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Automated Greenhouse Monitoring with Bluetooth IoT System

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***Abstract*—Greenhouse farming is an innovative farming model and a tool for achieving sustainable food production. The use of the Internet of Things (IoT) has revolutionized agriculture and can be used to automate greenhouse monitoring by controlling and real-time tracking of various environmental parameters using sensors and electronics devices. The proposed system is designed to optimize environmental conditions in greenhouses and nurseries. This cost-effective solution reduces manual intervention and supports precision agriculture, particularly in areas with fluctuating climates, contributing to sustainable farmingpractices.**

***Index Terms*—IoT, Greenhouse, Automation, Climate Management, Humidity, Temperature, Control, Bluetooth, Agriculture.**

I. Introduction

In recent years, IoT technologies have brought significant advancements to agriculture by enabling real-time environmental monitoring and automation. For instance, [1] and [2] propose IoT-based systems for automating greenhouse climate control and environmental monitoring, though they lack Bluetooth and cloud integration, limiting scalability and remote access. Similarly, [3] focuses on irrigation control, improving water efficiency but without addressing overall climate management. Systems like [4] and [5] offer energy-efficient solutions but face limitations due to the absence of Bluetooth and cloud-based features for long-term data storage and remote monitoring. Advancements in works such as [6-9] highlight automation and precision farming, incorporating temperature and humidity sensors for better microclimate management. However, these systems often fall short in terms of Bluetooth and cloud-based data storage and scalability.

More comprehensive solutions, like those presented in [10-13], integrate Bluetooth and cloud infrastructure, enabling remote access, long-term data analytics, and better scalability, addressing many challenges found in earlier systems. These cloud-integrated systems offer significant potential for improving agricultural management, though issues with broader scalability across diverse environments remain.The proposed system builds on these previous works by developing an IoT-enabled, Bluetooth-integrated system for automating humidity control in tropical greenhouses. This system leverages real-time data and relay systems to manage fans and humidifiers, aiming to create an optimized environment for plant growth with minimal human intervention.

Expanding on earlier research, we have designed a robust IoT system that not only automates temperature and humidity regulation but also integrates seamlessly with Serial Bluetooth platform app for scalable, real- time monitoring and data analysis. This integration addresses the limitations of earlier systems by providing a Serial Bluetooth app solution adaptable to diverse agricultural environments. By focusing on the unique climatic conditions of tropical regions like Konkan, our system enables data-driven decision-making to enhance climate control in greenhouses, fostering optimal growth for tropical plant species.

II. Related Works

Dinesh et al. (2020) presents an IoT-based greenhouse monitoring system using the Arduino platform. The system monitors environmental factors like temperature and humidity to optimize greenhouse conditions. While it offers efficient real-time monitoring, it lacks Bluetooth and cloud integration, limiting scalability and remote access capabilities [1].

Patil et al. (2018) developed a greenhouse automation system utilizing GSM technology. Their solution automates the environmental control of greenhouses via the SMS communication. While this system reduces manual oversight, it does not provide long-term data storage or analytics for deeper insights [2].

Shah et al. (2021) propose a smart irrigation system that uses IoT to enhance water efficiency by automating irrigation based on soil moisture levels. Although effective for water conservation, the system is limited to irrigation control and does not cover comprehensive greenhouse climate management, such as humidity regulation [3].

Kumar et al. (2016) propose an IoT-based smart agriculture monitoring system that tracks various environmental parameters to optimize agricultural practices. The system is designed to automate the monitoring of critical conditions like soil moisture and temperature, offering farmers real-time data to enhance decision-making. However, the solution lacks integration with Bluetooth and cloud services, which limits its scalability for large-scale agricultural applications [4]

Pulivendula et al. (2018) developed an energy-efficient IoT-based environmental monitoring system for greenhouses. Their system focuses on reducing power consumption while tracking essential environmental variables, such as temperature and humidity, to optimize plant growth. While effective in energy management, the system does not integrate Bluetooth and cloud-based storage, which limits its remote monitoring and scalability in larger operations [5].

Sharma (2021) introduces a cost-effective IoT-based greenhouse automation system. The system is designed to automate key greenhouse functions like climate control, reducing manual intervention. While it is affordable and efficient for small-scale operations, the lack of Bluetooth and cloud integration restricts its potential for remote data access and scalability [6].

Warse et al. (2020) proposed an IoT-based automated irrigation system aimed at improving water conservation and precision farming. The system utilizes IoT technologies to automate irrigation based on real-time soil moisture data, helping optimize water usage. However, the system focuses solely on irrigation and does not address broader environmental control, such as managing temperature and humidity in greenhouses [7].

IRJET (2018) presents an IoT-based automated greenhouse monitoring system, which tracks environmental parameters like temperature, humidity, and soil moisture. This system enables real-time monitoring, maintaining optimal conditions for plant growth and reducing manual labor. Despite its benefits, the absence of Bluetooth and cloud-based data storage limits its potential for long-term analytics and scalability [8].

The IOP Conference (2021) introduces an energy-efficient IoT- based remote greenhouse monitoring system. It focuses on minimizing energy consumption while providing continuous environmental monitoring for greenhouses. Although it offers a scalable solution for greenhouse management, challenges related to Bluetooth and cloud integration and real-time data analytics remain [9].

Warse et al. (2020) also explore an automated irrigation system using IoT for precision farming. This system aims to conserve water by automating irrigation through real-time data collection. While it improves water management in farming, it is limited in scope, as it does not encompass other environmental factors like humidity and temperature [10].

IRJET et al. (2018) propose an IoT-based automated greenhouse monitoring system that tracks key environmental factors such as temperature, humidity, and soil moisture. The system is designed to automate monitoring tasks and improve greenhouse management. However, it lacks Bluetooth and cloud integration for long-term data storage and remote access, which limits its scalability for larger greenhouse operations [11].

The IOP Conference et al. (2021) present an energy-efficient IoT-based remote greenhouse monitoring system. This solution aims to optimize energy usage while providing continuous environmental monitoring through sensors that track temperature and humidity. Although the system offers improved energy management, it faces challenges related to Bluetooth and cloud-based data analytics and real-time remote monitoring [12].

The system described by the authors in (2021) focuses on a low- cost IoT-enabled greenhouse monitoring system. It automates environmental monitoring tasks and provides real-time data collection. Despite being cost-effective, the system lacks advanced Bluetooth and cloud-based features for scalability and long-term data analytics, limiting its application in larger agricultural setups [13].

We referred to the work of Pallavi Deshpande et al. (2019) (2021) to guide the structure, format, and flow of this paper for conference publication. While their studies informed our organizational approach, no direct content or references were used, ensuring the originality of this work [14-15].

III. METHODOLOGY

In this automated greenhouse monitoring system, a relay module controlled by a microcontroller (Arduino Uno) manages high-power devices like a humidifier and fan based on data of temperature and humidity from the DHT11 sensor. When humidity falls below a set threshold, the relay activates the humidifier to increase moisture levels, and it turns off once the target is reached. Similarly, the fan operates when temperature or humidity exceeds upper limits to help regulate conditions. A water sensor monitors the humidifier's water level and, when low, signals a pump to refill from an external source, thus automating the process to maintain the greenhouse conditions. The system's flowchart, shown in [Fig. 1], illustrates key steps. The real-time temperature and humidity data is continuously updated on the LCD and transmitted via the Bluetooth module to the Serial Bluetooth app, allowing monitoring on connected devices.

The user receives notifications or alerts on the connected device via the Bluetooth module whether intervention is required in case any sensors or devices malfunction. This ensures efficient, automated environmental control, making it suitable for industrial applications in smart agriculture [Fig. 2], [Fig. 3], [Fig. 4] and [Fig. 5] display the system's hardware setup. This design reduces manual intervention, optimizes resource usage, and supports real-time automation.

The rationalization of this greenhouse systems introduces a greenhouse automation system as a means of environmental control regulation to minimize the extent of human control. This construction employs the Arduino Uno as the main device, and uses a DHT11 sensor to smartly operate the fan and humidifier within set temperature and humidity ranges

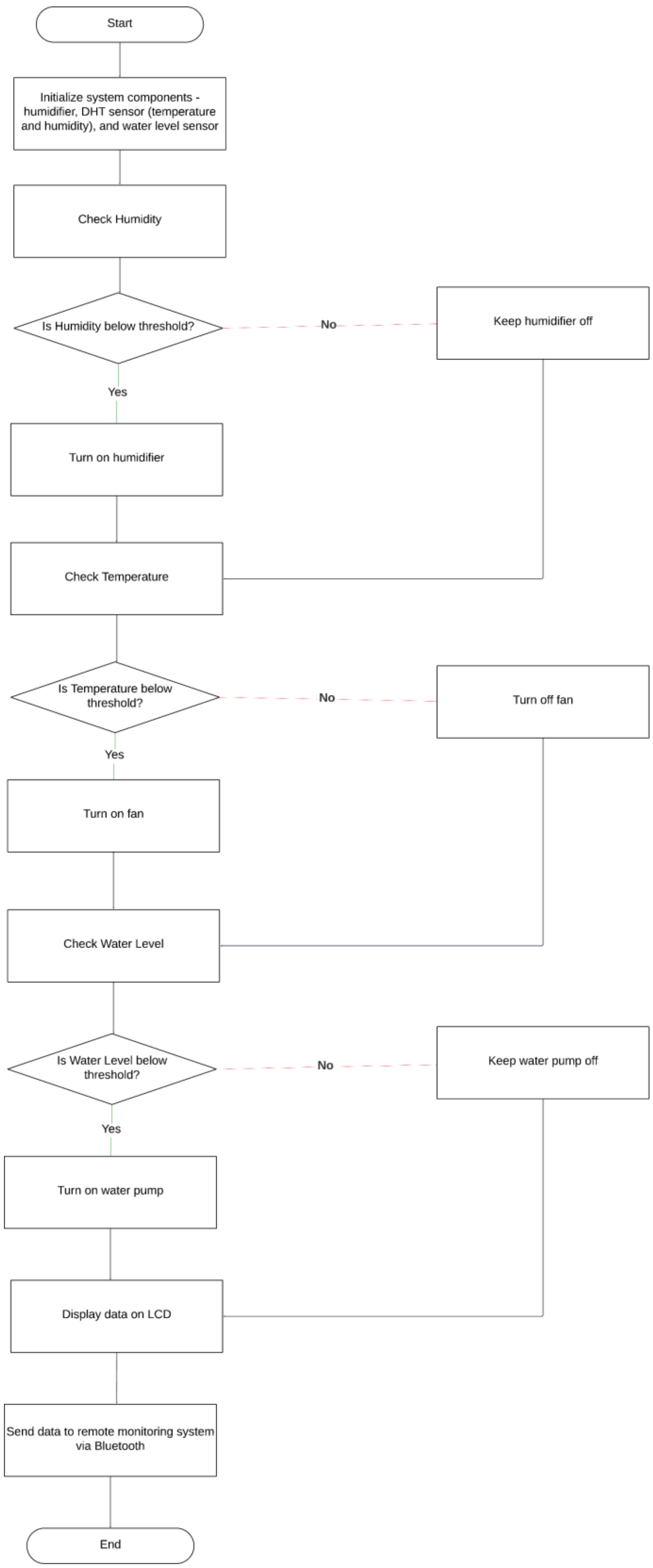

Fig. 1. System Flowchart

Fig. 2. System Hardware Setup

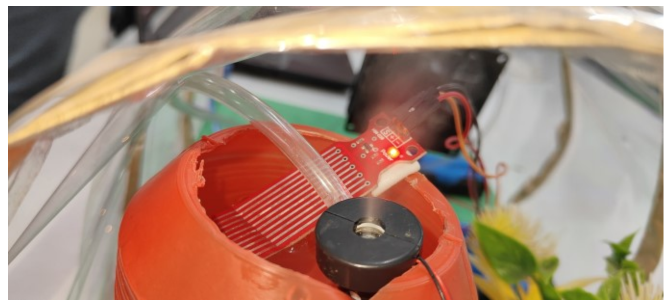

Fig. 3. Humidifier Module

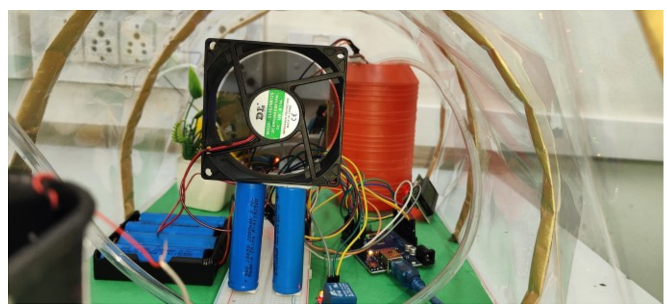

Fig. 4. Cross-section view of the Hardware Setup

Fig. 5. Cross-section view of the Hardware Setup (Other end)

without any manual controls. Such control helps save on energy and water thus helping in the proper utilization of resources. Further, the water level sensor and automated refill system helps in keeping the humidifier water levels appropriate for usage without any manual water refilling thus promoting continuous operation and offering less work. This system does allow any waste of resources while the greenhouse related functions are performed, by responding only when it is needed, unlike basic greenhouse systems which often have mists on or off cycles and demand much manual interventions. Such is the more sustainable and affordable practice. HC-05 Bluetooth module enables monitoring and control of greenhouse conditions at all times even when away, hence fostering quick adaptability to the changing climatic conditions. In this arrangement, the components are arranged to connect to the Arduino Uno board in the following manner: DHT11 Sensor is used to measure temperature and humidity, and the relay module is used to operate the humidifier and the fan based on the readings. A water sensor is used to check water levels of the humidifier and if the sensor indicates low water levels, the arduino switches on a pump through the relay module to refill the water. The mobile application receives sensor data through an HC-05 Bluetooth module for live data monitoring. The system was however built mostly for embedded monitoring and its design is amenable to cloud incorporation with either Firebase or ThingSpeak as web interfaces for remote usage and archival of data. This capability encourages the system to be used in big and more sophisticated greenhouses that require the use of data in order to improve performance further.

This configuration also encourages sustainability through the automation of processes and optimal rather than excessive utilization of inputs as is the case with traditional systems. Farmers can mitigate the effects of agriculture on the environment by using advanced technology to grow crops effectively and efficiently with a very low labour input.

IV. Results and Discussions

TABLE I
Temperature and Humidity Data

Time	Temp. (°C) App	Humid. (%) App	Temp. (°C) DHT11	Humid. (%) DHT11
14:00	28	91	31.5	69
14:30	27.5	91	30	68
15:00	26.5	91	29	68.5
18:00	24	91	28	68
18:30	23.5	91	28	68
19:00	23	91	27.5	69
19:30	23	91	27	68
20:00	23	91	27.2	68
22:00	22	91	26	69
22:30	22	91	27	69
23:00	22	91	28.4	70
23:30	23	91	28.4	69

For monitoring environmental conditions, both temperature and humidity data were gathered through real-time measurements and DHT11 sensor readings. The comparison of these values is presented in [Table I], which shows data collected at twelve specific time intervals. This table highlights a consistent, though slight, difference between the real-time measurements and the values detected by the DHT11 sensor. These variations are expected due to the sensor's inherent limitations in precision, though the overall trends in both datasets remain aligned. This indicates that the DHT11 sensor, while less precise than real-time instruments, is capable of providing sufficiently accurate measurements for general monitoring purposes. To further illustrate this comparison, [Fig. 6] contains two graphs, one representing temperature and the other humidity. These graphs plot the real-time data against the DHT11 sensor data across the same time intervals. The temperature graph demonstrates how both real- time and sensor readings follow a consistent upward trend, with the sensor values being marginally lower. Similarly, the humidity graph shows a parallel increase in both real- time and sensor readings. These visualizations were created using the MATLAB, providing a clear representation of the relationship between real-time and sensor-based data.

The analysis of this data yields several important insights:

- Sensor Accuracy: The DHT11 sensor is reasonably accurate for basic environmental monitoring, as the differences between its readings and real-time measurements are minor. Despite these small discrepancies, the sensor is a practical and cost-effective choice for applications that do not require highly precise data.
- Trend Consistency: The graphs in [Fig. 6] show that the DHT11 sensor reliably tracks changes in temperature and humidity over time, making it suitable for continuous monitoring in applications like automated greenhouses, IoT systems, and other embedded environments where simplicity and cost-effectiveness are prioritized.
- Validation of Sensor Performance: By comparing real-time values with sensor data, the performance of the DHT11 sensor can be validated.

This comparison ensures that the sensor operates within acceptable error margins. Thus, the data presented in [Table 1] and [Fig. 6] highlight the reliability and consistency of the DHT11 sensor for medium-accuracy applications. These results support the sensor's suitability for low-cost environmental monitoring systems.

The proposed system also uses Bluetooth technology to enable wireless monitoring of greenhouse conditions. By connecting sensors to a Bluetooth module (such as the HC- 05), data on temperature, humidity, and other environmental factors are sent directly to a smartphone or nearby device and can be viewed on the Serial Bluetooth App terminal as seen in [Fig. 7]. This setup allows users to monitor greenhouse conditions in real time within a range of about 10 meters, without needing to be physically present next to the system. With Bluetooth's short-range capability, the proposed system supports reliable, low-cost data sharing. It also offers the potential for user control adjustments, allowing real-time changes to greenhouse settings as needed. This makes the system ideal for local monitoring and does not complex internet connectivity. The DHT11 sensor, while cost-effective, has minor accuracy limitations, registering slightly lower humidity levels. To enhance precision, future versions could incorporate DHT22 or SHT75

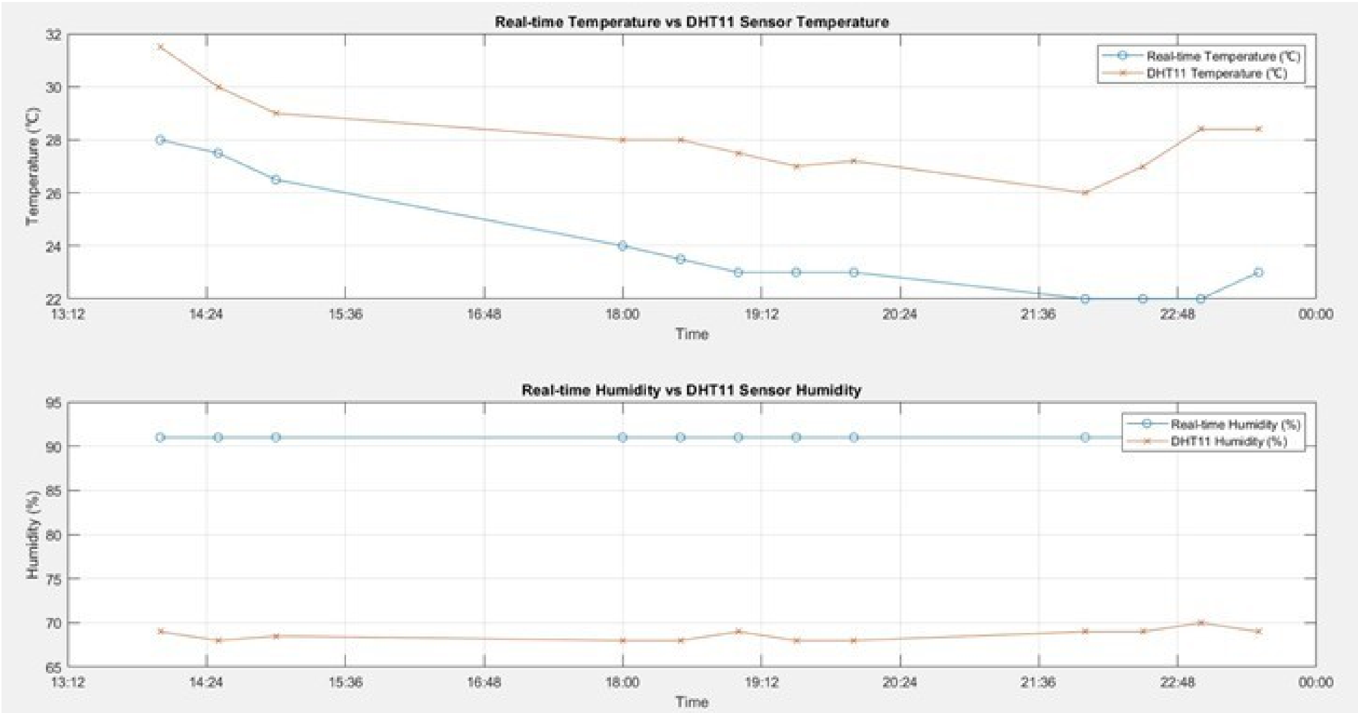

Fig. 6. Temperature and Humidity Graph

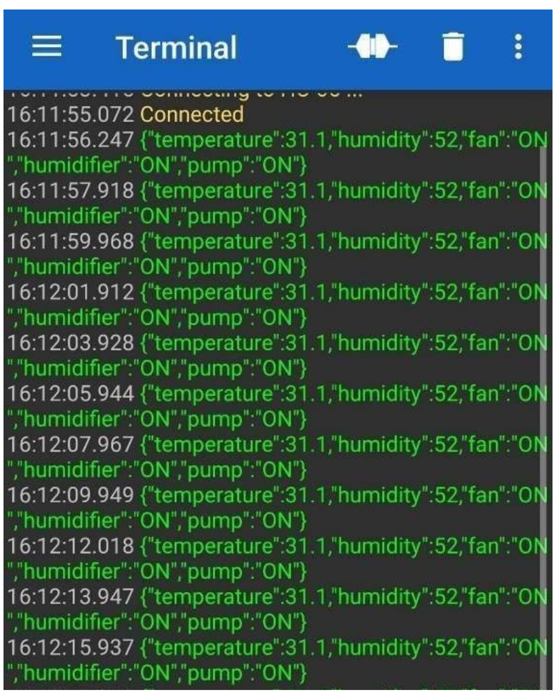

Fig. 7. Serial Bluetooth App terminal

sensors for higher accuracy in temperature and humidity monitoring. Scalability in a Bluetooth Automation System can be achieved through integration of Cloud platforms which allow centralized data storage, enabling data access and management from anywhere in the world. For multiple communication protocols, a range of communication options (Eg.LoRaWan, Zigbee, etc.) can be accommodated with different range and power requirements. The system provides precise and accurate monitoring, allowing it to maintain ideal conditions in the greenhouse. Its flexible design makes it easy to expand for bigger or more complex setups, making it a good fit for a wide range of agricultural uses.

Sensors should be regularly calibrated to maintain their accuracy over time. Periodic diagnostic helps in ensuring that the devices work properly avoiding issues like delay.

Running regular firmware updates and checking error logs can help keep sensors working well and catch any issues early. Alerts are generated if the system malfunctions, notifying the user for quick action. Scheduling regular maintenance especially for high power components (E.g. DC fan), reduces the chance of unexpected failures and prolongs the system's operational life, thus maintaining the automation process in a greenhouse. For handling power interruptions, UPS back-up system, battery powered back-up system or low power mode can be integrated to provide temporary power during outages. The Arduino Microcontroller being paired an external SD card module, can store and retrieve history of the sensors' data up to several months. And thus, helps in data management and updating it as per requirements. This automated refill system

TABLE II
COMPONENT COST COMPARISON

Component	Prototype System	Cost (Prototype)	Large-Scale System (3000-4000 sq. ft.)	Cost (Large-Scale)	Reason for Upgrade
DC Fan (12V)	Basic 12V fan for ventilation	100	Industrial Ventilation Fan (High CFM)	2,000 - 5,000 per fan	High airflow (CFM) needed for large space to ensure proper air circulation for temperature and humidity control.
DHT11 Sensor	Low-accuracy temperature and humidity sensor	80	DHT22/SHT75 for high accuracy	600 - 1,500 per sensor	High-precision sensors required for monitoring environment over a larger area.
Arduino Uno	Basic microcontroller for control	330	STM32F4/Raspberry Pi 4	1,500 - 3,000	More powerful microcontroller needed to handle additional sensors, real-time processing, and larger-scale system control.
Humidifier Module (Trio)	Basic humidifier for local humidity control	250	Industrial Humidification System	5,000 - 10,000	Higher capacity humidifiers required for managing humidity over larger areas effectively.
Relay	Relay	47	Industrial Solid-State Relay	400 - 800 per relay	Industrial relays can handle larger current loads for high-power devices like industrial fans and humidifiers.
IC LM7805	Voltage regulator for basic low-power circuits	20	Industrial Power Regulator	500 - 1,000	Provides stable power to multiple high-power devices across the larger system.
Water Level Sensor	Detects the level of water	50	Ultrasonic Water Level Sensor	1,000 - 2,000	Ultrasonic sensors offer better accuracy and reliability for monitoring large water reservoirs.
LCD Display	Basic local display for sensor data	250	Industrial Display	3,000 - 5,000	Industrial-grade touchscreens enable easier data visualization and control for real-time monitoring.
Power Supply	5V/12V adapter for small devices	300	Industrial Power Supply (24V/48V)	3,000 - 6,000	Larger systems need robust power solutions to support multiple high-power devices.
Water Pump	Small pump for humidifier refill	200	High-Volume Pump for irrigation	3,000 - 8,000	Powerful water pumps required for efficient irrigation and humidifier refills in large-scale systems.

ensures continuous operation of the humidifier without manual intervention. The entire system is seamlessly integrated with Serial Bluetooth App, which allows for remote monitoring and control of environmental parameters. The humidity levels, water sensor readings, and the operational states of the humidifier and fan are transmitted via an HC-05 Bluetooth module, providing users with real- time updates and enabling adjustments when necessary. This offers enhanced convenience and scalability for larger applications.

The prototype system uses cost-effective components such as basic fans, sensors, and relays, making it suitable for small-scale applications. However, for larger systems (3000-4000 sq. ft.), more powerful and accurate components are necessary. For instance, the basic 12V fan is replaced by industrial ventilation fans, and the low-accuracy DHT11 sensor is upgraded to high-precision sensors like the DHT22. Similarly, the simple Arduino Uno is upgraded to more powerful microcontrollers like the STM32F4 or Raspberry Pi. Other upgrades include industrial humidifiers, solid-state relays, ultrasonic water level sensors, and larger power supplies. These upgrades are essential to ensure reliable and efficient performance for larger-scale systems, as detailed in [Table II].

V. CONCLUSION

In conclusion, this system introduces an easy-to-use and affordable IoT-based climate control system for greenhouses. It uses Bluetooth technology for real-time monitoring and remote control, making it simple to manage greenhouse conditions. With DHT11 sensor for measuring temperature and humidity and an automated water refill system, it keeps the environment just right for plants. The system also turns on fans and humidifiers as needed, saving resources and improving efficiency. Scalable and energy-efficient, this solution is ideal for boosting plant growth, especially in tropical and resource-limited areas, while promoting sustainable farming.

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