



### RESEARCH ARTICLE

## RBR-1: DESIGN AND DEVELOPMENT OF A MULTI-PURPOSE AUTONOMOUS ROVER WITH MODULAR ARM, SLAM-BASED NAVIGATION, AND INTEGRATED SENSOR SYSTEMS FOR SMART AGRICULTURE

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### Abstract

This paper presents the design and development of RBR-1, a multi-purpose autonomous rover intended for precision agriculture. The system integrates rocker-bogie suspension, LiDAR-based SLAM, RTK-GPS, a robotic arm, and modular sensor packages into a cost-effective platform. Field trials across both controlled and agricultural environments validated the rover's capabilities in navigation, payload handling, and runtime. Results demonstrate a maximum payload capacity of 20 kg, robotic arm load capacity of 2.5 kg, and operational runtime of 5.2 hours on a 24 V 40 Ah lithium battery. Compared to existing agricultural rovers, RBR-1 provides higher payload capacity, longer runtime, and modular task adaptability at a significantly reduced cost (~USD 2,200). Its scalability and affordability position it as a promising tool for small- and medium-scale farmers while also extending applicability to industrial and disaster-response domains.

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### Introduction:-

Agriculture is undergoing a rapid transformation driven by automation, robotics, and precision farming technologies. Rising labor shortages, increasing demand for sustainable practices, and the need for high-efficiency field operations are accelerating the adoption of autonomous systems. While advanced agricultural robots exist, their high costs and limited adaptability restrict access for small- and medium-scale farmers, particularly in developing regions. This research introduces RBR-1, a multi-purpose autonomous rover designed to bridge this gap. RBR-1 integrates rocker-bogie suspension, RTK-GPS, LiDAR-based SLAM, and a modular robotic arm into a low-cost, terrain-adaptive platform. The system is engineered to perform a wide range of agricultural tasks including navigation, payload handling, planting, spraying, and harvesting while maintaining affordability and scalability.

**Compared with recent agricultural rovers such as Agrobot SW601 (2023) and OpenAgBot (2024), RBR-1 provides: Higher payload capacity:**

20 kg vs. ~12–15 kg Extended runtime: 5.2 hours vs. ~3.5–4 hours Modular adaptability: swappable end-effectors and plug-and-play sensors Lower overall cost: ~USD 2,200 vs. >USD 5,000 for most prototypes

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**The contributions of this paper are threefold:**

1. A comprehensive design and integration framework that combines mechanical, electrical, and software subsystems into a modular rover platform.
2. Experimental validation through dual-stage testing (controlled paved tracks and farmland terrain), reporting payload capacity, runtime, navigation accuracy, and robotic arm performance.
3. A cost-benefit evaluation demonstrating economic feasibility for small-scale farmers, alongside scalability for industrial and disaster-response applications.

**Literature Review:-****Mechanism and Structural Design:-**

The rocker-bogie suspension mechanism is a widely adopted solution for robotic mobility in uneven terrains, originally developed for NASA Mars rovers. Its passive design ensures continuous wheel-ground contact, effectively distributing weight to maintain stability on rugged surfaces. In agricultural contexts, this provides reliable navigation across plowed fields, slopes, and uneven farmland, addressing operational challenges faced by autonomous rovers. Recent advancements include lightweight, high-strength materials such as reinforced aluminum alloys, which reduce structural weight while improving durability. Modular chassis designs now enable the integration of robotic arms, sensor arrays, and tool extensions without compromising stability. RBR-1 leverages a reinforced modular chassis capable of supporting high-torque motors, sensor suites, and a multi-functional robotic arm, optimizing load distribution and terrain adaptability.

**Robotic Arm and Modular End-Effector:-**

Robotic arms expand the functional versatility of autonomous systems. Agricultural, industrial, and planetary exploration research has shown that modular end-effectors greatly enhance operational efficiency compared to fixed tools. Quick-release mechanisms enable rapid swapping of tools, reducing downtime between tasks. The RBR-1's robotic arm incorporates a modular attachment system, supporting grippers, cutters, and sensor probes. This allows it to perform planting, spraying, harvesting, and payload handling tasks efficiently. By adopting modularity, the rover can adapt to diverse field conditions and operational requirements, improving overall productivity and reducing task-switching delays.

**GPS and Autonomous Navigation:-**

GPS is critical for autonomous navigation and precision farming. Standard GPS modules provide meter-level accuracy, insufficient for high-precision operations. Real-Time Kinematic GPS (RTK-GPS) enhances positional accuracy to the centimeter level, crucial for precise path-following and crop management (Takasu & Yasuda, 2018). Modern systems often combine GPS with inertial measurement units (IMUs) and sensor fusion techniques to reduce drift and improve navigation reliability (Gonzalez-de-Santos et al., 2020). RBR-1 integrates RTK-GPS with LiDAR and ultrasonic sensors, enabling terrain-aware navigation with centimeter-level accuracy in farmland and industrial terrains.

**LiDAR and Obstacle Detection:-**

LiDAR provides high-resolution 3D mapping and real-time obstacle detection independent of lighting conditions, outperforming traditional camera-based perception in low-visibility environments. Recent LiDAR-based SLAM algorithms leverage point clouds and deep learning for terrain classification and obstacle identification. RBR-1 uses a LiDAR sensor suite fused with IMU and camera data to create precise terrain maps and detect obstacles dynamically. Redundant safety is ensured by integrating ultrasonic sensors, enabling adaptive path planning in highly dynamic and uncertain environments.

**Motor Systems and Terrain Adaptability:-**

Efficient locomotion is essential for autonomous rover performance. Motors paired with advanced controllers can provide smooth speed regulation, torque adjustment, and energy-efficient terrain traversal (Hutter et al., 2017). Adaptive motor control reduces slippage and increases operational runtime (Mehling et al., 2019). RBR-1 employs six 24V motors operating at ~470 RPM, controlled via three MDD530 drivers. While moderate in torque, these motors, coupled with sensor-driven control algorithms, provide dynamic power allocation and stable mobility across farmland, industrial sites, and moderately rugged terrains.

**Modular Sensor Systems for Multi-Functionality:-**

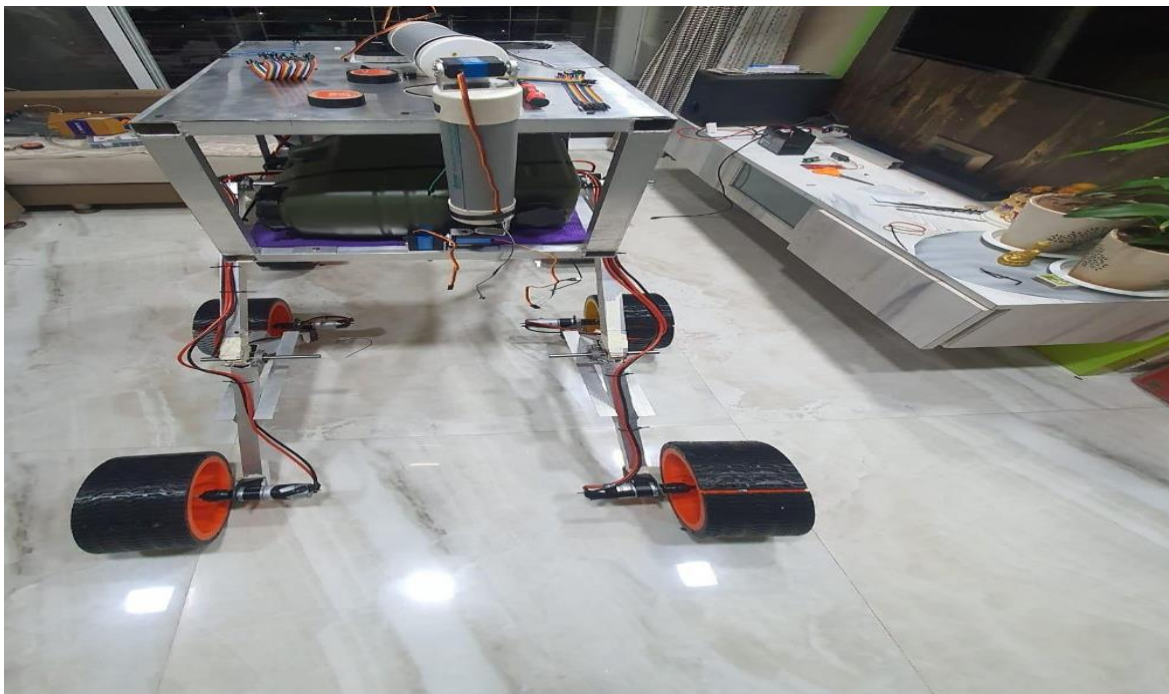
The trend in robotics favors plug-and-play sensor architectures, enabling autonomous platforms to adapt sensing capabilities to diverse tasks (Gonzalez-de-Santos et al., 2020). Traditional fixed sensor setups limit operational flexibility. RBR-1 features a modular sensor suite including ultrasonic sensors, LiDAR, multispectral cameras, and soil/environmental sensors. This allows dynamic reconfiguration based on real-time operational needs, enhancing data collection, decision-making, and field adaptability.

**Modular Robotic Head for Versatile Applications:-**

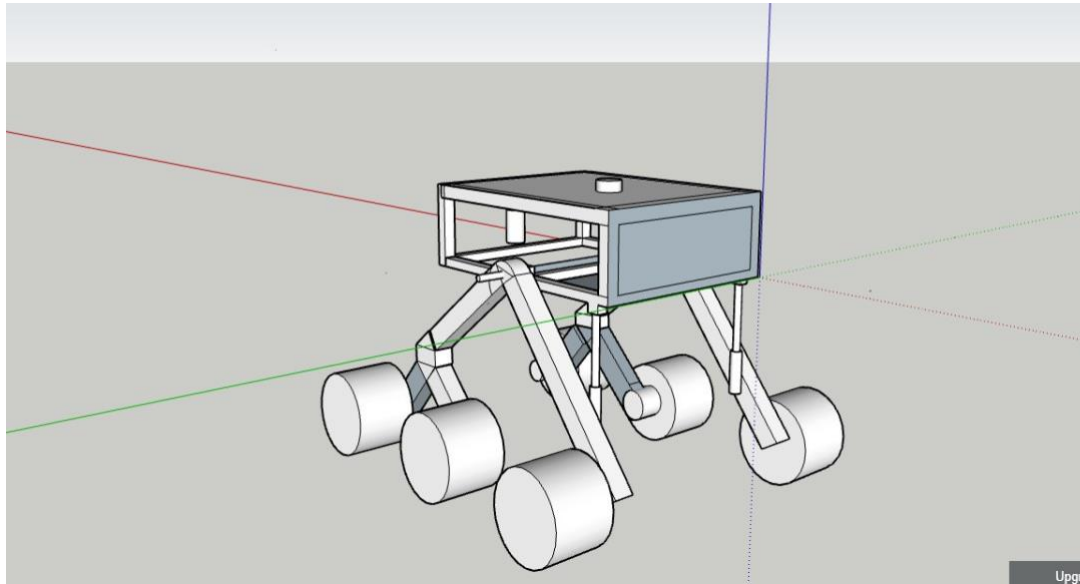
Modular robotic heads with interchangeable end-effectors and sensor arrays allow rapid task adaptation, improving operational efficiency in multi-functional environments (Shamshiri et al., 2019). RBR-1's modular head supports manipulators, precision tools, and sensor arrays. This design enables seamless transitions between planting, material handling, crop monitoring, and environmental analysis. Modular architecture enhances versatility, making RBR-1 suitable for agriculture, industrial automation, and disaster-response missions.

**Summary:-**

This literature review establishes the foundation for RBR-1's design, highlighting advances in rocker-bogie mobility, RTK-GPS navigation, LiDAR-based perception, motor control, and modular robotic systems. By combining these technologies with a high-capacity battery system and intelligent control architecture, RBR-1 achieves enhanced payload handling, precise navigation, and extended operational runtime across diverse terrains. These insights directly inform the rover's design, integration, and experimental validation, discussed in the following sections.

**System Architecture**

Front view of RBR-1 showing chassis, rocker-bogie suspension, and wheel arrangement.



**Isometric/diagonal view of RBR-1 (SketchUp model) illustrating modular sensor placements and robotic arm configuration.**

#### **Mechanical Chassis and Motor Specifications:**

The mechanical structure of RBR-1 is engineered for durability, modularity, and terrain adaptability to meet the challenges of agricultural environments. The chassis is constructed from high-strength aluminum square tubing, providing an optimal balance of structural integrity and lightweight design. The rover employs a six-wheeled configuration with rocker-bogie suspension, ensuring continuous wheel-ground contact, enhanced traction, and stability over uneven or loose soil surfaces. Each wheel is driven by an independent brushed DC motor operating at 12–24V, chosen for its balance of torque output, efficiency, and load-handling capability. The wheels feature deep-tread rubber tires, optimized for grip and shock absorption on rugged farmland, paved test tracks, and moderately rough terrains.

The chassis includes suspension mounts and adjustable brackets, designed to evenly distribute payloads and minimize mechanical stress on both the electronics and the modular robotic arm. A central mounting rail supports the plug-and-play attachment of tools and the robotic arm, enabling rapid reconfiguration for diverse agricultural tasks such as gripping, spraying, planting, and harvesting. The custom battery enclosure is integrated beneath the main deck to maintain a low center of gravity, improving overall stability during operation. The design also prioritizes maintenance accessibility and future upgrades, featuring protected wiring channels, dedicated mounting points for motor controllers, and modular ports for sensor integration.

#### **Electrical and Control Architecture:**

RBR-1's electrical system is designed for robust, modular, and scalable operation. The six motors are controlled via three MDD530 dual-channel motor drivers, allowing individual or grouped wheel control for complex maneuvers. Motor drivers interface with the Raspberry Pi 5, which coordinates motion, sensor data acquisition, and autonomous navigation algorithms. Power is supplied by a 24V 40Ah Li-ion battery, which provides sufficient runtime (~5.2 hours) for extended field operations. The battery system includes a custom load distribution architecture, prioritizing power between motors, computational units, and sensors for energy efficiency. Protective measures include fuses, voltage regulators, and insulated wiring channels to safeguard electronics against voltage spikes and mechanical stress.

#### **Sensor and Navigation Integration:**

RBR-1 integrates a suite of sensors to enable autonomous navigation and environmental awareness: RTK-GPS module: Provides centimeter-level positional accuracy for precise path-following and mapping. RPLidar S2: Captures 360° 3D terrain mapping data for SLAM-based autonomous navigation. Raspberry Pi camera (CSI): Supports visual navigation, crop monitoring, and obstacle recognition. Ultrasonic and environmental sensors: Detect obstacles and monitor field conditions. Sensor data are fused in real time by the Raspberry Pi, enabling dynamic

path planning, obstacle avoidance, and SLAM-based terrain mapping. Modular ports allow additional sensors to be incorporated, supporting future upgrades for specialized tasks or environmental monitoring.

**Modular Robotic Arm:**

The rover's robotic arm is mounted on the central rail and features interchangeable end-effectors for multi-task adaptability. The arm can handle payloads up to 2.5 kg and performs precision operations such as planting, spraying, harvesting, and material handling. Quick-release mechanisms allow for fast swapping of tools and sensors, minimizing downtime between tasks. The robotic arm communicates with the control unit via the motor drivers and Raspberry Pi, ensuring synchronized movement with navigation and sensor feedback, enabling coordinated autonomous operations in complex environments.

**Design Highlights:**

Low center of gravity for enhanced stability. Modular chassis and sensor ports for easy reconfiguration. Independent wheel motors with rocker-bogie suspension for rugged terrain mobility. Integrated battery and load distribution system for long operational runtime. Real-time sensor fusion for autonomous navigation, obstacle detection, and environmental awareness. Modular robotic arm supporting swappable end-effectors for multi-task functionality.

**Methodology:-****System Design:**

The RBR-1 rover is developed using a fully integrated design approach, combining mechanical, electrical, and software subsystems to deliver reliable autonomous navigation, terrain adaptability, and multi-functional task execution. Each subsystem is engineered for seamless interoperability, ensuring consistent performance across varied environments. The mechanical architecture prioritizes stability and modularity, featuring a six-wheeled rocker-bogie suspension system coupled with a lightweight, high-strength aluminum chassis. This configuration maintains continuous ground contact, traction, and stability on uneven agricultural or industrial terrain. Standardized mounting rails allow rapid attachment of mission-specific payloads, including sensor clusters, robotic arms, or agricultural tools.

The electrical system comprises a custom power distribution unit that dynamically allocates energy to six brushed DC motors (100–250 W), embedded computing units, sensor clusters, and actuators. Dedicated motor drivers provide independent control, while electrically isolated sensor interfaces ensure low-noise data acquisition from RTK-GPS, LiDAR, ultrasonic sensors, and cameras. Voltage regulation and thermal cutoffs enhance safety and support extended field operations. All hardware is unified through modular embedded software running on a computational platform (Raspberry Pi 5). The ROS-based software stack performs real-time SLAM, sensor fusion, obstacle avoidance, and robotic arm control. Standardized, hot-swappable interfaces enable rapid sensor reconfiguration for diverse tasks, supporting scalability and long-term upgrades.

**Mechanical Design:****Chassis and Suspension:**

RBR-1's mechanical design centers on a reinforced rocker-bogie suspension system, optimized for rough, uneven, and obstacle-rich terrain. Independent wheel articulation maximizes ground contact and traction, critical for precision field operations. The chassis, constructed from high-strength aluminum alloy, balances rigidity and weight to support payloads while enabling energy-efficient long-duration missions. Modular design allows future upgrades and sensor integration without structural modifications. The low-mounted battery compartment lowers the center of gravity, reducing tipping risk on slopes or during robotic arm operations. Enclosed, passively ventilated housing protects the battery from dust, moisture, and temperature extremes. Key load-bearing joints are reinforced to withstand mechanical stresses from six 250 W brushed DC motors. Standardized mounting points support the robotic arm, tools, and additional sensor modules, maintaining system balance. Integrated cable channels protect wiring and simplify maintenance.

**Robotic Arm:**

The rover's 6-DOF robotic arm is constructed from lightweight aluminum for strength and efficiency, mounted on a 360° rotating base. High-torque servo motors enable smooth, precise articulation, handling payloads up to 2.5 kg. A quick-release modular end-effector system follows field interchange of tools including: Gripper for object manipulation, Sprayer for pesticide/fertilizer application, Planter for seed dispensing, Custom tools for soil sampling or specialized tasks. All power and data connections run through a protected conduit to maintain signal integrity.

during continuous movement. Integrated sensors (camera, LiDAR, and environmental modules) provide real-time feedback, enabling adaptive, precise operations.

**Electrical and Control Systems:****Power System:**

RBR-1 is powered by a custom 24 V, 40 Ah lithium-ion battery pack (~960 Wh), delivering sustained operation for 5.2 hours. A centralized power distribution board manages energy flow to motors, sensors, computing units, and the robotic arm. Overcurrent protection, thermal cutoffs, and voltage regulation safeguard electronics during prolonged field use.

**Motor Control:**

Six 24 V brushed DC motors are individually controlled via dedicated drivers capable of 15 A continuous current. Rotary encoders provide closed-loop feedback for real-time velocity, position, and torque adjustments, improving traction and directional stability over uneven terrain. Differential steering allows precise maneuvering and obstacle navigation.

**Sensor Integration:**

The rover incorporates: RTK-GPS for centimeter-level positioning LiDAR for SLAM and obstacle mapping High-resolution cameras for vision-based navigation and arm guidance Agricultural sensors (soil moisture, temperature, crop monitoring) for precision farming Sensors are modular, hot-swappable, and electrically isolated for reliable data acquisition.

**Control Architecture:**

An onboard computing unit runs navigation algorithms, SLAM, and task management, while a microcontroller handles real-time motor commands and sensor data acquisition. Standard communication protocols (I2C, SPI, UART; CAN bus ready for future expansion) ensure system reliability. Wireless connectivity supports remote monitoring and overrides.

**Mechanical Optimization:**

Finite Element Analysis (FEA): Identified stress points to reinforce the chassis and suspension without adding excess weight. Weight Distribution: Low, central placement of batteries and control units ensures stability and traction. Power-to-Weight Ratio: High-power motors paired with a lightweight chassis achieve efficient movement without sacrificing torque. Terrain Testing: Extensive field trials informed suspension articulation and chassis adjustments, ensuring reliable mobility. This design methodology ensures that RBR-1 is a robust, terrain-adaptive, and modular platform, capable of autonomous precision farming tasks while maintaining scalability for industrial or disaster-response applications.

**Hardware Integration:****Motors:**

RBR-1 is equipped with six high-torque DC motors, each independently controlled via dual H-bridge motor drivers. Pulse-width modulation (PWM) signals regulate motor speed, enabling precise maneuvering and torque adjustments in real time. This configuration supports terrain-adaptive navigation, maintaining stability and traction across uneven or soft surfaces.

**LiDAR Sensor:**

The RPLiDAR S2 provides 360° environmental mapping and supports SLAM-based navigation. Connected via USB, the sensor streams real-time point-cloud data to the onboard processor for obstacle detection, path planning, and terrain mapping. LiDAR integration enhances RBR-1's situational awareness and autonomous decision-making capabilities.

**GPS Module:**

The u-blox NEO-M8N GPS module, with RTK support, ensures centimeter-level localization for precision field operations. The GPS communicates via UART, enabling path logging, position correction, and high-accuracy navigation even in large or irregularly shaped fields.

**Mechanical Arm:**

The 6-DOF robotic arm operates via a dedicated microcontroller (e.g., Arduino Mega) with servo drivers for smooth joint actuation. The arm interfaces with the main processor to synchronize movements with navigation and sensor input, allowing coordinated task execution such as gripping, planting, or spraying.

**Power System:**

A 24 V, 40 Ah LiFePO<sub>4</sub> battery supplies all rover components. The system incorporates voltage regulators, fuses, and a battery management system (BMS) to ensure stable, safe, and consistent power delivery during extended operations. Low-mounted placement optimizes the rover's center of gravity for improved stability.

**Modular Sensors:**

RBR-1 supports plug-and-play sensor integration via standardized ports, allowing rapid deployment of environmental sensors such as soil moisture probes, temperature sensors, and crop health monitors. Communication is handled through I2C or analog inputs, enabling seamless sensor data acquisition and fusion.

**Modular Robotic Arm Head:**

The robotic arm features an interchangeable end-effector interface, supporting tools such as grippers, sprayers, seed planters, and specialized probes. A quick-connect electrical interface allows fast tool swaps in the field, maximizing operational flexibility and minimizing downtime.

**Software Development:****Obstacle Detection and Navigation:**

RBR-1 processes LiDAR data through SLAM algorithms to generate high-resolution local maps in real time. Obstacle avoidance is implemented using dynamic distance thresholds and path re-routing logic to ensure safe navigation across complex terrains. The system is built on ROS2, which provides a unified framework to control navigation, motor actions, and sensor coordination.

**GPS Data Integration:**

GPS data from the u-blox NEO-M8N module is fused with LiDAR-generated maps to achieve accurate global positioning. Real-Time Kinematic (RTK) correction ensures centimeter-level localization, critical for precision agriculture and large-field operations. ROS2 handles the integration of GPS inputs with LiDAR data, enabling coordinated navigation and mapping.

**Mechanical Arm Control:**

The 6-DOF robotic arm is controlled using inverse kinematics algorithms to calculate precise joint movements. The arm operates in both autonomous and manual modes, executing predefined sequences for tasks such as gripping, planting, spraying, or sampling. ROS2 enables synchronized control of the arm based on real-time sensor data, ensuring accurate and adaptive task execution.

**Real-Time Communication:**

ROS2 manages inter-process communication across all subsystems, including navigation, sensor fusion, and robotic arm control. A local WiFi module facilitates real-time data relay to external devices, enabling monitoring, task overrides, and remote control when necessary.

**Multi-Sensor Integration:**

A sensor-fusion framework combines inputs from GPS, IMU, LiDAR, cameras, and environmental sensors to support autonomous decision-making and task execution. Priority-based data handling reduces computational overhead while ensuring critical inputs such as obstacle detection or crop analysis are processed in real time.

**Components Used:****Processing Units:**

Raspberry Pi 5 (8GB RAM) – Main Processing Unit  
ESP32 – Robotic Arm Processing Unit  
Arduino RD3235 Hiletgo PCA9685 – PWM Controller



**Sensing Units:**

RPLIDAR S2 – 360° LiDAR Scanner u-blox NEO-M8N GPS with RTK – Precision Positioning pH, Soil, and Temperature Sensors – Environmental Monitoring

**Actuation & Mechanical:**

6DOF Robotic Arm – Task Execution 24V DC Motors ×6 – Drive System MG996R Servo Motors (360°) Custom 3D-Printed Wheels

**Power & Control:**

24V 40Ah Battery – Power Source Motor Drivers (Cytron Dual Channel 30A) Voltage Regulators, BMS – Electrical Backbone 12 AWG 600V Wires – Connections

**Auxiliary Components:**

12-Liter Tank – Liquid Storage

**Experimental Validation, Testing, and Results:****Test Setup:**

**To rigorously assess RBR-1's capabilities under representative operational conditions, a two-stage experimental validation was conducted:**

1. **Controlled Trials (Paved Surface):** Conducted on a level, paved track to benchmark baseline performance under predictable and stable conditions. This minimized environmental variables such as surface irregularities, dust, and traction loss, enabling precise evaluation of the rover's inherent capabilities.
2. **Field Trials (Farmland Environment):** Conducted on natural farmland terrain featuring uneven ground, loose soil, scattered vegetation, and damp patches. This stage simulated real-world agricultural challenges. Both trial stages followed identical procedures to ensure direct comparability, with observed performance differences attributed solely to environmental complexity.

**Performance Metrics:**

Rover performance was evaluated using five critical metrics: **Navigation Accuracy:** Measured as mean lateral deviation between actual trajectory and pre-programmed path. **Runtime Efficiency:** Continuous operational duration on a single full battery charge under moderate payload. **Power Consumption Profile:** Average and peak current draw recorded, including thermal monitoring for overheating risks. **Robotic Arm Precision:** Repeated gripping and placement tasks; mean placement error quantified in millimeters. **Payload Capacity:** Incrementally increased load mass until stability, traction, or maneuverability were compromised.

**Results – Controlled Surface:**

On the paved track, RBR-1 demonstrated: **Navigation:** Average lateral deviation <20 cm. **Runtime:** Approximately 5 hours with moderate payload, no significant performance drop over time. **Robotic Arm:** Mean placement error of 5 cm across 10 repetitions. **Power Consumption:** Within projected operational limits, with only two minor instances of overheating or voltage-induced slowdowns. These results established a stable baseline, confirming design efficacy for extended autonomous operation under low-stress conditions.

**Results – Farmland Environment:**

On agricultural terrain: **Runtime:** Decreased to ~4 hours due to higher torque demands on loose soil. **Navigation Accuracy:** Path deviations ranged from 20–35 cm in soft ground areas. **LiDAR-based SLAM** maintained spatial precision within 5 cm, with minor dust interference in two instances. **Payload Capacity:** Sustained up to 26 kg without compromising stability or steering control. **Robotic Arm:** Maintained placement reliability with minor adjustments needed for irregular objects. These results highlight RBR-1's robust adaptability to real-world conditions, with predictable performance trade-offs under increased environmental complexity.

**Observations and Failure Cases:**

Key operational challenges and solutions: **Traction Loss on Damp Soil:** Intermittent wheel slippage reduced navigation accuracy. Mitigated by adjusting motor torque and optimizing wheel tread design. **Arm Misalignment with Irregular Objects:** Initial gripper failures on non-uniform shapes addressed via a real-time force adaptation protocol in the control software. Overall, RBR-1 demonstrates high performance in controlled settings and resilient adaptability in agricultural environments. The insights from these trials are informing iterative design improvements,



focusing on terrain-adaptive locomotion, enhanced sensor integration, and robotic arm precision under variable field conditions.

### Conclusion:-

The RBR-1 rover demonstrates the potential of low-cost, modular robotics in addressing critical challenges in modern agriculture. By integrating a rocker-bogie suspension, LiDAR-based SLAM mapping, RTK-GPS navigation, and a 6DOF modular robotic arm, the rover can autonomously perform tasks such as spraying, payload transport, planting, and precision manipulation in both controlled and farmland environments. Experimental validation confirmed stable operation for up to 5 hours under moderate load, with navigation accuracy improved through RTK correction and payload handling up to 26 kg without significant performance degradation. Beyond technical performance, RBR-1 emphasizes accessibility and scalability.

Leveraging off-the-shelf components, open-source software, and a modular design, it provides a cost-effective blueprint for mechanization that is feasible for small- and medium-scale farmers. A comparative evaluation against existing agricultural rovers (e.g., Agrobot SW601, OpenAgBot) highlights RBR-1's advantages in payload capacity, runtime, and modular adaptability, while maintaining a lower overall cost (~USD 2,200). Future work will focus on enhancing autonomy through AI-based crop detection, improving energy efficiency with renewable integration and optimized power management, and refining mechanical robustness for extended deployment in diverse agricultural scenarios. These improvements aim to further increase operational reliability, adaptability, and practical value for real-world farming applications.

In summary, the RBR-1 rover illustrates that affordable, versatile, and scalable robotic platforms can bridge the gap between advanced agricultural robotics and the practical needs of farming communities, fostering both productivity and sustainability.

### Author Contributions:-

- Deev Somil Mehta: Served as the project lead and primary researcher. Conceived and developed the overall rover concept. Secured all funding for materials and development, designed the system architecture, and executed both the mechanical and electrical design. Selected and justified the use of motors, integrated sensors including LiDAR and GPS, and led the testing and troubleshooting of the rover. Designed the robotic arm system, procured and sourced required components, and coordinated team efforts. Wrote and structured the complete manuscript, including technical analysis, figures, and literature integration.
- Satyamedh Hulyarkar: Independently designed and built the rover's wheels. Contributed significantly to the rover's software and system integration, including LiDAR-based mapping, GPS data handling, and incorporating aspects of the Robot Operating System (ROS). Developed a functional system dashboard and designed a physical controller to operate both the motors and the robotic arm, enhancing manual and semi-autonomous control.
- Kavish Gupta: Focused on the physical construction of the robotic arm. While the arm's design and specifications were created by the lead author, Kavish contributed by assembling and fabricating the parts into a functional arm module. His work translated the design schematics into a working physical subsystem of the rover.
- Shaurya Karmakar: Assisted in the initial stages of software development. Contributed by writing portions of the code framework, particularly for the robotic arm module, and experimented with GPS data handling for navigation-related functions. His inputs supported the early phases of integrating hardware with software.
- Note: All authors are currently 12th-grade students.

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