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IoT-Based Smart System for Monitoring and Automating Lemongrass Cultivation

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Internet of Things (IoT), Smart agriculture, Lemongrass cultivation, Soil moisture monitoring, NPK sensor, Automated irrigation

Abstract

This study presents the development and evaluation of an IoT-based smart monitoring and automation system for lemongrass cultivation aimed at improving irrigation and fertilization efficiency compared to conventional manual practices. The system integrates a capacitive soil moisture sensor, RS485 NPK sensor, ESP32 microcontroller, relay controlled water pumps, and cloud based data logging using Google Apps Script and Google Sheets for real time monitoring. Automated irrigation and fertilization are activated based on predefined soil moisture and NPK threshold values, operating in four daily cycles to optimize power consumption and resource usage. Experimental results demonstrate improved irrigation consistency, reduced manual labor, and more efficient water and nutrient management. The soil moisture sensor showed reliable performance in controlling irrigation, while the NPK sensor provided acceptable nutrient monitoring accuracy, although its readings were influenced by variations in soil electrical conductivity. The dual pump control strategy successfully prevented simultaneous operation, reducing nutrient dilution and water wastage. Overall, the proposed system offers a low cost, practical, and scalable IoT solution suitable for small scale farming, contributing to data driven precision agriculture and improved crop productivity.

1. Introduction

Lemongrass (Cymbopogon citratus) or commonly known as serai is an important high value crop grown for its essential oil that serves the pharmaceutical, cosmetic, and food industry [1]. The plant adapts well in tropical, subtropical conditions, thus exhibits temperature and drought tolerance. However, controlled soil moisture and nutrient supply in the form of NPK (nitrogen, phosphorus, potassium) [2] are required to achieve maximum development and yields.

Traditional methods of lemongrass farming are highly dependent on manual labor and manual observation. Farmers on the other hand tend to rely on experience rather than real time, this tends on scheduling and determining the optimal soil conditions. This usually leads to inefficient irrigation causing drought or waterlogging, while improper fertilizer application leads to runoff that is either nutrient deficient or excessively concentrated, due to the absence of plant specific nutrient management and the extensive time required for routine manual monitoring. These challenges are compounded because the plant-specific nutrient management is missing and routine manual checkups, especially in small-farms with less resources [3].

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The advent of Internet of Things (IoT) technology provides new prospects to tackle the above mentioned challenges with sensor based monitoring and automated systems. Smart agriculture solutions compliant to the internet of things (IoT) extract real time soil parameter measurements through environmental sensor and process with microcontroller, controlling irrigation and fertilization at different predetermined thresholds [4]. These systems have shown promise to reduce resource inefficiency, labour inputs and improvement in crop quality.

Moreover, there are some drawbacks in the current works on smart agriculture. Such systems as have been reported generally track soil moisture or nutrient content independently, and only a small number integrate both parameters. Also, there are several systems using complicated structure which necessitates plural communication modules and makes cost and installation inconvenient. Especially the knowledge on the agronomic demands of lemongrass is scarce and insufficient to predict its most suitable moisture and nutritional needs [5][6].

As such, the objective of this project is to design an affordable IoT solution for lemongrass cultivation which includes real time soil moisture and NPK monitoring and control with automated irrigation and fertilization undergirded by remote data logging, providing continuous constant feedback loop to small farmers enhancing cultivation efficiency.

2. Methodology

2.1 Materials

The implemented system using numerous basic electronic components. The major hardware components are summarized in Table 1.

Table 1: List of Major Component

Component	Specification	Quantity
ESP32 Microcontroller	Dual core processor with Wi-Fi	1
Soil Moisture Sensor	Capacitive type	1
NPK Sensor	RS485 output	1
MAX485 Module	RS485 to TTL converter	1
I2C LCD Display	20x4 character display	1
DC Water Pump	5V DC water pump	2
5V Relay Module	2-channel	2
Voltage Regulator	Step-down module	2
Li-Ion Battery	3.3V battery each	4
LED Indicators	White, Red, Green	3

The ESP32 serves as main control and managing Wi-Fi communication. Soil moisture content was measured with a capacitive soil moisture sensor and soil nutrient by RS485 NPK through MAX485. I2C LCD gave real time feedback, LED as indicator for Wi-Fi connection. Two DC pumps that were responsible for water and NPK fertilizer trigger control by relay modules, and a voltage step down regulator regulated 5V stable power from Li-ion batteries to ensure steady operation.

2.2 System Block Diagram

Figure 1 illustrates the hardware architecture of the IoT-based smart monitoring and automation system for lemongrass cultivation. The system comprised three main functional blocks: sensing, processing, and actuation.

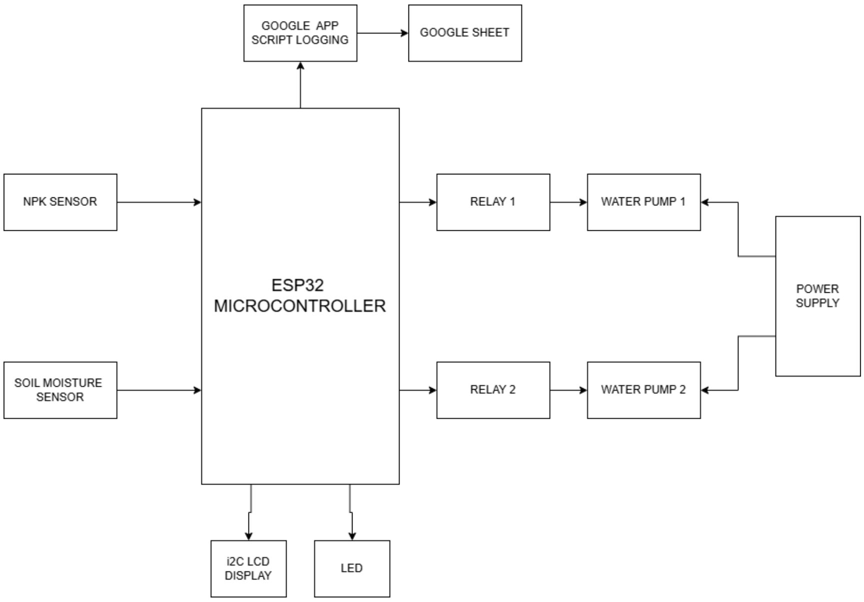

Fig. 1 *System Block Diagram*

The block diagram consisted of a soil moisture sensor and an RS485 connected NPK sensor connected to the MAX485 module for measuring soil water content and nutrient concentration. The ESP32 microcontroller was the processing unit that took in the sensor readings and compared them to set thresholds, performed control algorithms, as well as handling Wi-Fi half duplex communication for cloud updating. The sensor readings were averaged four times per day to minimize power usage but ensure the monitoring efficiency.

The actuation block comprised relays for controlling pumps for irrigation and fertilization, LED indicators, an LCD display, and buzzers to provide system feedback. Sensors below threshold limit actuated pump with provisions to inhibit concurrent operation. The system was cloud integrated via Firebase and Google Sheets to remotely monitor, while also logging data for performance analysis.

2.2 System Flowchart

Figure 2 presents the operational flowchart of the smart lemongrass cultivation system, detailing the sequential process from initialization through continuous monitoring and automated control.

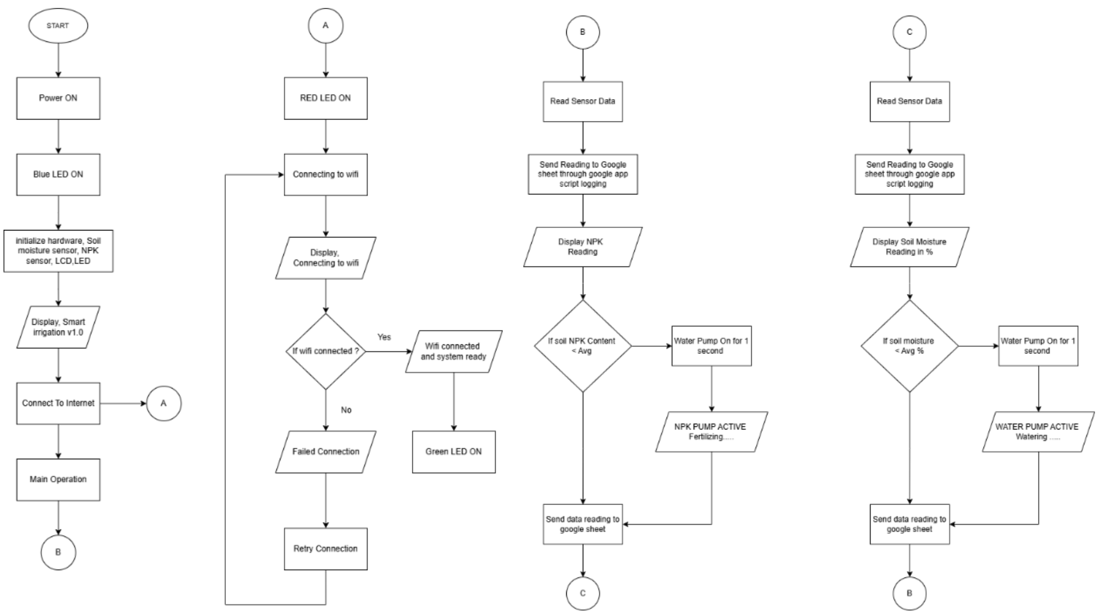

Fig. 2 *System Flowchart*

System initialization started by turning on all the hardware. The white LED represented the start, the red LED shows a Wi-Fi in connection status, while green led indicated a successful network setup and system ready. The procedure was repeated by the system, and soil moisture and NPK sensor data were collected and compared with threshold parameters.

If soil water content readings were below the lower threshold, the system showed a moisture alert and turned on the irrigation pump. If NPK values were outside the desired range, the pump fertilizer was turned on. Deliveries of fertilizer preceded irrigation to avoid dilution. A wait time after each activation cycle was provoked to avoid fast switching.

Sensor data and actuation events were sent to Google Sheets with the help of Google Apps Script for external logging. Each system functioned in a four-session wake protocol per day, going into low-power sleep mode in between to conserve power and extend longevity.

2.2 System Circuit Diagram

Figure 3 shows the detailed circuit schematic representing the IoT-based smart monitoring and automation system. The ESP32 microcontroller acted as the central controller, managing communication between all peripheral components through various interfaces.

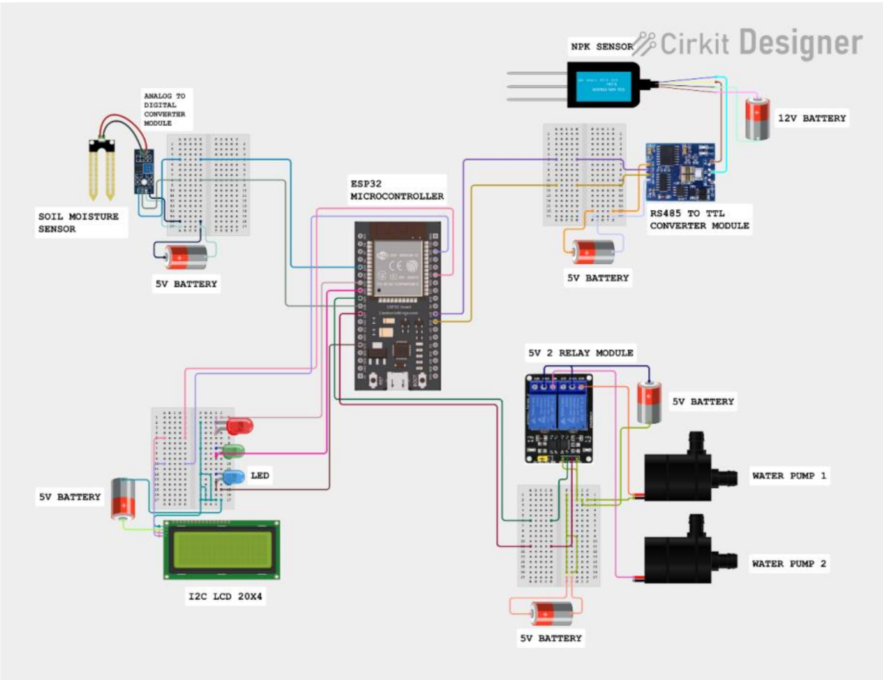

Fig. 3 *Circuit Diagram*

The soil moisture sensor was connected to GPIO34 for analog input and GPIO26 for digital threshold output. The NPK sensor communicated through the RS485 protocol using a MAX485 converter module, with RX connected to GPIO16 and TX to GPIO17. The MAX485 module was powered by a dedicated 12V supply to ensure stable long-range data transmission. The I2C LCD display was interfaced using GPIO21 (SDA) and GPIO22 (SCL) to present real-time sensor readings and system status. Three LED indicators were connected to GPIO13 (power), GPIO33 (Wi-Fi status), and GPIO32 (system ready) to provide visual feedback of operating conditions.

Two relay modules were used to control the irrigation and fertilization pumps, with Relay 1 connected to GPIO25 and Relay 2 connected to GPIO27. The pumps were supplied through separate regulated 5V rails to prevent electrical noise, and voltage drops from affecting the ESP32 and sensor modules. Power regulation was implemented using multiple 5V step-down converters derived from a 14.8V Li-Ion battery pack, supplying independent rails for logic circuits, interface modules, and pump loads. A passive buzzer was included for system alerts, and all components shared a common ground reference to maintain signal stability.

3. Result and Discussion

3.1 Sensor Based Monitoring and Threshold Triggering

The system utilized a dual sensor monitoring approach combining soil moisture and NPK nutrient concentration measurements. Each sensor continuously read environmental parameters and transmitted data to the ESP32 microcontroller for real time threshold comparison. The soil moisture sensor detected volumetric water content and provided both analog readings for precise percentage values and digital output for quick threshold detection. When soil moisture fell below the predefined threshold of 30-40%, the system immediately flagged the dry condition and prepared irrigation activation.

The NPK sensor measured nitrogen, phosphorus, and potassium concentrations in mg/kg through RS485 communication protocol via the MAX485 converter module. Testing demonstrated that the sensor effectively tracked general nutrient trends, with nitrogen measurements showing better correlation to reference values compared to phosphorus and potassium, which exhibited greater variability due to soil conductivity dependencies.

Table 2: Threshold Value for Parameter

Parameter	Threshold Value Low	Unit
Nitrogen	50	Mg/Kg
Phosphorus	10	Mg/Kg
Potassium	80	Mg/Kg
Soil Moisture	40	Percentage %

Table 2 above shows an implementation of the threshold value where incoming sensor readings were compared constantly against several lowest thresholds stored separately in memory. The control logic had trust checks to avoid false positives. This method dramatically reduced resource waste due to mistaken sensor spikes and retained responsive automation when actual dry or nutrient deficient conditions were encountered.

When threshold breaches were sensed, the system showed status messages on its LCD screen ("moisture low" or "NPK low"), activated corresponding LEDs, and turned on the target water pump via relays. The dual-layer validation (both sensors had to indicate suboptimal conditions) improved system reliability and avoided cycles of pumping that can consume water, while overdosing crops.

3.2 Soil Moisture Sensor Accuracy Testing

Accuracy testing compared soil moisture sensor readings against a commercial moisture testing kit across the full operational range from 0% (completely dry) to 100% (saturated). Table 3 and Figure 4 present the comparative data from ten measurement points.

Table 3: Moisture Testing Kit vs Soil Moisture Sensor

Actual Moisture %	Moisture Testing Kit%	Soil Moisture Sensor%
0	0	0
25	24	30
50	51	48
75	73	64
100	100	95

The results showed good agreement at extreme moisture levels (0% and 100%), with an average deviation of 2.5%. However, larger deviations were observed at mid-range values, particularly at 25% and 75% moisture, indicating a nonlinear sensor response in this range.

Measurement variations were influenced by electrical noise from system components, uneven soil compaction around the sensor, differences in soil mineral content, and temperature fluctuations. Field tests indicated reading variations of up to ±5% due to electrical interference and ±2% due to ambient temperature changes.

Although mid-range accuracy was limited, the sensor was suitable for threshold-based irrigation control. It reliably detected dry soil conditions below 30–40% moisture and recorded no missed dry events during 30 days

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of field testing. Occasional false activations were minimal and were reduced through validation logic requiring sustained low readings before pump operation.

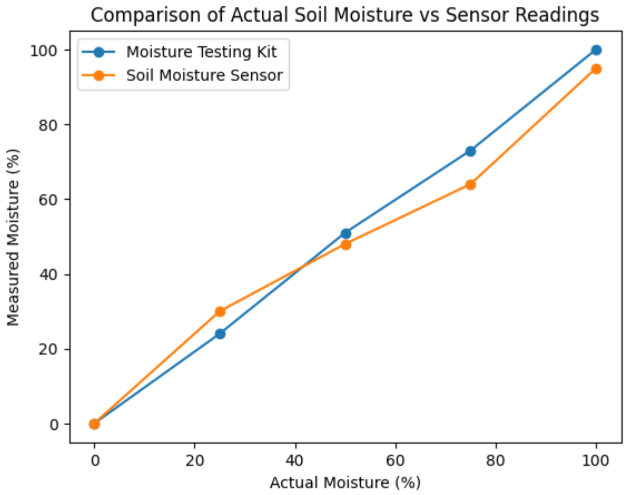

Fig. 4 *Soil Moisture vs Moisture Testing Kit*

3.3 NPK Sensor Accuracy Testing

NPK sensor performance was evaluated by comparing readings against chemical test kit results for nitrogen, phosphorus, and potassium across ten soil samples with varying nutrient concentrations. Table 4 consolidates the accuracy testing results for all three nutrients.

Table 4: NPK Testing Kit vs NPK Sensor Test

Test No	Nitrogen Kit (mg/kg)	Nitrogen Sensor (mg/kg)	Phosphorus Kit (mg/kg)	Phosphorus Sensor (mg/kg)	Potassium Kit (mg/kg)	Potassium Sensor (mg/kg)
1	10	0	120	5	20	0
2	200	168	240	1001	20	957
3	50	20	120	435	20	158
4	100	210	240	989	120	429
5	100	235	80	130	20	207
6	200	235	120	383	80	378
7	500	786	240	806	240	963
8	100	120	120	435	120	569
9	100	98	120	430	20	3
10	200	93	80	147	20	0

Nitrogen, phosphorus, and potassium measurements showed varying levels of accuracy when compared with the reference test kit. Nitrogen demonstrated the best overall performance, with several readings closely matching the reference values, although occasional large overestimations occurred. In contrast, phosphorus readings were generally much higher than the reference values, while potassium showed highly unstable behaviour, including both non detection and extreme overestimation. Overall, these results indicated that the sensor was more suitable for observing general nutrient trends than for precise quantitative measurement.

The comparative analysis revealed average measurement errors of approximately 67% for nitrogen, over 250% for phosphorus, and nearly 400% for potassium. These large deviations highlighted the limitations of the NPK sensor in providing accurate nutrient concentrations, particularly for phosphorus and potassium. While the sensor could distinguish between low and high nutrient conditions, the magnitude of error reduced its reliability for accurate fertilizer dosage determination.

The primary source of measurement inconsistency was the sensor's reliance on soil electrical conductivity, which is strongly affected by moisture content, soil composition, temperature, and ion mobility. Additional factors such as electrical noise from relay switching and pump operation, as well as localized probe contact with the soil, further influenced the readings. Despite these challenges, the sensor remained effective for threshold based fertilization control, allowing the system to detect nutrient deficiency trends and trigger corrective action, which aligned with the project's goal of improving efficiency in small scale agricultural applications.

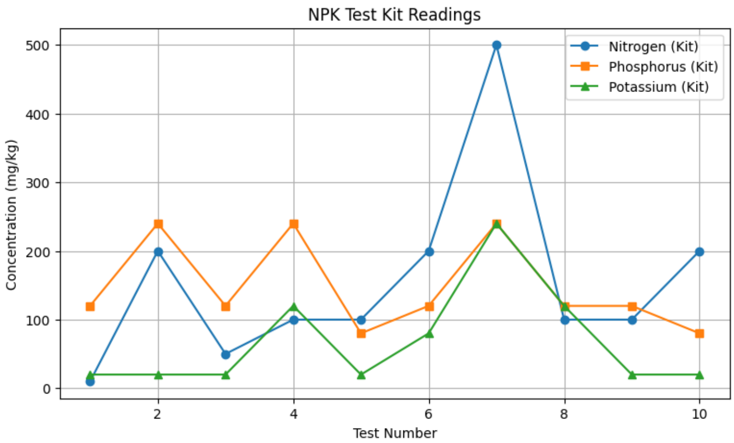

Fig. 5 *NPK Test Kit Graph*

Figure 5 illustrates the nitrogen, phosphorus, and potassium concentrations measured using the NPK test kit across ten soil samples. The horizontal axis represents the test number from 1 to 10, while the vertical axis shows nutrient concentration in milligrams per kilogram (mg/kg). Three distinct lines are plotted, each corresponding to nitrogen, phosphorus, and potassium respectively.

The nitrogen line exhibits considerable fluctuation throughout the tests. It begins with very low values, increases sharply in several samples, and reaches a prominent peak at Test 7, indicating a high nitrogen concentration in that soil sample. This is followed by a reduction in the later tests, demonstrating uneven nitrogen distribution across the soil.

Phosphorus values remain more consistent compared to nitrogen, showing moderate variation without extreme peaks or drops. Potassium readings stay relatively low for most samples, except for a noticeable increase at Test 7. Overall, this graph represents the reference nutrient profile of the soil samples and serves as the baseline for comparing sensor performance.

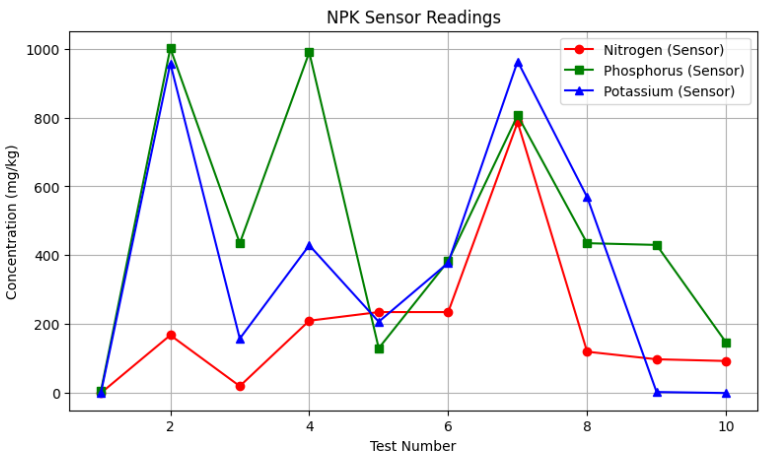

Fig. 6 *NPK Sensor Graph*

Figure 6 illustrates the nitrogen, phosphorus, and potassium concentrations obtained from the NPK sensor for the same ten soil tests. The x-axis indicates the test number, and the y-axis represents the measured nutrient concentration in mg/kg. Each line on the graph corresponds to one nutrient parameter measured by the sensor.

The phosphorus and potassium lines display significant fluctuations, with several sharp peaks occurring at Tests 2, 4, and 7, followed by sudden drops in subsequent tests. These abrupt changes differ greatly from the smoother reference pattern shown in the test kit graph. Nitrogen values vary less extremely but still show irregular behaviour. The overall instability of the lines highlights inconsistent sensor readings and visually demonstrates the deviation between the sensor measurements and the reference test kit values.

4. Conclusion

This project successfully developed and validated an IoT based smart monitoring and automation system for lemongrass cultivation. The system integrated soil moisture and NPK sensors with ESP32-based control logic to enable real time monitoring, automated irrigation and fertilization, cloud data logging, and user friendly local feedback through an LCD and LED indicators. Field testing confirmed reliable operation, achieving 100% data upload success and zero unintended pump activations, demonstrating robust hardware integration and control logic.

Performance evaluation showed that the soil moisture sensor provided sufficient accuracy for threshold-based irrigation despite minor variations caused by soil heterogeneity and electrical noise. The NPK sensor effectively captured nutrient trends, although its limited accuracy especially for phosphorus and potassium restricted its use to relative monitoring rather than precise nutrient quantification. The dual pump sequential control strategy successfully prevented over watering and nutrient dilution, while scheduled monitoring cycles ensured effective crop supervision with efficient power usage.

Overall, the system presents a practical and affordable IoT solution for small-scale and community farming, improving efficiency without requiring complex infrastructure or technical expertise. Cloud integration via Google Sheets enabled remote monitoring and long-term trend analysis, while the modular design provides a strong foundation for future enhancements such as improved sensor calibration, solar power integration, multi node expansion, and mobile application support. These advancements could further enhance accessibility, sustainability, and productivity in precision agriculture.

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