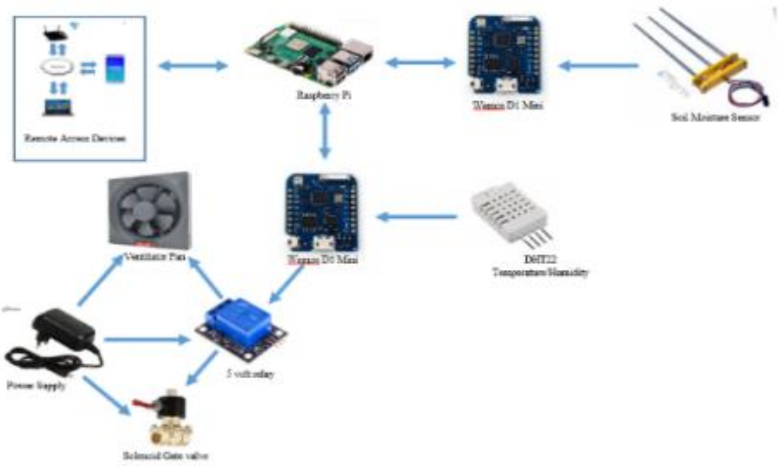

Figure 2. Hardware connections

Figure 3 shows the wiring connections of the different devices. It is the representation of the actual circuitry of the developed system. It shows the connection of the WEMOS D1 Mini microcontroller to the DHT22 temperature, humidity, soil moisture sensors to sense the temperature and moisture content of the soil. Likewise, it is connected to the channel relay that activates the solenoid gate valve and ventilation fan whenever there are irregularities on the threshold. The power supply is likewise connected to power on the devices, and a light indicator is connected to the microcontroller. This is an indicator for the user that the device is turned on/off.

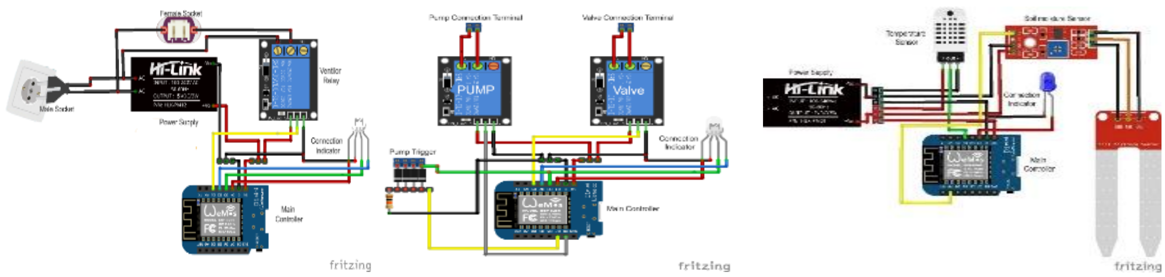

Figure 3. Wiring connections of sensors, water valve, and ventilator fan module

3.7 Software Design

In the software process, Arduino IDE was used to design the connection and all the interface processes. Afterward, the entire program designed to connect with the Wemos D1 Mini V 2.2 microcontroller was compiled using the C compiler program. Then, the hardware and software were combined to complete the system. The soil moisture sensor, temperature, and humidity sensors collected the reading in the greenhouse. The data were converted from analog to digital format. The data collected were sent to the microcontroller and later on to the server using wireless connectivity. To allow users to interact with the greenhouse controller, a web application was created. The data collected by the data sensor devices is stored in the database. MYSQL is the database engine that is used to manage the database's data.

3.8 Results and Discussion

This section covers data analysis and interpretation in relation to the system's description, features, and structure, as well as the system's description, features, and structure. The performance of the designed system in the following categories is shown in the table below: systems functionality, reliability, usability, connection, and user interface, accordingly. These criteria were taken from the ISO 25010 standard in order to confirm that the produced system meets the international standard. Anthony et.al used this set of criteria to determine the acceptability of the developed system in his study, and the outcomes of his research effort were extremely acceptable.

Table 2. Evaluation of the developed IoT-based Automated Greenhouse by IT experts and IT students

Item	Mean Score	Adjectival Description
A. Systems Functionality		
The system can irrigate the crop based on the schedule as directed by time interval, soil moisture sensor, and using any internet-connected device.	**4.93**	**Strongly Agree**
The system is capable of recording and saves date logs for backup purposes.	**4.93**	**Strongly Agree**
It provides real-time data such as soil moisture content, temperature, humidity, and heat index in graphical presentation for monitoring purposes.	**4.93**	**Strongly Agree**
The developed system has a user interface that allows the user to control and modify the irrigation and ventilation processes.	**4.87**	**Strongly Agree**
B. Reliability		
The system’s user interface is free from errors.	**4.73**	**Strongly Agree**
The developed automated device is reliable.	**4.87**	**Strongly Agree**
C. Usability		
The developed system is very useful in monitoring and controlling the environment of the greenhouse.	**4.73**	**Strongly Agree**
Perceived ease of use of the software is evident.	**4.87**	**Strongly Agree**
D. Connectivity		
The system is capable of handling multiple connections to the hardware.	**4.60**	**Strongly Agree**
The data gathered by the system can be sent online via MQTT Protocol through a Wi-Fi module provided that there is Wi-Fi point with an internet connection.	**4.80**	**Strongly Agree**
E. User Interface		
The system has a visually appealing interface.	**4.87**	**Strongly Agree**
Overall Mean	**4.83**	**Strongly Agree**

As reveals in the table, all of the criteria got an adjectival description of “strongly agree”. All the IT experts and IT students strongly agreed that the developed system’s functionality worked efficiently, reliably, and useful to the user. Based on the remarks of the respondents, the device demonstrated accuracy on the duration of the preset irrigation time. The device also sensed the soil moisture content and temperature which they set. The data gathered by the sensors were presented in graphical format and are accessible to the users for research purposes. The respondents also noted that the system is useful in monitoring and controlling the environment of the greenhouse. Meanwhile, in terms of connectivity, the system was capable of handling multiple connections to the hardware, and the data were sent wirelessly. Also, the developed web-based application has a clear, simple, and easy-to-understand user interface. Thus, it implies that the developed system’s components are functional, reliable, and useful, and their intended output capability is applicable to the greenhouse facility of PSAU. Moreover, the ISO 25010 standard is the appropriate tool in evaluating the system’s components.

Table 3. Evaluation of developed IoT-based Automated Greenhouse by Agriculture experts, project staff laborer, and Agriculture students

Item	**Mean Score**	**Adjectival Description**
1. The developed system for the ALIAS R&D Center can control and monitor the water requirement and climatic condition of the plants.	**4.60**	**Strongly Agree**
2. The developed system can help ALIAS R&D Center conserve water and electricity.	**4.50**	**Agree**
3. The developed system for the ALIAS R&D Center is efficient in the growth of plants.	**4.50**	**Agree**
4. The developed system reduces the workload of the farmer in irrigating and monitoring the greenhouse.	**4.55**	**Strongly Agree**
5. The system is applicable to any type of vegetable crop.	**4.50**	**Agree**
Overall Mean	**4.53**	**Strongly Agree**

Table 3 shows the Agriculture experts', project staff laborers', and Agriculture students’ opinions on the developed system. When asked how much they agreed with the developed system for indicators, the respondents said: 1 “The developed system for ALIAS R&D Center can control and monitor the water needs and climatic condition of the plants," 2 "The developed technique can help the ALIAS R&D Center save water and electricity," the researchers claims a few "The ALIAS R&D Center's established system is effective in plant growth" had a mean score of 4.50 and a verbal interpretation of "strongly agree." The developed system obtained a mean score of 4.55, with a verbal interpretation of highly agree, indicating that it reduces the farmer's effort in irrigating and monitoring the greenhouse. Indicator 5, "The technique is applicable to any type of vegetable crop," scored a 4.50 average and a strong verbal interpretation. The mean level of agreement with the developed method among the respondents was 4.53, with a verbal meaning of highly agree. This indicates that the system has achieved its objectives. Furthermore, the architecture of the system is suited for application in the PSAU greenhouse facility.

Figure 4 depicts the system's actual layout as well as the hardware integration. The system that was designed was fully functional and operating. To make the electromechanical gadget water-resistant, it was placed in a wooden box. A 3-meter PVC pipe connected the water pump to a water supply. The drip irrigation, on the other hand, was connected to a water pump via an 18-inch rubber line. The lettuce was chosen as a reference crop, therefore the required soil moisture content and temperature for the crop were employed. The sort of triggering used in this experiment was sensor-based. The automated drip irrigation and ventilation fan switched on and off based on the user-defined conditions. When the soil moisture level went below 130 percent or less, the automated drip irrigation continued, and when the soil moisture content reached 200 percent or more, the water pump was automatically turned off. The automated ventilation fan, on the other hand, continued to run when the temperature reached 32 percent or higher, and it turned off when the temperature dropped to 32 percent or lower.

Figure 4. The actual setup of the system in the greenhouse

Figure 5 shows the Input/Output node. Once the user had successfully logged in to the web-based app, then Input and Output Devices was displayed. The sensors were the input node. The data gathered by the input devices were displayed in graphical representation. The first graph indicated the data gathered by the DHT22 sensor, and the second graph indicated the data gathered by the soil moisture sensor. On the other hand, the output nodes were the solenoid gate valve and ventilator fan. The user could change the type of triggering like manual, schedule, or sensor-based.

Figure 5. Input/Output node

Figure 6 displays the node list, which displays the crop information such as the name, conductivity factor, potential hydrogen, electrical conductivity, parts per million, and the start and end date of planting. Also included in the node list was the sensor-based list. Automatic irrigation and ventilation highly depended on the soil moisture content and temperature threshold, but a specific condition set by the user should be first met in order for the drip irrigation and ventilation fan to automatically turn ON/OFF. The user here was also capable of adding new devices.

Figure 6. Node list

Figure 7 shows the real-time measurements collected by the sensors for greenhouse characteristics such as temperature, humidity, heat index, and soil moisture content. For backup purposes, the system automatically recorded data logs in.csv format, which can be seen in tabular form and accessed in Microsoft Excel. The recorded state of the water valve and ventilator fan was also shown in the figure.

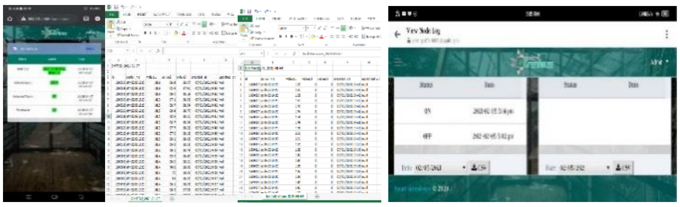

Figure 7. Real-time measurements and sample recordings of the water valve and ventilator fan

Summary, Conclusions, And Recommendations

4.1 Summary

The researchers designed and developed an IoT-based Automated Greenhouse for PSAU-ALIAS. The objective of the research study was to develop an automated greenhouse equipped with automatic irrigation and monitoring and controlling of climatic conditions that would help the project staff/laborers and agricultural faculty researchers in their activities in manual crop production management.

The developed system has the following components: automation of the irrigation and ventilation of the greenhouse. The irrigation and ventilation were based on three schemes: the sensor's activity based on the acquired soil moisture content and temperature of the surroundings, the periodic scheduling being set in the device, and using any internet-connected device to manually turn on/off the water valve and ventilator. Furthermore, the system also has a web-based application that allows the laborers and faculty researchers to interact with the system.

In the developmental process, the researchers had come up with the components based on their specifications. The researchers chose soil moisture sensor as its sensing device over humidity sensor based on the locale requirement, which cultivates solanaceous and Asteraceae crops. On the list of soil moisture sensors and temperature sensors available in the market, the DHT22 was found to be the most feasible sensor to be used due to its accuracy and sensing capability. The Wemos D1 mini microcontroller was used because of its capability of communicating with other devices wirelessly. It also has a built-in program and is compatible with Arduino IDE software. The Python programming language was used to write the code and develop the firmware. Moreover, the Raspberry pi was used to hold the web application system and the database. The researchers also incorporated IoT and MQTT protocol to allow remote monitoring and controlling of devices inside the greenhouse.

The researchers set up a 3m length x 3m height x 2m width size of the greenhouse and used lettuce as an experimental crop. The developed system was evaluated by IT experts, Agriculture experts, and project staff laborers of the different projects in the Pampanga State Agricultural University (PSAU) to test the system’s functionality, reliability, usability, connectivity, and user interface.

The results of the evaluation from the IT experts got an overall mean of 4.83 with a verbal interpretation of "strongly agree". This implies that the developed components of the system and their intended output capability are applicable to the Greenhouse of PSAU. On the other hand, the results of the evaluation of Agriculture experts and Project staff laborers got an overall mean of 4.53 and interpreted as "strongly agree". The respondents believed that the design of IoT-based Automated Greenhouse is applicable to the PSAU ALIAS greenhouse facility.

4.2 Conclusions

The following conclusions were reached based on the study's findings and the responses of the system's users.

1. The IoT-based automated greenhouse was designed using a microcontroller, soil moisture sensor, DHT22 sensor, and Raspberry pi. Through the use of a microcontroller, the water irrigation and ventilation can be controlled remotely, and the real-time data accumulated by the sensors can be viewed remotely through graphical representation.

2. Wemos D1 mini V 2.2 was used in this project since it had the most advanced specifications compared to other microcontrollers.

3. DHT22 temperature sensor is the most appropriate temperature sensor based on the availability in the market, sensing range, and percentage of accuracy than the other

temperature sensors available. Most of all, it can be integrated with a circuit and can be installed externally.

4. The overall performance of the developed IoT-based automated greenhouse in terms of functionality, reliability, usability, and connectivity were all obtained an adjectival description of "strongly agree". Thus, the design and the components of the developed system are appropriate in the PSAU-ALIAS.

4.3 Recommendations

For other researchers along this line, the following recommendations for further improvement are forwarded:

1. integration of additional components such as artificial lighting, cooling system, humidifier, and solar panel to power the electromechanical devices; current sensing will be the feedback for faulty devices;

2. for controlling multiple greenhouses, consider implementing a network of Raspberry Pi and sensors; and

3. tryout of the system in other fields/nursery types (ex-situ).

References

Gupta, L., Intawala, K., Khetwani, K., Hanamashet, T. & Somkunwar, R., (2017). *Smart irrigation system and plant disease detection*. International Research Journal of Engineering and Technology (IRJET), vol. 04

Anthony, J.E. (2017). *Auto GMS: An automated greenhouse monitoring system of abiotic factors for leafy vegetables production*. International Research Conference on Higher Education volume 2018

BusinessWorld (2018). *Smart tech to help PHL achieve sustainable agri goals* retrieved from https://www.bworldonline.com/smart-tech-to-help-phl-achieve-sustainable-agri-goals/

Food and Agriculture Organization (2016). *Climate change and Food Security: risks and responses*. Retrieved from http://www.fao.org/3/a-i5188e.pdf

National Development Economic Authority (NEDA, 2015). *Addressing the impacts of climate change in the Philippine agriculture sector* retrieved from http://www.neda.gov.ph/addressing-impacts-climate-change-philippine-agriculture-sector/

Doorenbos, J. & Pruitt, W. O. (1996). "*Crop water requirements*" http://www.fao.org/3/s8376e/s8376e.pdf

White, J. & Aldrich, A. (2015) *Progress report on energy conservation for greenhouses research*. RA 2015. Floriculture Review, 156: 63-65

Elaydi, Hatem., (2017). *An Automated Irrigation System for Greenhouse.* American Journal of Electrical and Electronic Engineering, vol. 5, no. 2: 48-57. DOI: 10.1269/ajeee-5-2-3. Retrieved from http://pubs.sciepub.com/ajeee/5/2/3

Diaz-Perez, J.C. & Eaton, T. (2016). *Plant growth and fruit yield as affected by drip irrigation rate.* American Society for Horticultural Science. Science Daily, 11 January 2016

Buttaroa, D., Santamariab, P., Signoreb, A., Cantorea, V., & Francesco, F. (2015). *Irrigation management of greenhouse using tensiometer effects on yield quality and water use*. Agriculture and Agricultural Science Procedia 4 pp 440-444

Montero, J.I., Lopez, J.C., Baeza., Lopez, J.C. & Kacira, Murat. (2013). *Greenhouse design and covering materials*. A chapter from formal publication of Food and Agriculture Organization of the United Nations.

Wollaeger, H. (2015). *Integrated pest management in greenhouse crops*. Michigan State University Extension Floriculture Newsletter. Based upon work supported by the National Institute of Food and Agriculture, US Department of Agriculture, under Agreement No. 2015-09785.

Baudoin, W., Nono-Womdin, R., Lutaladio, N. & Hodder, A., (2013). *Good agricultural practices for greenhouse vegetable crops: principle for Mediterranean climate areas*. FAO Plant Production and Protection Division. ISBN 978-92-5-107649-1

Ray, P. (2017). Internet of things for smart agriculture: technologies, practices and future direction. Article in Journal of Ambient Intelligence and Smart Environments. June 2017. DOI: 10.3233//AIS-17044.

Tzounisa, A., Katsoulasa, N., Bartzanas, T. & Kittasa, C. (2017). "*Internet of things in agriculture, recent advances and challenges*" https://doi.org/10.1016/j.biosystemseng.2017.09.007

Vu, Quan Minh, (2011). *Automated wireless greenhouse management system*: http://hdl.handle.net/10179/32311

Creswell, J. W. (1994). *Research design: Qualitative and quantitative approaches*. Thousand Oaks, CA: SAGE Publications.