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Green Engineering: IoT-based Greenhouse Automation for Effective Resource Management

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Abstract-This project presents a cutting-edge smart greenhouse system that uses Industrial IoT (IIoT) to automate and improve plant growing conditions. Its primary goal is to transform greenhouse management by integrating IoT and cloud technologies, ensuring optimal conditions for plant development, resource utilization, and remote accessibility. By combining sensors, data processing, and remote access supported by web applications and smartphone notifications, this technique dramatically decreases the requirement for continuous human monitoring. Using technologies such as Wi-Fi, Blynk, and Arduino Cloud, the effort aims to increase agricultural output and produce quality. Furthermore, this proposed approach adheres to sustainable agriculture principles while modernizing old practices to produce better results. Research on IoT based greenhouse automation systems is critical because it enables the development of innovative systems that help farmers improve productivity, profitability, and sustainability. The proposed system aims to help agricultural greenhouses by automating environmental condition management to optimize operations. It enables farmers to increase yields and improve product quality by managing environmental conditions via networked actuator devices. This automated procedure reduces manual intervention and allows for dynamic condition control, increasing energy efficiency.

Keywords: greenhouse, IoT, automation, resource optimization, IOT-based Automated Greenhouse Monitoring System

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1. Introduction

Now technology is everywhere and is primarily used to reduce or maximize human labor. Technology is becoming more prevalent in agriculture to increase crop quality and yield. The term "smart agriculture," which describes the application of technology like the Internet of Things (IoT), wireless sensor networks, positioning systems, and artificial intelligence (AI) on farms, is still distant to the majority of farmers (Sushanth & S. S., 2018; Naresh & P. M., 2019). Precision irrigation (Abioye et al., 2022), precise plant nutrition (Ullah, 2022), climate management and control in greenhouses (Ullah, 2022; Farooq et al., 2022), and other examples of such technology are used on farms. Together, they work with specialized software to monitor and control a farm or greenhouse to optimize its output.

Since agriculture is the main source of food and has a significant impact on the economy, it is the cornerstone of human civilization. A reduction in crop production is the result of farmers continuing to employ techniques that have been practiced for generations. Using contemporary science and technology is necessary to increase agricultural techniques' production. If IoT is used to monitor soil moisture level and effectiveness, temperature and humidity, precipitation amount, fertilizer effectiveness, water tank capacity, and theft detection, we can anticipate that IoT will increase productivity in agricultural areas at a reasonable cost. One strategy to achieve this is to integrate traditional farming practices with cutting edge technologies like wireless sensor networks and the Internet of Things (Simo et al., 2022).

The wireless network uses different kinds of wireless protocols to gather data from numerous sensors and transmit it to the main server. There are numerous more variables that also significantly affect production. The crop is vulnerable to attacks from a range of wild animals, birds, insects, and other pests during its growth. These can be controlled by applying the proper insecticides and pesticides. Crop yield is declining due to the unpredictable monsoon rainfall, which, when paired with a scarcity of water and excessive consumption, poses a concern (Simo et al., 2022).

The concept of Smart Greenhouses helps guide the necessary measures to be adopted for promoting agricultural systems' growth and ensuring food security in a climate change context (Tawfeek et al., 2022). Smart Greenhouses are an instrument that helps guide the actions needed to adapt and protect the environment. To increase agricultural productivity sustainably, to ensure climate change resilience and to reduce or eliminate greenhouse gas emissions are the three main objectives of this policy (Revathi et al., 2017) . One of the most important areas covered by the World Food Organization's Strategic goals for increasing crop production and resource mobilization is smart greenhouses. It is committed to the (Food and Agriculture Organization-FAO)'s mission of increasing sustainability in agricultural production, consistent with its food vision.

The integration of IoT technology in greenhouse automation is not new approach nowadays, this study aims to introduce a unique approach to resource management by leveraging advanced sensor networks, with added manual and automated adjustment thresholds which can help the greenhouse to adjust based on different plants and climate conditions and data analytics for real-time decision-making. Existing IoT systems primarily focus on monitoring environmental variables such as temperature, humidity, and light levels (Farooq et al., 2022). However, our system incorporates a combination of advanced environmental sensor thresholds to optimize resource usage, such as water and energy consumption, based on real-time weather data and crop-specific requirements. This approach differentiates our work from traditional systems by providing a more dynamic, adaptive control system, which has been shown to improve resource efficiency. This advancement provides significant value to both small-scale and large-scale agricultural operations by improving yield while minimizing waste and operational costs.

And this project presents an Industrial IoT-based Smart Greenhouse system to assist and enhance the growing conditions of plants. The initiative aims to transform greenhouse gas management through the use of the Internet of Things and cloud technologies to guarantee optimal conditions for plant development, energy efficiency, and accessibility from distant locations. To reduce the need for constant human supervision, this approach consists of sensors, data processing, and remote access through web applications and smartphone notifications.

The initiative is aimed at improving farm productivity and the quality of output through the use of technologies such as Wi-Fi, Blynk, or Arduino Cloud. This project solution is in line with the principles of sustainable agriculture and complements the modernization of conventional methods to achieve better results. In general, these newly developed and enhanced systems that help farmers boost their output, profitability, and sustainability make the study of Internet of Things (IoT)-based greenhouse automation systems crucial.

2. Literature Review

Danita & B. M. et al. (2018) have reported an IoT-based automated temperature control system to maintain a suitable climate inside the greenhouse using moisture sensors, temperature & humidity sensors, raspberry PI, and water pipes to supply water from the tank controlled by the DC motors. Also, they used temperature & humidity sensors (DHT11) and moisture sensors (YL69) to sustain suitable climate conditions in the greenhouse. Better cultivation is affected by some of the basic factors such as sunlight, the water content in the soil, temperature, and humidity, etc. and also, continuously observing the temperature and the moisture is very important in greenhouse cultivation.

Shirsath et al. (2017) proposed an IoT-based smart greenhouse automation system based on Arduino. And they deliver that the android-based system is not better for the greenhouse where one human resource always needs to be in a place to monitor the changes happening inside the house. They used many varieties of sensors to detect factors like soil, temperature, and water vapors in the air such as soil moisture sensors, LDR sensors, humidity sensors (DHT11), and (LM35) temperature sensors. in this study, they aimed to automatically control climate changes and improve plant cultivation of all year (Shirsath & P. K., 2017).

The authors (Chandra, 2018) mention that the humidity is the most crucial parameter in the greenhouse automation system, and also, the temperature inside the greenhouse directly affects crop growth, therefore they are using the MQ5, and MQ7 gas sensors to detect the gas leaks, or incident happens inside the environment. and they use XMPP, MQTT, CoAP as a communication technology used to transmit the information from the sensors and monitor the system and alert the users.

Chen et al. (2022) and Chowdhury (2022) claim that there are seven distinct varieties of privacy-enhancing technologies for applications in the Internet of Things, including enforcement, control over data, personal data protection, confidentiality, partial data transparency, anonymous authorization, and comprehensive privacy preservation. As an outcome, the five categories of authentication, confidentiality, non-repudiation, integrity, and access control can be used to group the security needs for IoT applications. The security processes for IoT-based green agriculture should satisfy these security and privacy requirements.

Furthermore, Samuel, Srinivas, and Bachu (2024) proposed a system where a soil moisture sensor measures soil moisture levels, and a temperature sensor monitors the ambient temperature within a greenhouse. Real-time data from the greenhouse is transmitted to the cloud, ISP, and internet, enabling seamless monitoring. Farmers can regulate soil moisture using a graphical user interface (GUI) on the app, which activates the water pump as needed. The system also controls temperature by activating a fan and a hot/cold Peltier module connected to the thermal pest system. An exhaust fan removes moist air from the greenhouse to maintain optimal moisture levels. Additionally, the filter pump is activated, and LED lights are turned on when required. This system provides users with real-time updates, ensuring efficient greenhouse management.

Farooq et al. (2020) proposed an IoT-based network infrastructure for a sustainable greenhouse environment. And control effective resource management. The system has been designed with applications, sensors, and communication protocols. And this study discusses some challenges throughout the smart greenhouse. And they have mentioned some other security concerns. The research summarized by developing an attack taxonomy and IOT-based Greenhouse farming management. This kind of IoT based large system consists of sensors, controllers, actuators, and cameras to monitor farming activities remotely. And the farming systems mostly focus on fertilization, watering, infection, and disease control (Rakesh et al., 2022).

Several scholars have explored the integration of IoT in agricultural systems, but the focus has largely been on monitoring rather than active control (Farooq et al., 2020). Previous studies have primarily emphasized IoT for data collection, with limited emphasis on the decision-making process enabled by real-time sensor data analysis. For example, Kumar et al. (2024) highlighted that while IoT systems can provide useful insights into environmental conditions, their effectiveness is often hindered by the lack of a comprehensive control mechanism that integrates environmental inputs with actionable outputs. Our study addresses this gap by incorporating an automated decision-making component that dynamically adjusts irrigation and climate control systems.

3. Research Methodology

This study proposed an innovative approach to managing greenhouse resources effectively by utilizing the integration of modern (IoT) technologies with efficiency in terms of energy techniques. A monitoring system based on IoT application is recommended to improve control and generate real-time data.

Developing an Industrial IoT-IioT (application of Internet of Things (IoT) technologies in industrial settings)-based project involves a structured methodology that encompasses various stages, from conceptualization to deployment. Initially, the project's objectives must be clearly defined, along with specific goals. Market research is conducted to understand the landscape and identify potential competitors and gaps. Ideas are then conceptualized, and a feasibility study is carried out.

The proposed system used environmental data collection methods. The temperature of the greenhouse was tracked throughout its whole construction and provided results in Celsius values. Our system collects data such as soil moisture level, air quality, and door sensors to effectively monitor and manage the greenhouse remotely.

To achieve this, we have used the Node MCU ESP–12 development kit. And this proposed system contains several sensors to monitor the greenhouse environment such as a Soil moisture sensor (capacitive soil moisture sensor v2.0), air quality sensor (MQ-135), temperature and humidity sensor (DHT11), and mini micro switch to detect the door status.

3.1. Iot-Based Automation through Data Acquisition

Temperature, humidity, soil conditions, air quality levels, and door operations were optimized from the sensor data that were gathered by utilizing IoT techniques. The temperature, humidity level, soil moisture level, and air quality levels can be set and adjusted through the threshold in the mobile app or web platform according to the different plant's needs to adjust and automate the functions of the actuators.

A. Humidity, temperature, and soil moisture level Assessment

The greenhouse average humidity levels and temperature levels have been determined. Analysis of the soil condition of the general plants and individual plants was carefully measured through the sensors.

B. Active management

Manual intervention was not necessary because of the data collection which enabled dynamic resource control. By evaluating sensor data and delivering specific commands to actuators, this system was directed by the IoT concept.

C. Optimization of Actuators

The goal of the study was to optimize actuators' on-off-cycle for precision and efficiency to achieve sustainable energy usage. The system uses sensors and actuators such as door switches, fans, and water pumps for monitoring and automating and controlling of the greenhouse process.

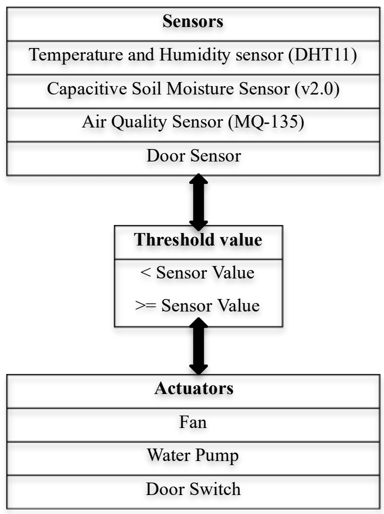

Figure 1. *Operational diagram*

The interaction between actuator optimization, dynamic control, and data collected from sensors is shown graphically in the operational diagram. (Figure-1) The system provides sensitive and energy efficient resource management in a smart greenhouse by synchronizing operations based on certain threshold values which can be adjustable through the web interface/ mobile app according to the plants' needs.

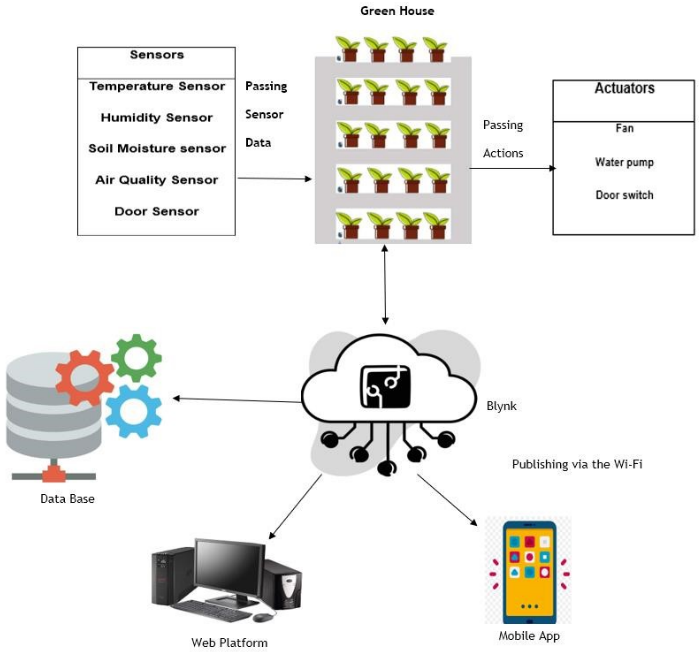

Figure 2. *System Architecture Diagram*

The following three primary components make up the proposed research: online platform, mobile application, and hardware. The system Architecture is shown in Figure 2 which illustrates the smooth integration of the elements. The data from sensors are captured by hardware. Then that information is assembled by the online platform, and user access is ensured by the mobile application.

This invention revolutionized traditional greenhouse options and provided an integrated and holistic approach to effective resource management in smart greenhouses.

D. Hardware

Air quality sensor (MQ-135): A keen guardian against harmful pollutants, this sensor monitored CO2 levels, triggering ventilation if the air grew stuffy.

Temperature and Humidity Sensor (DHT11): A temperature sensor circuit is a fundamental component in many electronic systems, providing a means to measure and monitor temperature variations in a specific environment. One common type of temperature sensor circuit is based on a thermistor, a resistor whose resistance varies with temperature.

Capacitive Soil moisture sensor (V2.0): is used to measure the soil moisture level. This detects soil moisture level and passes the parameter to the system.

ESP8266: The Brains of the Operation, The ESP8266 served as the central processing unit, interpreting sensor data and issuing commands to the actuators. This includes ESP8266 (node MCU). The ESP8266 Wi-Fi module is a self-contained SOC with an integrated TCP/IP protocol stack that allows any microcontroller to access your wireless network. The ESP8266 may host applications, or remove all functions from other application processors for wireless networking. It uses IEEE 802.11 bgn standards.

LM2596 Buck Converter and relay module: is used to alter the voltage value.

Water pump: When the moisture sensor dipped below a set threshold, the ESP8266 sprang into action, activating the pump for a precise dose of irrigation, mimicking a gentle rain shower.

Fan: To combat stifling heat or rising CO2 levels, the ESP8266 whirred the fan to life, ensuring proper air circulation and a breath of fresh air for the plants.

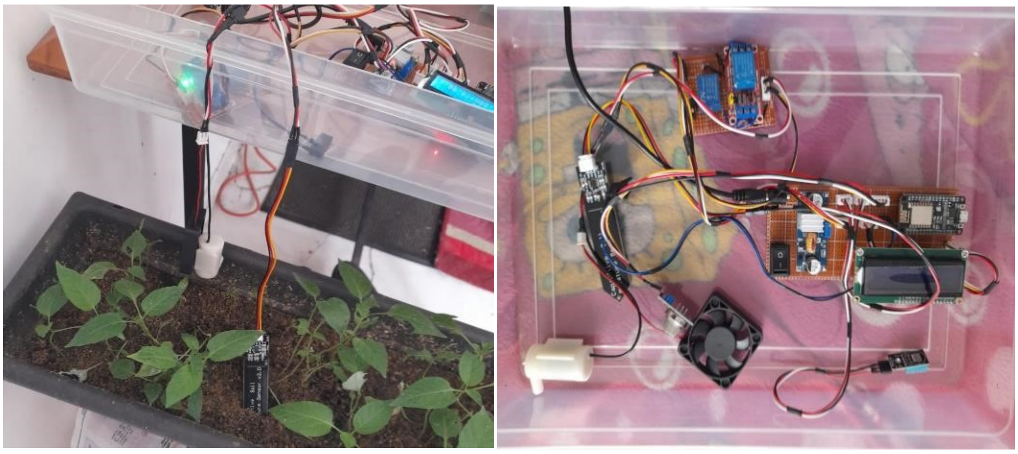

Figure 3. *Hardware components*

E. Software

Web Platform: The Blynk Console for a greenhouse is an effective tool that brings smart automation to cultivation. With this modern platform, users can remotely monitor and manage a variety of greenhouse operations. They can also access collected data and control features remotely through this user-friendly web platform. This type of control enables immediate responses to changing conditions, in addition to saving time.

All analytics details are displayed on the web dashboard. For example, temperature, humidity, and soil moisture values indications, air quality, door open or close status indications, and graphs of the greenhouse are available. Based on past trends, the Blynk Console also assists users in making informed decisions. This feature helps maximize the use of resources and adjust the greenhouse's conditions to improve crop yields.

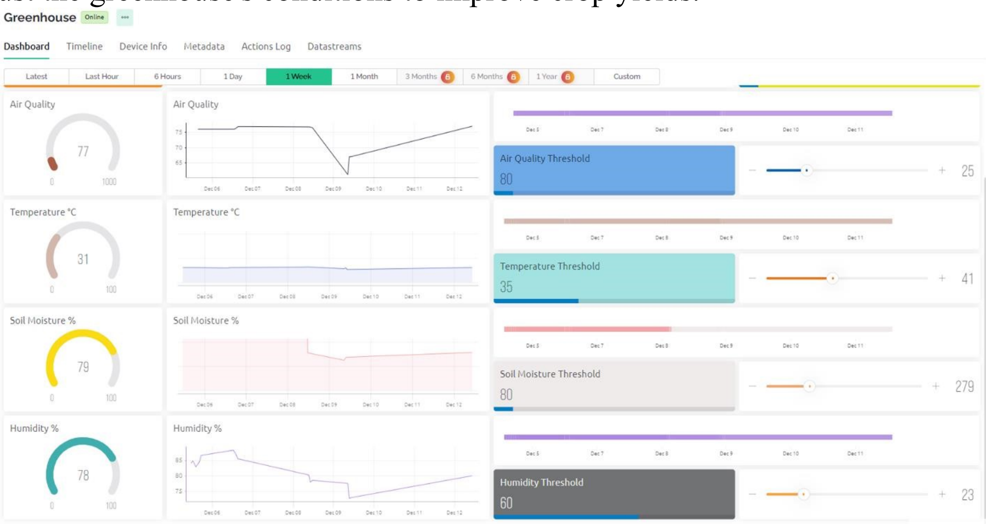

Figure 4. *Web Platform interface showing one-week's readings from sensors*

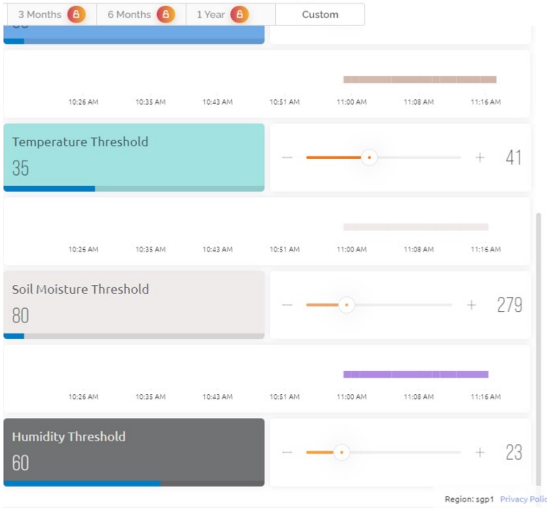

Figure 5. *Web Platform- Threshold adjustment option to adjust the values to activate the actuators.*

Mobile Application: Creating a mobile application to give greenhouse managers is so important because they can have remote access so they can monitor conditions and make changes from any location, saving time and effort from human mistakes. Hence this can be called an App for on-the-go management. The interfaces of the mobile application should be user-friendly. Then it provides greenhouse managers with real-time data and control capabilities. Data is visualized and displayed through a Phone display system. Additionally, data can be accessed and analyzed on a computer for further insights.

F. Connectivity

The system uses the node MCU ESP-12 board, which is a Wi-Fi-enabled technology. This allows any microcontroller to access the wireless networks. The ESP8266 may host applications, or remove all functions from other application processors for wireless networking. The following figure shows the greenhouse device connectivity information.

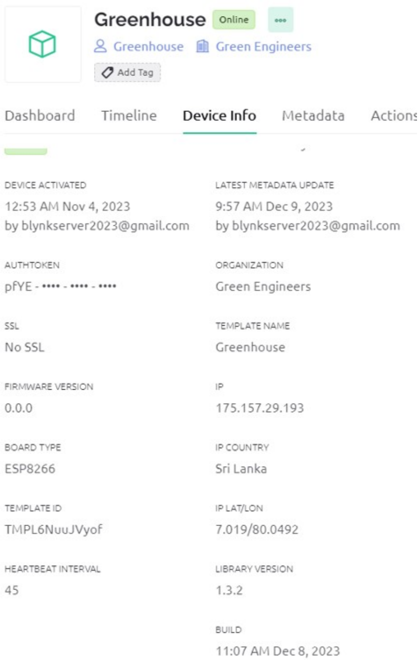

Figure 6. *Connectivity details*

4. Results and Discussion

This system was built as a Robust and Budget-Friendly IoT Greenhouse with the ESP8266. The ESP8266, a Wi-Fi-enabled microcontroller chip, has gained widespread popularity within the DIY IoT community due to its versatility and cost-effectiveness. Its affordability and ease of use have opened doors for creative projects, and our goal was to leverage this potential in building a robust yet budget-friendly IoT greenhouse.

Sensor Network and Data Acquisition: We equipped our greenhouse with a trio of environmental sensors: Moisture sensor and temperature sensor: This trusty capacitive soil moisture sensor kept tabs on soil moisture levels, sending real-time data to the ESP8266 whenever the plant thirsted for a drink. Likewise, the temperature sensor reads environment temperature-related data and sends the signal to the fan to switch on, whenever the temperature reading is higher than the threshold value.

Remote Monitoring and User Interface: We built a user-friendly web interface and mobile app accessible on any device. This dashboard displayed live sensor readings, visualized data trends, and allowed for manual intervention. We could adjust set points and fine-tune the thresholds for humidity, moisture, and CO2 levels to cater to specific plant needs online. This app can track the historical data from sensors and perform accordingly.

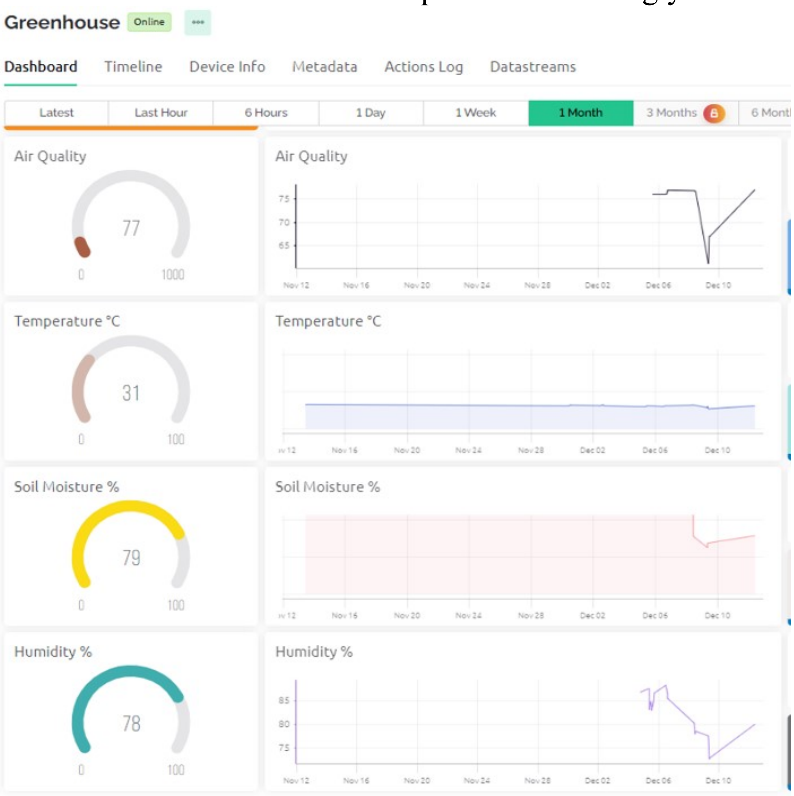

Figure 7. *One month Sensor reading historical data*

Figure 8. *Mobile Dashboard*

Trigger actions: Nudge the pump for extra water or activate the fan for a quick burst of ventilation.
Report generation: This system generates event and data reports. It provides a facility for customizing reports based on the customer needs.

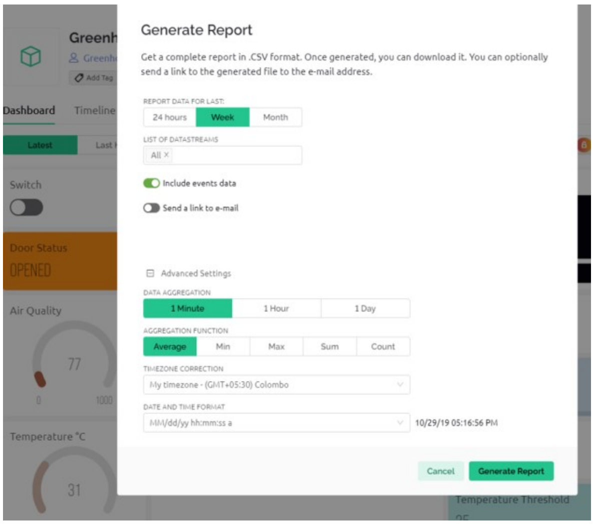

Figure 9. *Web Platform – Report generating Option based on system record*

	A	B	C	D
1	Time	Event Type	Name	Description
2	2012-12-23 11:05	WARNING	Temperature Alert	Temperature threshold exceeded!
3	2012-12-23 11:05	WARNING	Door Status Alert	The greenhouse door is open!
4	2012-12-23 11:04	WARNING	Air Quality Alert	Air quality threshold exceeded!
5	2012-12-23 11:03	WARNING	Humidity Alert	Humidity threshold exceeded!
6	2012-12-23 11:02	WARNING	Moisture Alert	Moisture threshold exceeded!
7	2012-12-23 11:01	WARNING	Temperature Alert	Temperature threshold exceeded!
8	2012-12-23 11:01	WARNING	Door Status Alert	The greenhouse door is open!
9	2012-12-23 11:00	WARNING	Humidity Alert	Humidity threshold exceeded!
10	2012-12-23 11:00	WARNING	Door Status Alert	The greenhouse door is open!
11	2012-12-23 11:00	WARNING	Smoke Alert	Smoke detected!
12	2012-12-23 10:59	WARNING	Humidity Alert	Humidity threshold exceeded!
13	2012-12-23 10:59	WARNING	Door Status Alert	The greenhouse door is open!
14	2012-12-23 10:59	ONLINE	Online	

Figure 10. *Events Report Screenshot*

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	
1	Time	Temperature	AirQuality	SoilMoisture	TempThreshold	Temp	Moisture Threshold	Moisture	Humidity	Door	Humidity Threshold	Humid	Air Quality	AQThreshold	AQ	Alert	AQI
660	2012-05-23 12:00	31		781.2727273					84				76				
661	2012-05-23 11:59	31		780.9538462	35		800		84		60		76	79			
662	2012-05-23 11:58	31		781.2033898	35		795.4347826		84		41.17391304		76	77			
663	2012-05-23 11:57	31		781.1818182					84				76				
664	2012-05-23 11:56	31		781.4242424					84.93939394				76				
665	2012-05-23 11:55	31		781.3030303					85				76				
666	2012-05-23 11:54	31		781.3939394					85				76				
667	2012-05-23 11:53	31		781.3384615	35		785		84.49230769		67.66666667		76	77			
668	2012-05-23 11:52	31		781.1846154	35		785		84		60		76	77			
669	2012-05-23 11:51	31		781.442623	35		788.4444444		84.13333333		59.83333333		76	77			
670	2012-05-23 11:50	31		781.4590164	33.84615385		799.5384615		84		60		76	77			
671	2012-05-23 11:49	31		781.5454545	36		800		84		60		76.01515152	76			
672	2012-05-23 11:48	31		781.3787879					84				76				
673	2012-05-23 11:47	31		781.530303					84				76				
674	2012-05-23 11:46	31		781.6515152					84				76				
675	2012-05-23 11:45	31		781.6212121					84.33333333				76				
676	2012-05-23 11:44	31		781.5757576					85				76.01515152				
677	2012-05-23 11:43	31		781.5606061					85				76				
678	2012-05-23 11:42	31		781.6515152					84.21212121				76				

Figure 11. *Data Report Screenshot*

Receive alerts: Get notified if sensor readings go haywire, ensuring timely intervention before harm to our precious greenery. This system also provides mobile alerts to the system users.

Figure 12. *Web Platform – Alerts and Notification of the system*

Impact and Observations: The results highlight an advanced and effective outcome compare to traditional methods. Based on the system results it is highlighted to recommend this model for advanced protection and resources management in agriculture.

5. Conclusion

The proposed IIoT-based Greenhouse is intended to assist agricultural greenhouses by automating the management of environmental conditions for optimal operation. It maintains environmental factors at benchmarked levels via connected actuator devices, supporting farmers in increasing yields or improving quality. This automation lowers manual involvement and allows for dynamic condition control, resulting in greater energy efficiency.

Various garden metrics can be remotely monitored and gadgets as needed using the Blynk app. With the help of this project, people with little time may monitor the greenhouse more easily by using the Blynk app on their phones to monitor the operations. The novel solution is an IoT-based platform designed to monitor and improve farm surroundings, including soil conditions, and air quality. It also has a complete dashboard with features like historical data analysis, quick notifications, and customized threshold settings. This system improves the precision and efficiency of agricultural practices greatly.

6. Limitations and Recommendations

This project has been a resounding success, proving that the ESP8266 can be a powerful tool for building efficient and affordable IoT greenhouses. However, there's always room for growth.

Sensor fusion: Integrating additional sensors like light intensity or Motion could provide even more granular environmental insights.

Machine learning: This greenhouse project doesn't include any data analytic and prediction features. Implementing AI algorithms to analyze sensor data and event data and predict plant needs could automate watering and ventilation to an even finer degree.

Mobile app development: A user-friendly mobile app would offer on-the-go monitoring and control, ideal for busy green thumbs. Presently Blynk provides its custom mobile app which can be accessed by providing Blynk account login credentials. Even though it provides many features, it has some limitations according to the subscription type. In the future researchers can implement a customized user-interfaced mobile app with more features and language adjustable capabilities. Since many farmers are not familiar with pure English.

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