INTERNATIONAL ROVER CHALLENGE 2025

YUVAAN

INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI

Team Name

YUVAAN IITG

Institute Name

Indian Institute of Technology, Guwahati

Team Lead

Anurag Baruah

Contact Info:

+91 8584037201

INTRODUCTION

This System Design and Development Review (SDDR) Report documents the comprehensive process and methodologies employed by our team in the design and development of “Yuvaan”, a rover specifically made according to the problem statement given for the International Rover Challenge (IRC) by Space Robotics Society (SPROS).
Our team's primary objective was to design a versatile rover equipped to navigate and explore uncharted terrains. It features capabilities for object retrieval, transport, and maintenance tasks through a robotic arm, along with soil sample collection and analysis via an integrated astrobiology testing module.

PROJECT MANAGEMENT

TEAM ORGANISATIONAL STRUCTURE

Hierarchy

Position	Responsibility
Mentor / Faculty Advisor	Coordinates access to institutional resources, including 3D printing and Central Workshop machinery. Provides technical guidance and expert advice to support the student team in overcoming challenges.
Team Lead	Oversees and coordinates subteams to ensure a seamless, modular workflow across the project. Manages essential non-technical aspects, including material procurement, arrangement of manufacturing facilities and more
Heads	Designated module leads who support the team lead in rover development, facilitating effective coordination with sub-teams. Each lead oversees specific modules, ensuring integration and alignment with project goals.

Team Division

Module / Sub Team	Responsibility
Chassis and Mobility	Point of contact for design, construction, and testing of the rover's structural and mobility components, ensuring robust and adaptable movement across terrains.
Manipulator System	Responsible for the development and integration of the robotic arm, including object retrieval, handling tasks, and coordination with other subsystems.
Astrobiology Module	Leads the design and functionality of the onboard soil sampling and analysis unit, collaborating on sample testing and data gathering.
Electronics and Power	Oversees all electrical systems, power distribution, and energy management, ensuring reliable and efficient operation.
Communication Systems	Manages wireless protocols, signal integrity, and communication reliability for remote control and data transmission.
Software and Control	Develops control algorithms, software architecture, and system integration, enabling responsive and autonomous rover functions.

RESOURCE MANAGEMENT

Materials and Components

Name	Procurement Source
Rhino RMCS series motors and Cytron Motor Drivers	Robokits India
Gearbox FW-40-30-71B5	Local Market - Guwahati
Stainless Steel Sheet and pipes (rectangular and round), Aluminium Sheet, Mild Steel Rods, Nuts and Bolts	Local Market - Guwahati
Aluminium T slot extrusion rods and L - Joints	Robokits India
Batteries (6s)	Robokits India
3D printer filaments (TPU, PLA)	Local Market - Guwahati

Facility Access

Name	Location
3D Printing	Various Labs in IIT Guwahati
Lathe, Milling, CNC Plasma Cutting, Welding etc.	Central Workshop, IIT Guwahati
Outsource Manufacturing	MSME-TRTC and Assam Metal Works Ltd.

Budget Allocation

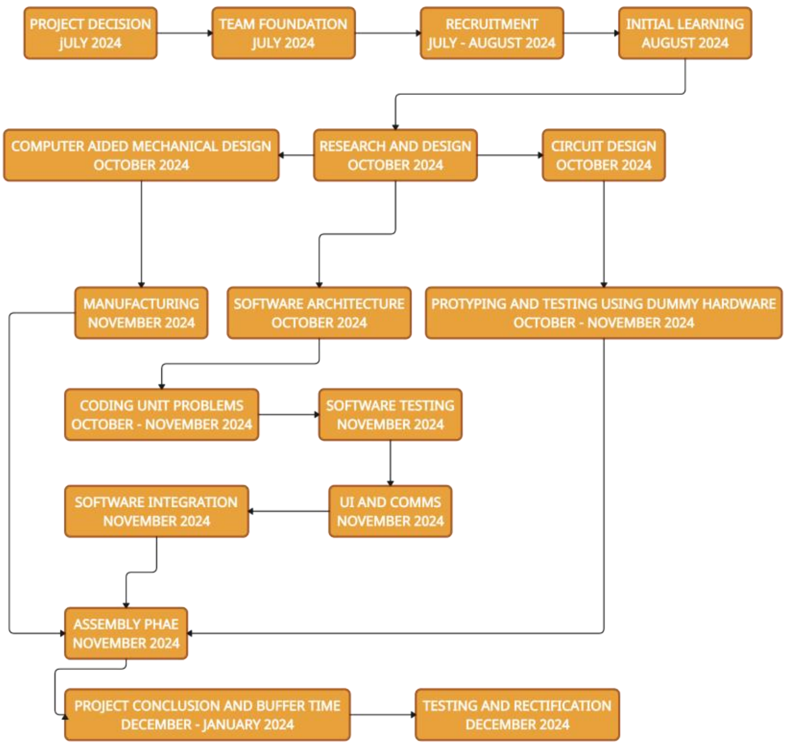
Name	Estimated Cost (in Rupees)
Raw Materials	14,000
Machine Parts, Nuts and Bolts etc.	11,000
Motors, Microcontrollers, Jetson, Battery	1,30,000
Outsourcing	25,000
Total	**1,80,000**

Funding Sources

1. Basic Robotics Club IITG funding through Techboard IIT Guwahati
2. Prize Money from various other competitions

PROJECT PLANNING

Phase	Timeline	Description
Project Decision	July 2024 (1st week)	Decided to participate in SPROS IRC and IRDC 2025.
Team Foundation	July 2024	Held meetings with team lead, heads, and mentor; recruited members for IRC 2025.
Recruitment	July - August 2024	Task-based submissions and personal interviews held during summer break.
Initial Learning	August 2024	No team division; members explored interests; analysed previous IRC submissions.
Research and Design	October 2024	Conducted research and design in CAD, electronics planning, and software design.
Manufacturing Start	October 2024	Began manufacturing key components of the rover.
Current Phase	November 2024	Manufacturing and assembly phase; high-quality 3D printing and finishing work.
Testing and Rectification	December 2024	Quality checks, mission testing, and rectification of any issues.
Project Conclusion	December 2024	Final assembly and testing. Ongoing software upgrades
Buffer Time	January (two weeks) 2024	Planned Buffer Time

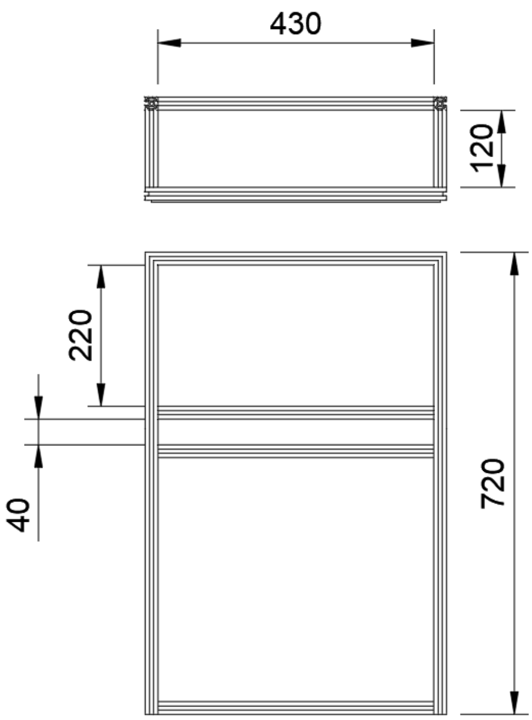


CHASSIS AND MOBILITY

CHASSIS

Chassis is one of the most fundamental parts of the rover. It serves as the backbone, providing the necessary structure and stability. It supports all the other components of the rover.

The chassis frame is made up of Aluminium T-Slot extrusions, clamped together to take the desired shape designed to hold the weight and support all the other components of the rover. The chassis base is a single piece sheet metal made of stainless steel (SS-304) with a hole to accommodate the drill assembly of the Astro-Bio module.



SUSPENSION

Our rover uses *Rocker* Suspension (modified to accommodate the *Z Axis* steering), containing 2 rigid angular members, able to rotate independently about an axis parallel to the chassis base in the lateral direction.

Primary Objective

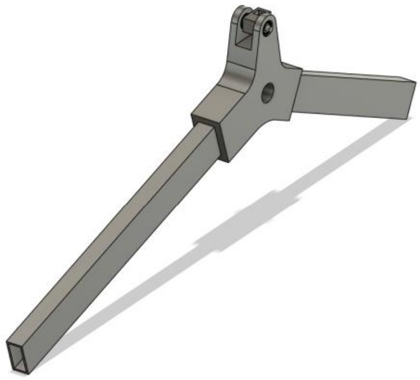
- Maintain wheel contact for optimal traction on diverse terrains.
- Distribute weight evenly and preserve ground clearance.

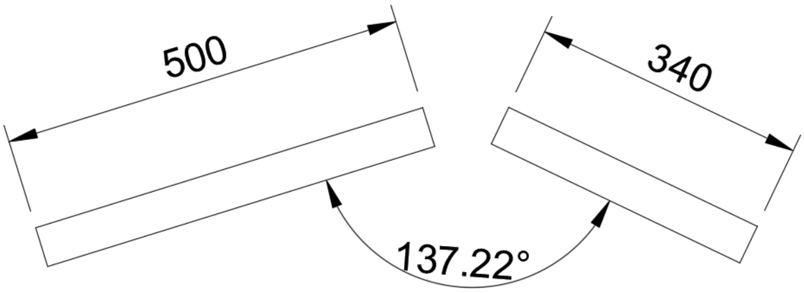
Load and Material Choice

- *Assumed Load*: Each suspension link is expected to support a maximum load of 32.5 kg (half the rover's 65 kg weight).
- *Factor of Safety:* Applied load increased to 40 kg per link, equating to a total force of 40 × g Newtons, where g represents gravitational acceleration.
- *Material:* Stainless Steel (SS-304) was selected for its high strength and resistance to abrasion and corrosion.

Angle Optimisation

- Using trigonometry principles, increasing angles θ (theta) and φ (phi) reduces downward load transfer to the wheel subsystem.
- Optimised angles help prevent excessive normal force, reducing risks of the rover digging into sandy or loose terrain.
- Angles were maximised to enhance ground clearance and maintain axle-to-axle distance.





WHEELS

Our wheel design is tailored for dynamic and rugged terrains, enhancing the rover's navigation and efficiency. Key features include:

Honeycomb Structure:

- Hexagonal cell design distributes weight effectively and allows controlled deformation at contact points.
- Increases contact area, improving grip and weight distribution over obstacles.

Aluminum Rim:

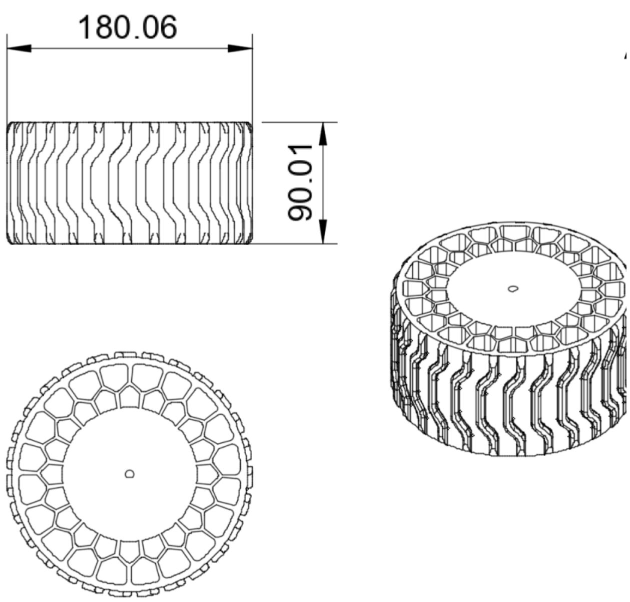
- Provides structural integrity and durability on rugged terrain.
- Serves as a protective housing for motors and encoders, shielding them from dust.

Material (TPU 95A):

- Thermoplastic Polyurethane chosen for flexibility and shock resistance.
- High abrasion resistance minimises grip wear on harsh surfaces.

This design enables reliable traction and resilience across varied terrains.

Displacement Analysis of the wheel



Z - AXIS STEERING MECHANISM

Each rover wheel is equipped with a Z-axis steering mechanism, enabling independent rotation about an axis perpendicular to the chassis.

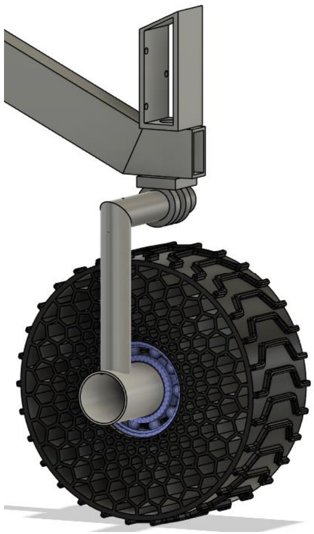
Function and Structure:

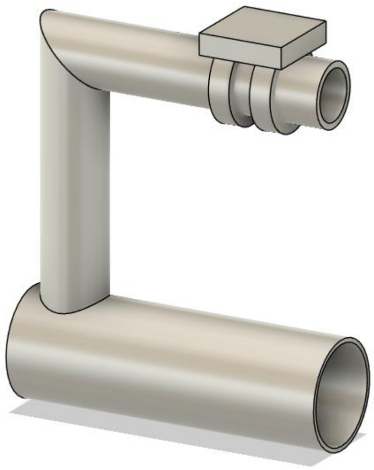
- Acts as a dynamic link between the suspension and wheel subsystems, allowing precise manoeuvrability.
- Constructed from hollow SS-304 stainless steel pipes that house motors, couplings, and shafts.

Load Distribution:

- Designed to ensure the load line passes through the wheel centre, minimising unbalanced moments on the suspension and motor housing.

This design enhances control and stability, essential for challenging terrains.





DIFFERENTIAL

The differential bar is essential for maintaining rover stability on uneven terrain, keeping the base nearly horizontal.

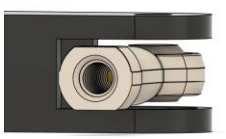
Balance and Counterbalance:

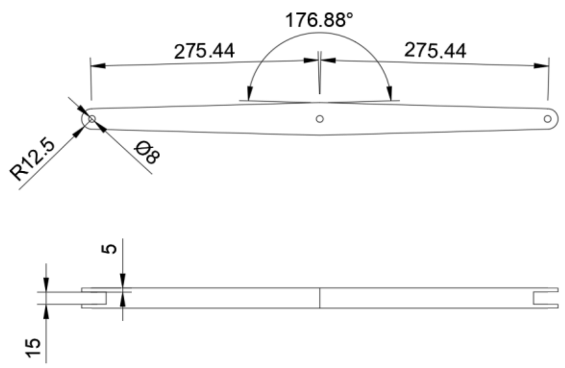
- Acts as a balancing scale, adjusting to weight shifts as the rover navigates rocks and craters.
- Maintains equal curvature radius of suspension links during turns for smooth operation.

Material:

- Constructed from aluminium for optimal strength-to-weight ratio and durability.

This component enables stable, balanced movement across challenging landscapes.





MANIPULATOR SYSTEM

ROBOTIC ARM

The robotic arm is the primary tool for the rover's pick-and-place mission. It is designed for stability, lightness, and a suitable workspace.

Specifications:

- Degrees of Freedom: 5
- Components:
    - Base, Link 1, Link 2, and Wrist Assembly
    - Base, Shoulder, and Elbow joints, with Pitch and Roll joints near the end effector.

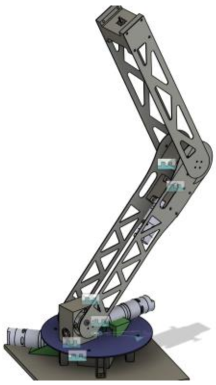
Joint Functions:

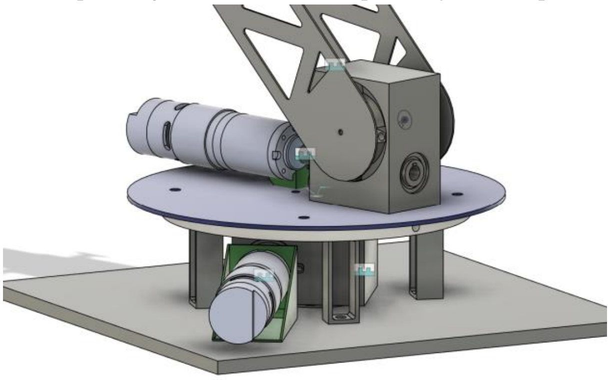
- Base Joint: Provides rotary motion about an axis perpendicular to the chassis.
- Shoulder Joint: Enables up-and-down movement, connecting the base to Link 1.
- Elbow Joint: Connects Link 1 to Link 2, mimicking an elbow-like motion.
- Pitch and Roll Joints: Provide final positioning flexibility for the end effector.

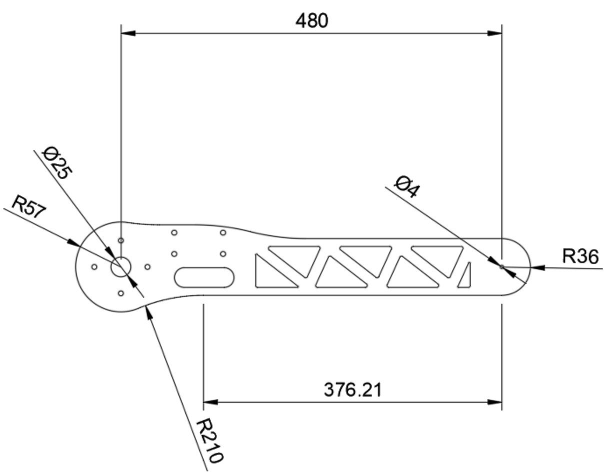
Construction:

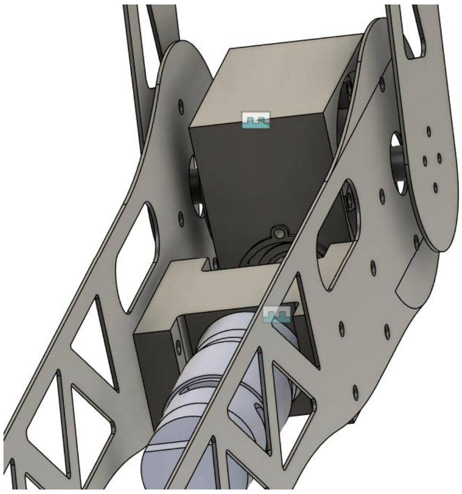
- Links are fabricated from SS-304 stainless steel sheets, cut to optimise area moment of inertia, reducing bending displacement while keeping the weight low.
- Links are attached to mild steel shafts using nuts and bolts for secure assembly.
- Mild Steel couplers connect various arm components for precise actuation.

This arm design ensures precise control and adaptability, essential for complex object manipulation.









GRIPPER

The end effector is a lead screw-actuated, double 4-bar, 2-finger gripper crafted from 3D-printed PLA (100% infill, triangle pattern) and is optimised for secure handling of varied object sizes. Key features include:

Base Module:

- Encases all linkage components and a firmly mounted DC motor.
- Integrates an Intel RealSense depth camera to provide close-up video and depth data during pick-and-place and maintenance operations.

Lead Screw Mechanism:

- The motor drives a lead screw coupled with a linear motion member containing a matching lead screw nut.
- Rotation of the motor initiates linear motion in this member, activating the dual 4-bar mechanism on each side.

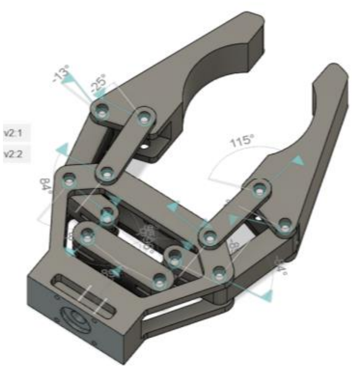
Gripper Linkage:

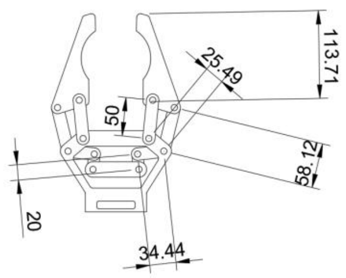
- The dual 4-bar linkage allows the outermost coupling members to act as the jaws, achieving an adaptable grip on diverse objects.
- The jaw ends feature a pinching design, facilitating manipulation of small objects with precision.

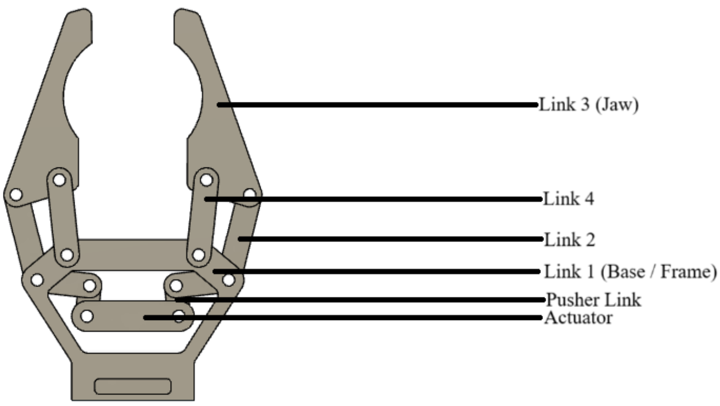
High-Friction Gripping Surface:

- "Palm" surface is layered with corrugated rubber (or low infill TPU), enhancing grip reliability through high friction contact.

This design enables robust and precise gripping capabilities, making it suitable for a variety of tasks.







ASTROBIOLOGY MODULE

DRILL MECHANISM AND SOIL COLLECTION

Our soil extraction system employs an auger drill bit and a linear actuator for efficient collection. The process includes:

- **Drilling:** A linear actuator drives the drill vertically to penetrate the soil.
- **Lifting:** Drill retracts without rotation, retaining soil on the bit.
- **Discharge:** Drill rotates upon retraction, releasing soil tangentially.
- **Collection:** Discharged soil is funnelled into designated containers.

This method ensures efficient soil retrieval and controlled sample collection.

TESTING MECHANISM

The testing mechanism consists of a plate carrying six beakers, and a syringe mechanism for the flow of chemicals. The chemicals from the syringe assembly will be dropped into four containers. After the complete reactions, the sample changes its colour. The spectrometer will detect the resulting colour, and the USB microscope will detect the texture of the soil.

Sample Detection Tests:

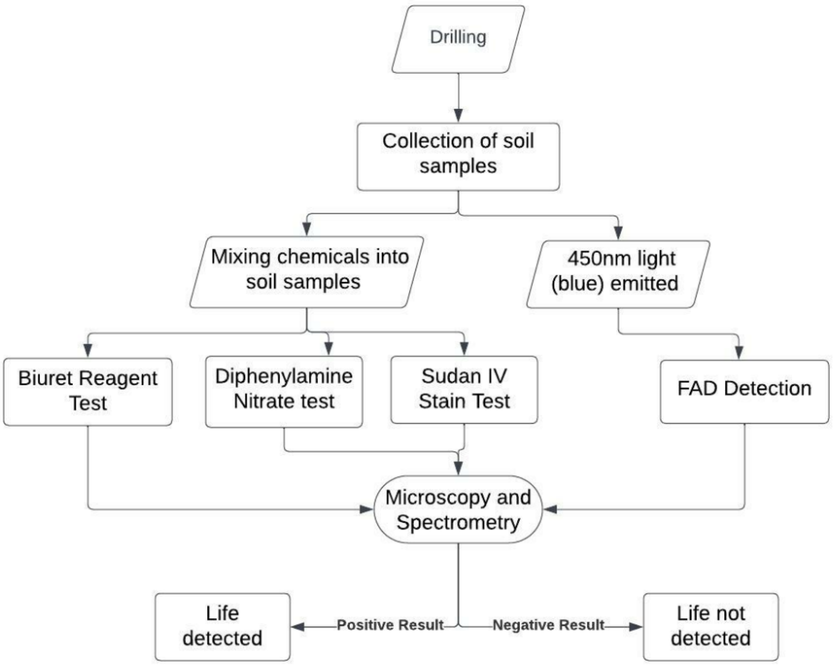
Detection of life chances is determined by the presence of some major organic compounds such as proteins, lipids and nitro compounds which are present in most living organisms.

- **Biuret Reagent Test:** Biuret Reagent is used to test proteins that give Purple Colour a positive result.
- **Diphenylamine Nitrate Test** used to test nitrates which gives Blue Colour as a positive result.
- **Sudan IV Stain Test** used to test lipids which gives Reddish Brown Colour as a positive result.
- **Flavin Adenine Dinucleotide** detected by fluorescence at wavelengths of 450nm, observed under a USB microscope and spectrometer.

These tests combined help to determine the presence of life or the chances of survival of living organisms by detecting the organic compounds mentioned above.

Sensors:

pH Sensor	**BME 280 Sensor**	**Spectrometer**	**MQ2 A Gas Sensor**
USB Microscope	**Soil Moisture Sensor**	**NPK Sensor**	



ELECTRONICS AND POWER

Power Distribution System

- Sub-Systems:
  - Ground Vehicle
  - Robotic Arm
  - Bio Assembly
- Battery Setup:
  - Three Li-Po batteries (25,000 mAh, 22.2V, 25C discharge rate) connected in series to power all subsystems.
- Control System:
  - The Jetson Orin Nano onboard computer connects to Arduino Mega and Uno microcontrollers for each sub-system, as well as webcams, ZED camera, and antenna.
  - Allows independent control of each sub-system as needed.

Components by Sub-System

- Ground Vehicle:
  - 4 DC 60 kg cm encoder geared motors (wheels)
  - 4 DC 140 kg cm encoder geared motors (steering)
  - 4 Cytron MDD20A motor drivers
  - Arduino Mega, Jetson
- Manipulator:
  - 3 planetary geared motors of 650 kg cm each further connected to 10 : 1 gearbox to be used for base, shoulder and elbow joints
  - 3 planetary geared motors of 140 kg cm each directly used to actuate the wrist joint and the gripper
  - 3 Cytron MDD20A or L298N motor drivers
  - Arduino Mega
  - Intel RealSense placed at the gripper for camera feed and depth perception data at the base station
- Bio Assembly:
  - 2 Linear actuators, 1 DC geared motor (12V)
  - 1 Cytron MDD20A and 1 L298N motor driver
  - Arduino Mega
  - Various sensors for testing (details mentioned in the Astro Bio section)

Communications & Navigation

- Antenna, webcams, ZED camera

Emergency Protection

- Kill-Switch Mechanism: Instantly disconnects power from batteries in emergencies.

PCB Design

- Purpose: Simplifies connections, reduces errors, and organises the electronics setup.
- Signal Integrity:
  - Short critical signal paths on PCB to minimise EMI and signal loss.
  - Stable voltage sources ensure consistent power delivery.

This setup provides efficient power management, structured component integration, and robust safety measures, ensuring reliable operation across all rover systems.

COMMUNICATION SYSTEMS

The communication setup for the rover involves configuring antenna systems, establishing a secure ROS (Robot Operating System) network, and automating program execution based on specific conditions. Key steps and configurations include:

Antenna Configuration

- Setting Up the Antenna:
  The rover utilises a reliable antenna setup to maintain strong communication links with the base station, ensuring stable data transmission and control over varied distances.
- Access Point and Client Configuration:
  - Configuring the antenna as an access point on the base station side and as a client on the rover side.
  - This setup enables seamless connection between the rover and the control station, allowing for remote operation and data transfer.
- Frequency Ranges and Bandwidth:
  - Setting optimal frequency ranges and bandwidth allocations to maximise communication stability and prevent interference.
  - Frequencies are selected based on environmental factors and interference potential, ensuring a stable and interference-resistant connection during operation.

ROS Network Configuration

- Configuration of ROS Servers:
  - Setting up ROS servers on both the rover (Jetson Orin Nano) and the base station to manage data flow and task execution.
  - Configuring nodes and topics within ROS to facilitate seamless inter-module communication, essential for coordinating subsystems like navigation, manipulation, and bio-sensing.
- Firewall Rules Setup:
  - Establishing firewall rules to protect the network from unauthorised access or data breaches.
  - Configuring port permissions to allow only essential communication, enhancing security by restricting access to necessary services.

Bash Script Automation

- Final Bash Script Development:
  - Writing a bash script on the Jetson that automates program execution.
  - The script enables condition-based control over key operations, including activating sensors, initialising motors, or engaging the manipulator system.
- Trigger Conditions:
  - The script is designed to respond to inputs from onboard sensors or pre-set task conditions, allowing the rover to perform operations autonomously or with minimal intervention.

This comprehensive communication setup ensures robust connectivity, coordinated control of rover subsystems, and secure data transmission between the rover and the base station.

SOFTWARE AND CONTROL

CONTROL FRAMEWORK

Our ROS Noetic-based control framework enables seamless communication between the Jetson module and workstation, supporting both Manual and Autonomous modes for mission flexibility.

Dual Operation Modes

Manual Mode	Direct operator control via a gamepad interface.
Autonomous Mode	Sensor-driven decision-making for independent navigation.

Communication and Data Flow

ROS Noetic facilitates smooth data and command flow between the Jetson and workstation. This ensures efficient communication between input sources, processing nodes, and output components.

Data Flow Breakdown:

- Input Sources:
  - Gamepad
  - ZED Camera (and other sensors)
- Processing Nodes:
  - Data processing algorithms (for both manual and autonomous control)
- Output:
  - Motor control
  - Actuator control

Modular Framework

The system's modular nature allows the easy integration of new sensors or algorithms, enhancing its adaptability and minimising disruptions during updates or enhancements.

Modular Components:

- New sensors (e.g., LIDAR, IMU, GPS)
- New algorithms (e.g., path planning, sensor fusion)

This framework ensures that both operational modes work together effectively, fully aligned with mission objectives, and adaptable to changing requirements.

MANUAL CONTROL SOFTWARE

Manual control enables the rover to be directly operated through a gamepad, with command signals processed on the workstation and transmitted to the Jetson for execution.

Control Flow

1. **Gamepad Input:**
   Operator inputs are captured through a gamepad interface connected to the workstation.
2. **Workstation Processing:**
   The workstation processes these inputs through the ROS Noetic framework, converting them into actionable commands.
3. **Network Communication:**
   Commands are then transmitted over the network to the ROS framework on the Jetson module.
4. **Serial Communication with Arduino:**
   The Jetson communicates with the Arduino controllers via serial communication, ensuring precise control of all connected components.
5. **Actuation:**
   Commands are executed by the Arduino, directing the motors and components to perform as required based on the gamepad inputs.

AUTONOMOUS CONTROL SOFTWARE

The autonomous mission requires the rover to navigate from a specified starting point to a destination, following a path marked by directional arrows at each intersection. Our solution leverages a machine learning pipeline with two key modules.

Arrow and Distance Detection

- Arrow Detection:
  - Using the YOLO (You Only Look Once) algorithm, we detect arrows that guide the rover's path.
- Distance Calculation:
  - A ZED camera provides distance frames, allowing us to determine the rover's distance from each detected arrow.
  - To prevent abrupt turns, we have set a minimum approach distance of 2 metres, after which the direction detection module is triggered.

Direction Detection

- Model Choice:
  - We utilise a ResNet (Residual Network) pre-trained model with weights from the ImageNet dataset, selected for its high accuracy in classification tasks.
- Mechanism:
  - ResNet's architecture includes residual connections in the feed-forward process, enhancing its precision and reliability in detecting directional cues.

Pipeline and ROS Integration

- Pipeline Flow:
  - Built in Python, the pipeline first detects the arrow and calculates distance, then determines the arrow's direction.
- ROS Topic Publishing:
  - Once the direction is classified, it is published as a ROS topic, enabling the rover to execute the corresponding turn

This machine learning pipeline enables the rover to navigate autonomously, responding accurately to directional cues in real-time.

ROVER CONTROL CENTRE SOFTWARE

The Rover Control Centre uses HTML, CSS, and JavaScript for the frontend, with Flask as the Python-based backend, to interface smoothly with ROS. This setup provides a responsive interface for monitoring video feeds, control commands, position, speed, and real-time error reporting, ensuring efficient rover control in both manual and autonomous modes.

System Initialization

Upon entering the webpage, the following steps occur before the HTML page loads.
A series of terminal commands are executed on the server, including:

- Initialising *roscore*.
- Connecting the joystick to the computer.
- Setting up the joystick as a node in the ROS system.

Once these processes are complete, the HTML page loads and presents the user interface, which consists of the following four key components:

Key Components of the Rover Control Centre

Component	**Description**
Video Displayer	Displays a real-time panoramic video feed from the rover's cameras.
Command Buttons	Controls to manage rover mode and joystick command listening.
Rover Position and Speed	Displays real-time values of linear velocity, angular speed, and joint positions.
Output Terminal	Shows error messages and debugging information.

Video Displayer

The Video Displayer fetches the video feed from the cameras mounted on the rover. Through the use of video stitching, it combines multiple camera streams to create a panoramic view. This video is then streamed in real-time on the website, providing live visual feedback of the rover's surroundings.

Command Buttons

There are two primary command buttons:

- Start Button: When clicked, the server begins listening to joystick commands, allowing manual control of the rover.
- Mode Button: This button allows the user to toggle between operational modes. The mode can also be changed directly from the joystick interface.
  The Mode Button enables the user to switch between manual control and autonomous mode seamlessly.

Rover Position and Speed

When the server listens to the joystick inputs, the website dynamically updates the following information:

- Linear Velocity: Displays the current forward/backward speed of the rover.
- Angular Speed: Shows the rover's turning speed (rotation rate).
- Joint Positions: Displays the positions of the manipulator joints and the biological survey part of the rover.

These data points are crucial for providing real-time feedback to the operator regarding the rover's current state and performance.

Output Terminal

The Output Terminal is a console window that provides immediate feedback on the system's health. It displays:

- Connection Errors: If there are issues with joystick connection or communication with ROS.
- Programming Errors: Any issues or bugs in the ROS system will be shown here for quick debugging and troubleshooting.

This feature ensures that the user can monitor the system status and take corrective actions without delay.