Smart Greenhouse System for Cultivating Medicinal Plants for Patient Care with IoT Integration

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ABSTRACT

Bangladesh is a developing and overpopulated coun- try, where the increase in population has led to a reduction in arable land while the demand for food is rising, and diseases are spreading due to people's lack of awareness. New diseases and pathogens are emerging and spreading among people. Due to the increase in population, the demand for medicines has also increased, but the decrease in arable land has made it difficult to obtain complete medicinal plants. This research proposes a low-cost IoT-based greenhouse system capable of creating a suitable environment for cultivating medicinal plants. The advanced system uses several gas sensor nodes to detect NH3, CO, smoke, and CO2, and if harmful gases increase, it triggers an alarm and notifies via email/messages. Additionally, by using soil moisture sensors, we can determine when the soil needs watering or how much water is available, and whether the soil is wet or dry. Temperature sensors inside the greenhouse provide information on the temperature, and if it gets too hot, a cooling fan is used to regulate the temperature. Moreover, there are other sensors such as a water level sensor, which indicates how much water is accumulated in the tank or specific water storage areas. If the water level decreases, it automatically refills through a motor. A rain sensor also detects external rainfall. Using these sensors, environmental parameters are monitored in real-time to create an ideal environment for cultivating medicinal plants. This system addresses common challenges in traditional agriculture, such as resource waste and unfavorable growth conditions. Furthermore, with the increasing population, we are facing challenges in meeting food and medicinal needs, but the smart greenhouse system can fulfill these demands for food and medicine.

Keywords: Smart Greenhouse, Internet of Things (IoT), En- vironmental Monitoring, Agricultural Automation, Resource Ef- ficiency, Medicinal Plants

INTRODUCTION

With the increase in population, Bangladesh is rapidly ur- banizing and industrializing. As a result, the amount of arable land is decreasing. Additionally, being a riverine country, Bangladesh is losing agricultural land to river erosion. This has led to food shortages and a lack of medicinal plants. Moreover, global issues like climate change, global warming, and various natural disasters are also contributing to food scarcity. In 1961, the per capita land available was 0.45 hectares, but by 2016, it had decreased to 0.21 hectares [1]. This represents a 53.33 % reduction in per capita land over the past 55 years.

However, the population has more than doubled during this period. As a result, food shortages and a lack of medicinal plants for producing medicines are becoming more prominent. Due to the reduction in agricultural land, it is projected that by 2050, food production needs to increase by 70% [1].To address these issues, it is essential to develop a system that can cultivate crops and medicinal plants in all environments and ensure a steady supply of food. A cost-effective, advanced IoT-based automated greenhouse system has been proposed for monitoring plants and maintaining the necessary growth conditions. This greenhouse system includes a soil moisture sensor that measures the volumetric water content, determines the moisture level of the soil, and supplies water to the plants accordingly.

Additionally, the system is equipped with an MQ-135 sen- sor, which detects harmful gases like CO and smoke emitted by the plants. These gases are expelled via a cooling fan, and alerts are sent via email or messages.The system also uses a DHT-11 sensor for measuring temperature, and if the temperature rises too much, the cooling fan helps regulate it. A water level sensor is used to monitor the water level in the tank, determining when and how much water needs to be supplied. Furthermore, a rain sensor is used to manage rainwater within or outside the greenhouse, alerting when it rains or when there's the possibility of acid rain.To store all the data collected by the greenhouse system, cloud storage and an SD card are used. Due to its low cost and compact size, this system can be used in urban rooftops, vacant plots, or rural areas. By implementing this system, the shortage of food and medicines can be addressed, and the environment will improve.

In conclusion, given the growing population and shrinking agricultural land, the greenhouse system can be a highly effective solution.

RELATED WORK

The Internet of Things (IoT) is a system of object inter- connection, an upgrade from the traditional Internet. These objects can range from machinery used at the workplace to home appliances and more. IoT is used as a monitoring system that maintains peer connections. To make the system intelligent, IoT creates a complex ecosystem that enables real- time interaction among various components [2] . In green- houses, IoT is used to monitor agricultural parameters such as temperature, humidity, moisture levels, soil quality, and effective pest control [3]. Additionally, the development of smart greenhouse technologies has progressed through various phases, characterized by advancements in automation, IoT integration, and artificial intelligence (AI) [4]. Early systems, such as the expert system described in [4], focused on rule- based environmental control, automating misting cycles for humidity regulation in Peperomia cultivation. While effective for basic tasks, these systems lacked real-time adaptability and IoT connectivity. In the 2010s, IoT integration began, enabling remote monitoring and energy-efficient control. For example, a Petri Net model reduced energy consumption by 38.45% by adjusting greenhouse temperatures during peak demand hours [5], and IoT-controlled hydroponics demonstrated the potential to save 80–90% of water in lettuce cultivation—a model adaptable to moisture-sensitive medicinal plants [6].

Recent advancements emphasize AI and edge computing for predictive analytics and real-time decision-making. The DLSHiForest algorithm has been introduced, which combines Locality-Sensitive Hashing and Isolation Forests to detect environmental anomalies with 88% accuracy, addressing chal- lenges such as concept drift in data streams [7] [8]. Similarly, an edge-cloud architecture was used to reduce latency in mush- room cultivation, preprocessing sensor-camera data at the edge and reducing cloud transmission by 60%. These innovations signal a shift toward decentralized, AI-driven systems capable of handling complex environmental dynamics [9].

Additionally, ThingSpeak cloud platform and mobile appli- cations offer remote monitoring capabilities [10]. The system integrates capacitive soil moisture sensors, electrochemical sensors, and acoustic devices to automate irrigation and pest detection. During calibration, an R^2 value of 0.967 and an RMSE of 0.014 were achieved, showing excellent performance in both laboratory and real greenhouse environments [11]. The neuro-fuzzy PID controller significantly reduced moni- toring errors, with temperature error decreasing from 0.35% to 5.04%, humidity error from -1.3% to 1.65%, and light intensity error from -3.5% to -0.79%. This reduction in errors resulted in quicker stabilization of humidity in the system [12]. Additionally, compared to traditional pot irrigation, this system saved 16.2% more water [13]. The deep convolutional neural network (DCNN) detected diseases with 88% accuracy, making it adaptable for medicinal species like Echinacea [14]. Resource efficiency remains a key focus, where dynamic adjustment of irrigation depth based on crop water uptake achieved an irrigation water-use efficiency (IWUE) of 41.23 kg/m³ [7], while solar-powered sensors reduced energy depen- dency [11].

Methodologically, hybrid architectures and predictive mod- els dominate modern frameworks. IoT-based smart greenhouse monitoring systems integrated with auto-tuned PID controllers have improved response times for remote monitoring [15], while edge-cloud hybrids ensure real-time control without TABLE I. bandwidth issues [9]. Predictive models like YOLO and Mask- RCNN networks achieved 85% accuracy in multispectral im- age analysis, providing insights to enhance bioactive com- pound synthesis in medicinal plants [9], [16].

Table I. Approximate Cost Breakdown of Proposed Iot-Based Device

Components	**Price**
ESP32	495 Tk
DHT22	250 TK
Soil Moisture Sensor	250 TK
Gas Sensor (MQ-135)	125 TK
Water Level Sensor	50 TK
Rain Sensor	210TK
SD Card Module	80 TK
LDR Sensor	320 TK
Total	**1780 TK**

The theoretical frameworks of these systems include preci- sion agriculture and cyber-physical systems (CPS). Precision agriculture optimizes phytochemical production by mimicking natural environments—maintaining 25–30°C temperatures and 65–70% humidity ensures glucosinolate synthesis in Brassica juncea. Meanwhile, greenhouses are modeled as fault-tolerant CPS, using Arduino microcontrollers and wireless sensors to create robust networks for real-time climate control [17].

SYSTEM DESIGN AND DEVELOPMENT

A. An Overview

The ESP32 is used as the parent controller. The DHT11 sensor is used to monitor the system's temperature. The soil sensor measures soil moisture and gas levels. The MQ-135 gas sensor is designed to detect gases such as carbon monoxide, LPG, and smoke, because carbon monoxide, LPG, and smoke hinder plant growth and affect crop yield. Additionally, a rain sensor is used in the greenhouse to detect whether it is raining outside or if rainwater is entering the greenhouse. A water level sensor is used to determine whether the tank has enough water and when it needs to be refilled. A block diagram explaining the functionality of the device is shown in Fig. 1. The block diagram shows that the sensors collect data from the monitored greenhouse system and send it to the microcontroller board. The microcontroller then imple- ments a wireless node, providing the necessary processing power and control functions required to operate the wireless communication hardware. The wireless node typically sends data to a gateway device, which collects data from multiple nodes and forwards it to a database through the WiFi module. The database generally stores various parameters such as temperature, humidity, air pressure, motion, carbon monoxide, LPG, smoke, etc., for further processing and decision-making. The mobile application also receives data directly from the database and sends feedback accordingly. Furthermore, if the parameters provided to the microcontroller board exceed the predefined limits, automatic email or messages will be sent, and the system will automatically activate the fan if the gas levels or temperature increase, or activate the motor if the soil moisture level rises.

B. Schematic Design

To demonstrate the connections between various compo- nents and how they interact with each other, the schematic design is shown in Figure-2. In this design, the ESP-32 is used as the microcontroller. An RGB LED (Red/Green/Blue) is added, which is connected to the D14/D12/D13 pins of the ESP-32 and indicates the system's status. (Green - Normal, Red - Error, Blue - Water Supply).

The DHT-11 temperature and humidity sensor's DAT pin is connected to the D34 digital pin of the ESP-32 via a 1-wire connection, and the VCC pin is connected to the Soil Moisture Sensor. This connection sends environmental temperature and humidity data to the ESP-32, which is used to control the fan and pump.

The Water Level Sensor's SIG pin is connected to the D35 analog pin of the ESP-32, which reads the voltage and sends it to the ESP-32. This detects the water level and alerts the ESP-32, turning off the pump automatically.

The Rain Sensor's DO pin is connected to the digital pin D- 25 of the ESP-32, which only sends high and low signals. This automatically detects rainwater and stops the water supply.

The Soil Moisture Sensor's DAT pin is connected to an analog pin of the ESP-32, which measures soil moisture and activates/deactivates the pump accordingly.

An SD card module's MoSI pin is connected to the D19 pin of the ESP-32, which is used for data logging and storage.

Additionally, a Buck Converter is used, with the input pin connected to the 12V battery, and the output pins are connected to the ESP-32's Vin and GND pins. This steps down the 12V battery to 5V/3.3V to power the ESP-32 and sensors. The 12V relay module's IN pin is connected to the D21 and D22 pins of the ESP-32, which triggers the relay to turn the fan, pump, or other high-voltage devices on/off. Pumps and fans are added for controlling water and temperature.

C. Design of Wireless Network

The wireless network is designed as a cloud-based system for a greenhouse. The edge computer uses the MQTT protocol to send data to the cloud, where the data is stored and further analyzed. Authorized individuals can access data and alerts from the cloud via a web browser or mobile app, and even greenhouse workers can monitor their environment using the mobile app.

Overall, this network design provides a powerful and scal- able solution for the greenhouse system.

IMPLEMENTATION AND RESULT ANALYSIS

For implementation, the device is powered by a DC power source, which is then rectified using a rectifier, and the voltage is regulated via a regulator to the microcontroller board. The relay module is connected to the ESP-32, with the GND of the electric power supply shorted to the relay for power source control. All sensors and modules are supplied with 5V through the dedicated 5V pin of the ESP-32 microcontroller board. Figure 4 illustrates the hardware prototype implementation of the sensor and control system of the device.

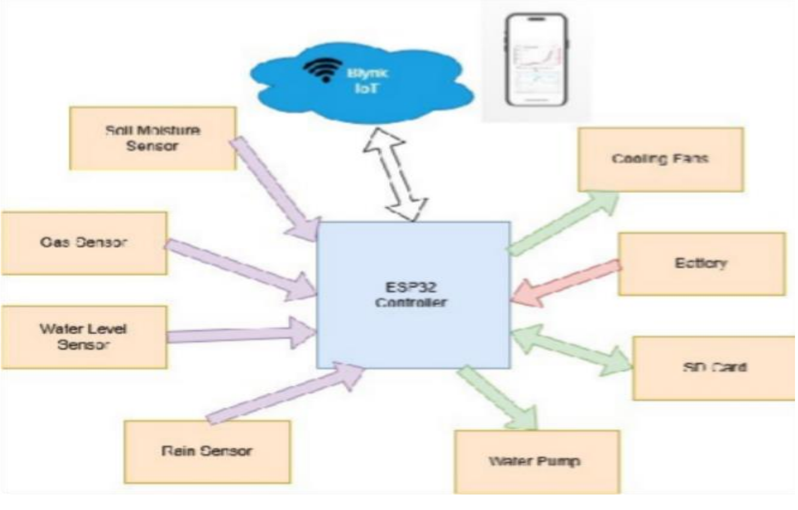


Fig. 1. the functional block diagram of the prototype

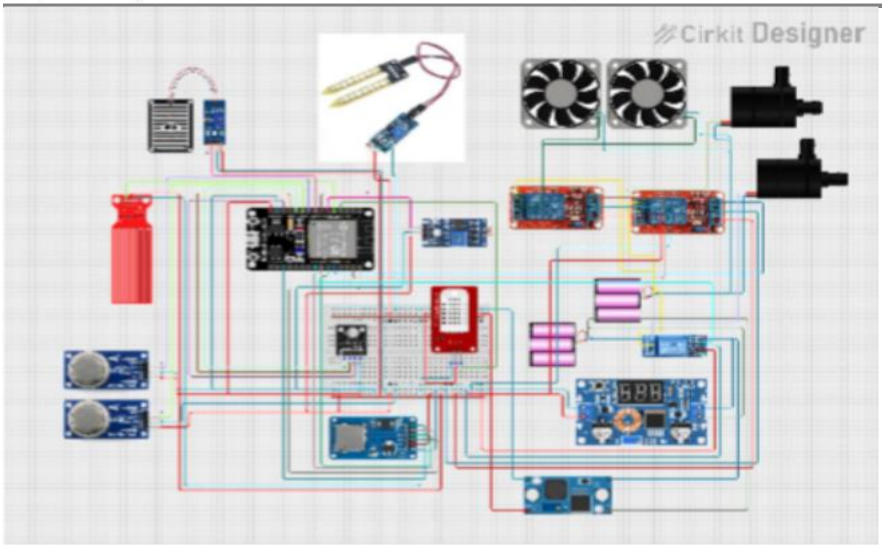


Fig. 2. The schematic design of fire prevention device

Fig. 3. Smart Greenhouse system Dashbord

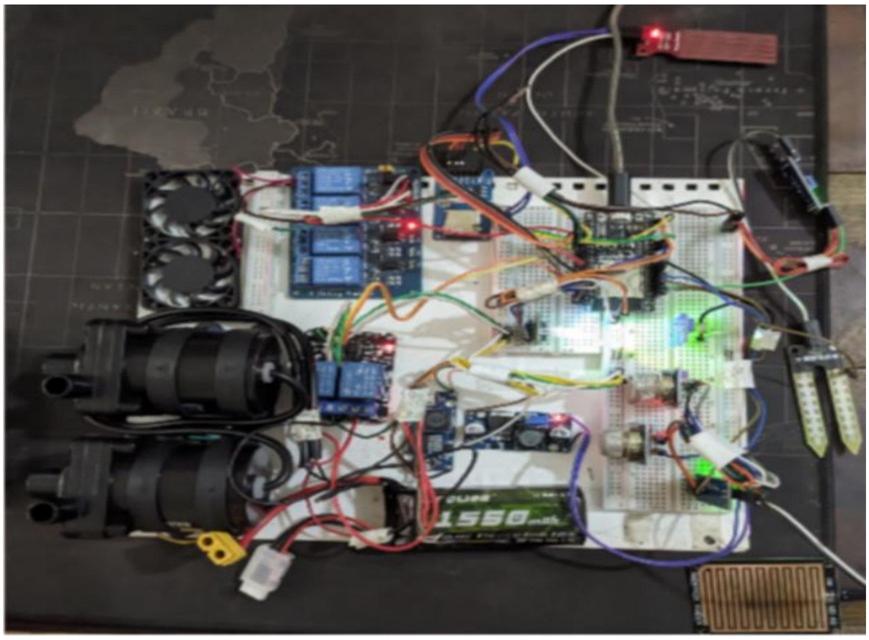
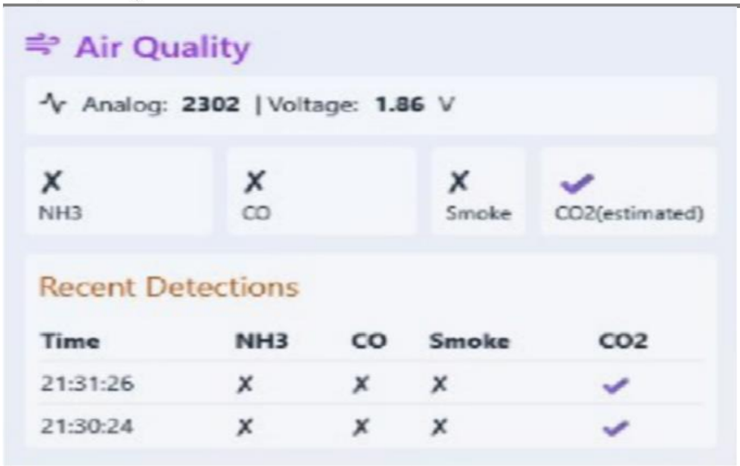


Fig. 4. The Hardware Implementation of Greenhouse prevention device



Air Quality

Analog: **2302** | Voltage: **1.86** V

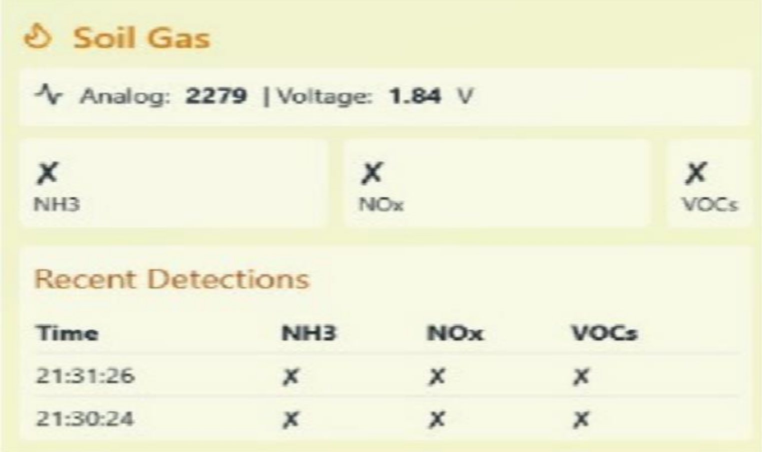
✗	✗	✗	✓
NH3	CO	Smoke	CO2(estimated)

Recent Detections

Time	NH3	CO	Smoke	CO2
21:31:26	✗	✗	✗	✓
21:30:24	✗	✗	✗	✓

Fig. 5. Real-time data analysis for Air

Figure-5 displays real-time cloud data showing air quality and the presence of harmful gases such as NH3, CO, Smoke, and CO2, along with the detection times of these gases. Figure- 6 shows the gases detected by the soil moisture sensor in the soil, while Figure 7 visualizes the water content level in the soil. Figure 8 demonstrates the operational status of the cooling fan (ON/OFF), the water tank pump (ON/OFF), and the garden irrigation pump (ON/OFF). Figure 9 presents a comprehensive data analysis graph that integrates all these parameters. All figures reflect real-time data monitoring.



Soil Gas

Analog: **2279** | Voltage: **1.84** V

✗	✗	✗
NH3	NOx	VOCs

Recent Detections

Time	NH3	NOx	VOCs
21:31:26	✗	✗	✗
21:30:24	✗	✗	✗

Fig. 6. Real-time data analysis for Soil gas

Water

3122

Current Level

Fig. 7. Real-time data analysis graph for Water

The research study aims to develop a low-cost, automated IoT-based device to address the growing shortage of food and medicinal plants caused by the decline in arable land due to population growth. The affordability and user-friendly design of the device make it accessible for household use. With a device cost of 1,780 BDT (Bangladeshi Taka), the total estimated expense for a medium-sized home or small industry, including servers, software, and hardware for the proposed IoT-based system, remains under 3,000 BDT. This cost is significantly lower than conventional machinery. Fig-10 is our TABLE II smart greenhouse prototype. For a functional comparison between our device and existing systems, please refer to Table II, which highlights the advantages of the proposed IoT-based device in terms of cost, features, and ease of installation. In the context of Bangladesh, this system is both economical and convenient for daily agricultural practices.

Actuators

Fan
ON

Water Pump
OFF

Soil Pump
ON

Fig. 8. Real-time data analysis for Actuators

Environment

Temp
31.3°C

Humidity
53.0%

Light Intensity
122lux.

Rain
No Rain

Soil Moisture
0.0%

Art. Light
50%

Fig. 9. Real-time data analysis graph

Fig. 10. Smart Greenhouse Prototype

Table II. Comparative Analysis of The Proposed System with Respect to Currently Available Industrial Products

Feature	Proposed Device	Conventional Machinery
Approximate Cost (TK)	3000	10000–15000
Latency	Moderate	Moderate
Temperature Detection	Yes	Yes
Humidity Detection	Yes	Yes
Air Pressure Detection	Yes	No
Gas Detection (CO, LPG, Smoke)	Yes	No
Remote Monitoring	Yes	No
Circular Wireless Node Topology	Yes	No
Ease of Installation	Easy	Hard

CONCLUSION AND FUTURE WORK

This paper provides a detailed description of the design and development of an IoT-based prototype for a greenhouse system that detects harmful gases for plants, particularly medicinal plants, and measures their concentration. It also monitors temperature, soil moisture, and harmful gases in the soil, notifying the user via email or text message. Additionally, if rainwater enters the greenhouse, it detects this and sends a warning. The water level sensor checks the amount of water in the tank and refills it when needed. The prototype has been successfully tested and experimented with. This system is affordable and can be used both by urban and rural people. It can help maintain a healthy environment for plants. If harmful gases increase or the temperature rises, the user can control the system remotely from their phone. The system is compact and user-friendly. Further research is ongoing to make the system more user-friendly and to add more features to improve its design.

In this proposed system, the ability to automatically control water, fans, and motors has been achieved using the Blynk smartphone application, which helps maintain a healthy envi- ronment for both medicinal and general plants. Furthermore, data collected from the sensors will be analyzed using machine learning technology to diagnose plant diseases and determine which medicines or fertilizers should be applied for specific conditions. Additionally, there are plans to develop a cloud- based smart phone application with these features.

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