

IOT-Enabled Intelligent Mini Greenhouse for Automated Crop Environment Management

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Abstract - This paper presents a Smart IoT-Based Mini Greenhouse designed to automate environmental monitoring and control for precision agriculture. The proposed system uses a NodeMCU ESP8266 with temperature, humidity, soil-moisture, and mist sensors to continuously observe greenhouse conditions. Based on predefined environmental thresholds, the controller automatically operates a water pump, exhaust fan, misting unit, and LED grow light to maintain suitable conditions for plant growth. An LCD provides local information, while the Blynk IoT platform enables remote monitoring, alerts, and actuator control through a mobile application. The system reduces dependence on continuous manual supervision and supports more efficient use of water and energy. The implemented prototype demonstrates the feasibility of combining IoT sensing, automated actuation, and remote connectivity for small-scale greenhouse applications. The modular design can also be extended with additional sensors, data analytics, machine learning, and predictive control techniques for improved crop management.

Key Words : IoT, Smart Greenhouse, Precision Agriculture, NodeMCU ESP8266, Environmental Monitoring, Automated Irrigation, Soil Moisture, Blynk, Greenhouse Automation, Remote Monitoring.

1. INTRODUCTION

Recent developments in agricultural automation have demonstrated the usefulness of combining environmental sensing with wireless communication and remote monitoring. Pochal and Patil developed an IoT-based agricultural robotic device capable of monitoring soil moisture, temperature, humidity, and illumination using sensors connected to an ATmega328 microcontroller and an ESP8266 Wi-Fi module. The collected information was transmitted to a cloud platform for visualization, while a 16×2 LCD provided local monitoring of the measured parameters [1]. This work demonstrates the feasibility of connected sensing and remote agricultural monitoring; however, there remains a need for compact greenhouse systems that integrate environmental monitoring with automatic irrigation, ventilation, misting, lighting, and user notifications. The proposed Smart IoT-Based Mini Greenhouse is developed to address this requirement by combining sensing, automated actuator control, local display, and Blynk-based remote monitoring within a single greenhouse platform.

Agricultural robotic systems demonstrate the potential for combining sensing, control, communication, and automated operation within farming environments. Robotic platforms can assist with agricultural activities while providing remote interaction through connected devices. These developments indicate that future greenhouse systems can integrate robotic functions with environmental monitoring and IoT-based control [2].

Deep-learning techniques have also been applied to image-based detection and classification problems. Such approaches can automatically learn complex patterns from visual data and can potentially be extended to agricultural applications such as crop-health monitoring and disease identification. Integrating computer vision with greenhouse systems could provide additional information for future automated crop-management strategies [3].

Machine-learning techniques provide opportunities to extend agricultural systems beyond simple threshold-based control. Historical and environmental data can be analyzed to identify patterns and develop predictive models for agricultural decision-making. The application of machine learning to agricultural problems demonstrates the potential for future smart systems to incorporate intelligent prediction capabilities [4].

Smart greenhouse technologies are increasingly being considered for controlled-environment agriculture because they provide opportunities to automate repetitive monitoring and control tasks. The combination of sensors, connected controllers, and automated equipment can create a more responsive growing environment. These technologies can be particularly useful for small-scale and urban agricultural applications [5].

Environmental monitoring and automatic control can be combined with IoT connectivity to provide users with real-time information about greenhouse conditions. Measurements from sensors can be processed by a central controller and presented through local or remote interfaces. This integration allows greenhouse operators to observe system conditions and respond to environmental changes more effectively [6].

Smart irrigation systems can use soil-moisture information to determine when water should be supplied to plants. Instead of depending entirely on fixed watering schedules, sensor-based

irrigation can respond to the actual moisture condition of the growing medium. This principle is particularly useful for small greenhouse systems where efficient water utilization is an important objective [7].

Automated greenhouse management can combine environmental monitoring with control mechanisms to maintain suitable conditions for crop development. The automation of ventilation, irrigation, lighting, and other greenhouse operations can reduce dependence on manual intervention. Such systems provide a foundation for more consistent and efficient controlled-environment crop production [8].

Energy efficiency is another important consideration in IoT-based agricultural systems. Wireless sensing devices and communication components may operate continuously, making efficient energy utilization necessary for reliable long-term deployment. Energy-aware sensor-network approaches can therefore contribute to sustainable and practical precision-agriculture applications [9].

Water management is a critical aspect of smart agriculture because irrigation must provide sufficient moisture without unnecessary water consumption. IoT-based water-management systems can use sensor information to determine irrigation requirements and control water delivery. This approach can improve the responsiveness of irrigation operations and support more efficient water utilization [10].

Wireless sensor networks provide an important foundation for precision agriculture because multiple sensing devices can collect information from different locations. Such networks can support monitoring of environmental parameters and provide data required for agricultural decision-making. Their application in precision agriculture demonstrates the importance of distributed sensing for automated crop management [11].

IoT technologies in agriculture have developed rapidly because they provide mechanisms for connecting agricultural environments with digital monitoring systems. Sensors can measure environmental conditions while communication networks transmit the collected information to processing or visualization platforms. This enables agricultural processes to become more responsive to actual environmental conditions [12].

The development of IoT systems depends on the effective integration of sensing devices, communication technologies, processing units, and application interfaces. IoT architectures provide a framework through which physical devices can collect information and communicate with software platforms. These principles are directly applicable to greenhouse automation systems that require continuous monitoring and control [13].

Digital agricultural systems require appropriate architectures for integrating physical devices, communication technologies, data management, and application services. A well-structured digital architecture can support the movement of information between different components and provide a foundation for intelligent agricultural applications. Such architectures are

relevant to the development of connected greenhouse-management systems [14].

Large volumes of agricultural data can provide valuable information about crop and environmental conditions when collected systematically. Data-driven farming approaches can assist in identifying patterns and improving agricultural decision-making. The use of historical information can also support the development of advanced monitoring and prediction methods for future smart-farming applications [15].

The combination of IoT and data analytics has expanded the possibilities for agricultural monitoring and decision support. Sensor-generated information can be stored and analyzed to identify environmental patterns and support future agricultural decisions. Integrating data analysis with IoT infrastructure can therefore contribute to the development of more intelligent agricultural management systems [16].

Precision agriculture can also be applied in rural and small-scale farming environments where efficient resource utilization is important. IoT-based systems can collect information from agricultural locations and provide monitoring capabilities without requiring continuous physical inspection. Such approaches can help farmers respond more effectively to changing environmental conditions [17].

Smart farming requires reliable communication between sensing devices, processing units, and agricultural applications. IoT technologies allow environmental parameters to be monitored continuously and provide users with access to collected information through connected platforms. This connectivity can support automated decision-making and improve the efficiency of agricultural operations [18].

The collection and analysis of agricultural data can provide useful information for understanding changing environmental conditions. Smart farming platforms can combine sensor measurements with data-processing techniques to support decisions related to crop management and resource utilization. Such systems demonstrate how IoT and agricultural data analysis can contribute to more informed farming practices [19].

IoT-based precision agriculture enables agricultural environments to be monitored through connected sensors and intelligent devices. Environmental information can be collected continuously and communicated to users or processing systems, allowing agricultural operations to be managed according to observed conditions. This technology provides opportunities for improving resource utilization and supporting data-driven agricultural practices [20].

Modern greenhouse automation involves the coordinated management of environmental parameters to provide suitable conditions for crop growth. Temperature, humidity, ventilation, lighting, and irrigation can be monitored and adjusted through automated systems. The development of controlled-environment agriculture has increased the importance of intelligent automation for improving productivity and resource management [21].

Reliability is an important requirement for automated greenhouse systems because failures in sensing, communication, or control can affect plant-growing conditions. IoT devices operating in closed-loop agricultural environments therefore require mechanisms for identifying abnormal device behavior and maintaining dependable operation. Reliable system operation is particularly important when greenhouse processes are controlled automatically without continuous human supervision [22].

A structured IoT architecture is important for coordinating sensing, communication, data processing, decision-making, and application-level services. A multilayer approach can organize these functions and allow information collected from agricultural environments to be processed before appropriate actions are performed. Such architectural organization supports the development of scalable precision-agriculture systems [23].

The increasing adoption of IoT in greenhouse agriculture has encouraged the development of systems capable of continuously collecting environmental information and transmitting it to connected platforms. These systems provide a foundation for monitoring greenhouse conditions remotely and supporting more efficient agricultural management. IoT-based greenhouse architectures can also be expanded by incorporating additional sensing and control capabilities [24].

Smart greenhouse systems combine environmental sensors, processing units, communication technologies, and actuators to provide automated crop-environment management. Sensor measurements can be processed by a controller, which then operates devices such as irrigation pumps, ventilation systems, and lighting units. Such integration can improve environmental control while reducing unnecessary manual operations [25].

Hydroponic and controlled-environment cultivation require careful monitoring of temperature, humidity, and moisture conditions to maintain suitable plant growth. Automated greenhouse systems can collect these parameters through sensors and use the measurements to control different devices according to predefined conditions. This approach demonstrates the usefulness of IoT-based automation in maintaining a consistent growing environment [26].

Traditional greenhouse management commonly depends on farmers or operators to observe environmental conditions and manually operate irrigation, ventilation, and lighting equipment. Such practices require continuous human involvement and may be affected by delayed decisions or human error. IoT-enabled mini-greenhouse systems can reduce this dependency by using sensors and automated controllers to monitor and regulate important environmental parameters [27].

Greenhouse cultivation is an important approach for producing crops under controlled environmental conditions. It allows factors such as temperature, humidity, soil moisture, and light to be managed according to the requirements of plants. However, maintaining these conditions continuously through manual observation can be difficult and may result in inefficient resource utilization. The integration of Internet of Things (IoT) technologies provides an opportunity to automate greenhouse monitoring and improve the management of crop-growing conditions [28].

Based on these developments, there is a need for a compact and affordable greenhouse platform that combines environmental sensing, automated control, local monitoring, and remote access. The proposed Smart IoT-Based Mini Greenhouse addresses this requirement using a NodeMCU ESP8266 controller, DHT11 temperature and humidity sensing, soil-moisture monitoring, mist detection, relay-based actuator control, an LCD interface, and the Blynk IoT platform. The system is designed to automate irrigation, ventilation, misting, and supplementary lighting while providing users with real-time information and notifications [29].

2. LITERATURE REVIEW

Pochal and Patil [1] presented an IoT-based agricultural robotic device designed to monitor important agricultural parameters, including soil moisture, temperature, humidity, and illumination. The system used an ATmega328 microcontroller together with an ESP8266 Wi-Fi module to collect and transmit sensor information for remote cloud visualization. A 16×2 LCD was also incorporated to provide local access to the monitored parameters. Experimental evaluation demonstrated the acquisition and visualization of soil-moisture, temperature, humidity, and illumination data through the developed system. This work establishes the importance of integrating agricultural sensing, wireless communication, and remote monitoring. However, the system primarily focuses on agricultural parameter monitoring and robotic operation, whereas the proposed work extends these concepts to a compact greenhouse environment by integrating automated irrigation, ventilation, misting, supplementary lighting, local display, and IoT-based notifications.

B.S.Pochal and Anitha [2] proposed an IoT-based agricultural robotic platform with Android-controlled navigation. Their work demonstrates the integration of agricultural hardware, connected technologies, and mobile-based interaction. Such approaches indicate the possibility of extending conventional greenhouse automation toward more autonomous agricultural platforms.

Rajguru and Pochal [3] investigated deep-learning techniques for automated disease detection. Their study demonstrates how deep-learning models can learn patterns from image data for classification purposes. Although the application is outside agriculture, comparable computer-vision approaches could potentially be incorporated into future greenhouse systems for plant disease identification and crop-health monitoring.

Arala and Pochal [4] presented a machine-learning framework for predicting common diseases. Their work demonstrates the potential of machine-learning methods for automated prediction based on available data. Although the study is not specifically focused on greenhouse crops, similar data-driven techniques could be considered for future systems requiring predictive crop-health analysis.

Silpa [5] discussed IoT technologies for smart greenhouse environments and their contribution to controlled-environment agriculture. The integration of connected sensing and automated control can improve greenhouse management and reduce manual involvement. Further development toward predictive analytics and intelligent decision-making can extend

these systems beyond conventional threshold-based automation.

Li et al. [6] investigated IoT-based environmental monitoring and control for smart greenhouse agriculture. Their work demonstrates how environmental measurements can be connected with automated control mechanisms to manage greenhouse conditions. Effective implementation, however, depends on accurate sensor measurements, appropriate threshold selection, dependable communication, and suitable actuator operation.

Urbano et al. [7] examined smart irrigation approaches using soil-moisture information and IoT technologies. Their work demonstrates the advantage of making irrigation decisions from measured moisture conditions rather than relying exclusively on predetermined watering schedules. Nevertheless, soil-moisture-based irrigation represents only one aspect of greenhouse management and needs to be combined with other environmental controls for comprehensive automation.

Research into greenhouse automation has demonstrated the importance of automatically regulating environmental conditions to support sustainable crop production [8]. Automated management can reduce repetitive manual tasks and provide more consistent environmental control. However, the complexity and cost of comprehensive automation systems can make simplified and modular solutions more appropriate for small greenhouse installations.

Jawad et al. [9] investigated energy-efficient wireless sensor networks for precision-agriculture applications. Their work emphasizes the importance of reducing energy requirements in distributed agricultural sensing systems. Energy efficiency is particularly significant for battery-supported agricultural devices, although complete greenhouse systems must also consider the power requirements of pumps, fans, lighting, and other actuators.

Kamienski et al. [10] examined an IoT-based platform for intelligent water management and irrigation. Their research demonstrates how connected sensing and control can be used to improve water-delivery decisions. Although intelligent irrigation is an important component of precision agriculture, greenhouse management also requires coordinated control of parameters such as temperature, humidity, ventilation, and lighting.

Wireless sensor networks have been investigated as an important technology for precision agriculture because they enable environmental information to be gathered from distributed locations [11]. Such networks can provide continuous measurements that assist agricultural decision-making. However, energy consumption, communication reliability, and maintenance can become significant concerns when sensing devices are expected to operate continuously.

Tzounis et al. [12] reviewed the development of IoT technologies in agriculture and discussed their applications and associated challenges. Their study identified sensing, communication, and automation as important elements of connected agricultural systems. The findings support the use of

IoT for agricultural monitoring, while practical systems must address reliability, connectivity, and integration issues.

Patel et al. [13] presented an overview of IoT concepts, architectures, enabling technologies, and applications. Their work provides fundamental information about connecting physical devices with communication and software systems. These principles are relevant to greenhouse automation, although the study does not specifically address the environmental requirements of controlled crop-growing environments.

Verdouw et al. [14] investigated digital architectures for integrating physical agricultural processes with information technologies. Their work illustrates how structured digital platforms can connect different components and information sources. Although the approach is relevant to digital agriculture, a compact greenhouse requires a more focused architecture for real-time environmental monitoring and actuator control.

Wolfert et al. [15] reviewed the role of big data in smart farming and discussed how agricultural data can support improved decision-making. The study emphasizes the value of combining historical and real-time information for agricultural management. However, large-scale data processing may introduce additional computational and infrastructure requirements for small agricultural installations.

Elijah et al. [16] examined the combination of IoT and data analytics in agriculture. Their study described how information generated by connected agricultural devices can be collected and analyzed for improved decision-making. The work highlights the importance of agricultural data management, while real-time automated control requires additional integration between analytical outputs and physical actuators.

Ahmed et al. [17] explored IoT applications for precision agriculture and farming in rural environments. Their work demonstrated how connected devices can assist in collecting agricultural information and enabling remote monitoring. Such approaches are useful where continuous physical observation is difficult, although connectivity and deployment constraints can influence system performance.

Farooq et al. [18] reviewed the role of IoT in implementing smart-farming systems. Their study discussed the application of connected technologies for agricultural monitoring, automation, and resource management. The review establishes IoT as an important technology for smart agriculture, while practical implementation still depends on application-specific system architecture and hardware selection.

Muangprathub et al. [19] investigated IoT-based smart farming combined with agricultural data analysis. Their approach demonstrated how sensor information can be collected and analyzed to support farming activities. The study illustrates the value of data-driven agriculture, but a dedicated mini-greenhouse system requires integration of environmental sensing with physical actuator control.

Ayaz et al. [20] examined IoT-based smart agriculture and the role of connected technologies in modern farming. Their research highlighted the use of sensors and communication systems for obtaining agricultural information and supporting management decisions. The study establishes the importance of IoT in agriculture, although specific greenhouse applications require additional environmental-control mechanisms.

Shamshiri et al. [21] reviewed developments in greenhouse automation and controlled-environment agriculture. Their study discussed the increasing role of automated technologies in managing environmental conditions and supporting controlled crop production. While advanced automation can improve operational efficiency, sophisticated greenhouse solutions may involve considerable technical complexity and infrastructure requirements.

Astillo et al. [22] focused on detecting abnormal behavior in embedded IoT devices operating within a closed-loop smart greenhouse farming environment. Their work highlights the importance of dependable device operation when automated decisions directly affect agricultural processes. However, the primary emphasis is on device reliability rather than comprehensive greenhouse environmental management.

Marcu et al. [23] proposed a five-layer IoT architecture for precision agriculture. The architecture separates sensing, communication, processing, decision-making, and application functions, providing an organized framework for agricultural IoT systems. However, a generalized layered architecture still requires suitable hardware and control strategies when implemented for a specific greenhouse application.

Bersani et al. [24] studied IoT architectures and technologies applicable to greenhouse environments. Their work emphasized the combination of sensing, communication, processing, and control technologies for developing connected agricultural systems. The study provides a broad foundation for greenhouse automation, while application-specific implementation and low-cost integration remain important considerations.

Fathurrahmani [25] presented a smart greenhouse design based on environmental sensors and automated actuators. The proposed approach aimed to improve plant-growing conditions by allowing the system to respond to measured environmental parameters. Nevertheless, additional facilities such as comprehensive remote monitoring, historical analysis, and intelligent prediction could further improve the usefulness of such systems.

Supriyanto and Fathurrahmani [26] developed a greenhouse monitoring and control prototype for hydroponic plants. Their system considered environmental measurements to assist in maintaining appropriate growing conditions. The study demonstrates the usefulness of automated greenhouse control, although its functionality is primarily directed toward basic environmental regulation rather than a broader integrated IoT management platform.

Rayhana et al. [27] examined the application of IoT technology in smart greenhouse environments. Their study emphasized connected monitoring and control for maintaining suitable

conditions for crop cultivation. Although IoT connectivity improves accessibility to greenhouse information, dependable communication and appropriate integration of sensing and control components remain important for practical deployment.

Cruz et al. [28] investigated an IoT-enabled mini-greenhouse architecture for monitoring and managing plant-growing conditions. The study demonstrated that sensor-based monitoring can be incorporated into a compact greenhouse environment to support automated operation. However, the work provides limited emphasis on combining several environmental-control functions with remote user interaction and advanced predictive capabilities.

The integration of Internet of Things (IoT) technology with agriculture has created new approaches for monitoring crop environments and automating routine farming operations. Recent studies have explored connected sensors, microcontrollers, wireless communication, automated irrigation, greenhouse climate regulation, and remote monitoring. These developments show that IoT can reduce dependence on continuous manual supervision and support more responsive agricultural management. However, challenges related to system cost, scalability, connectivity, reliability, and intelligent decision-making remain relevant for small-scale greenhouse applications.

3. PROPOSED METHODOLOGY

The proposed methodology focuses on developing an IoT-enabled mini greenhouse capable of continuously monitoring environmental conditions and automatically controlling essential devices according to predefined requirements. The system combines sensing, processing, actuation, local display, and cloud-based communication to reduce the need for continuous manual supervision. The overall methodology is divided into sensing, data processing, automated control, local monitoring, and remote notification stages.

1. Environmental Data Sensing

The first stage involves collecting information about the greenhouse environment using multiple sensors. A DHT11 sensor is used to obtain temperature and relative humidity values, while an analog soil-moisture sensor measures the moisture condition of the growing medium. A mist sensor is incorporated to identify the presence or condition of moisture in the greenhouse environment. These sensors periodically provide readings to the NodeMCU ESP8266 controller for further processing.

2. Data Processing Using NodeMCU ESP8266

The NodeMCU ESP8266 acts as the central processing unit of the proposed system. Sensor readings are received through the corresponding input interfaces and processed according to predefined threshold conditions. The controller compares the measured environmental values with the desired operating conditions and determines whether any actuator needs to be activated or deactivated. This approach enables the system to respond automatically to changes in the greenhouse environment.

3. Automated Actuator Control

Based on the processed sensor information, the controller operates the connected electrical devices through relay modules. The water pump is used to provide water when the soil-moisture condition indicates a requirement for irrigation. The exhaust fan assists in regulating the greenhouse environment when the monitored conditions reach the defined control level. A misting mechanism can be operated when additional moisture is required, while an LED grow light provides supplementary illumination when the specified condition is detected. Thus, actuator operation is performed according to the programmed control logic rather than requiring continuous manual intervention.

4. Local Monitoring Through LCD

A 16×2 LCD is included to provide immediate information about the greenhouse conditions. The display can present the measured temperature, humidity, soil-moisture status, and other relevant system information. This local interface allows the user to observe the operating condition of the greenhouse without depending entirely on an external application or internet connection.

5. IoT Connectivity and Remote Monitoring

The Wi-Fi capability of the NodeMCU ESP8266 is used to connect the greenhouse system to the Blynk IoT platform. The collected sensor information can be transmitted to the mobile application, allowing the user to observe greenhouse parameters remotely. The IoT interface also provides a convenient means of interacting with the system and receiving information about important environmental changes.

6. Notification and Alert Mechanism

The proposed system incorporates notification functionality to inform the user when monitored parameters require attention. When a predefined environmental condition is reached, the system can generate an alert through the IoT platform. This feature helps the user identify abnormal or undesirable conditions without being physically present near the greenhouse.

7. System Integration

All hardware and software components are integrated into a single control architecture. The sensors provide environmental inputs, the NodeMCU performs processing, relay modules interface the controller with the actuators, and the LCD provides local feedback. Simultaneously, the Wi-Fi connection transfers relevant information to the Blynk platform for remote access and notification. The integrated arrangement enables sensing, decision-making, control, and monitoring to operate as a coordinated process.

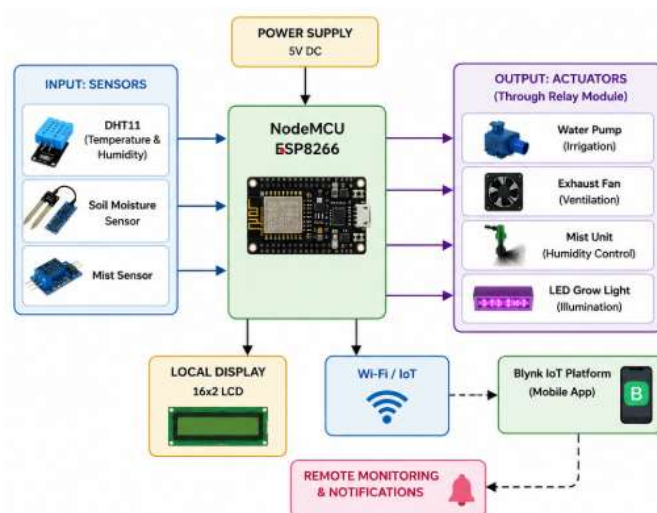


Fig. 1. Overall Architecture of the Proposed IoT-Based Mini Greenhouse

The proposed architecture illustrates the interaction between sensing, processing, actuation, and IoT communication components of the mini greenhouse. Environmental parameters are obtained using the DHT11, soil-moisture, and mist sensors and forwarded to the NodeMCU ESP8266, which evaluates the received values and generates appropriate control signals. Through relay modules, the controller operates the water pump, exhaust fan, mist unit, and LED grow light according to the programmed conditions. A 16×2 LCD provides local information, while the NodeMCU uses Wi-Fi to transmit greenhouse data to the Blynk IoT platform for remote monitoring and notifications. This integrated arrangement enables continuous observation and automated control of the greenhouse environment.

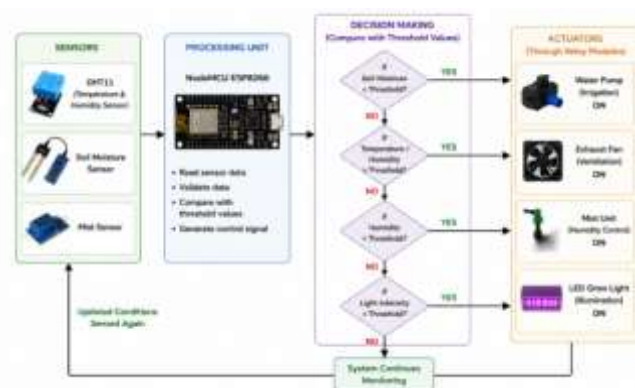


Fig. 2. Automated Greenhouse Control Mechanism

Figure 2 represents the automatic control sequence used to regulate the greenhouse environment. The DHT11, soil-moisture, and mist sensors continuously provide environmental readings to the NodeMCU ESP8266, where the incoming values are processed and evaluated against predefined threshold conditions. According to the detected condition, the controller sends signals through relay modules to operate the water pump, exhaust fan, mist unit, or LED grow light. If no corrective action is required, the system continues monitoring the environment. After each control cycle, updated sensor

values are acquired again, forming a continuous feedback loop for automated greenhouse operation.

4. MODEL CONFIGURATIONS

The developed mini greenhouse is configured as an IoT-based monitoring and control model in which environmental sensing, decision processing, actuator operation, and remote communication are integrated into a single system. The configuration is centered on the NodeMCU ESP8266, which receives data from the DHT11, soil-moisture, and mist sensors and uses the programmed control conditions to operate the connected devices. The selected hardware and software components are based on the configuration described in the project report.

4.1 Hardware Configuration

The hardware model consists of a NodeMCU ESP8266 controller, a 16×2 LCD, DHT11 temperature and humidity sensor, soil-moisture sensor, mist sensor, relay modules, water pump, exhaust fan, LED grow light, and a battery-based power supply. The NodeMCU provides both processing and Wi-Fi connectivity, while relay modules provide the switching interface between the controller and the greenhouse actuators.

4.2 Sensor Configuration

Three sensing units are incorporated into the model. The DHT11 supplies temperature and humidity measurements, the analog soil-moisture sensor determines the moisture condition of the growing medium, and the mist sensor is used to identify moisture or mist conditions within the greenhouse. These sensor readings are supplied to the controller for continuous environmental assessment.

4.3 Controller Configuration

The NodeMCU ESP8266 is configured as the central decision-making unit. It receives the sensor measurements, processes the input values, compares them with the programmed threshold conditions, and generates appropriate signals for the connected actuators. Its integrated Wi-Fi capability also allows the system to communicate with the IoT platform for remote observation and control.

4.4 Actuator Configuration

The actuator section contains devices for irrigation, ventilation, humidity management, and supplementary lighting. The water pump is used for irrigation, the exhaust fan supports ventilation, the mist unit assists humidity management, and the LED grow light provides additional illumination. Relay modules are used to interface these electrical loads with the NodeMCU control signals.

4.5 Display and IoT Configuration

A 16×2 LCD is configured as the local monitoring interface for displaying greenhouse parameters and device status. In parallel, the NodeMCU communicates through Wi-Fi with the Blynk

IoT platform, allowing sensor information to be viewed remotely and enabling notifications and remote actuator interaction as supported by the system configuration.

4.6 Software Configuration

The software model is developed using Embedded C and the Arduino IDE. The control program handles sensor acquisition, threshold-based decision making, actuator switching, LCD updates, and IoT communication. The software configuration is designed to repeatedly acquire new sensor values so that changes in greenhouse conditions can be addressed during operation.

4.7 Control Configuration

The control model follows a feedback-based approach. Sensor values are acquired and evaluated by the NodeMCU, after which the corresponding actuator is activated or deactivated according to the programmed conditions. The resulting environmental changes are sensed again, allowing the control cycle to repeat continuously. This configuration provides automated management of irrigation, ventilation, humidity, and lighting while reducing the requirement for constant manual supervision.

5. RESULTS AND DISCUSSION

The developed Smart IoT-Based Mini Greenhouse was evaluated by observing the interaction between the sensing units, NodeMCU ESP8266 controller, actuator devices, local display, and IoT monitoring platform. The evaluation focused mainly on whether the system could acquire environmental information, respond to predefined conditions, operate the required devices, and communicate the system status to the user. The experimental observations indicate that the integrated architecture can perform the intended monitoring and automated control functions.

A. Environmental Parameter Monitoring

The DHT11 sensor provided temperature and humidity information, while the soil-moisture sensor supplied information regarding the moisture condition of the growing medium. The mist sensor was used to identify moisture-related conditions inside the greenhouse. These sensor readings were continuously supplied to the NodeMCU for processing, providing the basic input required for automatic environmental management.

B. Automated Irrigation Response

The soil-moisture reading was used as the primary input for irrigation control. When the measured soil condition reached the programmed low-moisture threshold, the NodeMCU generated a control signal for the relay and activated the water pump. This mechanism enables irrigation to be performed according to the observed soil condition rather than relying entirely on manual watering.

C. Ventilation and Humidity Management

The exhaust fan and misting unit were incorporated to manage greenhouse environmental conditions. When the programmed temperature, humidity, or mist-related conditions required corrective action, the controller could operate the corresponding actuator through the relay interface. This automatic response helps maintain the intended environmental range and reduces the need for continuous manual intervention.

D. Automated Lighting

The LED grow light was configured as a supplementary lighting device for periods when the available illumination was insufficient. The controller can operate the lighting system according to the programmed control condition, allowing the greenhouse to provide additional illumination when required. This forms another part of the automated environmental-control process.

E. Local Monitoring Through LCD

The 16×2 LCD provided a direct interface for observing greenhouse parameters and system status. Temperature, humidity, soil-moisture information, and actuator conditions can be presented locally, allowing the user to inspect the system without depending on the mobile application. The LCD therefore improves the accessibility of real-time system information during operation.

F. IoT Monitoring and Notifications

The NodeMCU ESP8266 was configured with Wi-Fi communication to support interaction with the Blynk IoT platform. The system architecture enables environmental information to be viewed remotely and supports notifications when programmed environmental conditions require user attention. This provides an additional monitoring channel when the user is away from the greenhouse.

G. Overall System Performance

The observed operation demonstrates that the proposed system can combine environmental sensing, controller-based decision making, automatic actuator operation, local visualization, and IoT communication within a single greenhouse platform. The closed-loop arrangement allows updated environmental conditions to be sensed repeatedly and used for subsequent control decisions. The report also describes the prototype as capable of maintaining environmental conditions within the intended operating range and providing appropriate actuator responses and notifications.

H. Discussion

The main advantage observed from the implemented model is the integration of several greenhouse functions into one automated platform. Instead of treating irrigation, ventilation, humidity management, lighting, and monitoring as separate activities, the proposed system coordinates them through the NodeMCU controller. The LCD provides immediate local

feedback, whereas the Blynk interface extends monitoring and notification capabilities to the user remotely.

The modular configuration also provides scope for further development because additional sensors, data logging facilities, and predictive control techniques can be incorporated into the existing architecture. However, quantitative claims regarding water consumption, energy reduction, sensor accuracy, or crop-yield improvement should be supported by controlled measurements and comparative experiments before being presented as experimentally verified results.



Fig. 3. Prototype of Smart IoT-Based Mini Greenhouse

Figure 3 The physical prototype mesh design of Smart IoT-Based Mini-Greenhouse is presented in figure 1. It's the home of the NodeMCU, the sensors, the relay, the water pump, the exhaust fan, the batteries, and the LCD usage monitor. They way it is set up shows how to use electronic modules when combining electronics into the greenhouse structure for instant automation. This prototype provides experimental evidences of the feasibility of projected scheme architecture for controlled farming

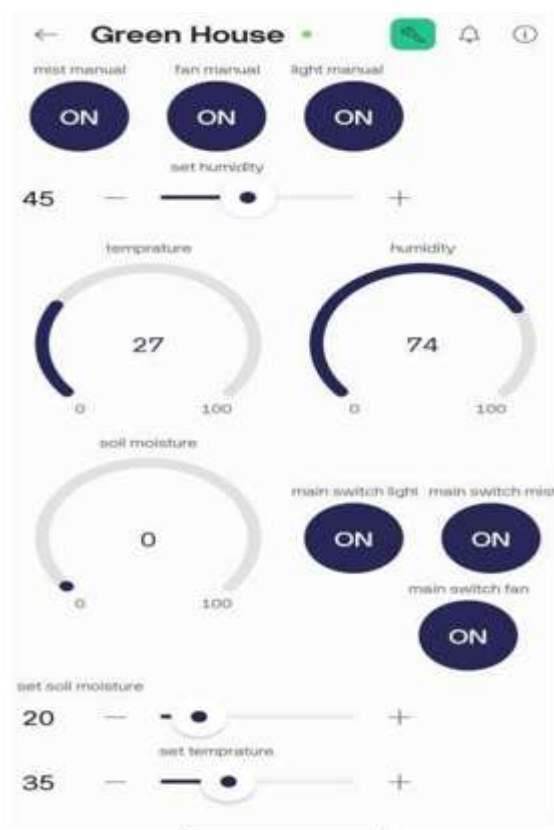


Fig. 4. Blynk app for Smart Greenhouse

Figure 4 Show the Blynk mobile app border for smart greenhouse control and monitoring. It shows the current values for temperature, humidity and soil moisture - also you can define set points for automation. Environment control can be performed manually or automatically with options available to switch those devices on or off like fan, mist and light through the interface. This makes remote access easy and guarantees the efficient control of the greenhouse climate.

6. CONCLUSION AND FUTURE SCOPE

The proposed Smart IoT-Based Mini Greenhouse combines environmental sensing, automated control, and IoT-based monitoring to support efficient greenhouse management. The NodeMCU ESP8266 receives data from temperature, humidity, soil-moisture, and mist sensors and controls the water pump, exhaust fan, misting unit, and LED grow light according to predefined conditions. A 16×2 LCD provides local information, while the Blynk IoT platform enables remote monitoring and notifications. The developed system reduces the need for continuous manual supervision and provides an integrated approach to greenhouse environmental management. In future, the system can be improved by incorporating machine learning for predictive control, additional sensors for detailed crop monitoring, computer vision for plant health assessment, solar-powered operation, and cloud-based data analytics, making the greenhouse more adaptive and suitable for advanced precision agriculture.

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