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Group L
Kavindu Magalage, Mehrdad Kaheh, Danial Khaledi
Nazanin Nakhaie Ahooie, Sepehr Samadi

SMART GREENHOUSE

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ABSTRACT

The Smart Greenhouse is an Internet of Things (IoT) [1] system designed to monitor and control a greenhouse environment using a range of sensors and actuators. The system uses sensor modules to collect data on temperature, humidity, air quality, and soil moisture, and actuator modules to control the HVAC, ventilation, watering, and lighting systems. The system can be controlled manually using a web or mobile application, or automatically using algorithms that make decisions based on the sensor data and preset thresholds. The system is implemented using a range of hardware and software components, including microprocessors, sensors, actuators, and a web application, and is designed to be scalable and adaptable to a wide range of applications. Despite its potential benefits, the system has a number of limitations, including its reliance on Internet connectivity, the accuracy and reliability of the sensor data, the range and capabilities of the actuators, and the complexity and cost of implementation. There are many ways in which the system could be improved in the future to increase its effectiveness and expand its capabilities, including the addition of more sensors, the development of advanced algorithms, the expansion of the actuator range and capabilities, and the improvement of user-friendliness and accessibility.

Keywords: Internet of Things (IoT), Smart Greenhouse, Sensor modules, Automation algorithms, Environmental monitoring, Sensor accuracy and reliability, Actuator range and capabilities

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TIIVISTELMÄ

Viedā siltumnīca ir lietiskā interneta (IoT) sistēma, kas izstrādāta, lai uzraudzītu un kontrolētu siltumnīcas vidi, izmantojot dažādus sensorus un izpildmehānismus. Sistēma izmanto sensoru moduļus, lai savāktu datus par temperatūru, mitrumu, gaisa kvalitāti un augsnes mitrumu, un izpildmehānismu moduļus, lai kontrolētu HVAC, ventilācijas, laistīšanas un apgaismojuma sistēmas. Sistēmu var kontrolēt manuāli, izmantojot tīmekļa vai mobilo lietojumprogrammu, vai automātiski, izmantojot algoritmus, kas pieņem lēmumus, pamatojoties uz sensora datiem un iepriekš iestatītajiem sliekšņiem. Sistēma ir ieviesta, izmantojot virkni aparatūras un programmatūras komponentu, tostarp mikroprocesorus, sensorus, izpildmehānismus un tīmekļa lietojumprogrammu, un ir izstrādāta tā, lai tā būtu mērogojama un pielāgojama plašam lietojumu klāstam. Neskatoties uz tās potenciālajiem ieguvumiem, sistēmai ir vairāki ierobežojumi, tostarp tās atkarība no interneta savienojuma, sensoru datu precizitāte un uzticamība, izpildmehānismu diapazons un iespējas, kā arī ieviešanas sarežģītība un izmaksas. Ir daudzi veidi, kā nākotnē sistēmu varētu uzlabot, lai palielinātu tās efektivitāti un paplašinātu tās iespējas, tostarp vairāku sensoru pievienošana, progresīvu algoritmu izstrāde, izpildmehānismu diapazona un iespēju paplašināšana, kā arī lietotāju uzlabošana. - draudzīgums un pieejamība.

Avainsanat: Lietu internets (IoT), viedā siltumnīca, sensoru moduļi, automatizācijas algoritmi, vides uzraudzība, sensora precizitāte un uzticamība, izpildmehānismu diapazons un iespējas

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FOREWORD

The Smart Greenhouse project is an ambitious and innovative effort to harness the power of the Internet of Things (IoT) [1] to improve the efficiency, productivity, and sustainability of greenhouse agriculture. By using a range of sensor and actuator modules, microprocessor programming, and a web application, the project aims to create a system that can monitor and control a greenhouse environment[2] in real-time, optimizing the conditions for plant growth and health.

The Smart Greenhouse project represents a significant step forward in the field of greenhouse agriculture[2], offering the potential to revolutionize the way we cultivate plants and manage the resources that sustain them. With its ability to collect and analyze data, make automated decisions, and enable remote control and monitoring, the Smart Greenhouse project has the potential to make a significant impact on the way we grow plants, conserve resources, and improve the environment.

This report provides a detailed overview of the Smart Greenhouse project, including its motivation, system architecture, data collection and analysis, algorithms and other works, limitations, and potential for future improvement. It is intended to provide a comprehensive understanding of the project and its potential impact, and to serve as a resource for those interested in exploring the possibilities of IoT in greenhouse agriculture [3].

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Group L
Kavindu Magalage, Mehrdad Kaheh, Danial Khaledi
Nazanin Nakhaie Ahooie, Sepehr Samadi

LIST OF ABBREVIATIONS AND SYMBOLS

IoT	Internet of Things
HVAC	Heating, Ventilation, and Air Conditioning
API	Application Programming Interface
SQL	Structured Query Language
HTML	HyperText Markup Language
CSS	Cascading Style Sheets
JS	JavaScript
JSON	JavaScript Object Notation
HTTP	HyperText Transfer Protocol
HTTPS	HTTP Secure
USB	Universal Serial Bus
UART	Universal Asynchronous Receiver/Transmitter
WiFi	Wireless Fidelity

MHz	Megahertz
Hz	Hertz
V	Volts
A	Amperes
mA	Milliamperes
pF	Picofarads
$k\Omega$	Kiloohms
Ω	Ohms
$\%$	Percent
$°C$	Degrees Celsius
$°F$	Degrees Fahrenheit
RH	Relative Humidity
ppm	Parts per million
g	Grams
kg	Kilograms
mL	Milliliters
L	Liters
mm	Millimeters
cm	Centimeters
m	Meters
s	Seconds
ms	Milliseconds

1. INTRODUCTION

The Smart Greenhouse is an innovative system that aims to improve the efficiency and productivity of greenhouses[4]. It does this by continuously monitoring and adjusting the conditions inside the greenhouse to ensure that they are optimal for plant growth. The system measures various parameters, including light levels, temperature, humidity, and CO2 concentration, and uses this data to make informed decisions about how to control the actuators within the greenhouse.

For example, if the light levels drop below a certain threshold, the system will turn on the lights to ensure that the plants receive sufficient light. Similarly, if the temperature or humidity levels rise above certain thresholds, the system will activate the HVAC system to bring the conditions back within an acceptable range. These automatic control mechanisms allow the Smart Greenhouse to maintain optimal conditions without the need for constant human intervention.

In addition to its automatic control capabilities, the Smart Greenhouse can also be controlled manually through a web app. This app allows the user to access the system remotely and adjust the actuators as needed. The app also includes various gauges and charts that display the current and historical values of the various parameters being monitored, allowing the user to get a clear understanding of the conditions within the greenhouse.

The Smart Greenhouse is a powerful and useful tool for optimizing plant growth in a greenhouse setting. Its ability to continuously monitor and adjust the conditions within the greenhouse, as well as its manual control capabilities, make it an invaluable asset for anyone looking to improve the productivity and efficiency of their greenhouse.

The Smart Greenhouse project is important for several reasons. Firstly, it provides a platform for managing and optimizing a greenhouse environment [5] for plant growth. By continuously monitoring parameters such as temperature, humidity, air quality, and soil moisture, and controlling actuators such as the HVAC system, ventilation, watering system, and lighting, the Smart Greenhouse system allows for precise control and optimization of the greenhouse environment to ensure optimal conditions for plant growth.

Secondly, the Smart Greenhouse system provides flexibility and convenience for the user through its ability to be controlled manually and remotely, as well as its implementation of an automated control system. This allows the user to control the greenhouse environment from any location and at any time, as well as to set up automated control algorithms to optimize the environment without constant manual intervention.

The Smart Greenhouse project is important for its ability to provide precise control and optimization of the greenhouse environment [5] for plant growth, as well as its flexibility and convenience for the user through manual and remote control, and its use of various technologies to facilitate its functionality.

2. SYSTEM ARCHITECTURE

The system architecture of the Smart Greenhouse project [6] consists of a combination of hardware and software components that work together to monitor and control the greenhouse environment. The architecture includes sensor modules, actuator modules, microprocessor programming, and a web application.

The hardware components of the system architecture include the sensor modules, which are responsible for measuring various parameters such as temperature, humidity, air quality, and soil moisture. These modules use a Wemos D1 Mini microprocessor to read sensor data and transmit it to a cloud server. An analog switch IC is used to access different sensors, as the Wemos D1 Mini has only one analog input pin. The actuator modules, on the other hand, are responsible for controlling the greenhouse environment. There are two types of actuators: latching relays and an electric water valve. The latching relays are used to control the HVAC, ventilation, and lighting systems and do not consume energy while in the "on" state. The electric water valve is used to enable or disable the watering system for plants and can be controlled by the latching relays.

The hardware system for the Smart Greenhouse [6] is an integral part of the overall system, as it is responsible for collecting data from the sensors and actuators, transmitting this data to the remote server, and receiving and carrying out commands from the server. The hardware consists of a range of sensors and actuators that work together to monitor and control the conditions within the greenhouse.

The MQ7 CO2 sensor is responsible for measuring the concentration of CO2 in the air within the greenhouse. This is important, as plants require a certain level of CO2 for proper growth. The light sensor, in the form of a photo resistor, measures the intensity of light within the greenhouse. This is important, as plants also require a certain amount of light for proper growth. The ADHT20 temperature and humidity sensor measures the temperature and humidity within the greenhouse, which is also important factors in plant growth.

The LEDs represent the lighting and HVAC systems within the greenhouse. The lighting system consists of a single LED in the hardware system, but in the actual greenhouse, there would be many LEDs to represent the full lighting system. The HVAC system is similarly represented by a single LED in the hardware system.

The hardware is connected to an Arduino module that collects data from the sensors and transmits it to the Raspberry Pi using the UART protocol over a USB cable. The Raspberry Pi then sends this data over Wi-Fi to the remote server, where it can be accessed and analyzed by the user. The Raspberry Pi also receives commands from the server over Wi-Fi and transmits them via a USB cable (serial cable) to the module, which carries out the necessary actions based on the commands. This allows for real-time monitoring and control of the greenhouse environment to ensure optimal conditions for plant growth.

The software components of the system architecture include microprocessor programming, which is written in C and uses the Arduino IDE. This programming handles hardware controls and transmits data and commands between the modules and the remote server. The web application provides a front-end interface for the user to monitor values and control the actuators manually, as well as view the current state of each device. The application may also include additional features such as histograms.

The system architecture follows a simple N-tier architecture, with the main app connected to a repository service which retrieves data from the database. The communication protocol used by the Smart Greenhouse system is the Universal Asynchronous Receiver/Transmitter (UART) protocol, which enables serial communication between the microprocessor and the cloud server.

The project uses the Flask web framework and SQL Alchemy to manage the connection between the database and the application, and the database used is SQLite. The software architecture follows a simple N-tier architecture, with a main app connected to a repository service which retrieves data from the database. This architecture separates the different functionalities of the system into different layers, which can make the code easier to understand and maintain.

The main file, "app.py", contains various functions or "endpoints" that can be called by the client application or raspberry pi hub using the Flask web framework and REST API. These functions include retrieving sensor data, retrieving sensor history, and updating sensors. The raspberry pi application is a simple Python application that retrieves data from sensors and sends it to the main app for processing and storage. The main app processes and stores the data, and sends commands to the actuators to control the various systems within the greenhouse.

The project uses Docker and Docker Compose for deployment, which allows the application to be easily set up and run on a server or machine. The Docker file contains various commands and configurations for setting up the application, such as installing dependencies and creating the database, and the Docker Compose file defines the number and configuration of containers to be used in the deployment.

The system architecture of the Smart Greenhouse project consists of hardware and software components that work together to monitor and control the greenhouse environment. The hardware components include sensor and actuator modules, while the software components include microprocessor programming and a web application. The system architecture follows an N-tier design and uses the UART protocol for communication. These components are necessary to enable the precise monitoring and control of the greenhouse environment, as well as the flexibility and convenience of manual and remote control, and the use of various technologies to facilitate the project's functionality.

3. IMPLEMENTATION

3.1. Data You Work with, How to Collect

In the Smart Greenhouse project[7], the data collected includes various parameters related to the greenhouse environment such as temperature, humidity, air quality, and soil moisture. This data is collected using sensor modules, which are responsible for measuring these parameters using a range of sensors such as an MQ7 CO2 sensor, a light sensor (photo resistor), and an ADHT20 temperature and humidity sensor.

The data collected by the sensor modules are then stored in a database using SQLAlchemy, a Python library for managing the connection between the database and the application. The data can be accessed and displayed in the web application, allowing the user to view real-time readings of the various parameters as well as historical data in the form of charts and graphs.

Overall, the data collected in the Smart Greenhouse project is used to monitor and optimize the greenhouse environment for plant growth. It is collected using sensor modules and transmitted to the cloud server via the UART protocol and is stored and accessed using SQLAlchemy and the web application. This data is essential for understanding the current conditions of the greenhouse and making informed decisions about how to control and optimize the environment for plant growth.

3.2. How You Set up the System, How Things Connected with Others

To set up the Smart Greenhouse system, the hardware and software components must be properly connected and configured. The hardware components, including the sensor and actuator modules, are connected using a Universal Asynchronous Receiver/Transmitter (UART) protocol over a USB cable. The sensor modules use a Wemos D1 Mini microprocessor to read the data from the sensors and transmit it to the cloud server, while the actuator modules use latching relays and an electric water valve to control the HVAC, ventilation, lighting, and watering systems.

The software components of the system, including the microprocessor programming and the web application, are also connected and configured to enable the monitoring and control of the greenhouse environment. The microprocessor programming, written in C and using the Arduino IDE, handles the hardware controls and communicates with the cloud server and web application via the UART protocol. The web application provides a user-friendly interface for viewing real-time data and manually controlling the actuators, as well as accessing historical data and other features such as histograms.

To set up the system, the hardware and software components must be properly connected and configured according to the desired functionality of the Smart Greenhouse. This includes connecting the sensor and actuator modules using the UART protocol and configuring the microprocessor programming and web application to communicate with each other and the cloud server. Once the system is set up, it can be used to monitor and control the greenhouse environment in real time, providing a convenient and efficient way to optimize the conditions for plant growth.

3.3. Algorithms or Other Works That You Have Done in This Project

In the Smart Greenhouse project, a range of algorithms and other work has been implemented to enable the monitoring and control of the greenhouse environment. This includes the development of a closed-loop control system to automate the decision-making process for controlling the actuators based on real-time sensor data and predetermined thresholds, commands, and algorithms.

To implement this closed-loop control system, algorithms have been developed to process and analyze the sensor data in real time, making automated decisions about how to control the actuators based on the current conditions of the greenhouse. For example, if the soil moisture falls below a certain threshold, the system can automatically open the electric valve to water the plants. Similarly, if the temperature or humidity rises above a predetermined threshold, the system can activate the HVAC or ventilation systems to adjust the conditions in the greenhouse.

In addition to the development of these algorithms, other work has been done in the Smart Greenhouse project to create a user-friendly and functional web application for accessing and controlling the system. This includes the development of a front-end interface for viewing real-time data, historical data, and other features, as well as a back-end system for managing the database and implementing the endpoints that enable communication between the application and the sensor and actuator modules.

Overall, the Smart Greenhouse project has involved the development of algorithms and other work to enable the monitoring and control of the greenhouse environment in a convenient and efficient manner. This includes the development of a closed-loop control system to automate the decision-making process for controlling the actuators, as well as the creation of a user-friendly and functional web application for accessing and controlling the system.

4. EVALUATION

4.1. The Sequence Diagram

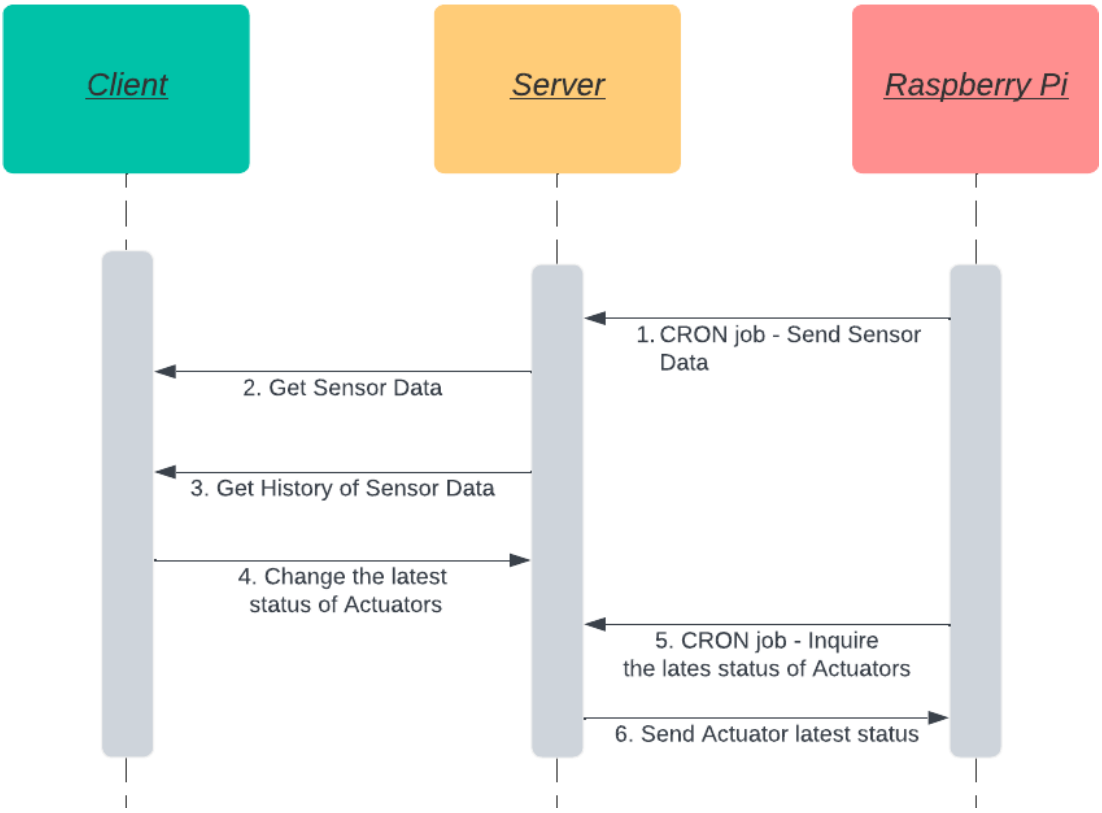


Figure 1. The sequence diagram

As shown in Figure 1the sequence diagram of data links between the client, server, and Raspberry Pi modules illustrates the flow of data between these different components of the smart greenhouse system. It shows how the smart greenhouse system is designed to collect and transmit data from the sensor modules to the client application, enabling users to monitor and control the environment of the greenhouse remotely.

4.2. The Circuit Board

As shown in Figure 2 circuit board is responsible for reading data from the sensor modules and transmitting it to the microprocessor, as well as receiving commands from the microprocessor and activating the actuator modules accordingly. It also serves as a power source for the sensor and actuator modules, providing the necessary voltage and current to operate them.

The circuit board plays a vital role in the overall functionality of the smart greenhouse system. It ensures that data is accurately collected and transmitted, and that the actuators are activated as needed to maintain optimal conditions within the

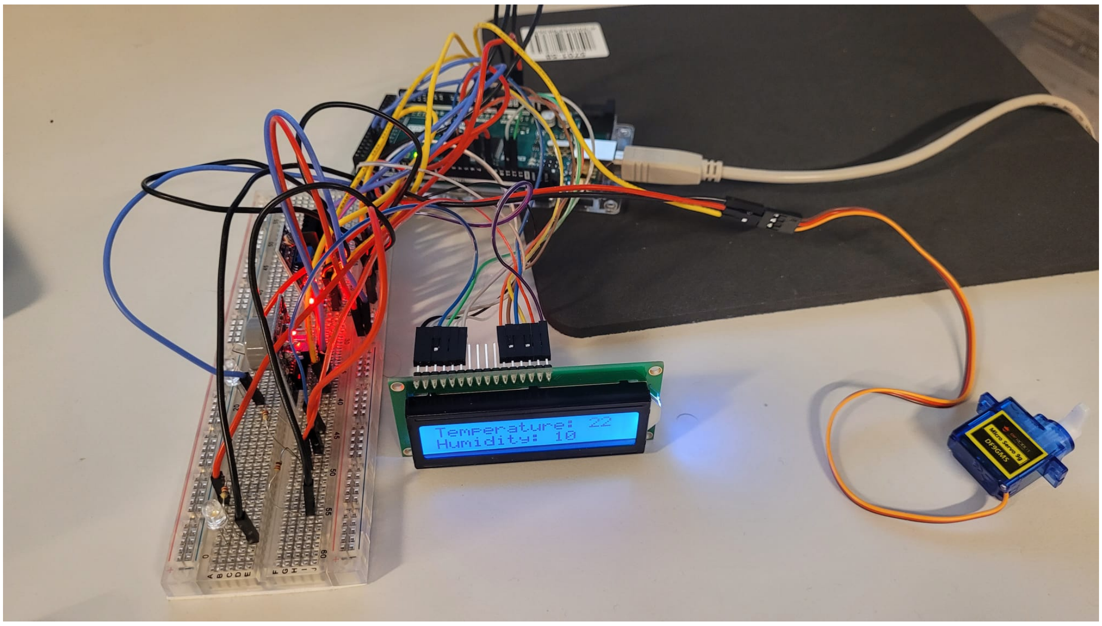


Figure 2. The circuit board

greenhouse. By carefully designing and building the circuit board, we can ensure that the smart greenhouse system performs reliably and efficiently.

4.3. Web Application

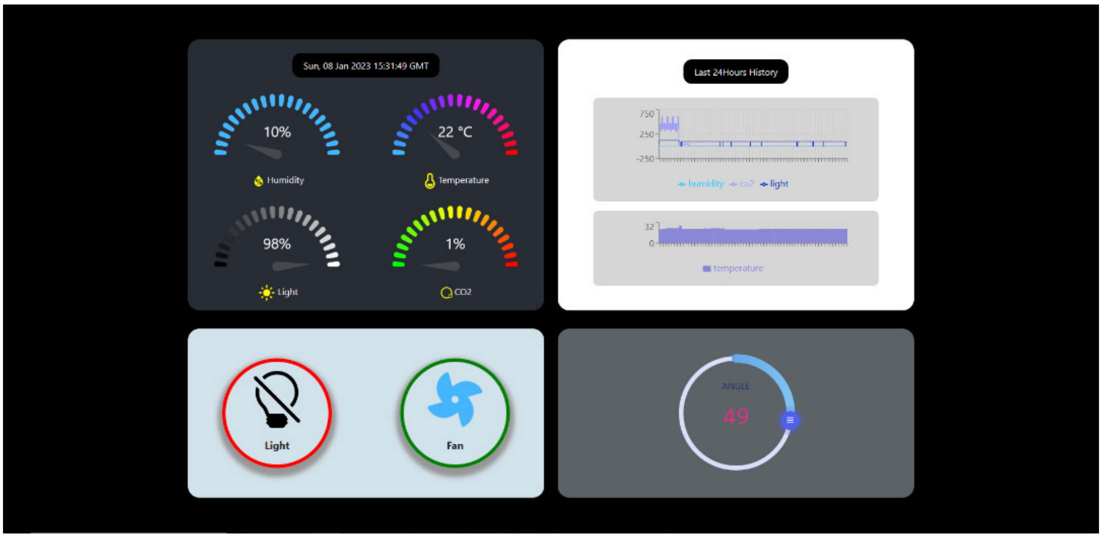


Figure 3. Web application

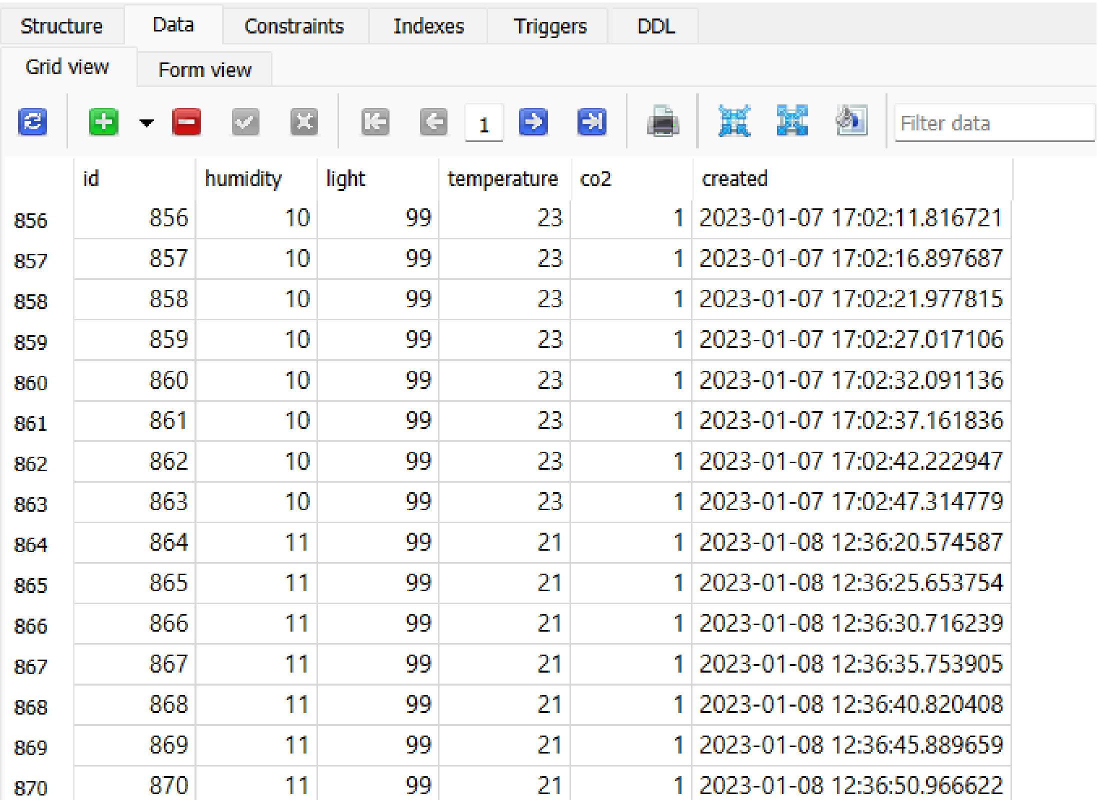
The web application is an essential component of the smart greenhouse project. It serves as the interface between the user and the system, allowing users to monitor the various parameters of the greenhouse environment and control the actuator modules remotely.

As shown in Figure 3 web application is designed to be user-friendly, with a modern and intuitive interface that allows users to easily access and view the data collected by the sensor modules. It also includes a range of controls and inputs that allow users to manually operate the actuator modules, such as turning on the light system or activating the fan.

4.4. Data Bases

SQL Alchemy, an open-source Python library, was used to interface with the database and perform queries. This library provided a simple and efficient way to create, modify, and delete database entries, as well as retrieve data in a variety of formats.

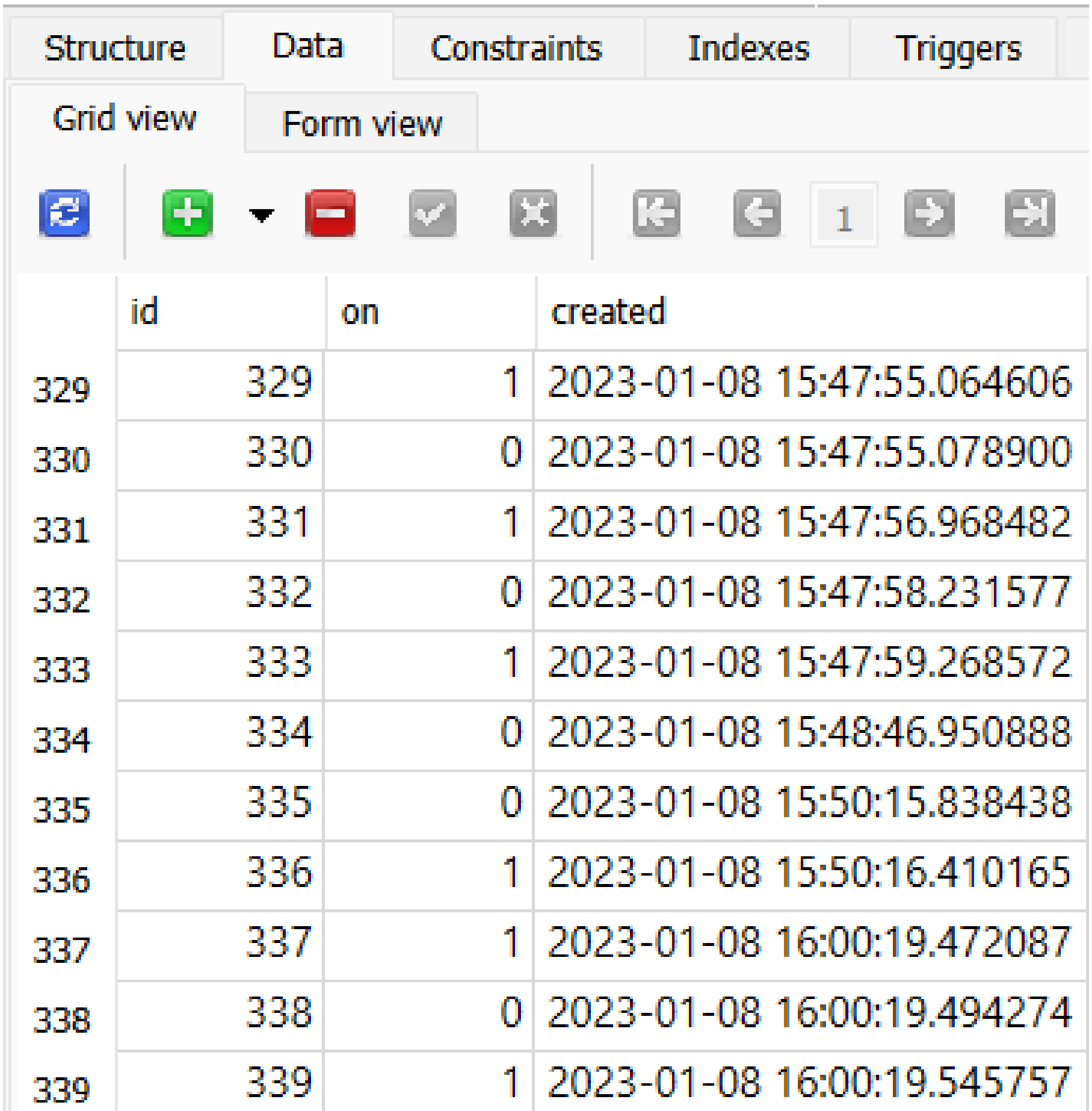
4.4.1. Sensor Data



	id	humidity	light	temperature	co2	created
856	856	10	99	23	1	2023-01-07 17:02:11.816721
857	857	10	99	23	1	2023-01-07 17:02:16.897687
858	858	10	99	23	1	2023-01-07 17:02:21.977815
859	859	10	99	23	1	2023-01-07 17:02:27.017106
860	860	10	99	23	1	2023-01-07 17:02:32.091136
861	861	10	99	23	1	2023-01-07 17:02:37.161836
862	862	10	99	23	1	2023-01-07 17:02:42.222947
863	863	10	99	23	1	2023-01-07 17:02:47.314779
864	864	11	99	21	1	2023-01-08 12:36:20.574587
865	865	11	99	21	1	2023-01-08 12:36:25.653754
866	866	11	99	21	1	2023-01-08 12:36:30.716239
867	867	11	99	21	1	2023-01-08 12:36:35.753905
868	868	11	99	21	1	2023-01-08 12:36:40.820408
869	869	11	99	21	1	2023-01-08 12:36:45.889659
870	870	11	99	21	1	2023-01-08 12:36:50.966622

Figure 4. Sensor data

As shown in Figure 4 the sensor table stores the data coming from sensors, which is aggregated by Raspberry and sent to the server. It includes 6 rows, id, humidity, light, temperature, and co2, and created time, in order to keep track of when the data is received from the sensors.



Structure | Data | Constraints | Indexes | Triggers

Grid view | Form view

	id	on	created
329	329	1	2023-01-08 15:47:55.064606
330	330	0	2023-01-08 15:47:55.078900
331	331	1	2023-01-08 15:47:56.968482
332	332	0	2023-01-08 15:47:58.231577
333	333	1	2023-01-08 15:47:59.268572
334	334	0	2023-01-08 15:48:46.950888
335	335	0	2023-01-08 15:50:15.838438
336	336	1	2023-01-08 15:50:16.410165
337	337	1	2023-01-08 16:00:19.472087
338	338	0	2023-01-08 16:00:19.494274
339	339	1	2023-01-08 16:00:19.545757

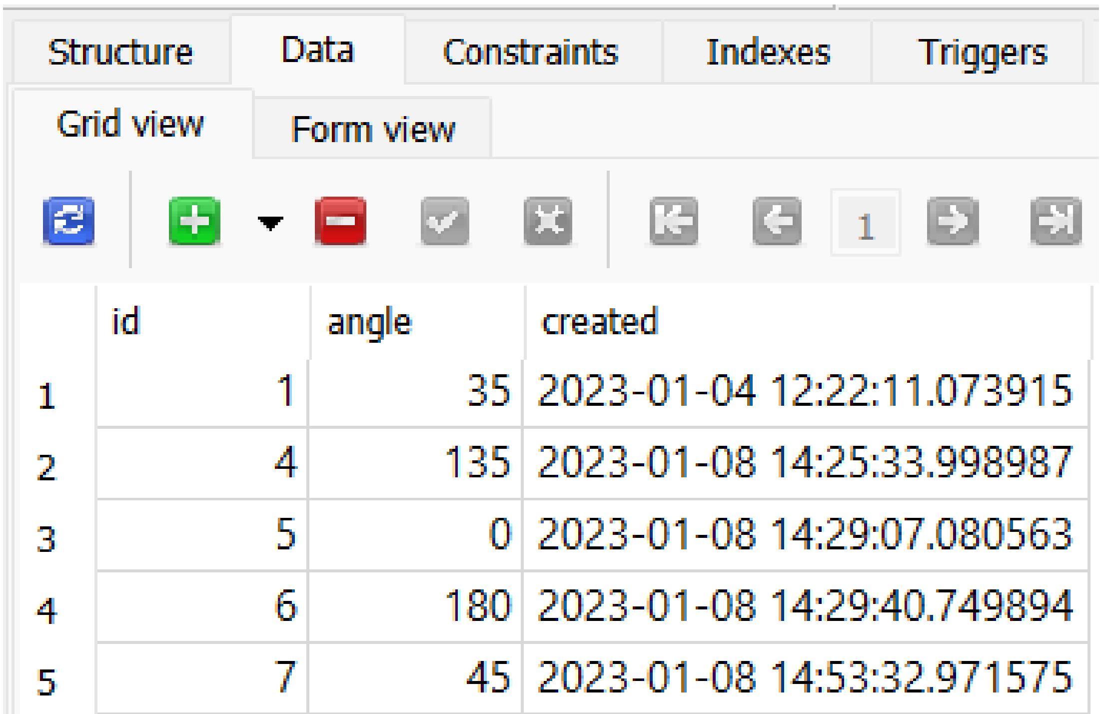
Figure 5. Light data

4.4.2. Light Data

As shown in Figure 5 light and HVAC tables are totally the same. They are responsible for preserving the latest status of light and HVAC sensors. They would be updated from the client side, and the Raspberry module inquires about the latest status from this table.

4.4.3. Servo Data

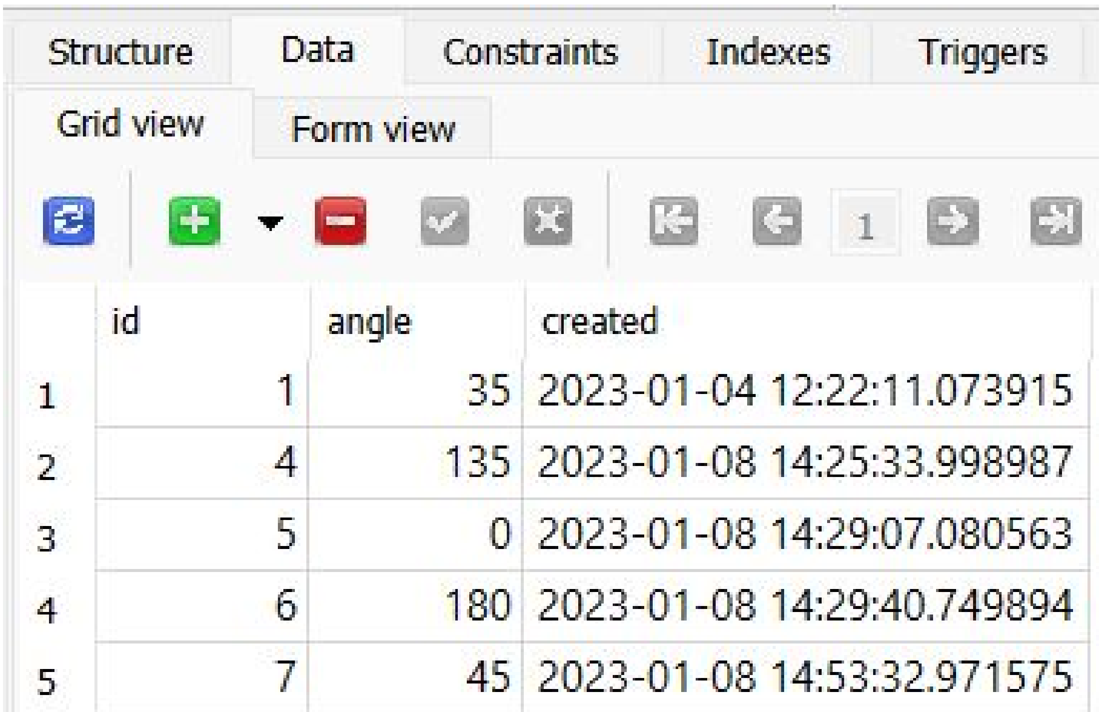
As shown in Figure 6 servo table keeps the changes in servo angle (greenhouse pallets) when the user sees that each part needs more light, they can change the servo angle from 0 to 180. Afterward, Raspberry pie gets the latest status and synchronizes the actuator according to the data it receives from the server



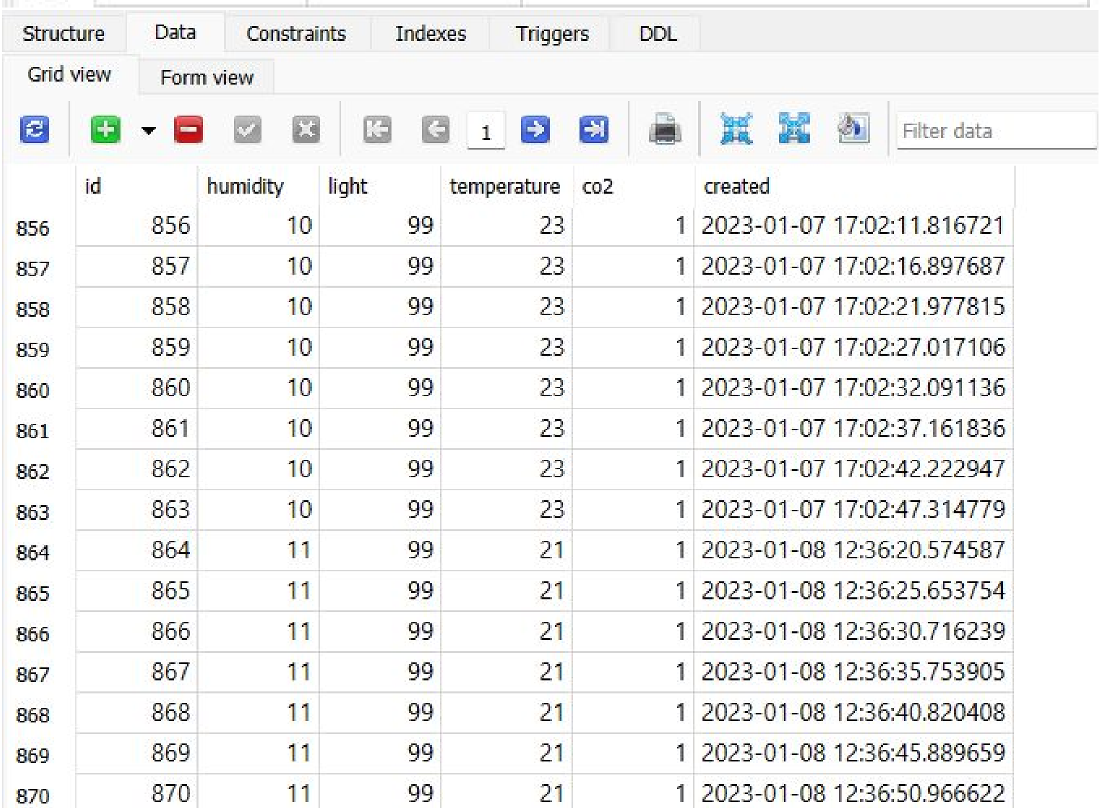
id	angle	created
1	35	2023-01-04 12:22:11.073915
4	135	2023-01-08 14:25:33.998987
5	0	2023-01-08 14:29:07.080563
6	180	2023-01-08 14:29:40.749894
7	45	2023-01-08 14:53:32.971575

Figure 6. Servo data

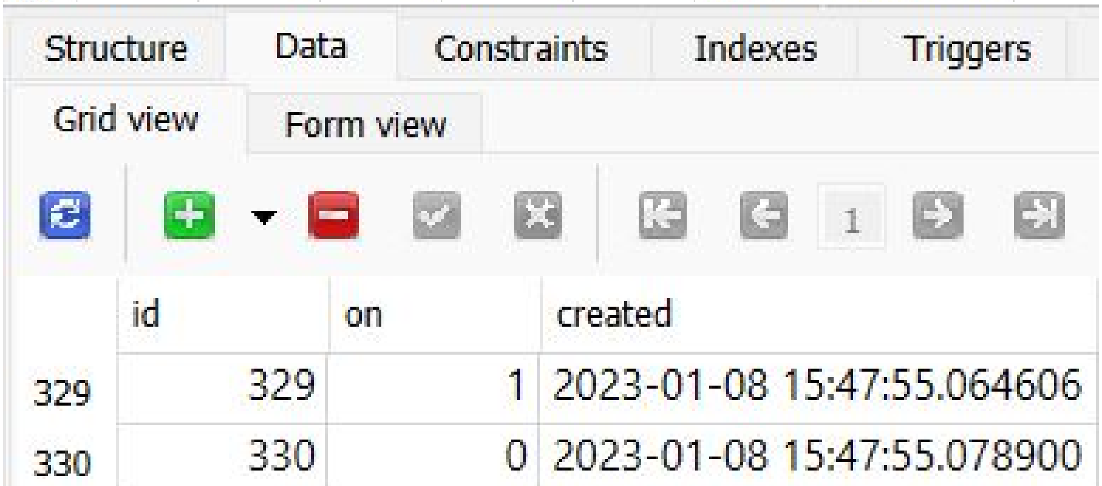
4.4.4. Sensor Data Sheets



	id	angle	created
1	1	35	2023-01-04 12:22:11.073915
2	4	135	2023-01-08 14:25:33.998987
3	5	0	2023-01-08 14:29:07.080563
4	6	180	2023-01-08 14:29:40.749894
5	7	45	2023-01-08 14:53:32.971575



	id	humidity	light	temperature	co2	created
856	856	10	99	23	1	2023-01-07 17:02:11.816721
857	857	10	99	23	1	2023-01-07 17:02:16.897687
858	858	10	99	23	1	2023-01-07 17:02:21.977815
859	859	10	99	23	1	2023-01-07 17:02:27.017106
860	860	10	99	23	1	2023-01-07 17:02:32.091136
861	861	10	99	23	1	2023-01-07 17:02:37.161836
862	862	10	99	23	1	2023-01-07 17:02:42.222947
863	863	10	99	23	1	2023-01-07 17:02:47.314779
864	864	11	99	21	1	2023-01-08 12:36:20.574587
865	865	11	99	21	1	2023-01-08 12:36:25.653754
866	866	11	99	21	1	2023-01-08 12:36:30.716239
867	867	11	99	21	1	2023-01-08 12:36:35.753905
868	868	11	99	21	1	2023-01-08 12:36:40.820408
869	869	11	99	21	1	2023-01-08 12:36:45.889659
870	870	11	99	21	1	2023-01-08 12:36:50.966622



	id	on	created
329	329	1	2023-01-08 15:47:55.064606
330	330	0	2023-01-08 15:47:55.078900

5. DISCUSSION

5.1. What Is the Limitation of This System

There are several limitations to the Smart Greenhouse system that should be considered when evaluating its effectiveness and suitability for a particular application.

One limitation of the system is its reliance on Internet connectivity to transmit data and control commands. If the Internet connection is lost or disrupted, the system may not be able to function properly, limiting its usefulness in certain situations.

Another limitation is the accuracy and reliability of the sensor data. While the sensors used in the system are generally accurate and reliable, there is still a possibility of measurement errors or malfunctions that could impact the accuracy of the data being collected.

Moreover, the system may be limited by the range and capabilities of the actuators used to control the greenhouse environment [5]. For example, the latching relays and electric water valves may not be sufficient to control certain aspects of the greenhouse, such as shading or watering larger plants, requiring the use of additional actuators or different types of actuators. The system may be limited by the complexity and cost of implementation, as it requires a range of hardware and software components that may be difficult or expensive to obtain and set up.

The Smart Greenhouse system has several limitations that should be taken into consideration when evaluating its suitability for a particular application, including its reliance on Internet connectivity, the accuracy and reliability of the sensor data, the range and capabilities of the actuators, and the complexity and cost of implementation.

5.2. What Could Be Improved in the Future

There are several ways in which the Smart Greenhouse system could be improved in the future to increase its effectiveness and expand its capabilities. One potential area of improvement is the addition of more sensors to collect a wider range of data on the greenhouse environment. This could include sensors to measure additional parameters such as soil pH, nutrient levels, and other factors that could impact plant growth and health.

Another potential improvement is the development of advanced algorithms to more accurately and effectively control the actuators based on the sensor data. This could involve the use of machine learning techniques to adapt the control algorithms based on past performance and optimize their performance over time.

Furthermore, the system could be improved by increasing the range and capabilities of the actuators used to control the greenhouse environment. For example, the use of more powerful or specialized actuators could enable the system to control a wider range of variables, such as shading or watering larger plants. The system could be improved by increasing its user-friendliness and accessibility, such as by developing a more intuitive and user-friendly interface for the web application, or by implementing additional features and functionality to enhance its usefulness and appeal to users.

Finally, there are many ways in which the Smart Greenhouse system could be improved in the future to increase its effectiveness and expand its capabilities, including the addition of more sensors, the development of advanced algorithms, the expansion of the actuator range and capabilities, and the improvement of user-friendliness and accessibility.

6. REFERENCES

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ABSTRACT

In this project, we developed a Smart Greenhouse system that utilizes the Internet of Things (IoT) [1] to monitor and control a greenhouse environment. The system consists of sensor modules that collect data on temperature, humidity, air quality, and soil moisture, and actuator modules that control the HVAC, ventilation, watering, and lighting systems. The sensor and actuator modules communicate with each other and with a central microprocessor using a combination of UART and WiFi protocols. The microprocessor, in turn, transmits the data to a cloud server and receives commands from a web application, allowing for remote monitoring and control of the greenhouse. The system also includes automation algorithms that can make decisions based on the sensor data and preset thresholds, enabling the greenhouse to operate in a closed-loop control mode. We implemented the system using a range of hardware and software components, including microprocessors, sensors, actuators, and a web application developed using Python, Flask, and SQLAlchemy. While the system demonstrated good performance and has the potential to improve the efficiency and effectiveness of greenhouse management, it also has a number of limitations, including its reliance on Internet connectivity, the accuracy and reliability of the sensor data, the range and capabilities of the actuators, and the complexity and cost of implementation. There are many opportunities for future improvements to the system, including the addition of more sensors, the development of advanced algorithms, the expansion of the actuator range and capabilities, and the improvement of user-friendliness and accessibility.

Keywords: Internet of Things (IoT), Smart Greenhouse, Sensor modules, Automation algorithms, Environmental monitoring, Sensor accuracy and reliability, Actuator range and capabilities