Smart Greenhouse Automation: IoT-Driven Intelligent Irrigation System

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Abstract. Owing to the advent of Wireless Sensor Networks (WSN) in the agricultural sector, a new method to plant cultivation has become available. The same is true, especially in confined settings like greenhouses. Plants and vegetables produced in greenhouses benefit from the protection of their surroundings. However, various environmental conditions need to be checked and controlled, in order to make this happen. There are several smart applications that have automated the control, and maintenance of greenhouses in various aspects, using different trending technological concepts. The agricultural field lacks smart greenhouses that support advanced automated irrigation systems. Hence, the use of Internet of Things (IoT) based WSNs in the greenhouses to bridge the aforementioned gap is focused on through this research. This research covers the background analysis regarding greenhouses, the IoT-based wireless technology utilized for sensor connection, actuators with the methodology used to pick the period or speed at which data is sent, and finally a justification of used wireless network technologies. For effective WSN integration and management in greenhouses, the study also examines a number of alternative prediction models and decision-supporting approaches

Keywords: Smart Greenhouse, Wireless Sensor Networks, Internet of Things, Artificial Intelligence, ESP32

1 Introduction

A greenhouse is an agricultural invention that gives plants a habitat that is both regulated and controlled. The greenhouse acts as its own self- contained closed system, protecting the plants within from the external environment. It provides a climate that is conducive to agriculture that is shielded from the elements, which is of utmost significance in our age of rapidly shifting weather patterns. The usage of a greenhouse is thus an illustration of precision agriculture. The greenhouse effect is the fundamental driving force behind how greenhouses function. The walls and ceiling of the greenhouse are translucent, so sunlight may enter via such openings. Because of its closed construction, the greenhouse contains an excessive amount of heat that cannot escape. Greenhouses of today are outfitted with manmade systems that provide them with air, light, heat, and others. A contemporary greenhouse could be equipped with sprinklers, exhaust fans, or cellulose cooling pads. There is a possibility that it has a facility for AI.

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According to Zhang and wang [1], the heating and ventilation systems in a greenhouse utilize the vast majority of the available energy. WSN can assist in the management of this equipment and offer an atmosphere that is optimized for the growth of plants. In order to assure the future efficiency and production of food, nutrition, and food security, as well as to tackle concerns like COVID-19, new horticulture research technologies need to be deployed. Optimizing plant growth via scientific study in today's climate has been developed thanks to technological advancements in greenhouses. These strategies include modifying elements of the internal climatic growth environment, such as temperature, light, and humidity concentration, to achieve the desired results.

However, as mentioned earlier, a greenhouse is a specially constructed building for cultivating plants under optimal conditions. As a result, greenhouses make it feasible to grow plants in climates and during seasons when it would be difficult to do so without one. Compared to other agricultural businesses, greenhouses use a disproportionate amount of energy; as a result, decreasing the amount of energy consumed by greenhouses in the agricultural sector has been identified as an essential objective for the sustainable growth of the industrial sector [2]. Without the need for a human operator, an autonomous greenhouse system can monitor and regulate the greenhouse's environmental conditions using a variety of sensors and actuators. In order to combine sensing, controlling, decision-making, signal processing, and wireless communication into a single system, a new kind of technology known as a WSN has emerged. In this research, this technological concept is focused on when proposing the solution for the identified problem.

2 Literature Study

The background of this study is mainly focused on two aspects. While there are many research works that focus on these two aspects, some of the most significant works are considered for the background study.

2.1 Sensor Networks in Greenhouses

Many different types of businesses are beginning to see the benefits of using wireless sensor networks. Agriculture, and more specifically the monitoring of microclimates [3], offer numerous attractive targets that might be explored to make use of the advantages of WSN. As long as the wireless sensor nodes in the greenhouse are kept within communication range of the coordinator device, the grower in the greenhouse is able to effortlessly move the sensor nodes about the greenhouse.

The number of greenhouse facilities is continually growing and being increased further. The circumstances that prevail inside a greenhouse have an immediate and decisive impact on the development of plants. As a result, the monitoring and management of this kind of indoor environment in real-time is something that should be prioritized. Improving the control technology of a greenhouse environment with the use of environmental automated control technology is an efficient way to enhance control technology [4].

The incorporation of WSN into the automation system design of contemporary greenhouses may prove to be beneficial. A wireless sensor network is a network of several small sensors, or nodes, that work together to monitor and record conditions in one region. This information will then be sent by these nodes to a network hub, which will then send it on to a central computer in order to be analyzed and have relevant information extracted from it. Through the use of the network-monitoring platform, this system offers authorized people the ability to monitor a variety of real-time data in a simple manner [5]. The readings, which may include temperature, light levels, soil moisture, and humidity, may be gathered with the use of a wireless connection if available. Installing a wireless sensor network is quicker, less expensive, and simpler than installing a cabled system [6].

In addition, it is simple to move the measurement points to a new position if this becomes necessary; all that is required is to move the movement of sensor nodes within the range of the coordination device from one area to another. It's possible, for instance, to hang the small and lightweight nodes from the branches of the plants themselves if the greenhouse's vegetation is very tall and dense [4]. One of the main benefits of these WSNs is their scalability (additional nodes and sensors can be added to the network with little effort) and their reconfigurability (changes can be made to individual nodes within the network). This indicates that a greenhouse enterprise may get started with a more compact WSN system and then progressively work its way up to more expansive systems as the demand arises. Until the user reaches a level of comprehension and familiarity with the system, it is possible to install and use for monitoring a small WSN consisting of at least two or three nodes in addition to a base station [7].

In order to deal with the challenges presented by these scenarios, new technology solutions are necessary. Aside from this, there is a shortage of water, there has been a rise in fertilization, and there have been dynamic changes in the climate, all of which have made it more difficult to integrate technology to accomplish the needed productivity in agriculture with the smallest number of wasted resources. WSN is a notable technology, including those in the fields of the military, defense, healthcare, agriculture, and others. WSN is especially useful in the field of agriculture for reaching a state referred to as the term for this kind of farming "precision agriculture" (PA) [8]. The phenomena of monitoring (through sensors) and responding (via actuators) are the basis for PA's operation, and it aims to achieve the parametric values and circumstances necessary for the crop to realize its maximum potential in terms of both its health and its production.

Moreover, there exists a potential for WSN to engender a transformative impact akin to a green revolution in greenhouse agriculture. Nevertheless, there has been limited research conducted on the subject. The quantity of published articles on greenhouse research facilitated by WSN technology in WSN-driven agricultural research is notably limited. Over the past decade, interest in the application of WSNs in greenhouses has increased significantly; however, further advancements are necessary in this field. Only papers published prior to the composition of this paper are considered.

2.2 Smart Greenhouse concepts in the world

Smart greenhouse management typically employs one of three main control algorithms: timing, ON-OFF, or PID control. Numerous algorithms for greenhouse automation control have been developed recently. According to Jiang *et al.* [9], one trend in this area of research is the use of newly developed technologies in the production of plants in contemporary greenhouses that are both sustainable and environmentally friendly. Despite this, the greenhouse continues to be one of the most important aspects of contemporary agricultural practices. In this context, the method of management and control is regarded as the primary field of inquiry for maximizing production while simultaneously minimizing expenses and amounts of energy used.

Smart sensors are universally recognized as crucial IoT devices for smart grids, as shown by existing studies. The device that relays information to control systems on certain parameters and the material that is being monitored is called a smart sensor. Rough information is provided by smart sensors so that information and comprehensive analysis may be handled [10].

In today's world, advances in a variety of cutting-edge sensors are intertwined in a variety of domains. The primary goals are to enhance both the quality and dependability of the system, as well as to create the necessary technological preparations to accomplish the accuracy of unexpected scenarios. The IoT demonstrates the presence of electric power system components that are intelligently linked to data collected by sensors, actuators, and other hardware. In the future, IoT need to improve both the happiness of its customers and the efficiency of its businesses, as well as rapidly disseminate additional administrative aspects that provide new prospects. The adaptation of the structure to the changing of the seasons is another essential component of the IoT [11].

This monitoring system comprises sensors and actuators, and the monitored resources are essential components. The sensor is able to detect natural phenomena and compile information. The intelligent gadgets that manage the planet employ sensor detectors as an interface to communicate with the Earth. In addition, it is more difficult to establish embedded controls and carry out information investigations when dealing with autonomous heads [12]. The controls that were obtained make use of observation as well as the shari.ng of information. domains that were seen and information that was gathered. Following the segregation, monitoring, and eventual disclosure of the information. The inspection division creates environmental simulations and gathers information about the planet. This will assist in predicting the outcomes of future events. The use of Multiple places is viable for installing smart sensors for use in transmission and distribution monitoring systems. These intelligent sensors may then be installed in energy distribution infrastructure including transmission lines, substations, and distribution transformers [13].

3 Methodology

With the intention of addressing the aforementioned identified problem of lacking smart solutions to control various conditions in a greenhouse effect, a smart agricultural system that operates with the use of the IoT, WSN, and cloud computing is proposed. To be specific, this IoT-based unique wireless assistant is to use an ESP-32 microcontroller, temperature sensor, and moisture sensor, to sense important environmental factors, and assist farmers in planning an irrigation schedule for their farms through the use of an agriculture profile in their mobile application, that can be edited based on the requirements of various farms. Accordingly, this proposed solution works as an automatic irrigation system, and it is powered by solar panels.

These sensors provide continuous monitoring of the parameters and transfer that information to the ESP, which serves as an IoT gateway, for further processing. The wireless capabilities of this gateway have been enhanced by the installation of a Wi-Fi module. It will be accountable for the process of uploading real-time data to the cloud. Hence, the user is able to view the real-time readings of the sensors placed in the root system of the plants. Also, the mobile application would be sending a notification to the user, when the soil conditions are deviating from the given thresholds. Therefore, this wireless assistant also has the capability to allow the user to control the use of water to the plants, or control the actuators, out of the schedule with the data that would be uploaded to the cloud.

4 The Proposed System Architecture

The primary elements of the suggested system are as follows. The system consists of sensors (LM35 temperature sensor, soil moisture sensor, and humidity sensor) for real-time environmental monitoring, actuators (fan, motor, and water pump) for automated control, a microprocessor (ESP-32) for processing and decision-making, wireless connectivity components (Wi-Fi module and repeater) for uninterrupted communication, an OLED display for local status visualisation, and a mobile application for user interaction, remote monitoring, and control.

4.1 Sensors

The system employs several sensors to gather real-time environmental and soil data, enabling accurate monitoring and decision-making for irrigation.

LM35 Temperature Sensor
The LM35 temperature sensor is used to measure the soil temperature. It is an integrated information-processing sensor that provides an electrical output proportional to the temperature, expressed in degrees Celsius. The sensor plays a critical role in monitoring the soil's thermal conditions, which can influence plant growth and water evaporation rates.

Soil Moisture Sensor
This sensor measures the water content in the soil, providing vital information about the soil's moisture level. It helps the system determine how much stored water is available for the plants. By continuously monitoring the moisture levels, the system can activate or deactivate the water pump to maintain optimal soil hydration.

Humidity Sensor
The humidity sensor measures the relative humidity in the surrounding air. This data is crucial for understanding the environmental conditions, as high humidity levels can reduce the need for irrigation by slowing down evaporation. This sensor helps the system adjust irrigation based on both soil and environmental conditions.

4.2 Actuators

The actuators are responsible for carrying out actions based on sensor readings, including activating fans, pumps, and other system components to regulate environmental conditions and soil moisture levels.

Fan
The fan is activated based on the temperature levels of the surrounding environment. If the temperature exceeds a predefined threshold, the fan circulates air to cool the area, preventing

overheating of the plants. The fan operates automatically based on sensor inputs, ensuring the system reacts in real time to temperature changes.

Motor
The motor controls the speed of the fan. Depending on the temperature level detected by the temperature sensor, the motor adjusts the fan's speed to regulate airflow effectively. This adjustment ensures energy efficiency while maintaining the desired temperature in the growing area.

Water Pump
The water pump is responsible for activating and deactivating water circulation through the system. It is triggered when the soil moisture level drops below a set threshold, signaling the need for irrigation. The pump ensures that water is delivered efficiently, avoiding over-watering or under-watering.

Repeater
The repeater extends the Wi-Fi signal coverage in the system’s environment. This component ensures that the microprocessor and sensors remain connected to the cloud and mobile application, even in large or signal-deprived areas. It guarantees seamless communication between all connected devices.

OLED Display
The OLED display visually presents the system’s current status and soil data. It provides users with real-time feedback on the temperature, moisture levels, humidity, and system operations. The display serves as a local interface for users to monitor and manually control the system if needed.

4.3 Microprocessor

ESP-32
The ESP-32 microprocessor serves as the core of the system, processing inputs from the sensors and sending commands to the actuators. It is a powerful, low-cost, and energy-efficient microcontroller that supports both Wi-Fi and Bluetooth communication. The ESP-32 ensures seamless integration of all components and allows for remote monitoring and control through a mobile application.

4.4 Wireless Connectivity

Wi-Fi Module
The Wi-Fi module enables the system to connect to the internet, allowing for cloud-based analytics and remote control. The module provides wireless communication between the sensors, actuators, and the mobile application, facilitating real-time data exchange and system updates. The module also enables notifications when certain thresholds are exceeded.

4.5 Smart Application Features

The system integrates with a smart mobile application, which enhances user interaction with the system. The application allows for easy configuration, monitoring, and control of the irrigation process. Below are the key features of the mobile application:

Irrigation Scheduling
Users can create irrigation profiles through the app, specifying a start and end time for irrigation on a given day. The system can also be set to repeat these irrigation schedules on a daily, weekly, or monthly basis, ensuring that the plants receive water consistently and according to their needs.

Manual Water Pump Control
The mobile app allows users to manually activate or deactivate the water pump at any time. This feature provides flexibility, enabling users to adjust irrigation based on changing weather conditions or specific plant needs.

Soil Condition Monitoring
The app continuously displays real-time data on soil conditions, including moisture levels, temperature, and humidity. This feature enables users to monitor the system's performance and make adjustments as necessary.

Notifications
The system sends push notifications to the user when soil conditions deviate from the predefined threshold values. For instance, if the soil moisture drops below a certain level, the user will be notified to take action or the system will automatically activate irrigation. This ensures that plants always remain in optimal growing conditions.

The high-level architecture diagram of the proposed system that utilizes the above components is depicted in Fig. 1.

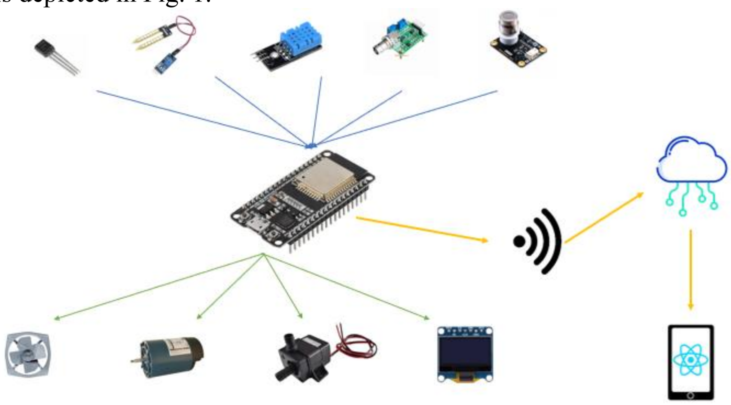

Fig. 1. High-Level system architecture

The system begins with various sensors integrated to monitor environmental and soil conditions. The temperature sensor measures the ambient temperature, the soil moisture sensor evaluates the water content in the soil, the humidity sensor tracks the air's relative humidity, the pH sensor assesses the acidity or alkalinity of the soil, and the CO2 sensor monitors gas levels in the environment. These sensors continuously collect real-time data, which is sent to the ESP32 microcontroller for processing. This ensures the system has accurate and up-to-date information about the environment.

At the core of the system, the ESP32 microcontroller processes the data received from the sensors and makes decisions based on predefined conditions. For example, if the soil moisture is low, the ESP32 activates the water pump to irrigate the soil. Similarly, if the temperature exceeds a threshold, the ESP32 triggers the fan to regulate the environment. The ESP32 ensures efficient control by analyzing data and sending commands to actuators, automating the entire process without requiring manual intervention.

The system utilizes multiple actuators to perform actions based on the decisions made by the ESP32. The fan regulates air circulation to control temperature, the motor drives mechanisms like vents or sprinklers, and the water pump activates to provide irrigation when necessary. Additionally, an OLED display provides a local visual interface, showing real-time data such as temperature, humidity, and soil moisture levels. These actuators work in tandem to maintain optimal conditions for the monitored environment.

The ESP32 is equipped with a Wi-Fi module that enables wireless communication. This module transmits processed data to a cloud platform for further analysis and storage. The cloud serves as a centralized repository, allowing for advanced analytics and historical tracking. Data trends, such as soil moisture patterns or temperature variations, can be visualized and used for decision-making, making the system not only real-time but also predictive.

The cloud platform is connected to a mobile application, which acts as a user-friendly interface for remote monitoring and control. Through the app, users can view real-time sensor data, such as temperature and soil moisture, receive alerts when certain thresholds are exceeded, and manually control actuators like the water pump or fan. The app ensures the system is accessible from anywhere, providing users with the flexibility to manage the environment remotely and respond to critical conditions immediately.

5 The Proposed System Design

The core of the Smart Greenhouse Automation System, depicted in Figure 2, is the ESP32, which serves as both the IoT gateway and the controller for all onboard operations. The system is equipped with multiple sensors, including soil moisture, CO_2, pH, light intensity, and temperature sensors, which monitor environmental and root-zone conditions. These sensors collect analog data about the physical environment and convert it into digital form. The ESP32 module facilitates the real-time gathering of this data and processes it to activate various actuators such as motorized vents, foggers, nutrient dispensers, and an automated irrigation system. In addition to controlling the actuators, the ESP32 also transmits the collected data to a cloud platform using a Wi-Fi/LoRaWAN module, making the information accessible for remote monitoring and control via a mobile application. The system is powered sustainably through a solar panel, also shown in Figure 2, ensuring uninterrupted operation.

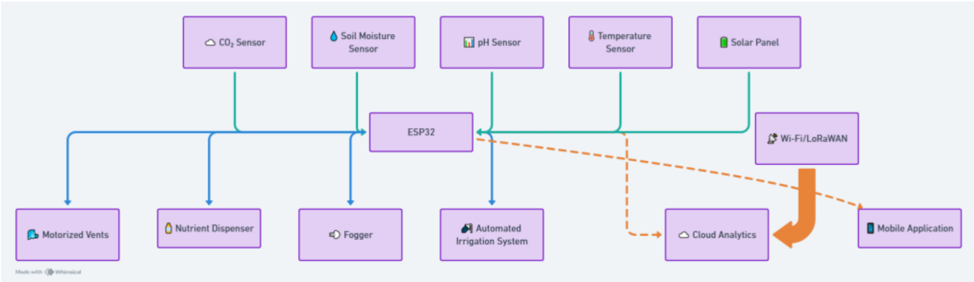

Fig. 2. System Block Diagram

The gateway is programmed with an algorithm that uses predefined threshold values for temperature and soil moisture to optimize water usage and notify users of any deviations in environmental conditions. When the data is sent to the cloud, the decision logic determines whether manual intervention, such as adjusting irrigation, is required. Furthermore, the ESP32 includes GSM functionality, which enhances communication capabilities and provides additional connectivity options. The workflow of the system demonstrates how the integration of sensors, actuators, and communication modules enables efficient automation. Additionally, the overall connectivity and relationships between components are depicted in Figure 3, illustrating the seamless interaction within the proposed system.

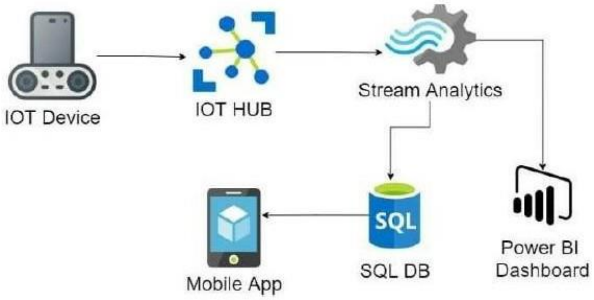

Fig. 3. Workflow of the proposed system

6 Discussion

WSNs are a type of technology that can be used in greenhouses to monitor environmental conditions and optimize crop production. WSNs consist of a large number of small, low-power, wireless sensor nodes that are distributed throughout the greenhouse and connected to a central control system. The sensors in the network can measure a variety of environmental parameters, such as temperature, humidity, light intensity, soil moisture, and carbon dioxide levels, and transmit the data wirelessly to the central control system.

There are several different types of wireless communication protocols that can be used in WSNs for greenhouse applications. Such as Zigbee, Bluetooth Low Energy (BLE), Wi-Fi, and LoRaWAN. Here in this study, Wi-Fi is used with the intention of achieving the below-mentioned advantages. High-speed data transfer: Wi-Fi networks can transmit data at high speeds, allowing real-time monitoring of greenhouse parameters such as temperature, humidity, and light intensity. This can help growers quickly identify and address any issues that arise in their greenhouse, leading to better crop yields [15].

Remote monitoring and control: By using a mobile application, growers can remotely monitor and control their greenhouse operations from anywhere, at any time. This can include adjusting the temperature or humidity levels, turning on or off irrigation systems, and receiving alerts if any parameters go out of range. Enhanced data visualization: Mobile applications can offer intuitive data visualization tools, such as graphs and charts, that allow growers to easily understand the sensor data being collected in their greenhouse. This can help growers make informed decisions about their operations, such as adjusting the lighting or irrigation systems.

Cloud storage and analysis: Wi-Fi networks can be used to transmit data to cloud storage, where it can be securely stored and analyzed. This allows growers to track greenhouse data over time and identify patterns or trends that can help improve their operations. Integration with other systems: Wi-Fi and mobile applications can be integrated with other systems, such as climate control or irrigation systems, to provide a comprehensive greenhouse automation solution [16].

Implementing a wireless sensor network in a greenhouse provides a set of advantages including optimizing crop production, reducing resource consumption, and improving environmental sustainability. However, it requires careful planning and execution to ensure that the network is reliable and provides accurate data. Implementing a wireless sensor network in a greenhouse involves several steps. The first step is to define the requirements of the wireless sensor network. This includes identifying the types of sensors needed to measure environmental parameters, such as temperature, humidity, light, and soil moisture, and determining the desired level of accuracy and precision. Once the requirements have been defined, the next step is to choose the hardware for the wireless sensor network. This includes selecting the type of sensors, wireless communication protocol, microcontroller or gateway, and power supply. The sensors should be installed at appropriate locations throughout the greenhouse, such as at different heights and in different zones, to ensure comprehensive coverage of environmental conditions. The next step is to configure the wireless sensor network. This includes setting up the wireless communication protocol, assigning unique IDs to each sensor node, and configuring the sampling interval and data transmission rate. After the wireless sensor network has been set up, it should be tested and validated to ensure that it is functioning properly. This includes checking the accuracy and precision of the sensors, verifying that the data is being transmitted correctly, and evaluating the performance of the network under different conditions. Finally, the wireless sensor network can be integrated with a control system to automate greenhouse operations, such as adjusting temperature, humidity, and light levels based on sensor readings.

7 Conclusion

In conclusion, the integration of smart wireless sensor networks with mobile Wi-Fi technology has shown great potential in enhancing greenhouse management systems. This research has demonstrated that such a system can effectively monitor and control environmental factors in greenhouses, such as temperature, humidity, and soil moisture, leading to increased plant growth and yield while minimizing energy consumption and environmental impact. The use of wireless sensors and mobile Wi-Fi technology allows for real-time data monitoring and analysis, enabling farmers to make informed decisions and take timely actions to improve crop production. Further, the proposed solution comes up with a set of actuators to respond to the changes accordingly. The microprocessor acts as the brain of the system and the Wi-Fi protocol ensures reliable communication with the help of a mobile app. As such, this technology holds promise for the future of sustainable agriculture, where efficient and eco-friendly farming practices are crucial for meeting the growing demand for food while minimizing the ecological footprint of agricultural activities

8 Future Work

There are potential directions for further studies. One area of interest could be the development of more sophisticated algorithms and data analytics techniques that can leverage the vast amounts of data generated by these systems to optimize plant growth and resource utilization. This could involve the use of machine learning and artificial intelligence techniques to develop predictive models that can forecast plant growth and resource requirements, allowing farmers to make more informed decisions about when to plant, harvest, and fertilize crops. Another area of future research could be the integration of wireless sensor networks with other emerging technologies, such as robotics and automation, to create fully autonomous greenhouse management systems. This could involve the development of intelligent robots that can perform tasks such as pruning, harvesting, and plant maintenance, using real- time data from wireless sensors to guide their actions. Such systems could greatly reduce the labor requirements and costs associated with greenhouse management while improving crop yields and quality. Finally, there is also potential for research on the environmental and economic impacts of wireless sensor networks with mobile Wi-Fi for greenhouses. This could involve the development of life cycle assessment methodologies to evaluate the overall sustainability of these systems, including their energy and resource requirements, greenhouse gas emissions, and economic viability. Such studies could help to inform policy decisions and industry practices related to sustainable agriculture and greenhouse management.

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