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(RESEARCH ARTICLE)

Design and construction of Arduino based greenhouse monitoring system using IoT

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Abstract

The rapid advancement of electronic device technologies has led to the creation of intelligent systems aimed at enhancing various aspects of human life. One of the most significant of these advancements is the Internet of Things (IoT), which has revolutionized monitoring, controlling, and security features across numerous applications. In agriculture, IoT-based systems are increasingly crucial for optimizing greenhouse conditions, essential for efficient crop cultivation. This research focuses on the design and construction of an Arduino-based greenhouse monitoring system utilizing IoT technology. The system automates the monitoring and regulation of key environmental parameters such as temperature, humidity, light, sodium, potassium, phosphorus and soil moisture, using sensors and actuators managed by the microcontroller. Prototyping methods was adopted. The integration of IoT enables real-time data collection and remote control, significantly reducing manual labor and enhancing crop yield. Additionally, the system incorporates dual power sources, utilizing both grid and solar energy to ensure uninterrupted operation. The lettuce crop yield increase by 20% which makes the system a better alternative to other. The implementation of this automated system showcases the potential of IoT in creating smarter, more sustainable agricultural practices.

Keyword: Arduino; IoT (Internet of Things); Greenhouse Monitoring; Environmental Control; Automated System

1. Introduction

The rapid advancement in electronic device technologies has ushered in an era of intelligent and automated systems designed to simplify and enhance various aspects of human life. Among these advancements, the Internet of Things (IoT) stands out for its ability to seamlessly integrate monitoring, controlling, and security features across diverse applications. In agriculture, IoT-based systems have become increasingly vital for optimizing environmental conditions within greenhouses, which are essential for efficient crop cultivation. These systems leverage IoT technology to automate the monitoring and regulation of crucial parameters such as temperature, humidity, and soil moisture, thereby enhancing crop yield and reducing the need for manual intervention [1].

Greenhouses offer a controlled environment to protect crops from adverse weather conditions and pests, allowing for year-round cultivation. Traditional greenhouses, however, require constant manual monitoring and adjustments, which can be labor-intensive and inefficient. IoT-based greenhouse systems address these challenges by providing real-time data collection and automated control mechanisms [2]. These systems utilize various sensors to monitor environmental conditions and actuators to maintain optimal growing conditions, all managed through a central microcontroller [3].

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Moreover, IoT technology enables remote monitoring and control of greenhouse environments, offering farmers the flexibility to manage their crops from anywhere with an internet connection. This not only improves efficiency but also reduces the physical presence required, thus saving time and labor costs [4]. The integration of IoT in agriculture represents a significant step towards smarter and more sustainable farming practices, crucial for meeting the growing global food demand [5].

1.1. Problem Statement

Traditional greenhouses require constant manual adjustments to maintain optimal growing conditions, which is labor-intensive and prone to errors, leading to reduced yields. Managing advanced inputs like NPK fertilizers and dual power sources (grid and solar) further complicates this process. Additionally, traditional methods lack real-time data monitoring and remote management, limiting timely responses to environmental changes. An IoT-based system is needed to automate these tasks, integrating advanced inputs and power management to enhance crop yield, reduce labor, and optimize resource use through real-time monitoring and remote control.

1.2. Aim

The aim of this research is to design and implement an IoT-based greenhouse monitoring and control system that automates the regulation of environmental conditions, integrates advanced agricultural inputs, and manages dual power sources to enhance crop yield, reduce labor dependency, and optimize resource utilization.

The research aims to design and implement an IoT-based greenhouse monitoring and control system. The specific objectives of the research are:

- To develop an IoT-based system for monitoring and controlling key environmental parameters in the greenhouse.
- To integrate mechanisms for automated application and monitoring of NPK fertilizers.
- To manage dual power sources, incorporating both grid and solar energy.
- To enable real-time data monitoring and remote control of the greenhouse.
- To enhance lettuce crop yield and optimize resource use through automation and precise control.

1.3. Review of Related Work

Recent advancements in IoT-based greenhouse systems have shown significant promise in enhancing agricultural practices. Shablu Deb Nath et al. [6] developed an IoT-based system that effectively monitors and controls greenhouse environments. This system utilizes sensors to measure temperature, humidity, and soil moisture, with data transmitted to a central microcontroller for processing and actuation. The capability for remote monitoring and control via an internet connection makes this system a robust solution for modern greenhouse management.

Elijah et al. [7] provided an extensive overview of IoT applications in agriculture, focusing on the role of wireless sensor networks (WSNs) in real-time data collection and environmental monitoring. Their work underscores the benefits of IoT in precision farming and automated irrigation systems, which are critical for enhancing crop yield and resource efficiency. This review highlights the transformative potential of IoT technologies in agricultural settings.

In a similar vein, Tolentino et al. [8] developed an IoT-based aquaponics monitoring and correction system that integrates a temperature-controlled greenhouse. This system combines various sensors and actuators to maintain optimal environmental conditions, demonstrating the feasibility and sustainability of IoT applications in agriculture. Their work emphasizes the importance of integrating IoT technology to support sustainable farming practices.

Cost-effective IoT solutions for agriculture have also been explored by Ramachandran et al. [9]. They proposed an automated irrigation system for smart agriculture that uses IoT to optimize irrigation parameters through real-time data collection and analysis. This approach provides a practical and economical solution to water management challenges in agriculture, showcasing the potential for IoT to improve efficiency and reduce costs.

Farooq et al. [10] conducted a comprehensive survey on the role of IoT in agriculture, discussing various applications and technologies that enable smart farming. Their study highlights the critical role of IoT in enhancing agricultural productivity through real-time monitoring, data analytics, and automated control systems. This survey serves as a valuable resource for understanding the broad applications of IoT in agriculture.

Akkaşa et al. [11] designed a greenhouse monitoring system using wireless sensor networks. The system transmits data wirelessly from sensor nodes to a base station, allowing for real-time monitoring and analysis of environmental conditions. This setup helps farmers maintain optimal growing conditions with minimal manual intervention, demonstrating the practicality and efficiency of WSNs in agriculture.

Mohan et al. [12] implemented a greenhouse monitoring system using ARM7 microcontrollers. Their system measures temperature, humidity, and soil moisture, using the collected data to control actuators such as fans and water pumps. This embedded system approach provides a low-cost and effective solution for greenhouse management, emphasizing the role of microcontrollers in agricultural automation.

Pallavi et al. [13] developed an IoT-based system for remote sensing and control of greenhouse parameters. The system utilizes various sensors to monitor environmental conditions and allows for remote adjustments via an internet-connected platform. This technology enhances the flexibility and efficiency of greenhouse operations, making it easier for farmers to manage their crops from a distance.

Manish et al. [14] designed an automated wireless drip irrigation system using linear programming techniques. The system monitors and controls irrigation activities in real-time, optimizing water usage and improving crop productivity. This IoT-based solution reduces labor and conserves resources, addressing critical challenges in modern agriculture.

Finally, Groener et al. [15] focused on designing low-cost greenhouse systems powered by solar energy. Their system integrates microcontrollers and sensors to monitor and control environmental conditions, emphasizing the importance of renewable energy sources in sustainable agriculture. This approach provides a versatile and cost-effective solution for greenhouse management, highlighting the potential for integrating renewable energy with IoT technologies.

2. Materials and Methods

2.1. Materials

To construct the IoT-based greenhouse monitoring and control system, a variety of materials were used. These materials were chosen for their suitability in creating a robust and efficient system capable of maintaining optimal growing conditions for crops. The structural materials provided the necessary physical support and insulation, while the electronic components enabled precise monitoring and control of environmental parameters.

2.1.1. Structural Materials

- *Plastic:* Used for various structural components and enclosures due to its durability and ease of molding.
- *Glass:* Utilized for the greenhouse covering, allowing light penetration while providing insulation.
- *Glue:* Employed to bond different parts securely.
- *Pipe and Hose:* Essential for the irrigation system, facilitating water transport within the greenhouse.
- *Plywood:* Used in constructing the base and other structural elements of the greenhouse.
- *Bulb and Lamp Holder:* Integrated to provide artificial lighting and ensure optimal light conditions.

2.1.2. Electronic Components

Microcontroller: Arduino Uno, used for processing and controlling the entire system.

2.1.3. Sensors

- Temperature and Humidity Sensor (DHT11): For monitoring temperature and humidity levels.
- Soil Moisture Sensor (YL69): For measuring soil moisture content.
- Gas Sensor (MQ-02): For detecting the presence of various gases.

2.1.4. Actuators

- Cooling Fan (12V DC): For temperature control.
- Water Pump (12V DC): For automated irrigation based on soil moisture levels.
- Heater and Light Bulbs: For maintaining optimal temperature and light conditions.
- Communication Module: ESP8266 Wi-Fi module for remote data transmission and control.
- Power Supply: Dual power source setup, including grid and solar energy systems.
- Display Unit: 20x4 Liquid Crystal Display (LCD) to show real-time status of sensors and actuators.

- Fertilizer Dispenser: Mechanism for the automated application of NPK fertilizers.

2.2. Methods

2.2.1. Review of System Hardware

The system design began with developing a comprehensive block diagram illustrating the interconnections between sensors, actuators, the microcontroller, the communication module, and the power supply. This design ensured efficient integration and data flow within the system. Temperature, humidity, soil moisture, and gas sensors were connected to the Arduino Uno. Proper calibration and placement of sensors within the greenhouse were essential for accurate monitoring of environmental parameters.

The cooling fan, water pump, heater, and light bulbs were interfaced with the Arduino Uno. The microcontroller was programmed to activate these actuators based on sensor readings to maintain optimal greenhouse conditions. A dual power source system, incorporating both grid and solar energy, was set up to ensure seamless switching between power sources and maintain continuous operation of the greenhouse system. An automated system for dispensing NPK fertilizers was implemented, ensuring precise control over fertilizer application to optimize crop growth.

2.2.2. Review of System Software

The software development involved programming the microcontroller to handle data collection from sensors, process the data, and control the actuators. Algorithms were implemented for decision-making based on sensor data to maintain optimal environmental conditions. The ESP8266 Wi-Fi module was integrated with the Arduino Uno for remote data transmission. A user-friendly interface was developed for real-time monitoring and control of greenhouse conditions via the internet.

Data management and analysis were also critical components. A database was set up to store sensor data for historical analysis. Scripts were developed to analyze collected data and identify trends in environmental conditions and system performance. A web-based or mobile application provided users with an intuitive interface for monitoring and controlling the greenhouse environment, displaying real-time data and allowing remote adjustments of system parameters.

2.2.3. System Testing and Validation

The complete system was tested under various environmental conditions to ensure reliable operation. Sensor readings were validated for accuracy, and the effectiveness of actuator responses was assessed. The performance of the remote control and monitoring capabilities was monitored to ensure user accessibility and system responsiveness. Data from sensors were collected over an extended period to analyze environmental trends and system performance. Control algorithms were optimized to enhance the efficiency and effectiveness of the greenhouse management system.

This structured approach ensured the development of a robust and efficient IoT-based greenhouse monitoring and control system that enhances crop yield, reduces labor dependency, and optimizes resource utilization.

2.2.4. Block Diagram of the System

The block diagram of the IoT-based greenhouse monitoring and control system integrates several key hardware components for efficient operation. The Arduino Uno microcontroller interfaces with various sensors (DHT11 for temperature and humidity, YL69 for soil moisture, MQ-02 for gas levels) to collect environmental data. Actuators, including a 12V DC cooling fan, water pump, heater, and light bulbs, adjust conditions based on sensor inputs. The ESP8266 Wi-Fi module enables remote control, supported by a dual power source (grid and solar). An LCD displays real-time data, and an automated NPK fertilizer dispenser ensures precise nutrient delivery.

2.3. Hardware Components Used

2.3.1. Microcontroller: Arduino Uno

Sensors

- Temperature and Humidity Sensor (DHT11)

- Soil Moisture Sensor (YL69)
- Gas Sensor (MQ-02)

Actuators:

- Cooling Fan (12V DC)
- Water Pump (12V DC)
- Heater
- Light Bulbs
- Communication Module: ESP8266 Wi-Fi module
- Power Supply: Dual power source setup (grid and solar)
- Display Unit: 20x4 Liquid Crystal Display (LCD)
- Fertilizer Dispenser: Automated NPK fertilizer dispenser

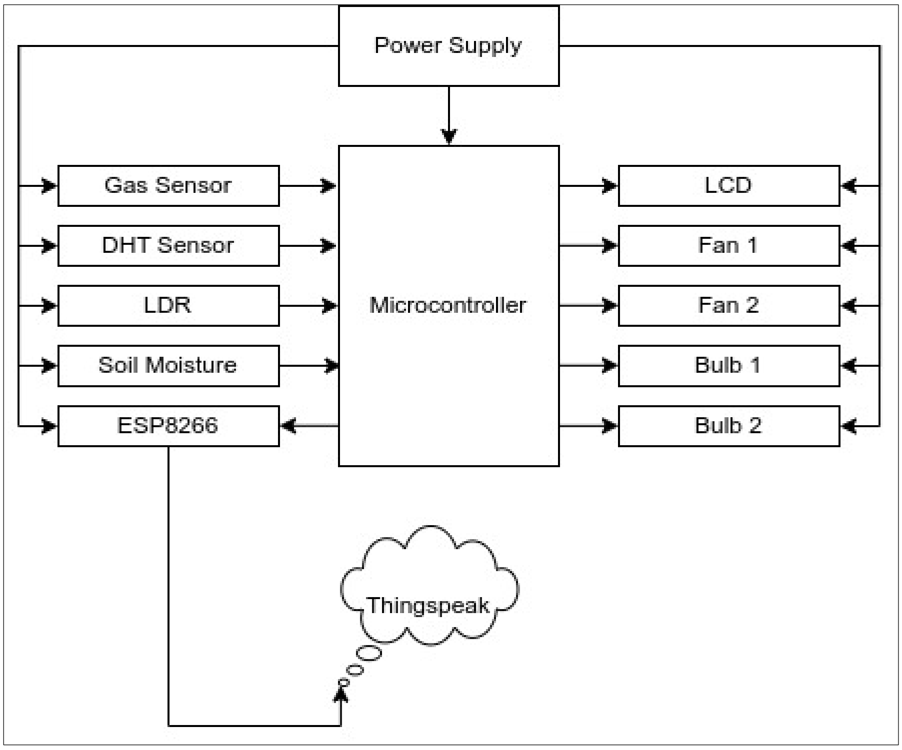

Figure 1 Block Diagram of the System

2.4. Model Setup

The model setup for the IoT-based greenhouse monitoring and control system involves a structured integration of hardware and software components to create an effective and efficient system. The hardware setup includes the Arduino Uno microcontroller as the central unit, interfacing with various sensors like the DHT11 for temperature and humidity, YL69 for soil moisture, and MQ-02 for gas detection. Actuators such as the 12V DC cooling fan, water pump, heater, and light bulbs are strategically placed to maintain optimal environmental conditions. The ESP8266 Wi-Fi module enables remote monitoring and control, while the dual power source system (grid and solar) ensures a reliable energy supply. The 20x4 LCD displays real-time data, and an automated NPK fertilizer dispenser is integrated for precise nutrient delivery.

On the software side, the Arduino Uno is programmed using the Arduino IDE to process sensor data and control actuators based on predefined conditions. The ESP8266 Wi-Fi module is configured to connect to a local network for remote data transmission. A user-friendly web-based or mobile application is developed for real-time monitoring and remote control of the greenhouse environment. This setup is tested under various conditions to ensure accuracy and reliability, with sensors calibrated and algorithms adjusted to maintain optimal performance. This comprehensive approach ensures a robust IoT-based system that enhances crop yield, reduces labor dependency, and optimizes resource utilization.

2.5. Flowchart

The flowchart illustrates the operational flow of the IoT-based greenhouse monitoring and control system, depicting the sequence of actions taken from sensor data collection to actuator control and remote monitoring.

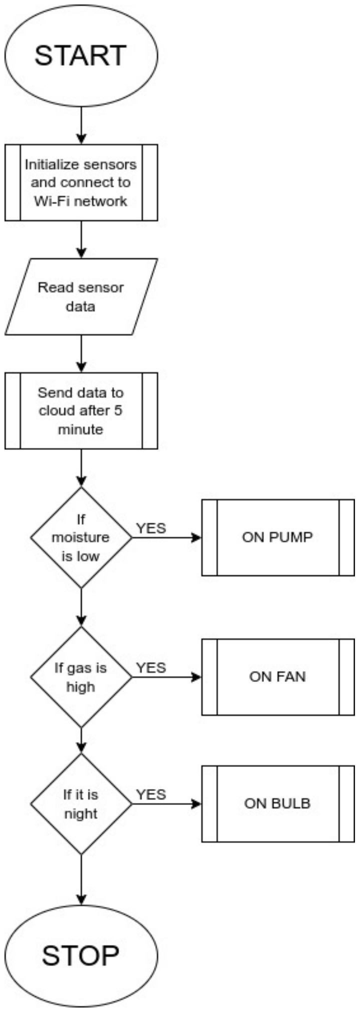

Figure 2 System Flowchart

2.6. Hardware Design of the System

The hardware design of the IoT-based greenhouse monitoring and control system integrates several key components to create a cohesive and functional setup. This design ensures efficient monitoring and control of the greenhouse environment, enhancing crop yield and optimizing resource utilization.

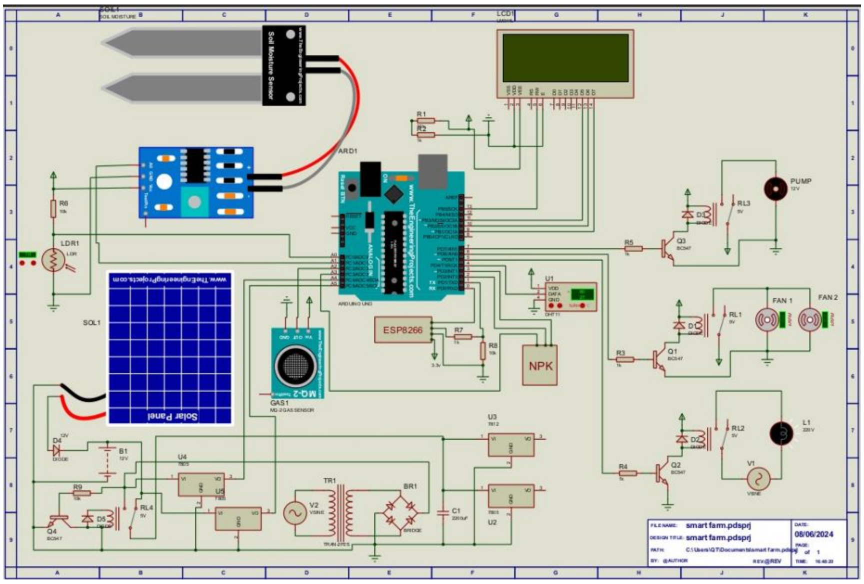

Figure 3 Circuit Diagram

3. Results and Discussion

The IoT-based greenhouse monitoring and control system demonstrated significant effectiveness in maintaining optimal environmental conditions for lettuce crop growth. The sensors accurately monitored temperature, humidity, soil moisture, and gas levels, while the actuators (cooling fan, water pump, heater, and light bulbs) promptly responded to deviations, ensuring stable conditions. The ESP8266 Wi-Fi module enabled reliable remote monitoring and control, allowing real-time data access and system adjustments via a web-based or mobile application. The dual power source setup, incorporating grid and solar energy, provided uninterrupted power, prioritizing sustainability and reducing operational costs.

Overall, the system enhanced lettuce agricultural productivity by automating environmental control and reducing the need for manual intervention. This has increased yield by 20%. The real-time data collection and remote capabilities significantly improved operational efficiency and convenience. The analysis of collected data over a month revealed consistent maintenance of optimal conditions, validating the system's reliability and effectiveness. Figure 10 shows the thinkspeak graphical representation of the monitored parameters. Future enhancements could include integrating additional sensors and advanced data analytics for further optimization. This IoT-based system represents a significant advancement in smart farming technologies, offering a scalable and efficient solution for modern agriculture.

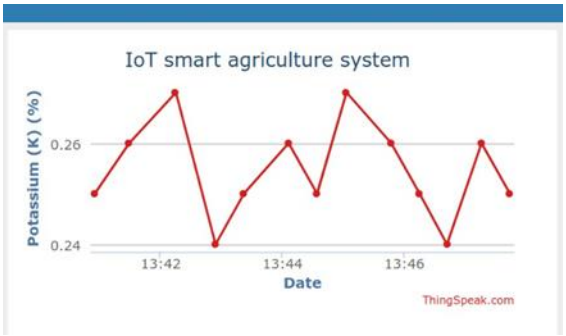

Figure 4 Potassium Graph on Thinkspeak

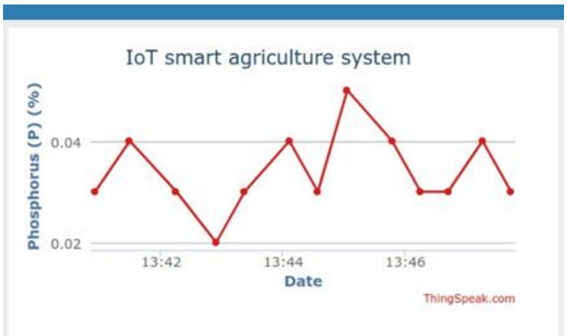

Figure 5 Phosphorous Graph on Thingspeak

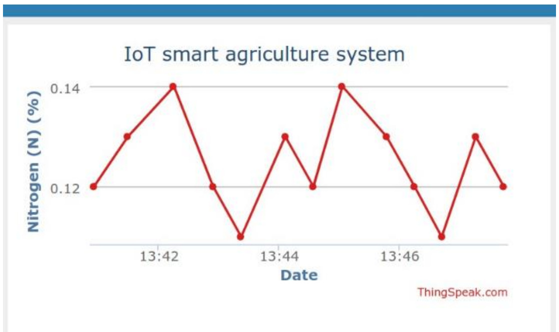

Figure 6 Nitrogen Graph on Thingspeak

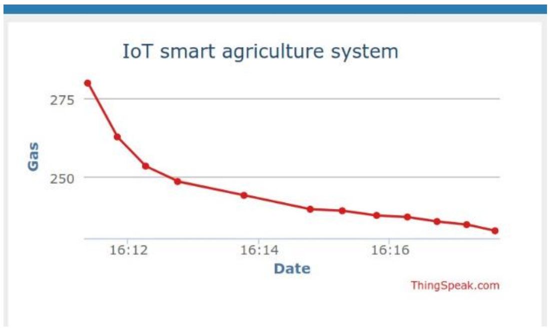

Figure 7 Gas Result on Thinkspeak

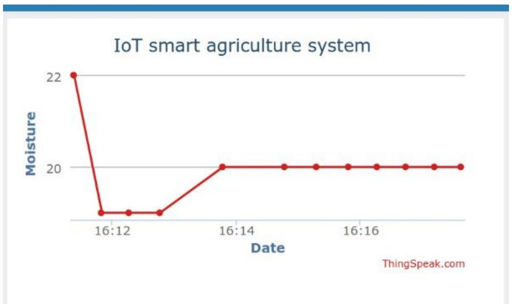

Figure 8 Moisture Graph on Thingspeak

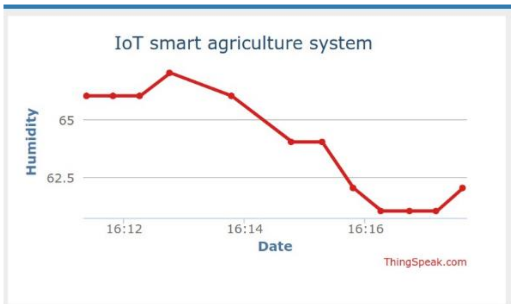

Figure 9 Humidity Graph on Thingspeak

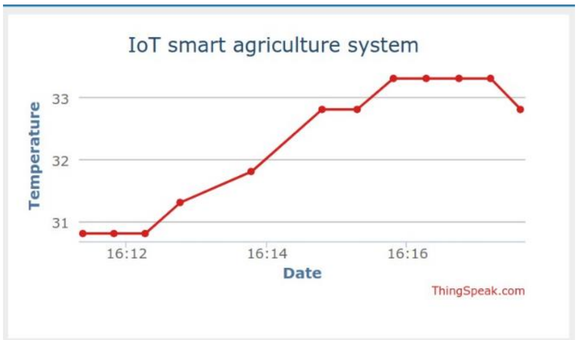

Figure 10 Temperature Graph on Thingspeak

3.1. Enclosure

The enclosure for the IoT-based greenhouse monitoring and control system is designed to protect electronic components from environmental factors such as dust, moisture, and temperature fluctuations. Constructed using durable, weather-resistant materials like plastic and plywood, the enclosure ensures the longevity and reliability of the system. It houses the Arduino Uno microcontroller, sensors, actuators, ESP8266 Wi-Fi module, power supply components, and the LCD display, with strategically placed openings for sensor and actuator connections that are sealed to prevent ingress of dust and moisture.

Ventilation slots are incorporated to ensure adequate airflow and prevent overheating, while mounting points allow for easy installation within the greenhouse. This practical design ensures that all components are securely fastened and protected, maintaining the system's integrity and functionality in the challenging agricultural environment. The enclosure thus plays a crucial role in ensuring the reliable operation of the IoT-based greenhouse monitoring and control system.

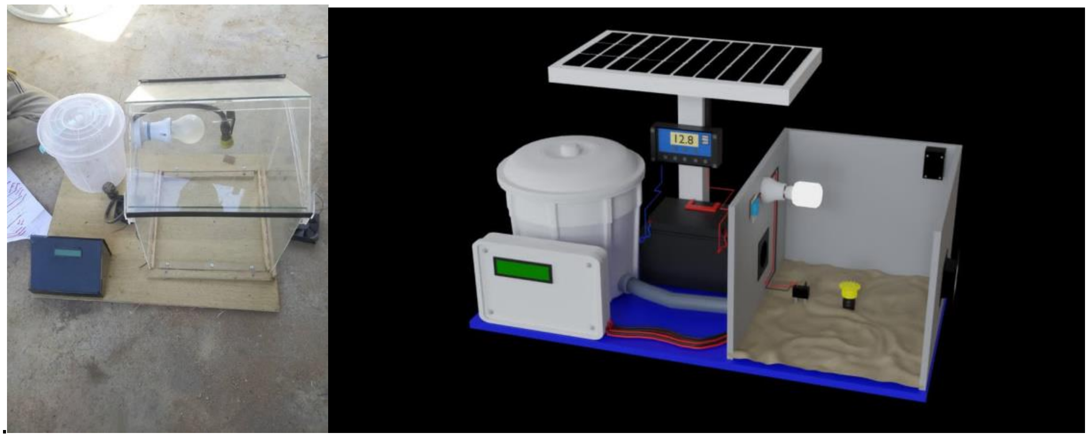

Figure 11 Enclosure

4. Conclusion

The implementation of the IoT-based greenhouse monitoring and control system successfully demonstrated its capability to maintain optimal environmental conditions, enhance crop yield, and reduce labor dependency. The integration of accurate sensors, responsive actuators, and reliable remote monitoring via the ESP8266 Wi-Fi module ensured efficient and effective management of the greenhouse environment. The dual power source setup provided a sustainable and uninterrupted energy supply, further optimizing resource utilization. Overall, this system represents a significant advancement in smart farming technologies, offering a scalable and practical solution for modern agriculture.

Compliance with Ethical Standards

Disclosure of Conflict of Interest

The authors declare no conflict of interest. This research received no external funding, ensuring the impartiality and independence of the study's outcomes.

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Statement of ethical approval

This study was conducted in compliance with all applicable ethical standards in research, ensuring integrity and transparency in data collection and analysis. No human or animal subjects were involved, and all components used adhered to licensing agreements and intellectual property rights.

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