A Review on Greenhouse Monitoring and Control System Using Internet of Things (IoT)

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ABSTRACT

The Internet of Things (IoT) has emerged as a transformative technology in agriculture, particularly for automating greenhouse monitoring and control systems. This literature survey explores the application of IoT in greenhouses, focusing on the integration of Arduino microcontrollers, Node microcontrollers and environmental sensors to manage crucial factors such as temperature, humidity, and soil moisture. The review highlights the advantages of these systems, including increased crop yields, optimized resource use, and reduced labour costs. Despite these benefits, challenges related to scalability, network reliability, sensor accuracy, and the integration of advanced analytics like artificial intelligence (AI) remain significant. This survey identifies current research gaps and proposes solutions to enhance the efficiency, adaptability, and sustainability of IoT-based greenhouse systems, positioning them as a key driver for the future of precision agriculture.

KEYWORDS: IoT, greenhouse automation, Arduino, Node MCU, environmental monitoring, smart agriculture, precision farming, sensor integration, AI in agriculture, scalability, network reliability.

I. INTRODUCTION

The **Internet of Things (IoT)** has rapidly evolved from a conceptual innovation into a powerful tool transforming industries across the globe, particularly those requiring precise environmental control, such as agriculture. IoT refers to the interconnected network of devices embedded with sensors, software, and technologies that communicate and exchange data over the internet. These devices enable real-time, autonomous operations, enhancing efficiency and productivity across various applications. In the context of agriculture, particularly greenhouse farming, IoT has revolutionized the way farmers monitor and control environmental conditions, optimizing crop growth while minimizing labour and resource use. To fully understand the transformative impact of IoT in greenhouse systems, it is important to trace its development and contrast it with the traditional, manual methods previously used to manage greenhouse environments.

The Internet is the universal structure of interrelated devices. These devices. Endlessly exchange or share resources and services. The Internet of Things is an Internet Protocol Network and all devices linked to it, must have an IP Address, which devices intersect through the IP Address. Internet have traversed many stages for its expansion like Internet of Boffins as scientists in 1969 to 1995, Internet of Geeks as Technologists in 1995 to 2000, Internet of Masses as Common people in 2000 to 2007, Mobile Internet as Handheld Devices in 2007 to 2011, and to finish Internet of Things in 2012 and further than.

Internet of Things is where different objects of our world are connected and controlled with the help of the internet. These things are able to sense or interact with the atmosphere and can retort to uses over the internet with the aid of technology. It is fundamentally a combination of Processer based system and the corporal world. Using data and communication technologies we can improve the excellence of recital and interactivity of airborne services.

FIGURE 1 Internet of Things (IoT)

Things, which can be no matter which, it can be observed or regulated. The internet of things, or IoT, is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to- human or human-to-computer interaction. A thing in the internet of things can be a person with a heart monitor implant, a farm animal with a biochip transponder, an automobile that has built-in sensors to alert the driver when tire pressure is low or any other natural or man-made object that can be assigned an Internet Protocol (IP) address and is able to transfer data over a network .Increasingly, organizations in a variety of industries are using lot to operate more efficiently, better understand customers to deliver enhanced customer service, improve decision-making and increase the value of the business.

An IoT ecosystem consists of web-enabled smart devices that use embedded systems, such as processors, sensors and communication hardware, to collect, send and act on data they acquire from their environments. IoT devices share the sensor data they collect by connecting to an IoT gateway or other edge device where data is either sent to the cloud to be analysed locally. Sometimes, these devices communicate with other related devices and act on the information they get from one another. The devices do most of the work without human intervention, although people can interact with the devices -- for instance, to set them up, give them instructions or access the data. The connectivity, networking and communication protocols used with these web- enabled devices largely depend on the specific IoT applications deployed. IoT can also make use of artificial intelligence (AI) and machine learning to aid in making data collecting processes easier and more dynamic.

Before the integration of IoT, greenhouse farming relied heavily on manual methods to monitor and regulate environmental conditions. Farmers used analog instruments such as thermometers, hygrometers, and soil moisture meters to track temperature, humidity, and soil moisture levels. Adjustments to the greenhouse environment, such as opening vents or turning on irrigation systems, were made manually based on intermittent readings. This reactive approach often led to inefficient resource use and suboptimal growing conditions, as real-time adjustments were not possible. Additionally, monitoring a large number of parameters required significant labour, and the inability to continuously track environmental changes increased the risk of crop loss due to sudden shifts in temperature or moisture levels.

The introduction of IoT-based greenhouse monitoring systems has drastically improved the precision and efficiency of environmental control. With sensors continuously measuring temperature, humidity, rain water, soil moisture, and light levels, these systems enable real-time monitoring and automatic adjustments to optimize plant growth. IoT-enabled systems can detect even the slightest deviations from ideal conditions and respond instantly, ensuring that crops receive the optimal amount of water, light, and ventilation. For example, IoT sensors can trigger irrigation systems automatically when soil moisture falls below a certain threshold, and temperature control systems can adjust greenhouse ventilation based on real-time temperature readings. This level of automation not only reduces labour costs but also maximizes resource efficiency and crop yields.

The evolution of IoT has fundamentally transformed how greenhouses are monitored and managed. By replacing manual methods with automated, real-time systems, IoT-based greenhouse monitoring solutions have made significant strides in improving crop productivity, resource efficiency, and operational flexibility. However, as these technologies continue to evolve, challenges such as sensor accuracy, data security, and network reliability remain critical areas for further research. With ongoing advancements, IoT has the potential to further revolutionize agriculture, ensuring that greenhouse environments are optimized with minimal human intervention and maximum efficiency.

II. IoT MODELS

Several IoT models have been developed to enhance the efficiency and productivity of greenhouse monitoring systems through the integration of various sensors, microcontrollers. These models rely on a combination of real-time data collection, communication protocols, and advanced analytics to optimize environmental conditions and automate agricultural processes. Each model possesses distinct architecture and functionality, contributing to the advancement of precision agriculture. This section outlines the key IoT models relevant to greenhouse monitoring, focusing on their applications in optimizing crop growth and resource management

First fundamental model is the SENSOR NETWORKS
Sensor networks are foundational to IoT-based greenhouse systems, consisting of interconnected sensors that continuously monitor key environmental parameters such as temperature, humidity, soil moisture, and light intensity. These sensors gather real-time data that is transmitted to a central system for analysis, helping maintain optimal growing conditions. Commonly used sensors include DHT11, LDR, and Soil Moisture sensors, integrated with Arduino or Node MCU microcontrollers. In this context, [1] demonstrates a greenhouse system using these sensor networks to automate environmental controls, significantly improving crop yield and resource use.

Second fundamental model is the WIRELESS SENSOR NETWORK (WSN) MODELS**.** Wireless Sensor Networks (WSN) are essential in automating the monitoring of greenhouse environments. These models use distributed sensors to gather real-time data on environmental conditions such as temperature, humidity, and soil moisture. This data is transmitted wirelessly to a central controller, enabling precise control of greenhouse parameters. As shown by [3], this WSN-based smart greenhouse system allows remote control of irrigation, ventilation, and lighting, effectively optimizing resource use and enhancing crop yields.

Third fundamental model is the ADVANCED IRRIGATION CONTROL MODELS. Advanced irrigation control models use real-time data from sensors to regulate water delivery to crops based on precise soil moisture levels and plant needs. These models prevent water wastage and ensure that crops receive the right amount of water at the right time. In [14], an embedded system is implemented to monitor environmental conditions and activate irrigation systems when necessary, leading to more efficient water use and improved crop management.

Fourth fundamental model is the AUTOMATION CONTROL MODELS**.** Automation control models are designed to autonomously adjust greenhouse conditions based on sensor readings, minimizing the need for manual intervention. These models regulate systems such as irrigation, ventilation, and lighting to maintain optimal growth conditions. For example, o3 outlines an automated greenhouse control system using Arduino and ESP8266 Wi-Fi modules, which automates irrigation and humidity regulation, enhancing efficiency. Such models minimize human error and labour costs while ensuring consistent, optimized conditions for plant growth. Additionally, integrated automation models improve decision-making by adapting to changing environmental factors over time.

Fifth fundamental model is the RENEWABLE ENERGY INTEGRATION MODELS .Renewable energy integration models leverage solar panels and other renewable sources to power IoT systems in greenhouses, reducing energy consumption and operational costs. These models utilize photovoltaic panels and buffer batteries to ensure continuous operation, even during low-sunlight conditions. As presented by [2], a renewable energy integration model was employed in their greenhouse system, using solar power to sustain operations, thereby enhancing sustainability and reducing reliance on conventional energy sources.

III. RELATED WORKS

The development of IoT-based greenhouse monitoring systems has evolved significantly over the years, with numerous studies focusing on automating environmental control, optimizing crop yields, and improving resource management. Early research, such as that of [9], explored the use of sensors and solar power to create cost-effective systems, particularly for small-scale farmers, emphasizing sustainability. As the field progressed, studies by [6] laid the groundwork for using Arduino-based frameworks to automate environmental monitoring. These systems highlighted the cost-efficiency and adaptability of IoT in optimizing plant growth through real-time control of temperature, humidity, and soil moisture. Additionally, [7] further refined these systems by reducing manual intervention and improving crop management via mobile applications and wireless sensor networks.

Researchers like [5] introduced AI and machine learning into greenhouse systems, enabling dynamic responses to changing environmental conditions and offering smarter, data-driven control mechanisms. Meanwhile, [4] emphasized the role of IoT in addressing agricultural challenges posed by climate change and pointed out the need for further integration of AI for predictive analytics. This marked a shift towards leveraging more advanced technologies to optimize resource use and boost productivity.

Further studies, such as those by [1], demonstrated how IoT-based systems powered by Arduino microcontrollers significantly improved crop yields, with examples like a 20% increase in lettuce yield by automating critical functions like NPK fertilizer application and environmental control. The [2] took this a step further by integrating photovoltaic panels and buffer batteries, reducing energy consumption and ensuring continuous operation in varying conditions. Throughout these years, scalability and cost-effectiveness remained critical challenges, with many researchers identifying the need for more long-term analysis of the systems' effectiveness in different geographic and climatic conditions.

Research by [14], [15], and [13] laid the foundation by developing systems that continuously monitored greenhouse environments using Arduino platforms. These systems focused on basic environmental adjustments (temperature, humidity, and light) while emphasizing affordability and ease of use, highlighting the potential for IoT to automate greenhouses, especially those with transparent materials like glass or plastic, requiring frequent environmental regulation.
As research progressed, [12] explored the integration of compressive sensing techniques within wireless sensor networks (WSN) to minimize data redundancy and reduce bandwidth usage. This study advanced the efficiency of data transmission in IoT-based systems, addressing challenges in managing large data sets in resource-constrained environments. Similarly, [11] focused on real-time data collection and analysis, underscoring the role of IoT in enhancing crop productivity through advanced data processing and automation, connecting farmers with digital technologies and underscoring the growing importance of IoT in agriculture.

Over time, the focus shifted towards sustainable and energy-efficient solutions. Research by [9] emphasized the integration of solar power with IoT systems, particularly beneficial for rural and small-scale farmers. Their studies showcased how renewable energy could be harnessed to maintain cost-effective, low-maintenance greenhouse operations. These early systems laid the groundwork for more complex and energy-efficient models that followed in subsequent years.

Research continued to expand with the inclusion of AI and machine learning. Studies by [6] and [7] developed smart greenhouse systems that optimized plant growth through real-time monitoring of key environmental parameters, reducing manual intervention. The [8] highlighted the integration of Raspberry Pi gateways for data transmission, achieving high data accuracy and low data loss, marking an improvement in real-time monitoring capabilities.

More sophisticated systems emerged with researchers like [5], who employed big data and machine learning to further automate greenhouse management. These models enabled adaptive control mechanisms, dynamically responding to environmental conditions and predicting changes. Simultaneously, [4] explored the broader application of IoT technologies in addressing climate change challenges, emphasizing AI's potential for predictive analytics in optimizing resource management.

Studies by [1] and [2] focused on advanced IoT-based systems incorporating energy-saving technologies, such as photovoltaic panels and dual power sources (solar and grid). These systems demonstrated significant improvements in crop yields and operational efficiency, especially in automating environmental controls and fertilizer application. However, challenges related to scalability, long-term cost-effectiveness, and the integration of advanced predictive technologies like AI remain areas for further exploration.

IV. IoT ARCHITECTURE

The Internet of Things (IoT) has emerged as a transformative technology across various sectors, enabling interconnected devices to collect, process, and exchange data over the internet. In critical industries such as greenhouses, IoT architectures are particularly valuable, as they form the backbone of systems designed to enhance and optimize operations, and provide real-time monitoring in hazardous environments. The architecture of IoT systems is complex and typically involves several layers, each with its distinct function. These layers work in unison to enable communication between physical devices, networks, data processing systems, and user interfaces. Understanding IoT architectures is essential for designing reliable and efficient systems that meet the specific requirements of applications like the greenhouse monitoring etc.

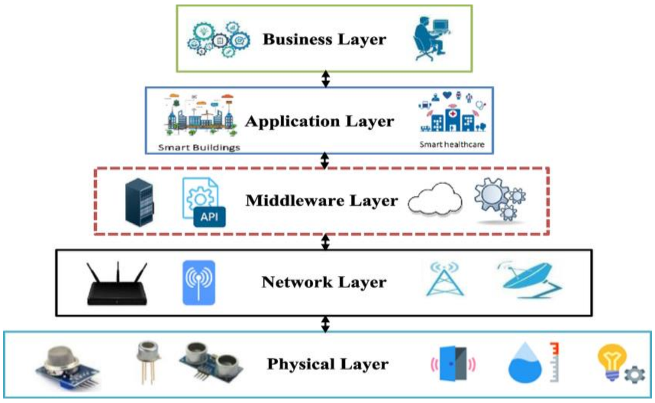

FIGURE 2 IoT Architecture

1. Physical Layer (Device Layer)
The physical layer, often referred to as the device layer, is the foundational layer in an IoT architecture. The device layer, is the foundation of the architecture and comprises various physical devices and sensors that interact with the environment to gather data. This layer includes temperature and humidity sensors, soil moisture sensors, and light intensity sensors, all of which provide real-time data crucial for maintaining optimal growing conditions. For instance, temperature sensors like the DHT11 can continuously monitor temperature levels, while soil moisture sensors detect moisture levels in the soil, enabling timely irrigation decisions.

From [11], we get to know that there was developed an IoT-based greenhouse monitoring system utilizing sensors like DHT11 and soil moisture sensors to gather real-time data from greenhouse setup, devices continuously collect environmental data, which is essential for maintaining optimal conditions for plant growth. This data-driven approach significantly reduces the need for manual checks, ensuring that any hazardous conditions are detected immediately.

2. Network Layer
The network layer is responsible for transmitting the data collected by the perception layer to processing systems. It ensures reliable communication, especially in remote greenhouse locations. This layer may utilize different communication protocols and technologies, such as Wi-Fi, ZigBee, or LoRa (Long Range), depending on the specific needs of the greenhouse. For example, LoRa is particularly effective for long-range communication in large agricultural fields, allowing continuous data transmission even in areas with limited connectivity.

The [13] highlighted the use of LoRa technology in their IoT-based greenhouse monitoring system, allowing effective communication even in remote locations .The coaction technology depends on factors such as range, power consumption, and environmental constraints. For example, Lora is particularly beneficial in large agricultural areas where traditional communication methods may fail.
3. Processing Layer (Middleware Layer)

The processing layer, often referred to as the middleware layer, analyses the data transmitted from the perception layer via the network layer. This layer aggregates, filters, and processes the collected data to derive meaningful insights. Processing can occur locally at the edge, reducing latency for immediate actions. This allows for predictive analytics, such as automatically triggering cooling systems when temperature sensors indicate a rise above optimal levels.

The [10] emphasized the importance of real-time data processing in greenhouse systems for enhancing climate control .Data processing can edge, close to the data source. Edge computing enables immediate processing of data, reducing latency.

4. Application Layer

The application layer serves as the interface between the IoT system and its users, presenting processed data in a user-friendly format. This layer connects to dashboards, mobile applications, and control centres that provide real-time information on environmental conditions and plant health. For instance, when a sensor detects high humidity levels, the application layer can send alerts to greenhouse managers through notifications, facilitating prompt action to prevent conditions that could harm crop growth.

The [7] developed a greenhouse monitoring system that integrates a mobile app for controlling environmental conditions remotely .When a sensor detects a signify conditions, alerts are sent to both the farmer and the control system, enabling prompt action. The application layer ensures that data is presented clearly, facilitating faster decision-making.

5. Business Layer

The Business layer (security layer) spans across all other layers of the IoT architecture, ensuring that the data transmitted by greenhouse sensors and other devices is protected from unauthorized access and tampering. In greenhouse monitoring systems, security is crucial because the data collected includes sensitive information about environmental conditions, crop health, and resource usage. Unauthorized access or a security breach could result in compromised system controls, leading to incorrect environmental adjustments, loss of crops, or disrupted operations, severely impacting greenhouse efficiency and productivity.

From [9] noted the implementation of encryption protocols to secure data transmission in their automated greenhouse system .Security measures such as access control and are crucial for maintaining the integrity of the data and ensuring the reliability of the system, especially in environments where unauthorized access could lead to significant safety risks.

V. EXISTING TECHNOLOGIES USED FOR MONITORING AND CONTROLLING IN GREENHOUSES

Greenhouse operations increasingly leverage advanced technologies to enhance safety and optimize environmental conditions for plant growth. The need for effective monitoring and management systems has driven the development of various technologies that monitor critical parameters such as temperature, humidity, soil moisture, and light intensity. Traditional greenhouse management practices have evolved significantly with the rise of technologies like the Internet of Things (IoT), artificial intelligence, and automation, leading to major improvements in operational efficiency and plant health. Today, many greenhouses employ a range of existing technologies to ensure real-time monitoring, improved communication, and automated responses to environmental changes.

Critical area of advancement is in automated irrigation systems. These systems use soil moisture sensors to determine when plants need watering, ensuring that water is delivered precisely when required. Traditional irrigation methods often led to over- or under-watering, negatively impacting plant health and resource use. Modern systems equipped with IoT capabilities can optimize irrigation schedules based on weather forecasts and soil conditions, reducing water waste and improving crop yields. For example, a greenhouse equipped with an IoT-based irrigation system can automatically adjust water delivery based on moisture levels, weather patterns, and plant requirements.

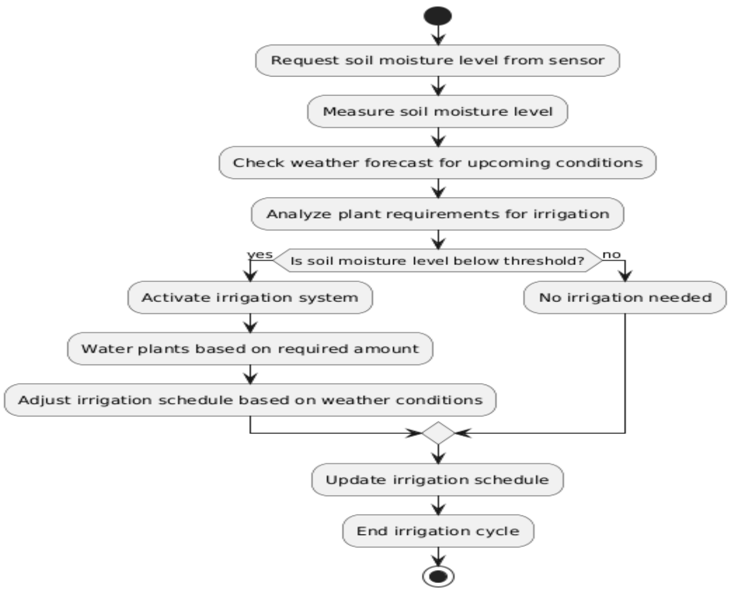

FIGURE 3 Automated Irrigation System

Automated climate control systems represent another significant technological advancement in greenhouse management. These systems utilize data from environmental sensors to control heating, cooling, and lighting, ensuring that plants thrive under optimal conditions. Traditional climate management relied on manual adjustments based on sporadic data collection, but automated systems continuously adjust conditions based on real-time data. For example, if a light sensor detects inadequate sunlight, the system can automatically activate artificial lighting to maintain optimal growth conditions.

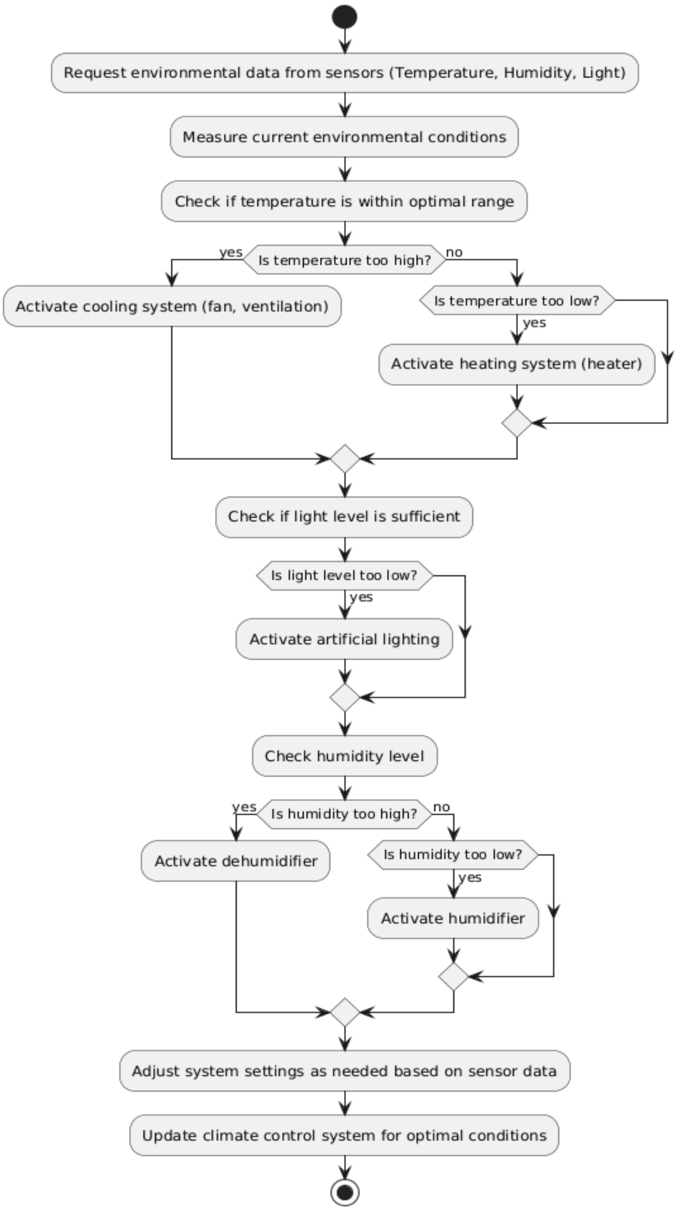

FIGURE 4 Automated Climate Control System

To further enhance decision-making, many greenhouse operations are implementing data analytics platforms powered by artificial intelligence. These platforms analyze data collected from sensors and provide insights into plant health and environmental conditions. By leveraging machine learning algorithms, greenhouse operators can identify patterns and predict potential issues, allowing them to take proactive measures. For example, AI-driven analytics can flag anomalies in temperature or humidity levels, prompting operators to investigate before conditions worsen.

Overall, the integration of advanced technologies into greenhouse management practices has significantly improved the ability to monitor environmental conditions and optimize plant growth. From environmental monitoring and automated irrigation systems However, despite these advancements, the agricultural industry continues to face challenges, and the adoption of even more sophisticated systems, such as IoT-enabled smart gear and data-driven decision-making tools, is critical to ensuring ongoing improvements in productivity and sustainability. As the industry evolves, so too will the technologies that support efficient and sustainable greenhouse operations.

VI. RESEARCH GAPS IN IOT FOR GREENHOUSE : AN IN-DEPTH ANALYSIS

The literature survey on IoT-based greenhouse monitoring and control systems reveals several critical gaps that hinder the broader application and effectiveness of these technologies in agricultural practices. Addressing these gaps is essential for optimizing plant growth, improving resource efficiency, and ensuring sustainability in agriculture.

1. Scalability Challenges

A prominent issue is the scalability of current IoT solutions, which are often designed for small-scale or experimental greenhouses with limited functionalities. These systems typically operate efficiently within controlled environments, but when applied to larger commercial farming operations, they face significant obstacles. For instance, the transition from small pilot projects to expansive agricultural enterprises can result in operational complexities, increased data volume, and challenges in sensor integration [1]. As agricultural demands grow and the need for precision farming intensifies, there is a pressing requirement for scalable solutions that can adapt to various farm sizes and types. Future research should focus on developing modular IoT systems that can be easily expanded or modified to meet the specific needs of diverse agricultural operations without compromising functionality or performance [2], [3].

2. Network Reliability and Connectivity Issues

Another critical gap pertains to network reliability and connectivity, particularly in rural or remote agricultural areas where internet access may be inconsistent or unavailable. Many IoT systems rely on stable internet connections for real-time monitoring and control, which can be impractical in these contexts [4]. The reliance on stable connectivity poses risks to timely interventions, potentially leading to adverse effects on crop yield and quality. To mitigate this issue, research into more robust communication technologies is necessary. This could include the development of decentralized communication networks that can function independently of traditional internet infrastructure, such as mesh networks, satellite communication, or long-range low-power wide-area networks (LPWAN) like LoRa [5], [6]. Additionally, exploring edge computing solutions could enable localized data processing, reducing the dependency on constant internet connectivity [7].

3. Integration of Advanced Technologies

The integration of advanced technologies, particularly artificial intelligence (AI) and machine learning (ML), remains insufficient in existing IoT systems. These technologies are pivotal for providing predictive analytics that can facilitate dynamic and proactive environmental control. However, many current systems lack the capability to harness AI/ML for analysing data patterns and predicting future conditions [8]. For example, machine learning algorithms could analyse historical data to optimize irrigation schedules or adjust climate controls based on forecasted weather conditions. Addressing this gap will require a concerted effort to develop AI-driven models specifically tailored for greenhouse environments. Research should focus on creating algorithms that can adapt to various crops, climates, and growth stages, thus enhancing decision-making processes [9], [10].

4. Security and Data Privacy Concerns

Security and data privacy concerns are paramount in the context of IoT-based greenhouse systems. As these systems often rely on cloud storage and remote access, they become vulnerable to cyber threats. The sensitivity of agricultural data—including proprietary information about crop management and operational metrics—raises significant risks associated with unauthorized access and data breaches [11]. To address this gap, it is essential to establish comprehensive security frameworks that incorporate encryption, secure access protocols, and regular security audits. Additionally, research into utilizing block chain technology could enhance data integrity by providing immutable records of transactions and changes in data, thereby ensuring that once data is collected, it cannot be altered without detection [12].

4. **Climate Considerations in Design**

Most existing systems fail to adequately consider the specific climate conditions of various geographic regions or the unique requirements of different crop types. Greenhouses located in different climates have diverse environmental needs, and systems designed without these considerations can lead to ineffective monitoring and management [13]. For example, a system optimized for a temperate climate may not perform effectively in arid or tropical regions, where different environmental factors come into play. In tropical climates, high humidity and temperature variations pose unique challenges that require specialized control mechanisms for effective plant growth. Similarly, in arid environments, water conservation becomes a critical factor, requiring a system that integrates efficient irrigation techniques and moisture monitoring. Future developments should prioritize the integration of a wider range of sensors tailored to specific crops and climatic conditions, ensuring that monitoring systems are adaptable and effective across diverse agricultural settings [14]. Additionally, climate-responsive algorithms and adaptive control strategies must be incorporated to adjust the system's functionality based on real-time environmental inputs, thus maximizing energy efficiency and minimizing resource waste.

5. **Sensor Reliability and Accuracy**

Sensor reliability and accuracy present significant concerns within IoT-based greenhouse monitoring systems. Several studies have indicated that while sensors are beneficial for real-time monitoring, they are often prone to inaccuracies or malfunctions when detecting precise environmental conditions. Factors such as calibration errors, environmental interferences, and sensor drift can result in false positives or delayed alerts [1]. For instance, an inaccurate temperature sensor might fail to trigger cooling systems in a timely manner, leading to heat stress on plants. Addressing these sensor-related issues is crucial for ensuring the effectiveness of monitoring systems and minimizing operational failures. Research should focus on improving sensor technology, including enhanced calibration techniques and advanced algorithms that can filter out noise and provide more accurate readings [6], [15].

7. Interoperability and Standardization

Another critical gap in the current landscape of IoT-based greenhouse monitoring systems is the lack of interoperability and standardization across different devices and platforms. Many existing systems operate in silos, which complicates integration and data sharing between various IoT devices and systems. This lack of standardization can lead to compatibility issues, making it challenging for farmers to implement comprehensive solutions that encompass multiple technologies [7]. Future research should aim to establish industry standards for IoT devices in agriculture, promoting interoperability and allowing for seamless integration across various platforms and systems.

8. Economic Viability and Accessibility

Finally, the economic viability and accessibility of IoT technologies in greenhouse management remain significant barriers to widespread adoption. Many advanced IoT solutions can be cost-prohibitive for small-scale farmers, limiting their ability to implement these technologies. Additionally, the complexity of some systems may deter farmers from adopting them due to perceived challenges in operation and maintenance [8]. Research into developing cost-effective, user-friendly solutions tailored to the needs of smallholder farmers is essential for promoting wider adoption of IoT technologies in greenhouse management. This could include exploring funding opportunities, subsidies, or cooperative models that enable collective investment in IoT infrastructure [9].

In summary, addressing these gaps is essential for advancing the application of IoT technologies in greenhouse monitoring. By focusing on scalability, enhancing connectivity, integrating advanced analytics, ensuring security, considering climate diversity, improving sensor accuracy, promoting interoperability, and enhancing economic viability, the agricultural sector can leverage IoT systems more effectively to optimize crop production and resource management.

VII. CONCLUSIONS

IoT-based greenhouse monitoring systems are revolutionizing agricultural practices by automating the control of environmental factors such as temperature, humidity, and soil moisture, leading to improved crop yields and resource efficiency. However, challenges like scalability, device interoperability, network reliability in remote areas, and the lack of advanced analytics integration remain. Overcoming these issues with more adaptive algorithms, enhanced communication technologies, and user-friendly interfaces will strengthen the overall effectiveness of IoT systems in agriculture. Addressing these research gaps will make IoT solutions more accessible, reliable, and adaptable, ensuring broader adoption and transforming modern farming practices.

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