Design of a Four-Wheeled Rocker Bogie Vehicle with Load-Pulling, Spraying, and Autonomous Navigation for Agricultural Applications

ME 306
Course project
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Abstract

This project presents the design of a four-wheeled rocker bogie vehicle capable of traversing uneven and rugged terrains while maintaining stability and balance. The rocker-bogie mechanism is a suspension system primarily used in space exploration rovers to allow them to traverse rough terrain and maintain contact with the ground. It consists of rocker arms connected to a bogie, which connects to wheels. This design allows the wheels to move independently, enabling the rover to climb over obstacles and maintain stability on uneven surfaces. Our design adapts this mechanism into a compact four-wheeled configuration, reducing structural complexity. The project involves the mechanical design of the vehicle chassis and spraying system. The significance and purpose of this project is to incorporate spraying technique in to this four-wheeled rocker bogie vehicle so that it can travel in uneven terrain and can be useful in agriculture and add pulling mechanism to carry transport essential items such as fertilizers, seeds, harvested crops, tools, or water tanks across uneven terrain, thereby reducing manual labor and increasing operational efficiency.

1 Introduction

The rocker bogie mechanism is a smart and simple way of allowing vehicles to move smoothly over rough and uneven surfaces. It was first developed by NASA for their Mars rovers to help them explore rocky terrain without getting stuck or tipping over. In this system, the vehicle's wheels are connected in such a way that when one wheel goes over an obstacle like a rock or bump, the others adjust naturally, keeping the vehicle stable. The design includes two main parts: a "rocker," which is a large arm connected to the main body, and a "bogie," which is a smaller arm with two wheels. Both sides of the vehicle are linked, so they work together to balance the load and maintain stability. Why its useful:

- It helps the vehicle climb over rocks or bumps almost twice as tall as the wheel size..
- It keeps the body of the vehicle level and steady, even when the ground is uneven.
- It doesn't need complex electronics or active suspension—it works purely through clever mechanical design.

1.1 Problem statement

On agricultural landscapes with rough terrain, normal wheeled tractors have difficulty retaining stability and efficiently transporting loads and spraying crops. There is a demand for a terrain-adaptive, multi-purpose vehicle that can handle rugged terrain and, in addition, reliably and conveniently undertake vital farming activities such as spraying and material handling.

1.2 About this project

This project focuses on designing and understanding the rocker bogie mechanism, with a simplified four-wheeled version to reduce mechanical complexity while maintaining terrain adaptability. The modified design is tailored for agricultural applications, especially in rural areas, to ease operations like load transport and crop spraying. Additionally, the project aims to incorporate autonomous functionality by mapping specific points on a field, enabling the vehicle to follow a predefined path without manual control, thereby increasing efficiency and reducing labor requirements.

1.3 Aim

The main aim of this project is to design and develop a four-wheeled rocker bogie vehicle equipped with load-pulling, spraying, and autonomous navigation capabilities for efficient agricultural use on uneven terrain.

1.4 Objectives

- To simplify the traditional rocker bogie mechanism by developing a stable four-wheeled version.
- To integrate a spraying system for agricultural applications like pesticide or fertilizer distribution.
- To enable the vehicle to pull loads across uneven terrains commonly found in farmlands.
- To incorporate basic autonomy by mapping coordinates and enabling the vehicle to follow a predefined path.

1.5 Scope of study

Through this project we learned,

- mechanical design of the chassis and suspension system
- basic calculations for hardware and component selection
- research into integrating an autonomous navigation system based on mapped coordinates.
- Full-scale fabrication and advanced autonomy are considered for future work beyond this initial phase.

2 Literature Review

IJRASET [1] during the research highlighted the growing relevance of rocker bogie mechanisms in agricultural applications. The paper emphasized how the mechanism, originally used in space rovers, can be adapted for farming environments to traverse uneven terrain efficiently. It discussed the importance of the system's passive suspension and ability to reduce human effort in manual tasks such as spraying and transporting loads across difficult landscapes.

SAGE Journals [2] in a comprehensive review of over 20 different rover designs, found that a four-wheeled rocker bogie system can maintain more than 90 percent of the traction efficiency offered by traditional six-wheeled NASA rovers. The study highlighted that the reduced-wheel configuration significantly lowers the mechanical complexity and weight, making it ideal for real-world rural applications where cost and simplicity are critical.

IJIRSET [3] during their research presented a practical fabrication model for a terrain-traversing rocker bogie vehicle. The paper focused on cost-effective material selection, ease of manufacturing, and functional testing on uneven surfaces. It also supported the integration of load-carrying and spraying systems, making the vehicle more useful for small-scale agricultural activities and enhancing field efficiency.

2.1 Suggestions Based on Literature Review

The review of multiple studies suggests that a four-wheeled rocker bogie mechanism offers nearly the same traction and stability as traditional six-wheeled designs while significantly reducing mechanical complexity. Therefore, opting for a four-wheel configuration is a smart approach. Studies like those from IJIRSET highlight the advantage of integrating additional features such as load pulling and spraying systems. Incorporating these into a single platform will maximize the utility of the vehicle, especially for small and marginal farmers.

3 Design

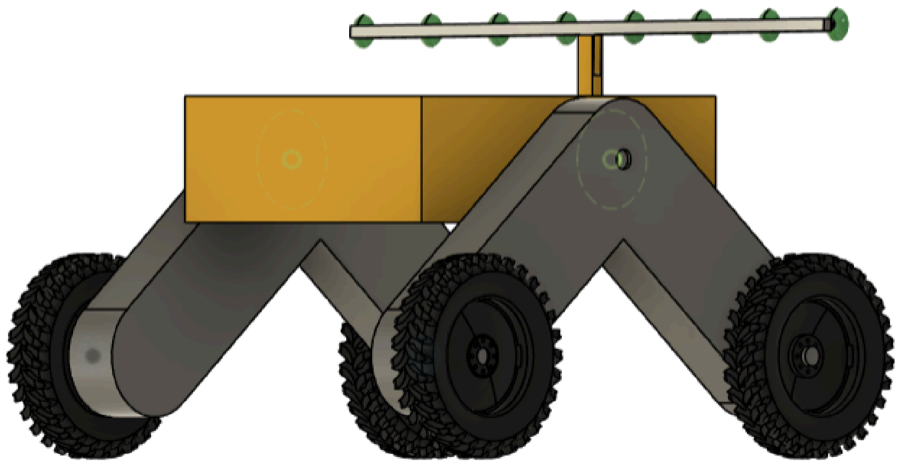
The project main goal is to design a four-wheeled rocker bogie vehicle capable of navigating rough agricultural terrains while also performing spraying and load-pulling tasks. The design ensures that the center of gravity remains low and centrally located, improving vehicle stability on sloped or uneven terrain. All electronics including the Raspberry Pi, GPS module, IMU, motor drivers, and power regulator are mounted on a separate acrylic board fixed on top of the chassis. The battery is placed inside a metal box for protection from dust and moisture.
Wheel type: 48 cm diameter rubber wheels
The structure is designed with sufficient ground clearance of 58 cm to avoid obstruction by soil clumps or uneven surfaces in the field.
Dimensions: height 1063mm, length 1650, width 1445mm,wheel base 1149mm

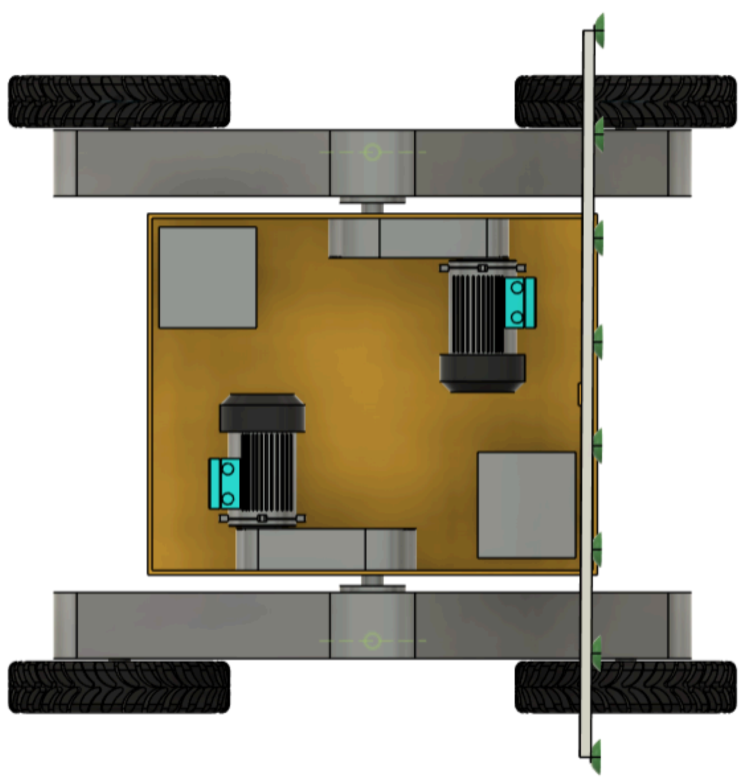
The design ideas were modeled using Fusion 360 to produce 3D model.(see next page) Additional information: For our design, we have chosen structural steel as the primary material for fabrication due to its excellent mechanical and practical properties.Structural steel is known for its high strength and durability, making it ideal for applications that involve carrying loads or operating on rough terrain.Its rigidity ensures minimal deformation under mechanical stress, which is essential for maintaining the vehicle's stability and geometry during operation.

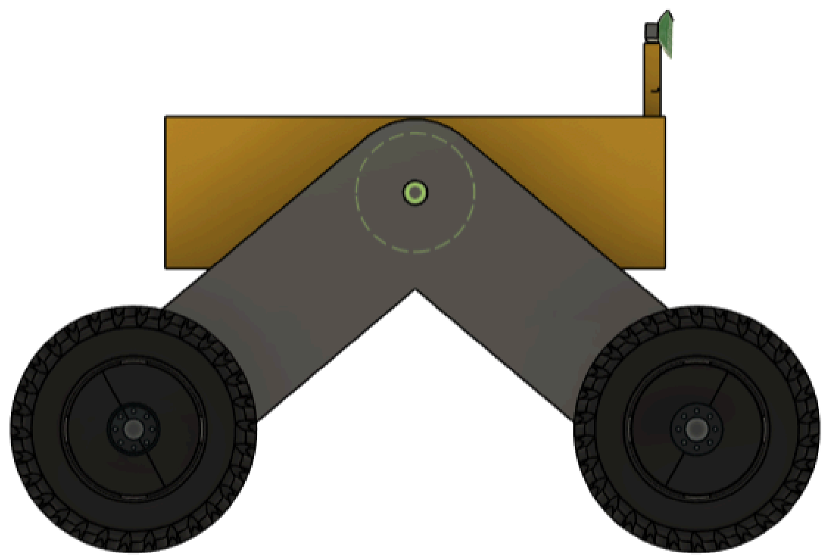
3.0.1 Sprayer Design:

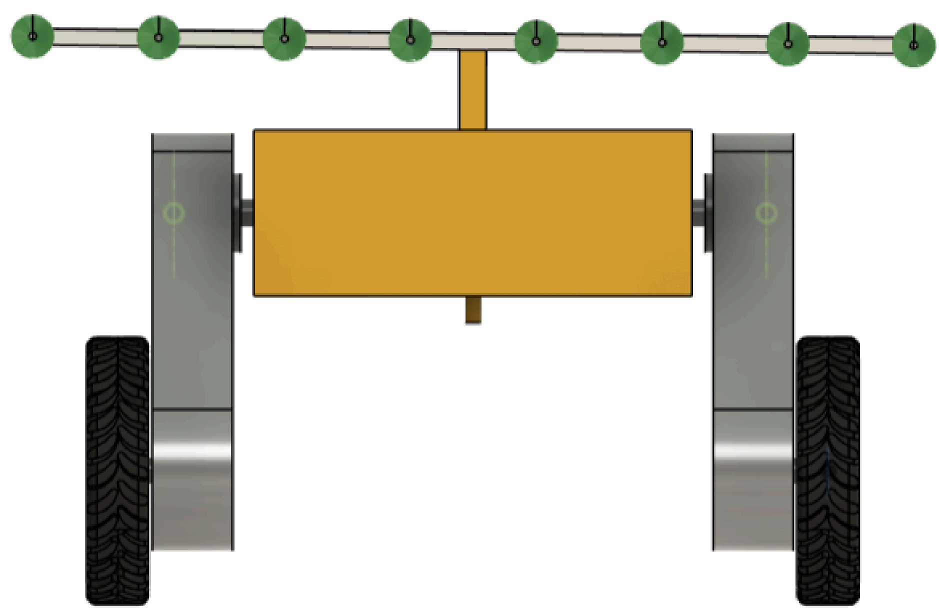
The spraying mechanism in our vehicle design was inspired by traditional agricultural spray carts commonly used by farmers in rural areas. One such example is shown in the figure ,where a manually pushed trolley integrates a mounted tank, a pump system, and spray nozzles positioned on a horizontal boom. This setup allows for efficient and uniform spraying across multiple crop rows in a single pass. From this concept, we designed our own sprayer system.

Figure 1: Caption









4 Hardware

4.1 Motor Specifications

- Rated Power: 500W
- Style: Brushed Motor Permanent Magnet.
- Supply Voltage: 24V.
- Current Draw (Rated): 27.4A.
- Rated (constant) Torque: 1.9 Nm.(19.37kgcm)
- Speed: 2750 RPM.
- Number of teeth: 11, Pitch 6.35 25 Chain.
- Speed: 2750 RPM.
- Motor Shaft Dia: 11.8mm
- Weight: 4.30 Kg.

[Motor+gear pinion combination to operate the wheels and the whole system]

4.2 Load-Pulling Capability Analysis of Rocker-Bogie System

Total Mass and Weight Distribution (Under no load conditions)

- **Total vehicle mass:** $M_{total} = 4 \times 12\ kg + 40\ kg = 88\ kg$
- **Total weight (W):** $W = M_{total} \times g = 88 \times 9.81 \approx 863\ N$
- **Assume equal load distribution per wheel:** Weight per wheel $\approx \frac{863}{4} \approx 216\ N$

Rolling Resistance Force (F_{rr})

- Assuming soft soil, rolling resistance coefficient:

$$C_{rr} \approx 0.2 \quad ; \quad F_{rr} = C_{rr} \times W = 0.2 \times 863 = 172.6\ N$$

Slope Climbing Force (F_{slope})

- **Worst-case scenario (15° incline):**

$$F_{slope} = M_{total} \cdot g \cdot \sin(\theta) = 88 \cdot 9.81 \cdot \sin(15^\circ) \approx 223.6\ N$$

Total Force Per Motor (F_{motor})

- **Since each motor drives two wheels:**

$$F_{motor} = F_r + F_{slope} = 172.6 + 223.6 \approx 198\ N$$

- **Speed:**
  $5\ km/h = 1.39\ m/s$ (Assume a speed of approximately 5 km/h for agricultural use)
- **Angular velocity:**
  $\omega = vr = 1.390.235 \approx 5.9\ rad/s$
- **Required Motor RPM (with gearbox):**
  Required motor RPM $= 5.9 \cdot 602\pi \approx 56.3\ RPM$
- **Required Torque Calculation:**
  Using $T = F \cdot r$
  Wheel radius: $r = 0.235\ m$

$$T_{motor} = 198 \cdot 0.235 = 46.5\ Nm$$

  Required torque with safety margin: $T_{required} \approx 60\ N{\cdot}\text{m}(Add30\%SafetyMargin)$

Basic Gear Reduction Principle

$$T_{wheel} = T_{motor} \cdot G$$

$$G = N_{driver}N_{driven}$$

where

- T_{motor}: Torque output from motor
- T_{wheel}: Torque delivered to wheel
- ω_{motor}: Angular speed of motor
- ω_{wheel}: Angular speed of wheel
- N_{driven}: Number of teeth on the driven gear
- N_{driver}: Number of teeth on the driving gear

Gear Reduction Considerations

Gear Ratio Calculation and Load Capacity Estimation

To achieve the desired torque of approximately $60\ Nm$ at the wheels, a gear reduction system is necessary. Assuming the motor's rated torque is approximately $1.8\ Nm$ (typical for a 500W motor operating at 2750 RPM), the required gear ratio can be estimated as:

$$RequiredGearRatio = \frac{DesiredTorqueatWheel}{MotorTorque} = \frac{60}{1.8} \approx 33.3:1$$

$$Or \quad GearRatio = \frac{T_{wheel}}{T_{motor}} = \frac{60\ Nm}{1.8\ Nm} \approx 33.3:1$$

Therefore, a gear reduction ratio of approximately $35:1$ should suffice. This can be practically implemented using a combination of gearbox stages and sprocket-chain arrangements.

Estimated Load Pulling Capacity

Assuming a total available torque at the wheels of $T_{wheel} = 60\ Nm$, and a wheel radius of $r = 0.235\ m$, the available tractive force F at the wheel-ground interface is:

$$F = \frac{T_{wheel}}{r} = \frac{60}{0.235} \approx 255.3\ N$$

Assuming negligible losses and soft soil with a rolling resistance coefficient $C_{rr} \approx 0.2$, the maximum theoretical load (W_{load}) that can be pulled is:

$$F_{rr} = C_{rr} \cdot W_{load} \Rightarrow W_{load} = \frac{F}{C_{rr}} = \frac{255.3}{0.2} \approx 1276.5\ N$$

$$\Rightarrow M_{load} = \frac{1276.5}{9.81} \approx 130\ kg$$

Conclusion: With the given motor and gear reduction, the rocker bogie system can theoretically pull a load of approximately **130 kg** on soft soil.

4.3 Field Load Capability Analysis with Gear-Pinion Drive

Torque Transmission via Gear-Pinion Mechanism

- Torque at wheel using gear-pinion:

$$T_{wheel} = T_{motor} \times G = 1.9 \times 30 = 57 \ Nm$$

- Torque transfer method (gear-pinion vs gearbox) does not affect magnitude, only efficiency and mechanical losses vary slightly.
- Considering typical gear-pinion efficiency of 90%:

$$T_{available} = 57 \times 0.9 = 51.3 \ Nm$$

Field Resistance Analysis

Assume:

- Loose soil/mud (agricultural terrain): $\mu_r = 0.15$
- Slope angle: 5° (mild incline)
- Safety factor (SF): 1.3

Total Resistance Force (per motor): Let total mass: $M_{total} = 88 + X \ kg$, where X is the additional payload.

$$F_r = \frac{M_{total}}{2} \cdot g \cdot (\mu_r + \sin(5^\circ)) \cdot SF$$

Given:

$$\sin(5^\circ) \approx 0.087, \quad g = 9.81 \ m/s^2$$

$$F_r = \frac{(88+X)}{2} \cdot 9.81 \cdot (0.15 + 0.087) \cdot 1.3 = \frac{(88+X)}{2} \cdot 9.81 \cdot 0.237 \cdot 1.3$$

$$F_r \approx 1.51 \cdot (88+X)$$

Torque required:

$$T = F \cdot r = 1.51 \cdot (88+X) \cdot 0.235$$

Set $T \leq T_{available} = 51.3 \ Nm$:

$$1.51 \cdot 0.235 \cdot (88+X) \leq 51.3 \Rightarrow 0.354 \cdot (88+X) \leq 51.3 \Rightarrow 88+X \leq \frac{51.3}{0.354} \approx 145 \Rightarrow X \leq 57 \ kg$$

Conclusion: Maximum extra payload on agricultural terrain with slope and rolling resistance is approximately **57 kg** (including 30% safety margin).

Motor Capability Check:

With a gear-pinion reduction ratio of 30:1, the motor provides 51.3 Nm torque at the wheel (factoring in gear losses).

4.4 Sprinkler System Setup (Manual Operation)

Sprinkler System Components

A. Water Tank

- Size: 10–20 L recommended (based on payload and balance)
- Position: Mount near center of chassis for balance

B. Water Pump

- Type: DC diaphragm pump (12V or 24V)
- Flow rate: 2–5 L/min
- Pressure: 0.5–1.0 MPa
- Example: 12V Mini Diaphragm Pump, 130 PSI

C. Nozzle/Sprinkler

- Type: Rotary or fixed head
- Range: 1–3 m based on pressure
- Mounting: On a vertical pipe (front, back, or center)

D. Pipes and Valves

- Material: Lightweight PVC or silicone pipes
- Add-on: Solenoid valve (12V or 24V) to control water flow electronically

Control System Design

A. Microcontroller

- Use an **Arduino**, **ESP32**, or **Raspberry Pi** depending on system requirements.
- Connect components:
  - Water pump (via relay)
  - Solenoid valve
  - Optional: Environmental sensors (e.g., soil moisture)
  - Motor controller (shared with drive system)

B. Automation Triggers

1. Distance traveled (e.g., trigger every 5 meters)
2. Soil moisture sensor
3. Time-based irrigation schedule
4. Manual override via remote control

Pin Definitions (Arduino Example)

```
#define PUMP_PIN 8
#define VALVE_PIN 9
#define SOIL_SENSOR_PIN A0
```

5 Autonomy

For autonomous operation in farming environments, a combination of sensors and onboard processing devices is employed. This integrated system enables the vehicle to follow a pre-programmed route, detect obstacles, and make navigation decisions automatically without human intervention.

The **GPS Module (u-blox NEO-6M)** is used to provide real-time global positioning in terms of latitude and longitude. This information helps in mapping the vehicle's location and tracking its path across the agricultural field. It serves as the primary input for location-based control strategies.

An **Inertial Measurement Unit (IMU), such as the BNO055**, along with a **compass sensor like the HMC5883L**, is employed to detect the vehicle's orientation. These sensors measure yaw, pitch, and roll, allowing the system to understand the vehicle's heading and body posture. They assist in maintaining stability while navigating uneven terrains and help align the directional movement.

Wheel encoders are used to measure the number of wheel rotations, from which the distance traveled by the vehicle is calculated. This is particularly useful in dead reckoning — a technique that estimates position based on known velocity and time — especially when GPS signals become weak or are temporarily lost.

The **LiDAR sensor (RPLiDAR A1)** plays a crucial role in obstacle detection by performing 360° scanning of the surrounding environment. It enables real-time detection of static and dynamic objects in the field. For more advanced levels of autonomy, the LiDAR data can be used in Simultaneous Localization and Mapping (SLAM), allowing the robot to build a map while tracking its own location.

The **Raspberry Pi 4** acts as the primary processing unit or the "brain" of the autonomous system. It fuses data from various sensors like the GPS, IMU, and wheel encoders to estimate position using dead reckoning. It processes these inputs to either follow a pre-defined navigation path or dynamically build maps using SLAM. The

Raspberry Pi also handles higher-level decision-making and sends appropriate motion commands to the motor driver.

Finally, the **Motor Driver (L298N)** receives control signals from the Raspberry Pi regarding speed and direction. It converts these signals into electrical outputs that drive the DC motors, thus enabling forward, reverse, or turning motions based on the autonomous system's decisions.

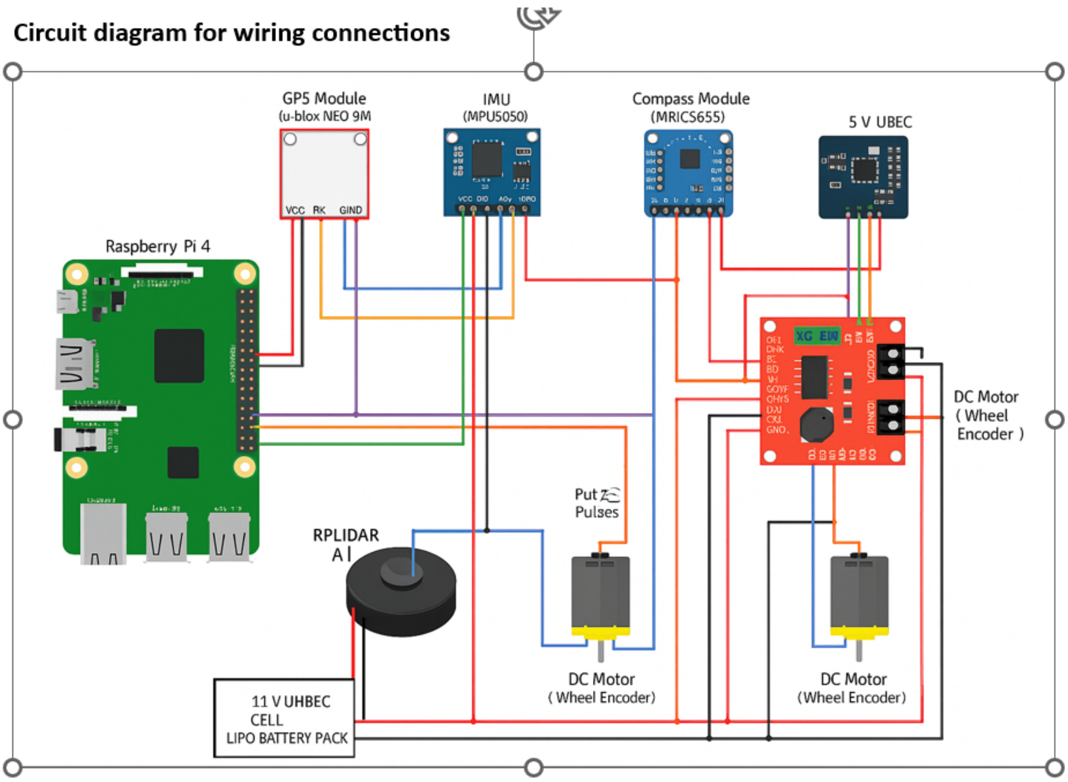


Figure 2: Circuit diagram for wiring connections:

6 Observations and Discussion

6.1 4-Wheel Rocker Bogie Advantages and Considerations

6.1.1 Advantages

Simpler Design: The 4-wheel rocker bogie system features a reduced mechanical complexity compared to its 6-wheel counterpart. With fewer moving parts—such as joints, arms, and wheels—the design becomes more straightforward to conceptualize and implement. This simplicity can lead to faster prototyping, easier troubleshooting, and lower fabrication costs. For agricultural or field-based applications where extreme terrain traversal is not critical, a 4-wheel setup offers a robust yet manageable alternative.
Potentially Reduced Weight: By utilizing fewer structural and mechanical components, a 4-wheel system naturally results in a lighter vehicle. This weight reduction can have multiple benefits, such as easier transportation, reduced stress on structural joints, and improved energy efficiency. Lighter vehicles also tend to be more responsive to control inputs and can operate longer on limited power sources like batteries or solar panels—an important factor for autonomous field robots.

6.1.2 Considerations:

Cost and Complexity: While 6-wheel rocker bogie systems provide superior stability and obstacle-handling capabilities, they come with increased costs and technical demands. More wheels require additional motors, sensors, and control logic, making the system more complex to assemble and maintain. For budget-sensitive or time-constrained projects, this increased complexity can pose significant challenges.
Weight and Power Consumption: The additional components in a 6-wheel system inevitably add to the overall weight of the vehicle. Heavier systems require more power to operate, particularly during uphill traversal or when carrying payloads. This not only affects battery life but may also necessitate larger power supplies, which further adds to the system's weight. In comparison, a 4-wheel design minimizes these concerns by maintaining a lighter frame and reducing the number of active drive units, thereby conserving energy and enabling longer operational durations.

7 Future Scope

While the current design successfully demonstrates autonomous navigation, load-pulling, and spraying functionality on uneven agricultural terrain, there are several areas where the system can be enhanced to further improve efficiency and functionality.

One potential improvement is the development of a fully **automated sprinkler system**. This can involve integrating real-time soil moisture sensors and programmable irrigation logic, allowing the vehicle to make intelligent decisions about when and where to spray water or pesticides. This advancement would not only reduce manual intervention but also optimize water usage, which is critical in precision agriculture.

Another promising direction is the **implementation of seed sowing mechanisms**. By integrating a controlled seed dispensing unit with a soil-cutting or trenching attachment, the vehicle can be adapted to perform sowing operations in addition to spraying. This would transform the system into a multi-functional agricultural robot capable of handling the entire crop cycle—from sowing to spraying—especially useful for small and medium-scale farms.

Additionally, **increasing efficiency through optimized gear setups** can significantly improve both power consumption and performance. By dynamically adjusting gear ratios or integrating electronically controlled variable transmission systems, the vehicle can adapt to different terrains, loads, and task requirements. This optimization could lead to smoother operation, extended battery life, and better speed-torque balancing depending on the activity being performed.

In summary, the system lays a strong foundation for a modular and scalable agricultural robot. Future work can expand its capabilities to cover a broader range of field operations, making it a highly versatile tool in sustainable and smart farming.

References

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