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Full Length Article

Smart Farming Robot for Detecting Environmental Conditions in a Greenhouse

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Abstract
Climate change poses significant challenges to agricultural productivity, necessitating the adoption of advanced technologies for sustainable crop production. Greenhouse cultivation provides a controlled environment that enhances crop growth while minimizing the impact of pests and adverse weather conditions. This paper presents the design and implementation of an autonomous greenhouse monitoring robot integrated with Industry 4.0 technologies, including the Internet of Things (IoT), wireless sensor networks (WSNs), and machine learning techniques. The robot autonomously navigates predefined routes within the greenhouse, collects real-time environmental parameters, and transmits data for analysis. An unsupervised clustering algorithm is employed to classify greenhouse regions into optimal, standard, and deficient zones, enabling efficient decision-making and resource management. A user-friendly monitoring interface is developed to assist farmers in visualizing crop conditions and planning operational routes. Furthermore, the robot is designed to operate effectively on uneven terrain through advanced motion control mechanisms, ensuring accurate navigation and stability. The proposed system improves greenhouse management, enhances crop productivity, and supports the sustainability and profitability of small- and medium-scale agricultural enterprises.

Keywords— *Autonomous Robot, Greenhouse Monitoring, Internet of Things (IoT), Wireless Sensor Networks (WSNs), Machine Learning, Industry 4.0, Precision Agriculture, Environmental Monitoring, Unsupervised Clustering, Smart Farming.*

Introduction

Agriculture is vital for society and global trade, but climate change and improper farming practices pose significant challenges, including reduced crop yields and degraded soil quality. Greenhouses, combined with advanced technologies like IoT, machine learning, and autonomous robots, can address these issues by providing controlled environments and optimizing crop management. This research proposes an autonomous robot equipped with sensors to navigate pre-planned routes in small-to-medium-scale greenhouses, collecting environmental data and clustering areas into optimal, standard, and deficient zones using the k-means algorithm. The robot uses a PID controller for movement on uneven terrain and operates without internet dependency, sending data to a central node via Lora WAN. The gathered insights are displayed on a GUI, enabling farmers to monitor conditions, plan routes, and make informed decisions for better productivity and sustainability. Moreover, this approach reduces dependence on traditional manual methods, minimizing human errors. It also facilitates improved resource management by ensuring targeted intervention in crop zones based on analyzed data. Ultimately, it empowers farmers to adapt to climate challenges and increase efficiency while maintaining environmental and economic sustainability.

Literature Review:

The reviewed literature emphasizes the significant advancements in agricultural robotics, IoT, and precision farming technologies. J. Pak (2022) evaluated autonomous mobile robot path-planning algorithms, demonstrating their effectiveness in enhancing navigation and operational efficiency in smart farms. Yang et al. (2022) addressed the challenges of harvesting delicate crops by modeling and force-analyzing a robot for button mushrooms. Soheyb et al. (2021) explored Agriculture 4.0, highlighting the integration of IoT and robotics to optimize farming environments for improved crop management. Similarly, Garg et al. (2021) proposed a precision agriculture framework utilizing IoT and machine learning for resource optimization and enhanced decision-making. Kabir et al. (2020) introduced a cost-effective IoT-based indoor farming system with robot assistance and app-based control, catering to small-scale farming needs. Fathallah et al. (2020) emphasized energy- efficient smart farming through a novel IoT routing protocol tailored for agricultural applications. Singh et al. (2019) extended the application of IoT to environmental monitoring, using vehicle-mounted sensors to map greenhouse gas emissions. Durmus and Günes (2019) integrated mobile robotics and IoT to automate data collection from agricultural fields, enabling real-time monitoring and analytics. Zheng et al. (2019) contributed to precision agriculture by presenting "Crop Deep," a dataset leveraging deep learning for crop classification and detection, advancing computer vision applications in agriculture. Finally, FAO (2017) underscored the role of smart farming and IoT in ensuring sustainable agricultural practices and meeting future food demands. These studies collectively reflect the strides made in leveraging innovative technologies for efficient, sustainable agricultural systems.

Smart Farming Robot for Greenhouse Environmental Monitoring:

Agriculture is crucial to societal welfare and global economic exchange, but it faces significant challenges due to climate change, inefficient farming practices, and growing food demand. Greenhouses offer controlled environments for cultivation but require advanced technologies to manage uniform conditions effectively. The integration of IoT, machine learning, and autonomous robots has transformed agriculture, enabling efficient monitoring, resource optimization, and proactive decision-making. Autonomous robots, equipped with PID controllers, navigate harsh terrains while collecting environmental data, supported by localized machine learning algorithms for real-time insights. User-friendly graphical interfaces further empower farmers to plan routes and monitor conditions, bridging the gap between technology and agricultural expertise. This comprehensive approach addresses modern agricultural challenges, ensuring sustainability, enhanced productivity, and efficient crop management without reliance on cloud infrastructure.

Raspberry Pi in Estimation of Agriculture Parameters:

The Raspberry Pi Pico plays a critical role in enabling smart farming systems within greenhouses by integrating and managing various components efficiently. It acts as the central controller, interfacing with sensors such as the ultrasonic sensor, DHT11 sensor, and rain sensor to collect real-time environmental data, including proximity, humidity, and rainfall conditions. This data is processed locally using embedded programming in MicroPython or C, ensuring reliable and energy-efficient operations without relying on high- bandwidth connectivity, which is often unavailable in rural setups. The Pico also controls the driver circuit to operate the robot mechanism, ensuring precise movement across uneven terrain while collecting data. Additionally, it manages alarms to alert farmers of unfavorable conditions and facilitates interaction with a graphical user interface (GUI), where farmers can plan robot routes and monitor environmental parameters. Although the Pico lacks built-in communication capabilities, it can be paired with WiFi or GSM modules to transmit data wirelessly and send alerts during critical conditions. Its compact design and power efficiency make it an ideal choice for seamless integration and operation in smart farming systems, bridging the gap between technology and agricultural practices for enhanced productivity and sustainability.

Proposed System

The proposed system leverages cutting-edge technologies and a robust hardware-software framework to revolutionize greenhouse farming. A smart, mobile farming robot equipped with advanced sensors, including ultrasonic sensors, DHT11, soil moisture sensors, light intensity detectors, and CO_2 monitors, autonomously detects and monitors environmental conditions to support precision agriculture. Real-time data collection and processing are enabled by a microcontroller such as Arduino or ESP32, serving as the central control unit. The robot's autonomous navigation capabilities, supported by motor drivers and obstacle-detection sensors, allow seamless movement across crop rows.

The system integrates key components such as ultrasonic sensors, DHT11 sensors, a rain sensor, and Raspberry Pi Pico to collect real-time environmental data, including temperature, humidity, soil moisture, and rainfall, ensuring precise monitoring of greenhouse conditions. The robot mechanism, controlled via motor drivers and navigation sensors, autonomously moves through crop rows, detecting variations in climate and soil properties. An OLED display provides farmers with real-time feedback, while an alarm system alerts them to critical environmental fluctuations, facilitating prompt intervention. By utilizing sensory data fusion, the system recommends optimal adjustments for irrigation and ventilation, enhancing crop growth conditions and minimizing manual labor. This intelligent framework empowers farmers to make data-driven decisions, improve resource utilization, and maintain sustainable greenhouse operations through advanced automation and monitoring solutions.

Block Diagram

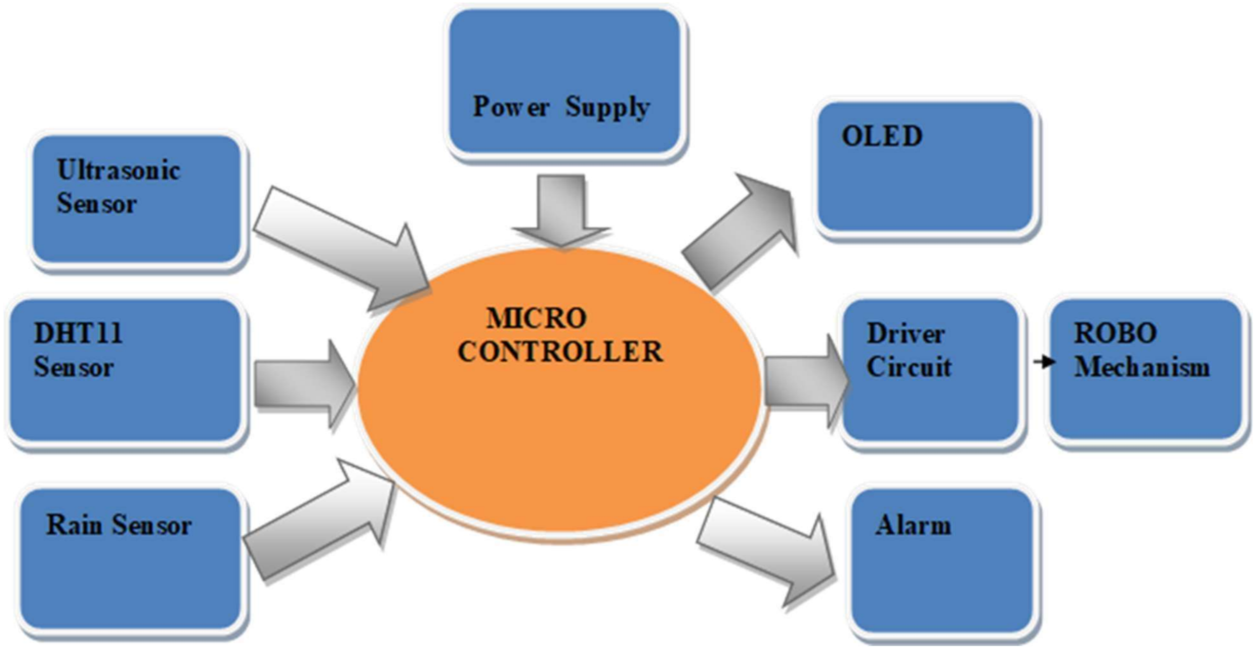

FIG 1; Block diagram of Smart Farming Robot for Detecting Environmental Conditions in A Greenhouse

Raspberry Pi Pico Microcontroller:

The Raspberry Pi Pico is a microcontroller board based on the Raspberry Pi RP2040 microcontroller chip. Like Raspberry Pi computers, Raspberry Pi Pico features a pin header with 40 connections, along with a new debug connection enabling you to analyze your programs directly from another computer (typically by connecting it directly to the GPIO pins on a Raspberry Pi). Raspberry Pi Pico is a brand new, low-cost, yet highly flexible development board designed around a custom-built RP2040 microcontroller chip designed by Raspberry Pi. Raspberry Pi Pico – 'Pico' for short – features a dual-core Cortex-M0+ processor (the most energy-efficient Arm processor available), 264kb of SRAM, 2MB of flash storage, USB 1.1 with device and host support, and a wide range of flexible I/O options.

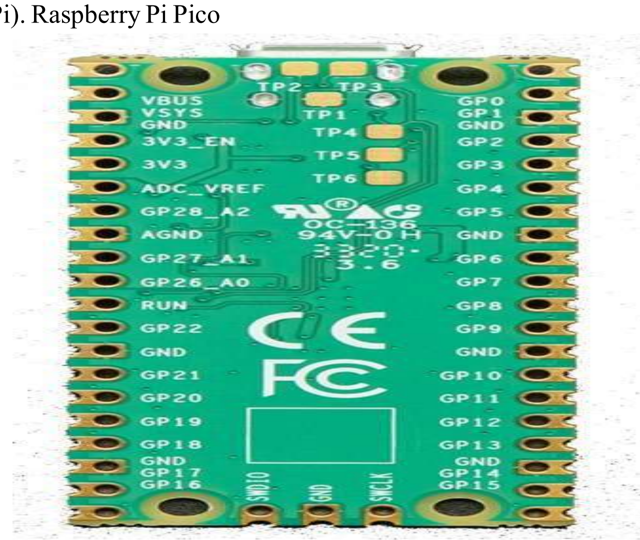

Fig 2: Raspberry Pi Pico

Raspberry Pi Pico Pin Description:

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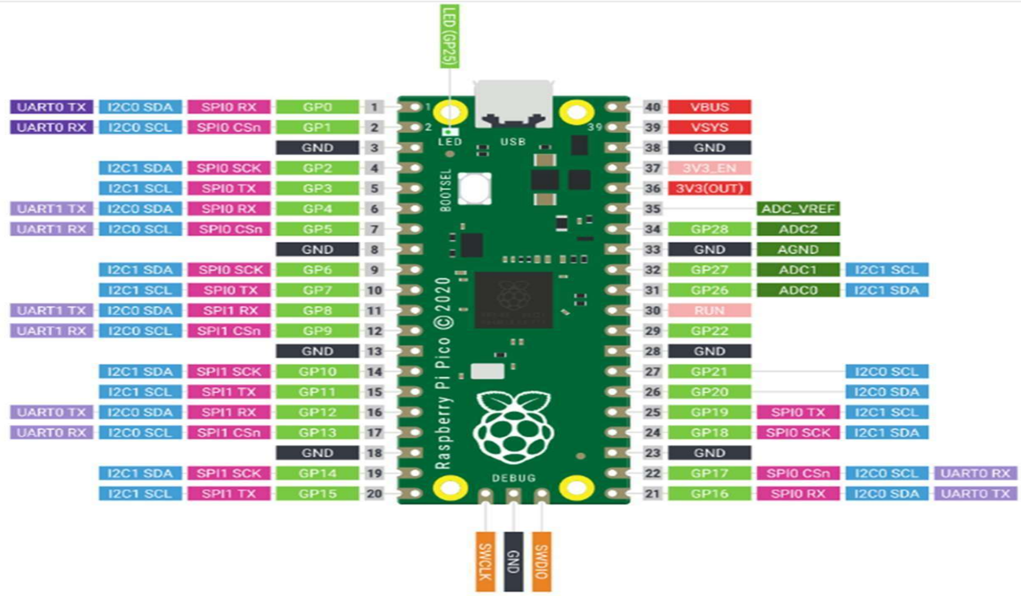

Fig-3; Raspberry Pi Pico Pinout

ULTRASONIC SENSOR

Ultrasonic sensors are industrial control devices that use sound waves above 20,000 Hz, beyond the range of human hearing, to measure and calculate distance from the sensor to a specified target object. Ultrasonic sensors use electrical energy and a ceramic transducer to emit and receive mechanical energy in the form of sound waves. Sound waves are essentially pressure waves that travel through solids, liquids and gases and can be used in industrial applications to measure distance or detect the presence or absence of targets Ultrasonic sensors (also known as transceivers when they both send and receive) work on a principle like radar or sonar which evaluate attributes of a target by interpreting the echoes from radio or sound waves respectively. Ultrasonic sensors generate high frequency sound waves and evaluate the echo which is received back by the sensor. Sensors calculate the time interval between sending the signal and receiving the echo to determine the distance to an object.

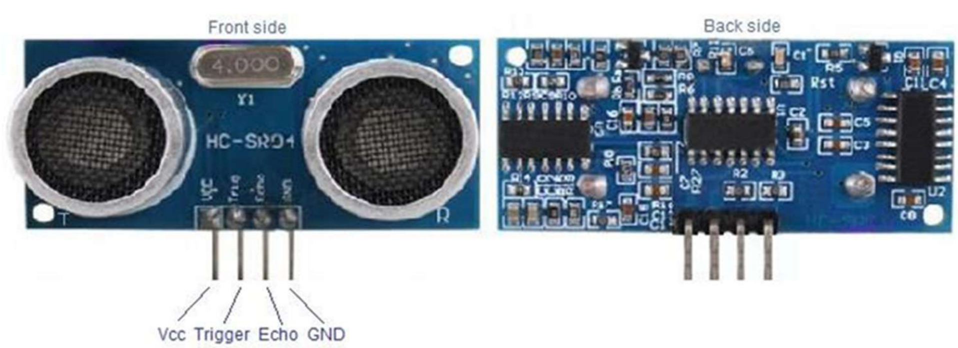

Fig -4: Ultrasonic Sensor

OLED (Organic Light Emitting Diodes):

OLED (Organic Light Emitting Diodes) is a flat light emitting technology, made by placing a series of organic thin films between two conductors. When electrical current is applied, a bright light is emitted. OLEDs are emissive displays that do not require a backlight and so are thinner and more efficient than LCD displays (which do require a white backlight). OLED displays are not just thin and efficient - they provide the best image quality ever and they can also be made transparent, flexible, foldable and even rollable and stretchable in the future. OLEDs represent the future of display technology.

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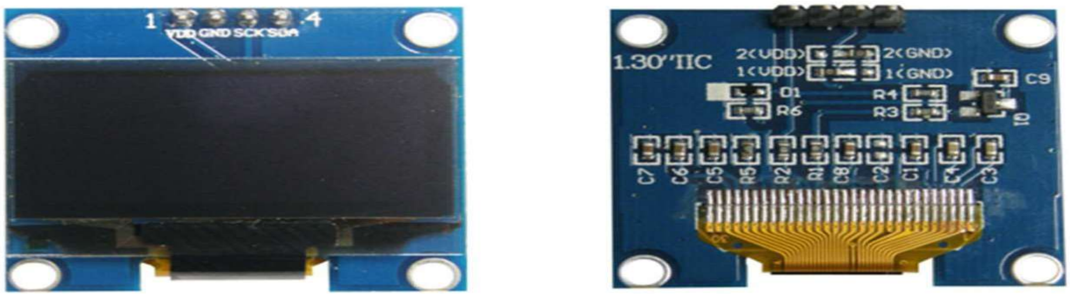
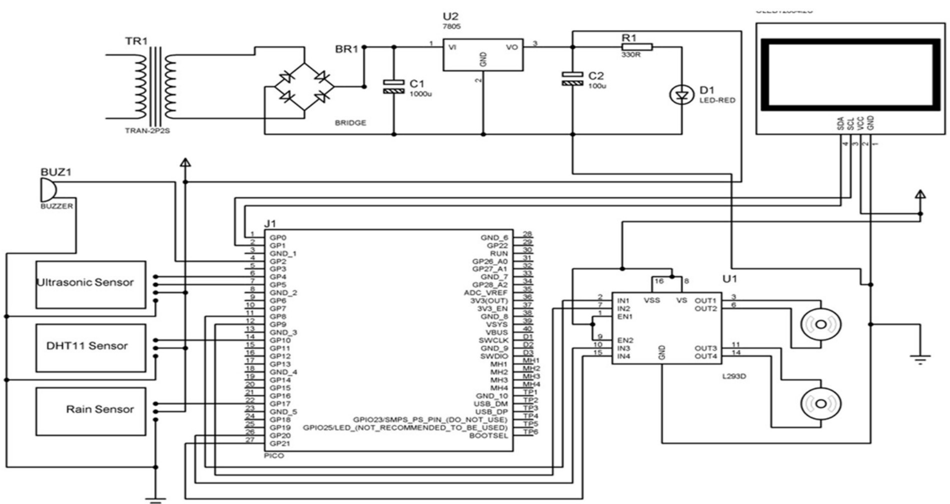


Fig 5: OLED Module

Schematic Diagram



Result

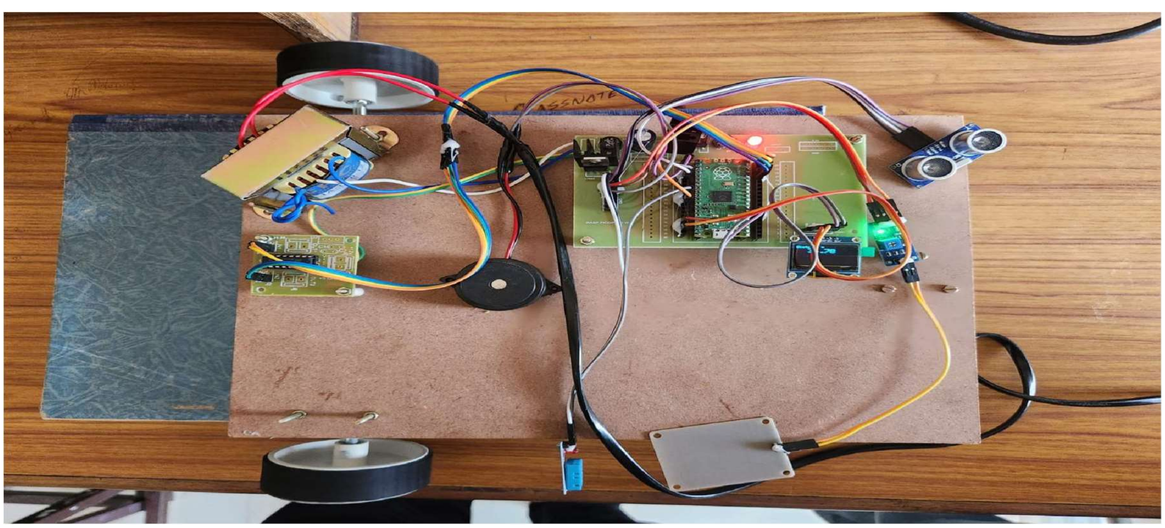


Fig-6 : Hardware Kit When in ON condition

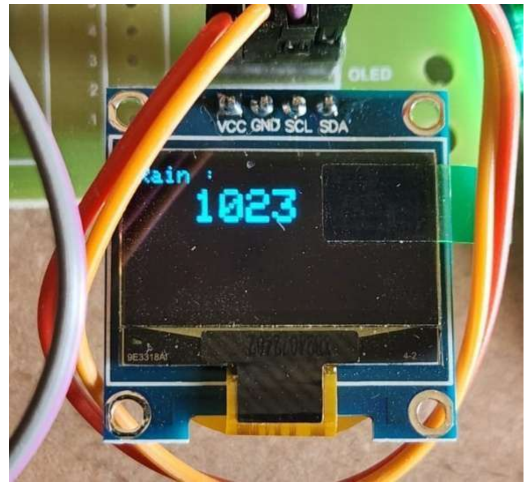


Fig 7;OLED displaying Temperature and Humidity Levels **Fig 8: Display of Rain Detection**

Fig 9; OLED displaying Object Detection

Results and Discussion

The successful development and implementation of the smart farming robot for greenhouse environmental monitoring produced several significant outcomes. The system demonstrated effective precision crop monitoring by continuously measuring key agricultural parameters such as temperature, humidity, soil moisture, and rainfall using sensors including the DHT11 sensor, ultrasonic sensor, and rain sensor. This real-time monitoring capability enabled accurate assessment of greenhouse conditions, helping farmers maintain optimal environments for plant growth and maximize crop yield.

The proposed system integrated data from multiple sensors to provide a comprehensive understanding of crop health, soil conditions, and environmental variations. Through data fusion techniques, the collected information was analyzed to generate recommendations for irrigation, ventilation, and pest management, thereby supporting more efficient greenhouse operations. The Raspberry Pi Pico microcontroller efficiently processed environmental data in real time, ensuring reliable monitoring and control of greenhouse conditions. The software, developed using Embedded C and MicroPython, facilitated smooth operation and effective data analysis.

Wireless communication modules enabled stable and reliable transmission of sensor data, allowing farmers to remotely monitor greenhouse conditions from a convenient location. An OLED display was incorporated to provide real-time environmental readings and system status updates, while an alarm mechanism alerted users whenever critical environmental changes occurred, enabling timely corrective actions. The system also featured adaptive control functions that automatically regulated irrigation and ventilation based on sensor readings, ensuring optimal growing conditions while minimizing manual intervention.

Future Scope

The smart farming robot for greenhouse monitoring offers substantial opportunities for future development and advancement in agricultural automation. Future enhancements may include the integration of artificial intelligence and machine learning algorithms to predict plant diseases, recommend corrective measures, and optimize crop growth through predictive analytics based on environmental trends. Additional advanced sensors, such as carbon dioxide detectors, UV light sensors, and nutrient analyzers, can be incorporated to provide more comprehensive environmental assessment and crop monitoring. The use of multispectral and hyperspectral imaging technologies can further improve precision agriculture by enabling detailed analysis of plant health and growth patterns.

Future versions of the system may also support fully autonomous decision-making through AI-driven control mechanisms that automatically manage irrigation, fertilization, and pest control based on real-time sensor data. The robot could dynamically adjust its operational parameters, including movement patterns and scheduling, according to changing environmental conditions. Cloud computing and advanced IoT integration can facilitate remote monitoring, predictive analysis, and automated notifications while enabling centralized management of multiple greenhouse facilities from a single platform.

The integration of blockchain technology and smart contracts presents another promising direction by enabling secure agricultural data storage, transparent tracking of farming activities, and automated transactions within agricultural supply chains. Beyond greenhouse applications, the smart farming robot can be adapted for open-field agriculture to monitor soil and environmental conditions, as well as vertical farming systems to support sustainable urban food production. These advancements will further enhance agricultural productivity, resource efficiency, and the adoption of smart farming practices in the future.

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