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Agriculture Rover for Soil and Crop Data Collection

Shrutika kotwal, Sanskruti Manjare , Pranay Masalkar ,Vedant Masalkar , Mr. V.B. Takle

Shrutika .V.Kotwal E&TC & JSPM's BSP

Sanskruti.S.Manjare E&TC & JSPM's BSP

Pranay. D. Masalkar E&TC & JSPM's BSP

Vedant.H.Masalkar E&TC & JSPM's BSP

Mr. V.B. Takle E&TC & JSPM's BSP

Abstract - Traditional farming often requires farmers to walk through large fields to check soil moisture, crop health, weeds, and pests. This work presents a low-cost autonomous rover designed to help with these tasks. The rover uses an ESP32 microcontroller and sensors to measure soil moisture, temperature, and humidity. An ultrasonic sensor helps it avoid obstacles as it moves through crop rows using a four-wheel-drive system. A camera supports visual crop monitoring, while GPS records the location of field observations. A buck converter provides a stable power supply, and a voltage divider protects the
ESP32's inputs. The prototype costs approximately ₹2,100– ₹3,800. Field tests showed that it could navigate crop rows, avoid obstacles at distances of 20 cm or less, and provide consistent soil and climate readings.

Keywords: Agricultural Rover, Soil Analysis, Crop Detection, Soil Moisture Monitoring, Crop Health Monitoring, Precision Agriculture, Smart Farming,
Internet of Things (IoT), Machine Learning, Computer Vision, Autonomous Navigation, Agricultural Robotics, Soil Nutrient Detection, Plant Disease Detection, Real-Time Monitoring, Environmental Sensing, GPS-Based Navigation, Automated Crop Monitoring, Sustainable Agriculture, Sensor-Based Agriculture.

1.INTRODUCTION

**Agriculture is essential for food production and livelihoods, but farmers face growing challenges such as changing weather, rising input costs, and limited availability of farm labor. To maintain crop production, farmers need reliable information about soil and plant conditions. In many farms, however, crop inspection is still done by walking through the field and checking plants by sight. This approach can be tiring and slow, particularly across large areas, and may fail to identify early signs of dry soil, crop stress, weeds,
or pests.**

When field conditions are not measured regularly, farmers may apply water or chemicals uniformly across the field instead of treating only the areas that need attention. This can waste resources and may contribute to soil degradation and environmental pollution. Regular and location-specific monitoring can help farmers make better decisions about irrigation and crop care.

Remote sensing technologies, including satellites and drones, can monitor crops over wide areas. However, satellite images may not capture small or early changes in plants, and cloud cover can reduce their usefulness. Drones can provide detailed images, but their operating time is limited, and they cannot directly measure conditions near the soil. Fixed sensors can collect measurements continuously, but each sensor covers only a limited location and may not represent the whole field. To address these limitations, this paper presents an affordable, ground-based agricultural rover for monitoring crop fields. The rover moves through crop rows and measures soil moisture, temperature, and humidity. An ultrasonic sensor helps it avoid obstacles, while an onboard camera and GPS support visual inspection and record the locations of field observations. The system is designed to provide consistent field data using low-cost components and may serve as a practical platform for precisionfarming applications.

2. 2.Body of Paper

The Agriculture Rover for Soil and Crop Detection is a smart robotic system designed to monitor agricultural fields and collect useful information about soil and crops. The rover moves through the field using a motorized chassis controlled by a microcontroller such as Arduino or ESP32. It can be operated manually or automatically, depending on the system design. The main objective is to reduce farmers' manual effort and improve the efficiency of agricultural monitoring. The rover uses different sensors to detect soil conditions such as moisture, temperature, and pH, depending on the sensors installed. These sensors collect soil data and send it to the microcontroller for processing. The collected information helps farmers understand soil conditions, identify areas that may require irrigation, and make better decisions about soil management and crop growth. For crop detection, the rover can use a camera to capture images of plants growing in the field. Image processing or machine learning techniques can be
used to identify crops and analyze visible signs of plant disease or stress when suitable detection models are implemented. The processed information can be displayed on a computer or mobile device. Wireless communication can also be used to transmit the data for real-time monitoring.

**The working process begins when the rover moves through the agricultural field and collects soil and crop data. The microcontroller processes the sensor readings and coordinates the rover's functions, while the crop detection system analyzes captured images. The results help farmers monitor field conditions, identify potential problems, and manage agricultural resources more efficiently. In the future, GPS navigation, artificial intelligence, and automated irrigation can be integrated to improve the performance of the rover and support
precision agriculture.**

LITERATURE SURVEY

Researchers have explored diverse sensing architectures to automate farm management, each presenting distinct trade-offs between coverage, resolution, and deployment feasibility. Satellite remote sensing provides macro-level vegetative indices, such as the Normalized Difference Vegetation Index (NDVI), for large-scale yield forecasting and regional monitoring. However, its coarse spatial resolution (typically 3 m to 30 m per pixel) fails to capture localized weed outbreaks or early-stage foliar diseases, while atmospheric cloud cover and fixed orbital revisit cycles severely limit timely decision-making during critical growth windows. Unmanned Aerial Vehicles (UAVs) have emerged as a high-resolution alternative for aerial photogrammetry, but they remain heavily constrained by brief flight endurances (15 to 30 minutes), aerodynamic rotor downdrafts that disturb fragile crop canopies, and strict regional airspace regulations. More importantly, both satellite and aerial platforms are physically incapable of gathering subsurface soil properties, restricting their utility strictly to visible top-canopy traits.

To obtain direct soil parameters, researchers widely implement static Wireless Sensor Networks (WSNs) across agricultural fields. While these stationary nodes provide continuous temporal logging of soil moisture, temperature, and ambient variables, achieving adequate spatial granularity requires dense, cost-prohibitive hardware deployments. Furthermore, the presence of above-ground antennas, solar mounts, and cabling across furrows creates continuous physical obstructions that are easily damaged by mechanical tillers, weeding equipment, and harvesters during standard agronomic operations. To overcome the static limitation, preliminary mobile ground robots have been developed; however, most entry-level prototypes drag basic analog capacitive or resistive probes along the topsoil. In practical field environments, this surface-dragging approach merely reads dry crust and dust rather than the actual rootzone micro-environment (5 to 10 cm depth), yielding inaccurate hydration and nutrient data. At the commercial and high-end research level, autonomous platforms such as Earth Sense and Naio Technologies deploy multi-beam LiDAR and RealTime Kinematic (RTK) GPS for under-canopy phenotyping. While technically capable, their acquisition costs—often exceeding tens of thousands of dollars—render them impractical for small-tomedium-scale farming enterprises. Additionally, existing field telemetry architectures frequently depend on Wi-Fi or cellular networks, which are either severely range-restricted or entirely unavailable across rural farming acreage. While Sub-1 GHz LoRa radio protocols have proven effective for long-range, low-power agricultural telemetry exceeding 1 km, their integration into low-cost ground mobile platforms remains underexplored.

**Consequently, a distinct research gap exists for an affordable mobile ground robot that integrates depth-resolved root-zone probing with undercanopy navigation and edge visual diagnostics. The autonomous agricultural rover proposed in this work addresses these limitations by pairing a motorized vertical penetration gantry with an RS-
485 Modbus NPK probe array, side-mounted**

Time-of-Flight, laser ranging sensors for GPSindependent furrow tracking, on-device edge-AI foliar disease screening, and a long-range SX1278 LoRa telemetry link, achieving comprehensive proximal sensing within an accessible hardware.

2. SYSTEM CIRCUIT DIAGRAM / BLOCK DIAGRAM

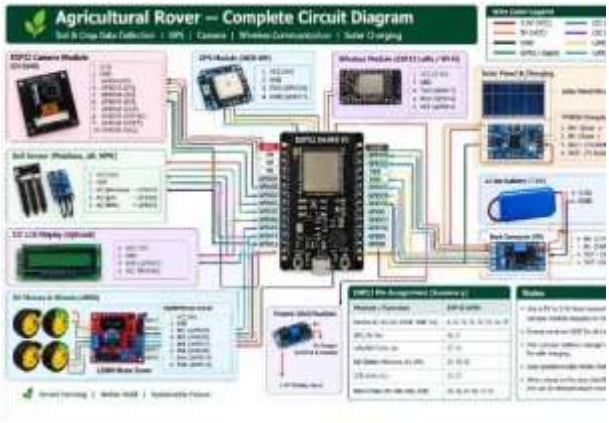


Fig -2.: Circuit Diagram

The proposed Agriculture Rover circuit is designed to collect soil and crop information using an ESP32 microcontroller as the main processing unit. The ESP32 interfaces with soil sensors to measure moisture, pH, and NPK levels, while the ESP32 camera captures crop images for identifying visible defects using image-processing techniques. The NEO-6M GPS module provides geographical coordinates, allowing soil measurements and crop observations to be associated with specific field locations.The rover uses four DC motors controlled by an L298N motor driver to move across agricultural fields. A wireless communication module enables the collected data to be transmitted to a monitoring system for analysis. An optional I²C LCD displays selected sensor readings and system status locally.

The ESP32 coordinates sensor data collection, camera operation, and rover movement according to the implemented control program.The power supply consists of a rechargeable battery, a solar necessary for reliable operation.Overall, the circuit integrates soil monitoring, crop image acquisition, GPS-based location tracking, wireless data communication, and mobile navigation into a single agricultural platform. The collected information can be displayed on a monitoring dashboard to help users assess soil conditions and identify potential crop problems. This system aims to support precision agriculture by improving field data collection and assisting farmers in making informed crop-management decisions.

3. HARDWARE-BASED SYSTEM

A. Soil pH Sensor



Fig-3.1:soil pH sensor.

A soil pH sensor is an important component of an agriculture rover used to measure the acidity or alkalinity of soil. The pH value generally ranges from 0 to 14, where 7 indicates neutral soil, values below 7 indicate acidic soil, and values above 7 indicate alkaline soil.

The sensor is inserted into the soil to measure its pH level. It detects the soil's chemical properties and sends an electrical signal to a microcontroller, such as ESP32. The microcontroller processes the readings and displays or transmits the results to the user. In an agriculture rover, the pH sensor helps farmers understand whether the soil is suitable for a particular crop. Different crops require different soil pH conditions for healthy growth. Regular soil pH monitoring can help farmers make better decisions about soil treatment and fertilizer application. *The sensor should be calibrated before use to improve measurement accuracy. Its performance may depend on soil moisture, temperature, probe quality, and the calibration procedure.*

B.NPK Sensor



Fig -3.2: NPK Sensor

The ESP32-CAM is a compact development board that combines an ESP32 microcontroller with a camera interface. It can capture images of crops, leaves, and surrounding field conditions. Its wireless capabilities also allow image transmission over Wi-Fi when a suitable network is available. In an agriculture rover, the camera captures crop images while the rover moves through the field. The captured images can be sent to a computer or another processing system for crop observation and

imagebased analysis. Computer vision techniques can be used to investigate plant growth, visible leaf damage, weeds, or disease symptoms.

The ESP32-CAM has limited processing resources compared with a computer or advanced AI board. Therefore, complex image recognition may need to be performed on an external computer, server, or more powerful edge device.

Adequate lighting, camera positioning, image resolution, and stable power supply are important for obtaining useful images. The camera can be integrated with soil sensors to combine visual crop information with soil measurements.

C. GPS Module



Fig 3.3: GPS Module A Global Positioning System (GPS) module determines the geographical location of the agriculture rover using signals received from navigation satellites. It generally provides latitude, longitude, and other information such as speed, altitude, and time, depending on the module. The GPS module receives satellite signals and calculates the rover's approximate position. It sends the location data to the ESP32 or another controller through a communication interface, commonly UART. The controller can associate soil pH and NPK measurements with the corresponding geographical coordinates.

In an agriculture rover, GPS is useful for mapping soil conditions across a field. By recording sensor measurements at different locations, farmers can identify areas with different soil properties and plan targeted agricultural activities.

GPS accuracy depends on the module, antenna placement, satellite visibility, and environmental conditions. Basic GPS modules may provide meterlevel accuracy under suitable conditions and can perform poorly under dense vegetation or near buildings.

D.ESP32-CAM



Fig 3.4: ESP32-CAM

The ESP32-CAM is a compact development board that combines an ESP32 microcontroller with a camera interface. It can capture images of crops, leaves, and surrounding field conditions. Its wireless capabilities also allow image transmission over Wi-Fi when a suitable network is available. In an agriculture rover, the camera captures crop images while the rover moves through the field. The captured images can be sent to a computer or another processing system for crop observation and imagebased analysis. Computer vision techniques can be used to investigate plant growth, visible leaf damage, weeds, or disease symptoms. The ESP32-CAM has limited processing resources compared with a computer or advanced AI board. Therefore, complex image recognition may need to be performed on an external computer, server, or more powerful edge device.

Adequate lighting, camera positioning, image resolution, and stable power supply are important for obtaining useful images. The camera can be integrated with soil sensors to combine visual crop information with soil measurements.

E. Motor Driver and Wireless Connectivity



Fig 3.5: Motor Driver and Wireless Connectivity The motor driver and wireless connectivity system enable the agriculture rover to move and receive control commands. A motor driver acts as an interface between the microcontroller and the DC motors. Since the GPIO pins of an ESP32 cannot directly supply the current required by most drive motors, a suitable driver is needed.

A motor driver, such as an appropriate H-bridge module, controls motor direction and speed according to signals from the microcontroller. By controlling the left and right motors independently, the rover can move forward, reverse, and turn. Wireless connectivity allows the rover to communicate with a mobile phone, computer, or remote monitoring system.

The ESP32 supports Wi-Fi and Bluetooth, depending on the selected operating mode and software. Commands and sensor measurements can be transmitted wirelessly when a connection is available.

The motor driver must be selected according to the motors' operating voltage and current requirements. Wi-Fi range, interference, power consumption, and communication reliability should also be considered during implementation.

F. Battery and Charging Circuit

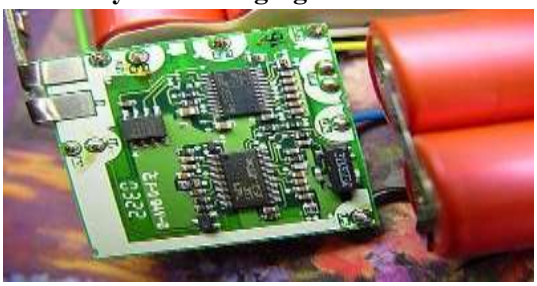


Fig3.6 : Battery and Charging Circuit

The battery and charging circuit provide electrical power to the agriculture rover. The battery supplies energy to the microcontroller, sensors, camera, wireless modules, and motor system. A rechargeable battery is suitable for a mobile rover because it allows repeated operation without a continuous external power connection.

The charging circuit manages battery charging and, where supported, provides protection against conditions such as overcharging, excessive discharge, and overcurrent. A suitable voltage regulator or DCDC converter may be required to supply the correct voltage to different components. The battery capacity determines how long the rover can operate before recharging. Motor current, camera activity, wireless transmission, and sensor operation all affect total power consumption.

For safe operation, the battery chemistry, cell count, charger voltage, and protection circuit must be compatible. Motors may require a separate regulated supply path to reduce electrical noise and prevent microcontroller resets.

G. Solar Small Panel



Fig-3.7: Small Solar Panel

A small solar panel converts sunlight into electrical energy through the photovoltaic effect. It can be added to an agriculture rover to provide supplementary power and reduce dependence on frequent battery charging. When sunlight falls on the panel, it produces a DC electrical output. This output can be connected to a compatible solar charging controller, which manages the energy supplied to the rechargeable battery. The panel should not normally be connected directly to a lithium battery without a suitable charging and protection system.

In the proposed rover, the solar panel may help extend operating time under favourable sunlight conditions. However, a small panel may not generate sufficient power to operate drive motors continuously. Its main role may be supplementary charging or powering lowconsumption electronics, depending on its wattage.Solar performance depends on sunlight intensity, panel orientation, shading, temperature, and conversion losses.

The panel's voltage and current ratings must match the charging circuit and battery requirements.

The MQ-135 sensor is used to monitor gas-related and air-quality conditions around the smart pole. It provides environmental information to the controller and can help identify abnormal air conditions. The collected data can be processed locally and transmitted through the IoT communication system for monitoring and possible safety alerts.

4.COST ANALYSIS

No.	Component	Qty	Cost (₹)	Function
1	ESP32 DevKit	1	350–500	Controller, Wi-Fi
2	4WD chassis + wheels	1 set	600–1,000	Frame and tires

3	Geared DC motors	4	Included	Drive
4	L298N driver	1	130–250	Motor driver
5	Capacitive soil sensor	1	100–200	Soil moisture
6	DHT11	1	50–100	Air climate
7	HC-SR04	1	60–120	Obstacle detectio
8	12 V battery pack	1	500–1,000	Power supply
9	DC-DC buck converter	1	80–150	12 V to 5 V
10	Wires and switch	1 set	130–250	Wiring, toggle
11	Screws/nuts	1 set	100–200	Assembly
	Total		2,100–3,800	

5.Working of the System

The working process of the Agriculture Rover for Soil and Crop Detection begins with the movement of the rover through agricultural fields using wheels and DC motors controlled by a motor driver. The ESP32 microcontroller acts as the main control unit, managing the movement of the rover and the operation of the connected sensors. The rover is powered by a rechargeable battery, and a small solar panel can help recharge the battery and extend its operating time.

The soil pH sensor measures the acidity or alkalinity of the soil, while the NPK sensor measures the levels of nitrogen, phosphorus, and potassium. These parameters help determine the condition and nutrient status of the soil. The collected readings are processed by the ESP32 and used to identify areas where soil improvement or additional nutrients may be required. This information helps farmers make suitable decisions regarding fertilizer The ESP32-CAM captures images of crops to monitor their condition and identify visible symptoms such as discoloration, damaged leaves, or possible disease. GPS records the geographical location of the rover, allowing farmers to identify the specific areas where soil measurements or crop problems are observed. By combining sensor readings, crop images, and location information, the rover provides a more detailed

Finally, the ESP32 transmits the collected data to a mobile device or monitoring system through wireless connectivity. Farmers can view the soil parameters, crop images, and GPS coordinates to monitor field conditions and plan appropriate agricultural activities. The collected information can support targeted fertilizer application, early investigation of crop diseases, and improved crop management. Thus, the proposed agriculture rover combines robotics, IoT, sensors, GPS, and camerabased monitoring to reduce manual field inspection and support precision agriculture.

Accurate crop disease identification requires suitable image-processing software or a trained AI model.

6. CONCLUSION

The prototype demonstrates the feasibility of developing a low-cost ESP32-based agricultural rover for basic field monitoring. During testing, the rover successfully avoided obstacles in 28 out of 30 attempts, corresponding to a success rate of approximately 93.3%. The soil moisture sensor also distinguished between dry and wet soil conditions, while the system monitored surrounding air conditions. The reported operating time of 2.5–3.5 hours and estimated prototype cost of ₹2,100–₹3,800 indicate its potential for affordable agricultural applications.

Future improvements will focus on integrating an ESP32-CAM with a lightweight convolutional neural network (CNN), such as Tiny-YOLO, for leaf disease classification; a GPS module for location-based soil data collection; and a solar panel for supplementary battery charging. A linear actuator could enable rootzone soil probing, while LoRaWAN could support long-range data transmission. Multi-sensor ranging and row-following control could further improve navigation accuracy and operational reliability. **It is important to distinguish the tested system from the proposed enhancements. Although the camera,**

GPS module, and solar panel are visible in the prototype photograph, they were not included in the reported experimental configuration. Therefore, their performance and contribution to the system have not yet been validated. Further testing under different soil, lighting, and field conditions will be necessary to evaluate the reliability and practical suitability of the proposed system.

7.ACKNOWLEDGEMENT

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suggestions and technical assistance helped us understand the practical implementation of embedded systems, sensors, robotics, and IoT-based agricultural monitoring.

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BIOGRAPHIES



Shrutika Vilas Kotwal of E&TC Department JSMP's BSP Wagholi,Pune
Email: shrutika kotwal78@gmail.com



Pranay Dattatary Masalkar of E&TC DepartementJSMP'sBSPWagholi,Pune
Email:pranaymasalkar6275@gmail.com



Vedant Hanumant Masalkar of E&TC Departement JSMP's BSP Wagholi,Pune.
Emailvedantmasalkar6@gmail.com



Sanskruti Sachin Manjare Of E&TC Department JSMP's BSP Wagholi,Pune.
Email: sanskrutimanjare292@gmail.com



Mr.Takale VikasBhiku of E& TC Departement JSMP's BSP Wagholi,Pune.
Email:vbtakale_entc@jspmbspoly.edu.in