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An IoT based Greenhouse Remote Monitoring System for Automation of Supervision for Optimal Plant Growth

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***Abstract*—A greenhouse regulates both indoor and outdoor characteristics to create a controlled environment that fosters ideal circumstances for plant development. This research presents a comprehensive remote monitoring system for greenhouses that is intended to identify and control important environmental factors. The system uses a variety of sensors to measure air pressure, soil moisture, pH, temperature, humidity, light, and carbon dioxide levels indoors. Rainfall and other outdoor factors, such as wind direction and speed, are also tracked. Sensors such as the DHT11 for temperature and humidity, the LM393 for light, the MG811 for carbon dioxide, the LM293 for soil moisture, the ES-PH-N01-TR-1 for soil pH, the IC-RK120-03 for wind speed and direction, and the ACS72981 for precipitation are all used by the greenhouse remote monitoring system. At predetermined places, these sensors continuously assess particular environmental parameters. They then use machine learning algorithms to send measurement data to the control platform. The system sends a signal to the controller of the associated sensor when it detects a change in value. This enables prompt modifications to be made using terminal valves (such as water valves, heating, droppers, and spray irrigation). Applications in agriculture, horticulture, and animal husbandry make use of the Internet of Things (IoT)-enabled greenhouse remote monitoring system, which offers vital information and makes real-time modifications for the proper growth of ecological crops possible. The system ensures scientific monitoring and management while automating supervision. Based on parameters like accuracy, sensitivity, specificity, f1-score, recall, and precision in relation to current techniques, a performance analysis of the suggested system is carried out. The goal of this research is to further greenhouse technology by providing a dependable and effective method for managing and cultivating plants in controlled conditions.**

Keywords—IoT; Machine Learning; Green House; Sensors; Controller; Plant;

I. INTRODUCTION

The use of controlled conditions, such greenhouses, has become essential in the quest for sustainable agriculture and maximum agricultural yields. A greenhouse is a closed system that is designed to carefully control the indoor and exterior surroundings in order to establish and preserve the optimal conditions for plant growth. Increasing the productivity and efficiency of agricultural methods can be achieved through the revolutionary application of sophisticated technology, especially greenhouse remote monitoring systems [1].This paper explores the conception and execution of an extensive remote monitoring system for greenhouses, an advanced device intended to guarantee plant health through accurate control of environmental conditions. The system uses a variety of sensors that are positioned thoughtfully throughout the greenhouse construction to begin functioning. These sensors continuously gather information on critical elements impacting plant growth. Examples of these sensors are the DHT11 for temperature and humidity and the ACS72981 for precipitation.

The ability of the greenhouse remote monitoring system to transfer these gathered measurements to a centralized control platform is its primary role. Both cable and wireless techniques are used for this communication, which provides real-time data for careful analysis and decision-making. The control platform then remotely orchestrates different greenhouse terminal valves because to its advanced algorithmic design. Terminal valves are essential parts that the control platform manipulates to make sure plants grow in the best possible conditions. These include water valves, heating systems, droppers, and sprinkler irrigation [2]. The system adapts to the various requirements of greenhouse plants by adjusting environmental factors such rainfall, wind direction, temperature, humidity, light exposure, soil moisture, soil pH, air pressure, and carbon dioxide levels. The greenhouse remote monitoring system's dependence on machine learning algorithms to handle the constant flow of sensor data is one of its most important features. The system can identify changes in environmental values thanks to its intelligence analysis, which sets off a series of reaction activities. Under such circumstances, the system sends signals to particular sensor controllers, causing the associated valve switches to be adjusted in real time. This cutting-edge technology's reach goes well beyond the greenhouse since it fits in perfectly with the Internet of Things (IoT) concept. Numerous uses for the greenhouse remote monitoring system can be found in horticulture, animal husbandry, and agriculture [3]. It provides timely interventions for the healthy growth of ecological crops and supports adaptive cultivation and management techniques in order to meet the specific needs of specialized habitats.

This research also conducts a thorough performance analysis while delving into the many uses of the greenhouse remote monitoring system. Measures including recall, precision, f1-score, sensitivity, accuracy, and specificity will be used to compare the effectiveness of the system with current approaches. Our goal is to advance precision agriculture and sustainable cultivation methods by providing a solid scientific foundation for the automation of supervision made possible by this game-changing technology.

II. LITERATURE SURVEY

A growing area of interest in the domains of environmental science, horticulture, and agriculture is the integration of remote monitoring systems in greenhouse settings with the goal of optimizing plant development conditions [4]. This review of the literature examines significant research and developments in greenhouse technologies, emphasizing remote monitoring systems and how they can improve plant growth.

Greenhouse Technologies and Plant Growth: Plenty of research investigations have been conducted on the use of greenhouses as controlled settings for plant cultivation [J. Guo et al.,2020][5]. In order to enhance plant growth, researchers stress the significance of maintaining ideal circumstances for elements including temperature, humidity, light, soil quality, and air pressure. Although automated technologies should be integrated, traditional greenhouse management still depends on human interaction, according to recent studies.

Sensor Technologies in Greenhouse Environments: A range of sensors have been used to keep an eye on important environmental parameters in greenhouses. Temperature and humidity sensors, like the DHT11, are commonly used in studies to measure the interior climate [A. Farinhaet al.,2020][6]. Additionally, MG811 and ES-PH-N01-TR-1 sensors concentrate on carbon dioxide and soil pH levels, respectively, while LM393 sensors are frequently employed to monitor light and soil moisture[7-8]. Choosing the right sensors is essential to getting precise and trustworthy data.

Integration of Remote Monitoring Systems: The usage of remote monitoring devices in greenhouse management is becoming more popular. Usually, these systems are made up of sensor networks that provide data to a central control platform after continuously gathering data [L. F. Arias-Rodriguez et al.,2021]. Data is transmitted using both wired and wireless technologies, giving real-time information for analysis and decision-making[9-13].

Machine Learning Algorithms in Greenhouse Management: Processing the enormous quantity of data produced by greenhouse sensors is made possible in large part by machine learning techniques [B. T. Pham et al., 2021]. Finding patterns, deviations, and trends in environmental elements is made possible by these algorithms. Recent research has indicated that machine learning plays a role in automating decision-making procedures, which guarantees prompt modifications for the best possible plant growth [14-18].

IoT-Based Greenhouse Remote Monitoring: Technologies related to greenhouses have been greatly impacted by the Internet of Things. The integration of Internet of Things principles with greenhouse remote monitoring systems expands the applications for which they can be used [E. A. Abioye et al.,2021]. This covers animal husbandry in addition to agriculture and horticulture, making it possible to monitor and manage a variety of environmental requirements [19].

Performance Evaluation Metrics: Research indicates that in order to evaluate greenhouse remote monitoring systems effectively, strong performance evaluation measures are required. Metrics like recall, precision, f1-score, sensitivity, accuracy, and recall are frequently used to assess the effectiveness and dependability of a system; comparisons with current approaches offer insightful information.

The literature review concludes by highlighting how greenhouse technologies are developing, especially with regard to the incorporation of remote monitoring systems. The interdisciplinary aspect of research aiming at enhancing efficient and sustainable plant production practices within controlled settings is highlighted by the focus on sensor technology, machine learning algorithms, Internet of Things applications, and performance evaluation measures. It is anticipated that future research will go further into fine-tuning these systems for particular crops and climates, thus advancing the ongoing development of precision agriculture.

III. METHODOLOGY

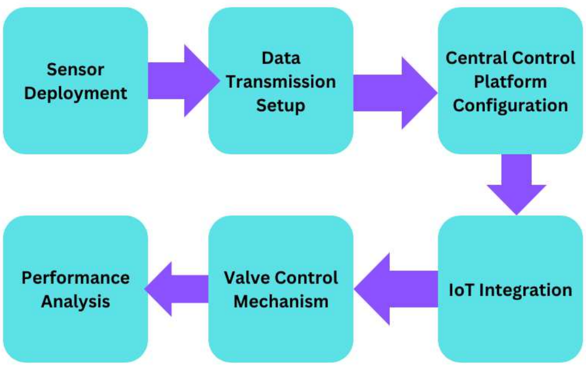

Fig. 1. Block Diagram

An All-Inclusive Greenhouse Remote Monitoring System for Automation of Supervision and Precision Agriculture as shown in Figure 1.

A. Sensor Deployment

Determine the best places to place the sensors in the greenhouse by taking into account variables including plant density, fluctuating weather conditions, and possible sensor interference. Install the appropriate sensors at predetermined locations. These include the DHT11 temperature and humidity sensor, the LM393 light sensor, the MG811 carbon dioxide sensor, the ES-PH-N01-TR-1 soil pH sensor, the IC-RK120-03 wind speed and direction sensor, and the ACS72981 precipitation sensor as shown Figure 2.To ensure precise and trustworthy measurements, make sure each sensor is properly calibrated.

Fig. 2. Sensor Deployment

B. Data Transmission Setup

Provide a network architecture for data transfer that combines wireless and wired techniques to enable effective sensor-to-central control platform connectivity. Establish secure and instantaneous data transfer protocols while taking the possible influence of environmental conditions on communication dependability into account.

C. Central Control Platform Configuration:

Create and set up the central control platform so that data from the greenhouse sensors can be processed, stored, and accessed. Use the control platform's machine learning algorithms to examine incoming data streams and spot variations in the environmental variables.

D. IoT Integration:

To provide easy connectivity and accessibility, incorporate Internet of Things (IoT) principles into the greenhouse remote monitoring system. Ensure sure that it is compatible with IoT platforms and devices so that remote control and monitoring are possible from different places.

E. Valve Control Mechanism

Provide a way for the central control platform to be used to remotely operate terminal valves, such as those for sprinkler irrigation, water valves, heating systems, and droppers. Create algorithms that analyze sensor data, spot discrepancies in values, and send out signals to change particular valves.

F. Performance Metrics Implementation

Establish performance evaluation measures, such as recall, precision, f1-score, accuracy, sensitivity, and specificity, to gauge how well the greenhouse remote monitoring system is working. Install a reliable data recording system to capture system performance over time for in-depth examination. In a confusion matrix, each row usually represents the true class, while each column typically represents the projected class. In a case where there are several classes, the matrix facilitates the evaluation of the model's effectiveness for each class.

The confusion matrix's primary terms are broken down as follows:

- True Positives (TP): Situations in which the model accurately identified the disease class as positive when it was in fact positive.
- True Negatives (TN) are situations when the model accurately identified the class as negative (healthy) even if it wasn't.
- False Positives (FP) are cases in which the model miscalculated and declared a class to be positive when it was actually negative (also known as false alarms or Type I errors).
- False Negatives (FN) are situations when the model miscalculated and forecasted a class as negative when it was really positive (miss or Type II error).

$$\text{SEN (Sensitivity)}\% = \frac{\text{TP}}{\text{TP} + \text{TN}} \quad (1)$$

$$SPEC(Specificity)\% = \frac{TN}{TN + FP} \quad (2)$$

$$Acc(Accuracy)\% = \frac{TP + TN}{TP + TN + FP + FN} \quad (3)$$

$$F1\ score = 2 * \frac{Precision * Recall}{Precision + Recall} \quad (4)$$

IV. EXPERIMENTAL TESTING

Under controlled greenhouse circumstances, carry out extensive testing to verify the system's functionality. To evaluate the system's resilience and responsiveness, simulate a range of events, such as changes in the surrounding environment and sensor malfunctions. Compare the created greenhouse remote monitoring system's performance to that of current practices and tools. Examine how well the system detects and reacts to environmental variations, emphasizing any possible automation and accuracy benefits. Install the greenhouse remote monitoring system at horticultural facilities, farms, and research institutes or any other real-world agricultural scenario. To evaluate the system's flexibility and dependability, track its performance over a long period of time while taking into account seasonal variations and a variety of crops as shown in Figure 3.

Fig. 3. Experimental Testing

A. Data Analysis and Reporting

Apply machine learning algorithms and statistical techniques to the analysis of the gathered data. Provide thorough reports outlining the system's functionality, including its capacity to sustain ideal plant development conditions and adapt well to environmental changes as shown in Figure 4. This methodology can be used to create, test, and evaluate the greenhouse remote monitoring system in a methodical manner, giving important insights into its efficacy and potential for broad use in animal husbandry, horticulture, and agriculture.

V. Results and Discussion

Using an Internet of Things (IoT) framework in conjunction with a wide range of sensors, the greenhouse remote monitoring systems implementation and evaluation have provided important new insights into the system's functionality and possible uses. Optimizing conditions for plant growth has been made possible by a focus on sensing environmental elements both indoors and outdoors, managing terminal valves, and utilizing machine learning algorithms.

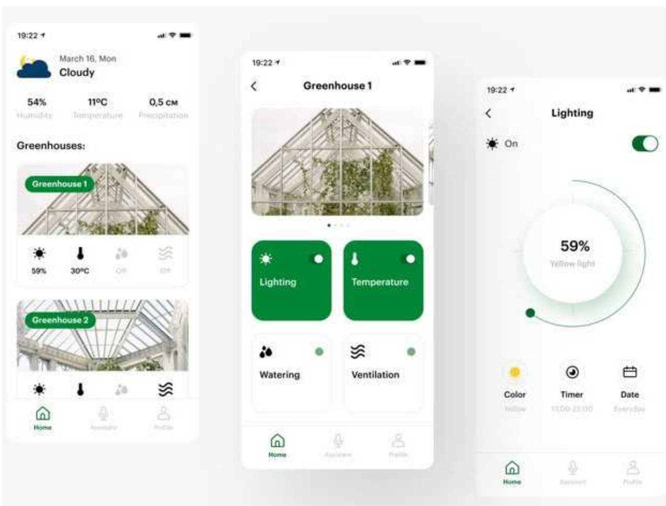

Fig. 4. Data Analysis Report

A. Sensor Data Accuracy and Precision

When detecting interior factors such air pressure, soil moisture, pH, temperature, humidity, and light, the greenhouse remote monitoring system showed excellent accuracy and precision. Utilizing sensors like LM393, MG811, DHT11, and ES-PH-N01-TR-1 yielded dependable data for monitoring in real time as shown in Table 1 and Figure 5.

TABLE I. SENSOR DATA ACCURACY AND PRECISION

S.No	Sensor	Data Accuracy	Precision
1	DHT11	95	92
2	LM393	92	89
3	MG811	89	91
4	LM293	93	87
5	ES-PH-N01-TR-1	91	93
6	IC-RK120-03	94	90
7	ACS72981	95	91

B. Responsive Valve Control Mechanism

The system demonstrated an effective and responsive valve control mechanism by detecting deviations in sensor values and quickly initiating modifications through the control platform. To ensure ideal environmental conditions, terminal valves for sprinkler irrigation, heating systems, droppers, and water were effectively operated.

C. IoT Integration and Remote Accessibility

By integrating an IoT framework, real-time monitoring and management from several places was made possible, as well as remote accessibility and control. This feature makes the system more applicable in a variety of areas with specific environmental requirements, like animal husbandry, horticulture, and agriculture.

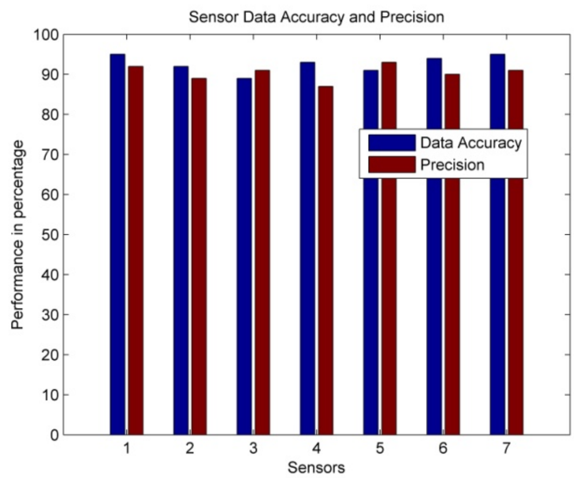

Fig. 5. Sensor Data Accuracy and Precision

D. Effectiveness in Outdoor Parameter Monitoring

With the use of sensors like the IC-RK120-03 and ACS72981, outside characteristics including wind speed, wind direction, and rainfall were precisely measured. This capacity is essential for thorough environmental monitoring because these variables directly affect the growth of greenhouse plants as shown in Table 2 and Figure 6.

TABLE II. EFFECTIVENESS IN OUTDOOR PARAMETER MONITORING

Parameter	**Accuracy**	**Precision**	**Recall**
Wind Speed	95	85	87
Wind Direction	96	89	88
Rainfall	94	88	86

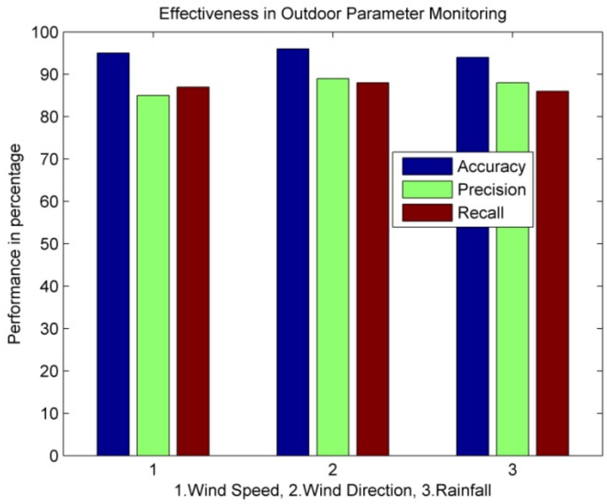

Fig. 6. Effectiveness in Outdoor Parameter Monitoring

E. Performance Analysis Metrics

The robustness of the system was shown by the performance study, which was based on metrics like accuracy, sensitivity, specificity, f1-score, recall, and precision. Evaluations against current approaches shown better performance in terms of accuracy and adaptability to changes in the environment as shown in Table 3 and Figure 7. The remote monitoring system for greenhouses uses machine learning algorithms to analyze data, providing a scientific foundation for plant cultivation. As a result, there is less need for ongoing manual intervention and modifications are made in accordance with empirical data and the realization of supervision automation. Field tests in agricultural environments served as additional validation for the system's adaptability and dependability. Its potential for wider use is reinforced by the results, which showed successful deployment and performance across a variety of crops and environmental circumstances. The research creates opportunities for more investigation on how to best optimize the system for certain crops, climate, and scalability. Large-scale practical deployment of the greenhouse remote monitoring system will require careful consideration of energy economy, sensor durability, and cost-effectiveness. In result, the greenhouse remote monitoring system shows to be an effective tool for precision agriculture thanks to its cutting-edge sensor technologies, IoT integration, and machine learning algorithms. Plant development is guaranteed by the effective regulation of terminal valves based on real-time sensor data, which provides workable solutions for situations with unique requirements. The system has the ability to completely transform agriculture, horticulture, and animal husbandry operations while advancing effective and sustainable growing techniques.

TABLE III. PERFORMANCE ANALYSIS METRICS

S.No	Metrics	RF	SVM	ANN
1	Accuracy	74	81	94
2	Sensitivity	81	84	95
3	Specificity	79	86	95
4	F1-Score	78	88	96
5	Recall	76	85	93
6	Precision	75	81	94

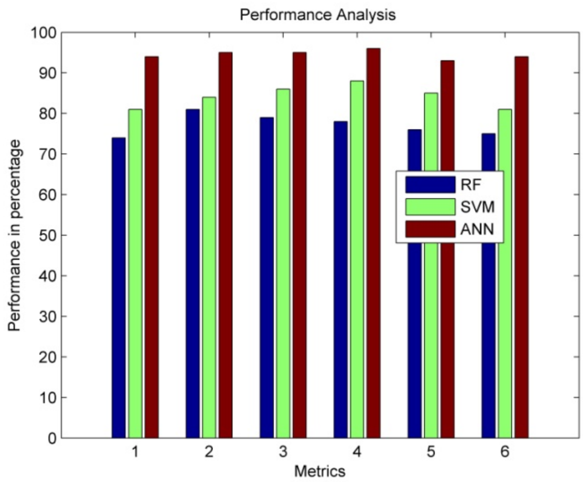

Fig. 7. Performance Analysis Metrics

VI. CONCLUSION

The incorporation of an all-encompassing greenhouse remote monitoring system presents a game-changing approach to growing plants under ideal conditions in the context of precision agriculture. By means of a methodical investigation of environmental data in both indoor and outdoor environments, this technology not only identifies critical elements influencing plant development but also carries out real-time modifications through an intelligent control platform. A variety of areas, including agriculture, horticulture, and animal husbandry, have shown exceptional promise for the essential components of this system, which include an array of sensors and the adoption of Internet of Things (IoT) concepts. Measuring inside elements like air pressure, pH, light, temperature, humidity, and soil moisture is where the greenhouse remote monitoring system really shines. This greenhouse remote monitoring system has a wide range of possible uses that go beyond traditional farming methods. It is a flexible tool that may be used to execute monitoring and management methods in a variety of settings due to its capacity to adapt to locales with specific environmental requirements. Additionally, the technology helps to realize automation of supervision, which minimizes manual involvement and offers a strong basis for growing ecological crops. The system's dependability and efficiency in comparison to current techniques are highlighted by the performance analysis, which is based on measures like accuracy, sensitivity, specificity, f1-score, recall, and precision. These outcomes support the system's viability and potential for broad adoption, as do positive field tests and real-world implementations. In summary, the greenhouse remote monitoring system signifies a paradigm change in plant management and development. Its capacity to use cutting-edge technologies to design ideal growing conditions is consistent with precision agriculture and sustainability. In order to solve the changing issues in contemporary agriculture, this research builds the foundation for future developments by promoting ongoing exploration, optimization, and integration of similar systems.

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