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Artificial Intelligent Enabled IoT-Based Autonomous Greenhouse Climate Control System

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ABSTRACT: Climate change has already proven its terrible effect on agriculture, resulting in reduced crop yields, loss of production and further decline in agricultural income. Catastrophic weather, disease and pests adversely affect agricultural production and cause huge economic losses annually. Unfortunately, traditional treatments incur additional cost for growers and are largely ineffective. Addressing the critical global need to combat agricultural scarcity, this research focuses on addressing global challenges in food production caused by population growth, climate change and urbanization. Automation of greenhouse environment using simple timer-based actuators or by means of conventional control algorithms that require feedbacks from offline sensors for switching devices are not efficient solutions in large-scale modern greenhouses. Wireless instruments that are integrated with artificial intelligence (AI) algorithms and knowledge-based decision support systems have attracted growers' attention due to their implementation flexibility, contribution to energy reduction and yield predictability. Sustainable production of fruits and vegetables under greenhouse environments with reduced energy inputs entails proper integration of the existing climate control systems with IoT automation in order to incorporate real-time data transfer from multiple sensors into AI-algorithms and crop growth models using cloud-based streaming systems. This research provides a full automation workflow in greenhouse environments by means of distributed wireless nodes that will be designed based on the powerful dual-core 32-bit microcontroller with LoRa modulation. The IoT hardware and software will be provided to show connection stability, robustness and reliability. The presented set-up allows deployment of AI on embedded hardware units such as CPUs and GPUs or on cloud-based streaming systems that collect precise measurements from multiple sensors in different locations inside greenhouse environments.

KEYWORDS: Greenhouse environment, Artificial Intelligence (AI), IoT Automation, Sensor-network.

I. INTRODUCTION

Control and automation of microclimate and fertigation inside greenhouses have contributed to improving the sustainability of closed-field environment agriculture by reducing water, fertilizer and energy demand, while at the same time increasing yield and profit (Shamshiri et al., 2018). The trend of environmental monitoring in modern farming is towards shifting from offline systems to wireless and cloud-based data collection architecture (Shamshiri et al., 2020). Advances in sensing technology have made possible the best quality of greenhouse production with the capability of yield prediction. Digital technology such as the Internet-of-Things (IoT) offers parallel solutions for automation engineers, which can be customized specifically for greenhouse applications. Wireless sensors and IoT enabled devices are used for real-time monitoring and control of the greenhouse environment through a secure internet connections on any mobile devices (Rezvani et al., 2020). With multiple sensors that transmit data to a central computer installed with knowledge-based automation software, growers can monitor all internal and external data and apply

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any required changes to the environment in real-time. For example, a fertigation control system that monitors certain aspects of the irrigation, such as flow rate, electrical conductivity (EC) and pH of the fertigation solution, as well as the external variables such as solar radiation and external climate conditions can take advantage of the collected data and incorporate them into models or artificial intelligence algorithms in a way that particular control commands, such as triggering specific pumps or switching other processes, are sent to alter the greenhouse environment. In this research work, the flexibility of the monitoring system and the knowledge behind the control algorithms are the key factors for an effective automation system.

II. PROBLEM STATEMENTS

In the context of the general economic crisis, Nigerian agricultural sector has suffered a significant blow in terms of reduced demand for products and limited necessary resources (water, soil and energy) for its development. At the same time, it suffers strongly from the consequences of market instability, as well as the effects of climate change, which exacerbates the frequency and severity of extreme weather events, resulting in reduced crop yields, loss production and a further decline in agricultural income. Conventional greenhouse monitoring techniques frequently fail to deliver the comprehensive and real-time data required for accurate decision making. This research proposes precision agriculture, which involves the integration of the Internet of Things (IoT) and Artificial Intelligence (AI) to develop a capacity for independently predicting and controlling devices, to maximize crop yields and reducing the negative effects on the environment while increasing farming’s cost-effectiveness, sustainability and efficiency in the aim.

III. RELATED WORKS

Gordillo et al., (2023) designed smart agricultural robot that can identify the greenhouse's environmental conditions. Since crops, vegetables, fruits, and pest infestation are all impacted by climate change, agricultural output is a top priority for most nations. Professional farmers therefore have the problem of attaining optimum production outcomes and they view greenhouse as a very good choice to ensure these results. In this situation, the use of sensors is essential for gathering information and data that will aid in the farmer's decision making. This research provides a fully autonomous robot that travels through greenhouse agricultural paths with pre-planned routes and can gather environmental data from a wireless network of sensors in situations when the farmer lacks prior crop knowledge. This robot is a viable alternative for small farms.

Chakraborty et al., (2022) worked on Precision farming technology using an IoT-based greenhouse environment monitoring system and smart watering system. The production of food for agriculture in recent decades has been drastically impacted by a number of crucial factors, including soil erosion, population explosions, water shortages, lack of cultivated land and changes in the climate like global warming. The farming sector may become more productive and of higher quality by implementing IoT and new technology. This study suggests an intelligent use of IoT to provide irrigation and environmental monitoring systems in order to address the present agricultural predicament. The system allows for both on-site and remote (IoT) monitoring of a greenhouse's humidity, soil moisture, temperature and light intensity. For effective water delivery, an intelligent system for irrigation has also been included. The BLYNK program is used for real-time data monitoring and IoT connectivity. In the event that an issue arises with the smart irrigation system, the IoT system also offers direct control over the water pump.

Mellit et al., (2021) worked on creation of a cutting-edge deep convolutional neuron network and internet of things-based remote monitoring solution for smart greenhouses. The prototype enables the greenhouse to be equipped with a suitable artificial environment, including water supply, ventilation, intensity of light and CO2 concentration. With the use of suitable sensors and an inexpensive Wi-Fi module (NodeMCU V3), the regulated parameters (air temperature, humidity level, capacitive soil wetness, brightness of light and CO2 level) were measured as well as uploaded to a planned webpage thanks to the internet of things approach. Photographs of the plants were taken using a cheap camera and sent to a webpage for the purpose of classifying and maybe identifying illnesses. In this instance, a Raspberry Pi 4 was equipped with a deep-learning convolutional neural network that A small-scale businesses photovoltaic system was constructed in order to power the prototype. The outcomes of the trial proved the prototype's viability and revealed its capacity to remotely monitor and manage the greenhouse in addition to determining the condition of the plants. Farmers can receive real-time remote sensing and measurement services from the smart prototype that has been created.

Fernando et al., (2020) developed AI powered robotically monitored greenhouse agricultural assistance system. Since greenhouses allow farmers to grow plants under regulated climatic conditions and maximize productivity, they play a significant role in modern agriculture. Since greenhouses are typically constructed in regions with subpar climates for plant development, productivity must be increased using artificial setups. Climate factors must be monitored and controlled in order to automate a greenhouse's operations. The ultimate goal of this investigation is to create an automated system that can perfectly regulate and track the environmental variables inside a greenhouse. This will be achieved by using a mobile robot that is connected to the cloud to monitor temperature, humidity, soil moisture and pH and by using the processing of images and machine learning to identify unhealthy plants. To store acquired real-time data, a database server was developed.

Malende et al., (2017), used Internet of Things to construct a smart agriculture system. A unique Internet of Things (IoT)-based wireless mobile robot was created and put into use to carry out a variety of tasks in the field. This suggested wireless robot has a number of sensors installed to measure various aspects of its surroundings. Hardware for the Raspberry Pi 2 version B is also included to carry out the entire procedure. This innovative intelligent wireless robot's primary capabilities include its ability to sense wetness, frighten birds and animals, spray pesticides, move forward or backward and turn on and off an electric motor. A wireless camera was installed on the robot to provide real-time activity monitoring. After testing the suggested wireless mobile robot in the field and monitoring its readings, good results were seen. These findings suggested that; the system has a great deal of potential for application in smart agricultural systems.

IV. MATERIALS AND METHODS

The design involves both hardware and software. The hardware was implemented using modular design method while the software developed using embedded C language.

Step I: Initially, a proposal to design and implement an automatic irrigation system AI-based and IoT was done.

Step II: The work was designed using the microcontroller (FLC). A storage tank was connected to it, to store water that can be drawn whenever the moisture level in the soil drops. It also consists of three LEDs which worked as indicators to indicate the level of water stored in the storage. Whenever the water would reach a low level in the storage, it would instruct the microcontroller to turn on the pump to draw water until it reaches a high level and all three LEDs glow.

Step III: Later, the project was developed and made more specific by cascading three different parts to it-

- A Solar tracker system
- An Automatic Pump controller
- An Automatic Irrigation system

Step IV: The Solar Tracker captures energy from sun and converts it into electricity which will turn the automatic pump control system ON, especially during the day.

Step V: The Automatic Pump controller ensured that, there was always water in the storage and consists of an indicator and a detector.

Step VI: In the Automatic Irrigation System, input was taken from the moisture sensor as to whether the soil moisture was less than the pre-defined standard. This information fed to the microcontroller, which decides whether to turn ON, the solenoid valve or not to water the field depending on whether the moisture level in the soil is below the required level. The moisture level was displayed on the LCD display.

Step VII: Proper communication was ensured between every component parts, minimize the cost of the whole system and to make the whole system user friendly. This research work was developed for users to control the amount of water to a plant. If used commercially, this research work would be beneficial to individuals as well to the economy as a whole.

I. The AI Enabled-Based IoT greenhouse System

The system consists of local station and a central station, where the local station is used to measure the environmental parameters and to control the operation of controlled actuators such as fans, heaters and water pump to maintain climate parameters at pre-defined set-points for the temperature, humidity and light intensity. The central station is used to monitor the environmental parameters. Therefore, a suitable selection for the sensors and their compensation circuit can be achieved. Mechanical and electronic solutions such as ventilation, irrigation and heating systems will be connected to the greenhouse.

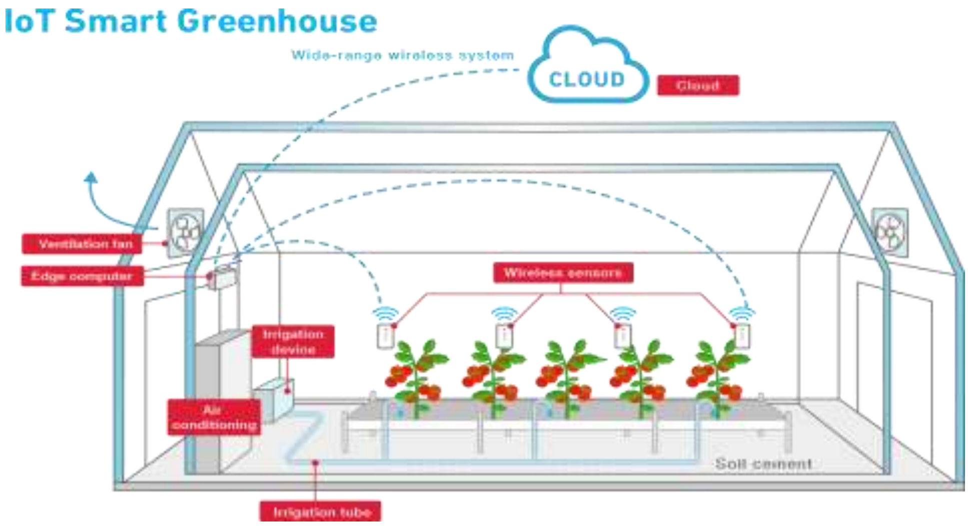

Fig. 1: The AI-Enabled IoT-Based Smart Greenhouse structure

Multiple wireless sensors were set up within the Smart Greenhouse. Temperature, humidity, lighting intensity, and carbon dioxide levels was measured through electronic and environmental sensors and data collected were exported to an edge computer. Furthermore, this data was also stored in Cloud. However, in a Smart Greenhouse, a single computer can control multiple equipment, minimizing the number of wiring and all data were automatically collected to the edge computer through a wirelessnetwork. There was no need to go back and forth to the greenhouse, since each setting for the cultivating environment to watering the crops are automatically controlled based on a predetermined formula.

II. Irrigation System

An irrigation is a significant factor influencing greenhouse production benefit. The application of micro-irrigation control in the greenhouse ensures water requirements of greenhouse crops, promote water utilization rate and efficiency, controls crop growth environment microclimate for water savings, increase in productivity and income as well as ecological environment benefits.

III. Types of irrigation

A. Surface irrigation (conventional irrigation)
B. Sprinkler irrigation
C. Drip irrigation

D. Micro-Sprinkler Irrigation System

As per the proposed layout, bed to bed spacing for tomato works out 1.2 m and hence there was three rows of tomato on each bed. There was 4 beds in the greenhouse. Soil at greenhouse site was of sandy loam type. So it was used micro sprinkler (41 lph) in the second greenhouse. One sprinkler was fed water to three plants as its spreading was 2 m on both sides and lateral was placed on middle line of bed. Sprinklers was fixed at every 1 m spacing on lateral.

Number of tomato plant / row = row length / spacing of plant in row = 20 / 0.45 ~ 45
Total number of plants in greenhouse = Number of rows x (plants/ row) = 45 x 12 = 540
Total water requirement (V) = 540 x 2.55 = 1377 litres / day
Numbers of drippers per laterals = Lateral length / sprinkler spacing = 20 / 1 = 20
Total number of drippers in greenhouse = Number of laterals x (sprinklers / Laterals) = 4 x 20 = 80
Capacity of irrigation system (Q) = Total number of sprinklers x sprinkler discharge
= 80 x 41
= 3280 ltr/hr.

Irrigation duration was calculated as:

$$It = \frac{Q}{V}$$

$$It = \frac{1377}{3280}$$

$$It = 0.42\ hrs\ (30, mins)$$

IV. Design of Lateral

For micro sprinkler system, not more than 20 per cent pressure variation and 10 per cent flow variation are desirable. As was used non-pressure compensating pressure, allowable head loss in sub-main and lateral was 20 per cent of operating head of dripper.

Head loss in lateral, sub-main, and main line was calculated by using Hazen Williams equation which is as follows:

$$H_f = 1.526 \times 10^4 \times \frac{Q^{1.852}}{C} \times (D)^{-4.873} \times (L) \times f$$

… (2)

Where:

H_f -Head loss, m

Q- Discharge, m^3 /m

C- Roughness factor for pipe

D- Inside diameter of pipe, cm

L -Pipe length, m

f - Outlet factor (depends on number of outlets)

For lateral pipe,

$$Q_l = \frac{L_l}{S_d} \times Q_d$$
$$Q_l = 20 \times 41$$
$$Q_l = 820\ lit/hr$$

Roughness coefficient, Cl = 140 (for LLDPE pipe). As there are 34 drippers on one lateral, outlet factor for lateral is 0.3. So, equivalent length for each dripper is 0.3 m.

$$E_{ol} = 0.3 \times 20$$
$$E_{ol} = 6m\ .$$
$$D = 1.5cm$$
$$D = 15mm$$

It was selected 16 mm lateral pipe.

Again using equation (2) for lateral of 16 mm,

H_{fl} = 1.5 m.

V. Design of Sub-main

There were four laterals on one sub-main. Sub-main is PVC pipe with roughness coefficient of 150.

Qs = 0.820 x 4 = 3.28 m3 /hr

H_{fas} = 0.5 m

Cs = 150

L_b = 6 + 0.37 x 6

= 8.22 m

f = 0.37.

Using equation 1 for sub-main design, required diameter of sub-main = 24.5 mm. It was quite impossible to drill holes on 15, 20, 25, 32 mm PVC pipe for lateral connections. It was selected 40 mm pipe of pressure rating 6 kg/cm^2 for sub-main. Using equation (2) for head loss through pipe of 40 mm (inside diameter 36.55 mm),

H_f = 0.5 m.

VI. Design of Mainline

Distance of water source from plot was assumed as 150 m. So mainline was of this much length. Mainline carried water for cooling system, irrigation and greenhouse operation which are as follows:

Cooling system = 37 ltr/min

= 2.2 m^3 /hr

Drip system = 3.28 m^3 /hr

Greenhouse Operation = 1

lps = 3.6 m^3 /hr

Total mainline flow,

Q_m = 9.00 m^3 /hr

Mainline is usually of larger size than sub-main considering future expansions, so 63 mm (inside diameter 59.35 mm) pipe was chosed. Outlet factor for mainline was 1. Using equation (2), head loss of main pipe:

$$H_f = 1.526 \times 10^4 \times \frac{(9.00)^{1.852}}{150} \times (5.935)^{-4.871} \times (150)$$
$$H_f = 2.2m$$
$$T_l = L_l + E_{ol}$$
$$T_l = 20 + 6$$
$$T_l = 26m$$

Operating pressure head for micro sprinkler was taken as 10 m (1.03 kg/cm^2).

Allowable head loss in lateral and sub-main = 2 m of this, keeping 1.5 m head loss in lateral and 0.5 m for sub-main.

Using equation (1) for lateral design

$$1.5 = 1.526 \times 10^4 \times \frac{0.820^{1.852}}{140} \times (D)^{-4.871} \times (26) \times 0.36$$

VII. Selection of Control Head Unit

Drip system capacity is 3.28 m^3 /hr, 3/4"(25 mm) plastic screen filter match this flow requirement. Considering good degree of filtration and future expansion, chosen 1"(32 mm) plastic disc filter for filtration.

Total Head Requirement Head against which pump will operate for required flow output is total head. It includes all head losses, static head and operating head of dripper.

$$H = H_{fl} + H_{fs} + H_{fm} + H_{fil} + H_{fer} + H_o + H_{ele} + H_w + H_{it}$$

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For our system,
$H_{fl} = 1.5m, \quad H_{fil} = 6m, H_{fs} = 0.5m, \quad H_{fer} = 4m, \; H_o = 10m, \; H_w = 10m \; (Assumed).$
Total head will be,
H = 1.5 + 0.5 + 2.2 +2+ 6 + 4 + 10 + 10
= 36.2 m
≈ 37 m

VIII. Selection of Pump

Required pump duty conditions are as follows.
Total flow = 9.00 m^3 /hr (2.5 ltr/sec)
Total head = 37 m

Horse-power of the motor is calculated as:

$$H.P = \frac{Q_m \times (LPS) \times H}{75 \times Epump \times Edrive \times Emotor}$$

$$H.P = \frac{2.5 \times 37}{75 \times 0.7 \times 0.8 \times 0.75}$$

$$H.P = 2.9 \text{ HP}$$

Pumps available in market close to our requirement are,
Single phase - 2 H.P. Three phase - 3 H.P. We will go for 3 H.P. pump set.

IX. Design and Irrigation Data of System

Crop Tomato Spacing 0.45 x 0.45 m
Area 120 m^2
No. of plants 540

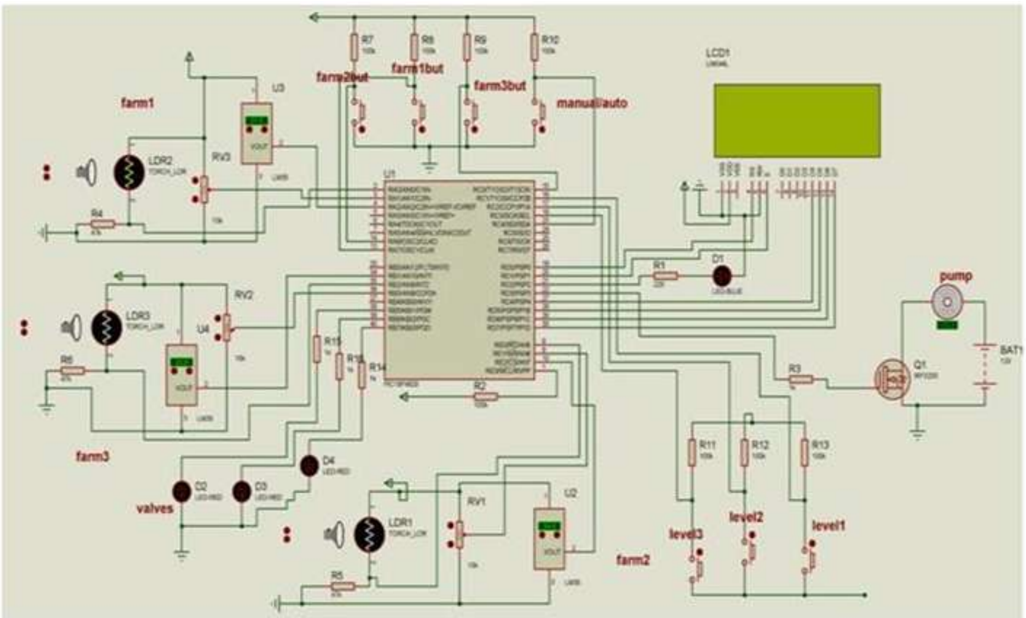
System Micro sprinkler Dripper discharge	41 lph
S/S spacing	1.00 m
L/L spacing	1.2 m
Maximum pan evaporation	15 mm/day
Peak water requirement	2.55 ltr/day/plant
Irrigation duration	0.42 hrs(30 mins)
No. of operations per cycle	1

Irrigation frequency on basis of tensiometer reading.

Total irrigation time	0.42 hrs (30 mins)
Flow per operation	3.28 m3 /hr
Total head	37 m
Pump unit	3 HP, three phase, monoblock
Laterals	16 mm / 2.5 kgf
Sub-main	40 mm / 6 kgf
Main	63 mm / 4 kgf

V. RESULTS

Figure 2 shows the circuit design of the whole system, which was developed and simulated using proteus (which is an IDE for developing, testing and simulating proposed circuit designs virtually) and based on this circuit design the smart irrigation system was built.



Figre 2: Circuit Design of the prototype Smart Irrigation system

All the components were put together as shown in the circuit diagram. Fig 2 shows the system control box consisting of the PIC-18F4620, capacitors and connection of the system. Each farm comprises of a soil moisture sensor, a light level sensor (LDR) and a temperature sensor. It also shows the LCD displaying the parameters being measured by the sensors situated in the farm. These sensors measure farm parameters and send it to the microcontroller for processing. The signals from the sensors are analogue and are converted to digital quantities using the microcontroller Analogue to Digital Converter ADC; after which values are derived from the sensor reading. These values are analyzed and used to decide whether to irrigate the farm or not.

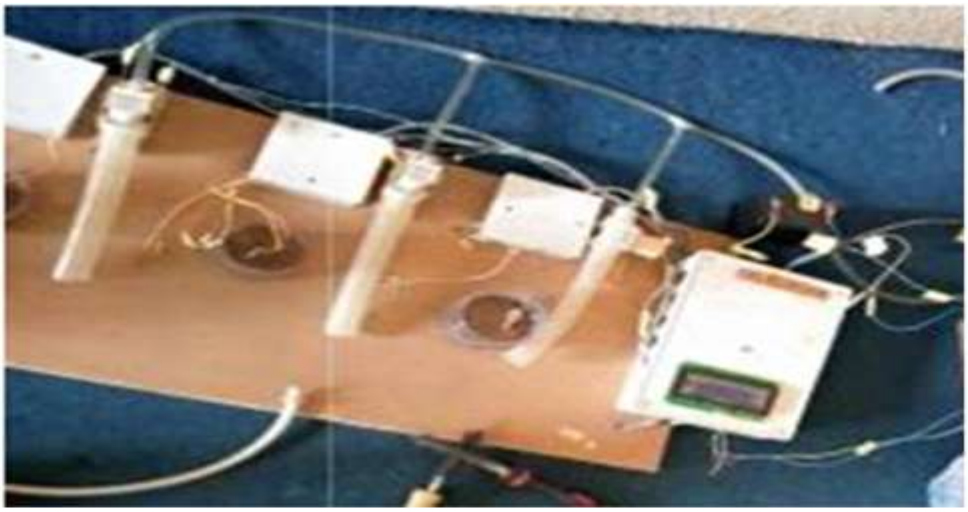


Figure 3: Developed irrigation system

The system can only work when the irrigation requirements are met which include that the soil moisture level must be below the required threshold and that the amount of insolation and temperature is within the acceptable range. So, if the parameters being measured by the soil moisture, light and temperature sensors meet this criteria, then the PIC micro-controllers will send a command to the relay of that specific valve linked to a farm to open the valve and a command is also sent to the relay of the pump to irrigate the farm that needs to be irrigated.

VI. CONCLUSION

This project work used Internet of Things technology to overcome major issues with traditional greenhouse farming practices. With this project, it was able to create a smart growing crops environment within a greenhouse environment that gather data in real time. Farmers may make well-informed decisions and maximize crop management techniques thanks to the accurate and effective data gathering provided by the integration of sensing for soil moisture, humidity, temperature, and light levels. Proactive intervention made possible by this real-time monitoring capabilities improves crop yields, the effectiveness of resources, and overall farm output. This technology has the ability to completely transform greenhouse farming methods by utilizing the Internet of Things (IoT) to make them more effective, sustainable, and robust to changing environmental constraints.

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