MARS ROVER MANIPAL

International Rover Challenge 2023

System Design and Development Report

Team Name: Mars Rover Manipal

Name of Team Lead: Yashash Rao Punugoti

Name of Institution: Manipal Academy of Higher Education

Rover Name: Arceus

1 Team structure and a description of the role of each of the subsystems:

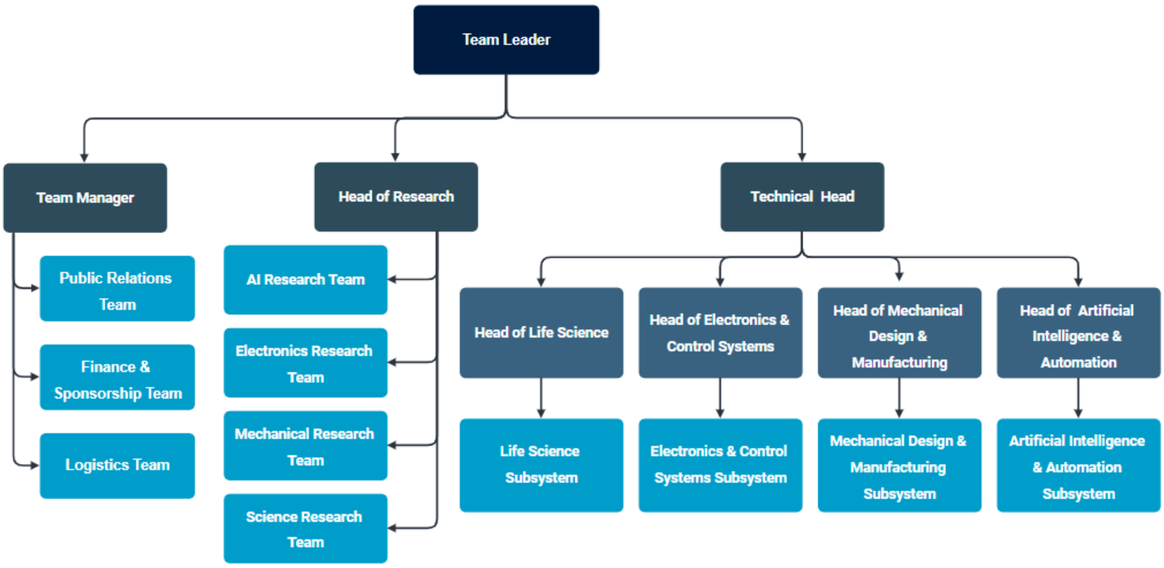


Figure 1: Team Structure

The team consists of 50 engineering undergraduate students from different departments like Mechanical, Electronics and Electrical, Electronics and Communications, Computer Science, Mechatronics, Biotechnology, etc. The team is divided into 6 subsystems for efficient planning and timely execution namely Mechanical Design and Manufacturing, Electronics and Control Systems, Artificial Intelligence and Automation, Life Science, Management, and Research. The roles of the board members are as follows:

- The Team Leader is responsible for managing the operations of the team.
- The Team Manager is responsible for efficient functioning and logistics for the team.
- The Technical Head is responsible for the smooth functioning and collaboration between different technical subsystems.
- The Mechanical Design and Manufacturing Head is responsible for the functioning of the Mechanical Design and Manufacturing subsystem.
- The Electronics and Control Systems Head is responsible for the functioning of the Electronics and Controls subsystem.
- The AI and Automation Head is responsible for the functioning of the Artificial Intelligence and Automation subsystem.
- The Life Science Head is responsible for the functioning of the Life Science subsystem.
- The Research Head is responsible for overseeing the research projects of the team.

1. **Electronics & Controls System (ECS):** The ECS subsystem specialises in designing the control systems, data architecture and power layout of the rover along with overseeing all the communications on-board.
2. **Artificial Intelligence & Automation (AIA):** The AIA Subsystem specialises in the automation of the rover's traversal. The subsystem works on interfacing sensors, implementation of multiple path planning algorithms and mapping techniques for autonomous movement of the rover from two specified locations. The subsystem also deals with the development of machine learning and deep learning models for image processing and classification.
3. **Mechanical Design and Manufacturing (MDM):** The MDM subsystem specialises in design and fabrication of the skeleton of the rover which consists of the drive system, robotic manipulator and the science module.
4. **Life Science:** The Life Science Subsystem specialises in studying the site's characteristics to identify the soil's habitability prospects both in the past and the present. To draw inferences, visual feed, stratigraphic profiling, rock and soil identification, sensor technology, and chemical assays would be employed, along with the knowledge from the fields of astrobiology, geology, and planetary sciences.
5. **Management:** The Management subsystem is responsible for the overall progress of the team by handling sponsorship, finance, public relations, publicity, media platforms, team events, and human resource management.
6. **Research:** The Research subsystem is responsible for publishing research papers in indexed journals and presenting them in national and international conferences.

Table 1.1 - Subsystem-wise Team Composition

S.no	Subsystem	No. of Members
1	Artificial Intelligence & Automation	6
2	Electronics & Control Systems	6
3	Mechanical Design & Manufacturing	10
4	Life Science	5
5	Management & Public Relations	5
6	Research	10
7	Board	8
	Total	**50**

Table 1.2 - Branch Wise Team Composition

S.no	Branch	No. of Members
1	Aeronautical	3
2	Bio-Medical	1
2	Biotechnology	1
3	Chemical	2
4	Computers & Communication	1
5	Computer Science	4
5	Computer Science (AI/ML)	3
6	Data Science	5
7	Electronics & Communication	7
8	Electrical & Electronics	3
9	Information Technology	1
10	Mechanical	8
11	Mechatronics	6
	Total	**50**

1.1 Resource Management

Mars Rover Manipal is one of the major student project teams under the Manipal Academy of Higher Education and has been given access to a state of the art workshop that contains the following resources. To manage the resources available at hand, a hierarchy system has been built.

Manufacturing Resources: 1. CNC TC & Manual Lathe Machine 2. CNC VMC & Manual Milling Machine 3. Clutch, Power, Bench, and Radial Drilling Machine 4. Grinding Wheels & Angle Grinder 6. Dremel Tool & Bandsaw 8. Planing and Shaping Machines 9. Wire and Hole EDM Machine 10. FDM-based 3D Printers	**Equipment and Devices:** 1. Bench Power Supply 2. Oscilloscope 3. Soldering Station 4. Workstation with Xeon 12 core processor, 24GB RAM, and NVIDIA GTX 950M
Laboratories: 1. Biotechnology Lab. 2. Central Instrumentation Facility. 3. UR5 Arm in Robotics Lab 4. Strength of Materials Testing Lab 5. Robotics Lab/UR5/tbot 6. UTM SOM Lab	**Sponsorship & Licenses:** 1. Solidworks Student Licenses 2. Coursera

Figure 2: Resources Allocated to MRM

The board acts as a mediator between the University, its facilities and the team that is actively working on designing and building the rover. The existing resources are allocated and divided between the individual subsystems as per their requisites. For an efficient resource allocation process, the subsystems were further divided into specializations for an efficient use of the aforementioned resources; i.e. a specific team member who specialises in using the Soldering Station to its best capacity is preferable rather than the whole ECS subsystem using the station in an inefficient manner that can lead to a wastage of both human hours and material. A resource management plan was crafted meticulously to strategically prepare the team members for better budget efficiency, enabling resource forecasting hence allowing the team to predict unforeseen costs and the project's scope beforehand.

1.2 Project Planning

Mars Rover Manipal secured the 2nd place in the Remote Edition of European Rover Challenge 2022, along with honourable mentions for the Science, Maintenance, and Presentation Tasks. We were also awarded the 2nd position in the International Rover Design Challenge 2022. Extensive discussions have been conducted to analyse upcoming competition strategies and set deadlines for forthcoming tasks. Currently, we are heading into the testing phase for our rover. Consistent work ethic and time management have aided in meeting deadlines comfortably. Our rover will be prepared, with ample time to test and troubleshoot any unexpected issues, before the competition.

Figure 3: PERT Chart Key

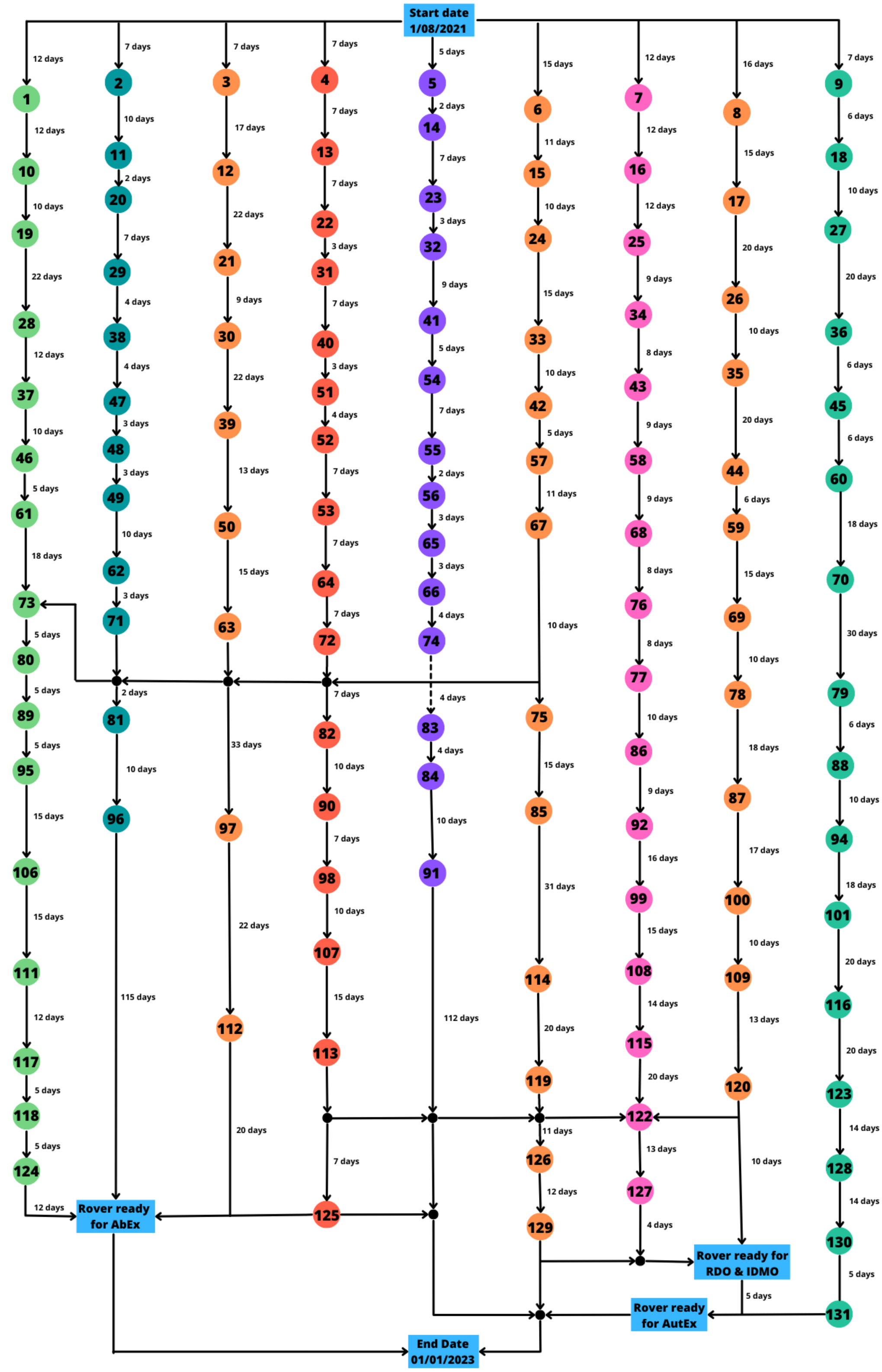


Figure 4: PERT Chart

1.3 Recruitment

The team conducts recruitment for the new members in the month of November every year. First and second-year students from all disciplines of the university are eligible to join the team. As restrictions were lifted, the team was able to recruit in-person after 3 years. The recruitments were publicised using social media as well as posters and showcases of the rover on campus. The process consists of a written test followed by a personal interview round. The shortlisted candidates then go through a meticulously curated task phase which involves an introduction to the basic and advanced concepts required in the team as well as the development of a rover prototype. The selected candidates are then admitted into the team. The recruitment plan for the team is illustrated below:

1.4 Educational and Public Outreach

We take full advantage of the large number and diversity of students that can be seen at Manipal Academy of Higher Education. We conduct multiple seminars for students from our University as well as from other schools and institutes. At our workshop, we display our rover and explain the principles behind its workings; we conduct sessions at technical fests and events with the goal of inspiring young minds to join STEM and contribute to advancements in the field. We have launched an online series, "Inception MRM", where we post facts about various upcoming start-ups native to our University and others. We host meetings with these firms to discuss the inception of our as well their organisations. We have showcased our rover at the Indian Army UGV Experiment 2021 for the co-development of a ruggedised military-grade rover for defence applications. We also regularly post on social media about the progress of our rover and record a podcast with informational content about Astrobiology, Space Exploration, Robotics and AI to incite enthusiasm about the fields and get maximum outreach.

1.5 Sponsorships

MAHE's generous sponsorship helps cover the cost of shipping and accommodation in Bangalore and any additional expenses during the duration of the competition. Our extensive collection of 3D printers (Volterra, Ender 5 plus, Ender 3 and Tevo Tornado) helps procure any spares or facilitate any changes that are required on the rover in time. The team's funding has provided enough resources to manufacture the new articulated arm design, the arm assembly is complete with spares to replace essential components in power transmission. All components obtained from our sponsors have been implemented on the rover to improve the rover's automation and life detection capacity.

1.5.1 List of Sponsorships Raised

Table 1.3 - Sponsorships Raised

S.no	**Name of Sponsor**	**Description of Product or Service**	**Value (INR)**	**Subsystem**
1	Nvidia	NVIDIA JETSON TX2	70,000	AIA
2	Wheeleez	Balloon Tires	40,000	Mechanical
3	LPS Bossard	Fasteners	30,000	Mechanical
4	KelpeTech	Waterjet Machining	6,000	Mechanical
5	SICK Sensor Intelligence	3D LIDAR	4,50,000	AIA
6	Aeroqual	Ozone Sensor	20,000	Science
		Total	6,16,000	

1.6 Initial Budget

The team's financial requirements are met by a budget allotted to us separately by the university as well as by obtaining product-based and monetary sponsorships from corporate firms. The team plans to reuse most components from the previous rover. The financial management plan has been elaborated in Tables 1.4 and 1.5.

Table 1.4 - **Sources of Funding**	
Funds provided by the University	₹11,00,000
Seed Money from Team Members	₹60,000
Sponsorship (Raised till 1st November 2022)	₹6,16,000
Total	₹17,76,000

Table 1.5 - Subsystem-wise Expenditure	
Subsystem	**Anticipated Expenses**
Mechanical	₹5,05,000
Electronics & Controls	₹2,92,000
AI & Automation	₹1,45,000
Life Science	₹1,55,000
Management	₹63,000
Total	₹11,60,000

1.7 Fund-Raising

For several years, Mars Rover Manipal has been one of MAHE's top student-led project teams and one of Asia's top rover teams. Building off this robust foundation with immense knowledge being transferred year after year, Mars Rover Manipal aims to be a self-funded and independent organisation which it achieves by the following:

- All the subsystems are collaborating to create an online specialization or MOOC on platforms like Coursera, Udemy or EDX that will in detail, explore the various technical skills involved in Rover development.
- We conduct various workshops throughout the year:
  1. Artificial Intelligence and Automation
     (a) Robotics and Simulation using ROS
     (b) Computer Vision using OpenCV
  2. Mechanical Design and Manufacturing
     (a) Computer Aided Engineering
     (b) 3D Printing
  3. Electronics and Control System
     (a) PCB designing using KiCAD
     (b) Soldering components
     (c) MATLAB simulations
  4. Life Science
     (a) Spectrometry
     (b) Introduction to Astrobiology
- We are in discussions with multiple companies to take on research and development projects on their behalf on contract basis.
- The team is extremely experienced with FDM based 3D Printing, and has 3 personal 3D printers in the workshop. We manufacture parts on contract basis for other student project teams.
- We are attempting to translate our extensive knowledge about off-road and unmanned exploration vehicles into consumer products that can be utilised in industries such as Defence, Law Enforcement, Agriculture, Space Exploration, Mining, Disaster Relief and Rescue.
- We are collaborating with Janyu Tech in the co-development of a ruggedised military-grade rover for defence applications, wherein the robot is designed and fabricated in Manipal, by MRM. Janyu Tech will be responsible for supplementing finances, specialised equipment and technical expertise for the development of the robot.

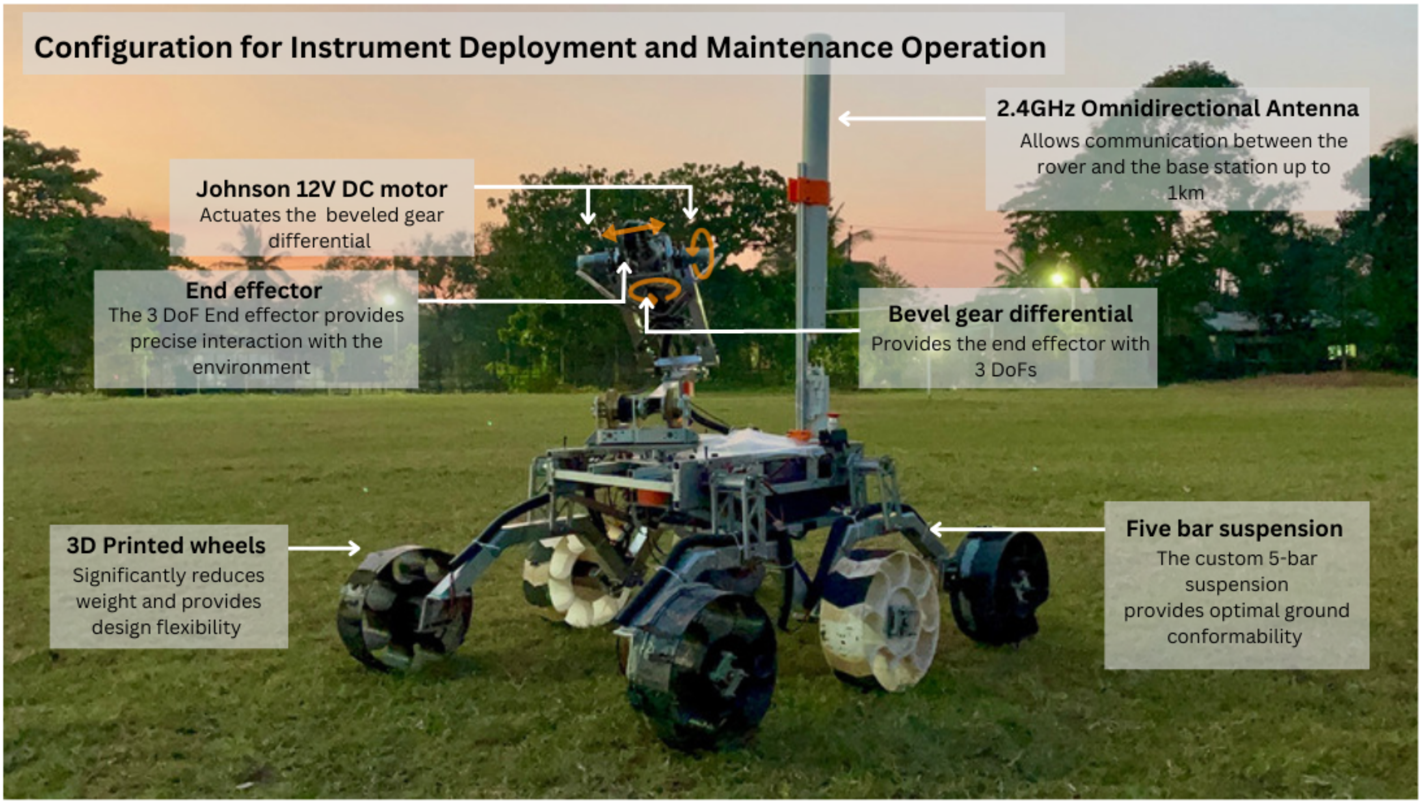


Figure 5: Rover configuration for IDMO

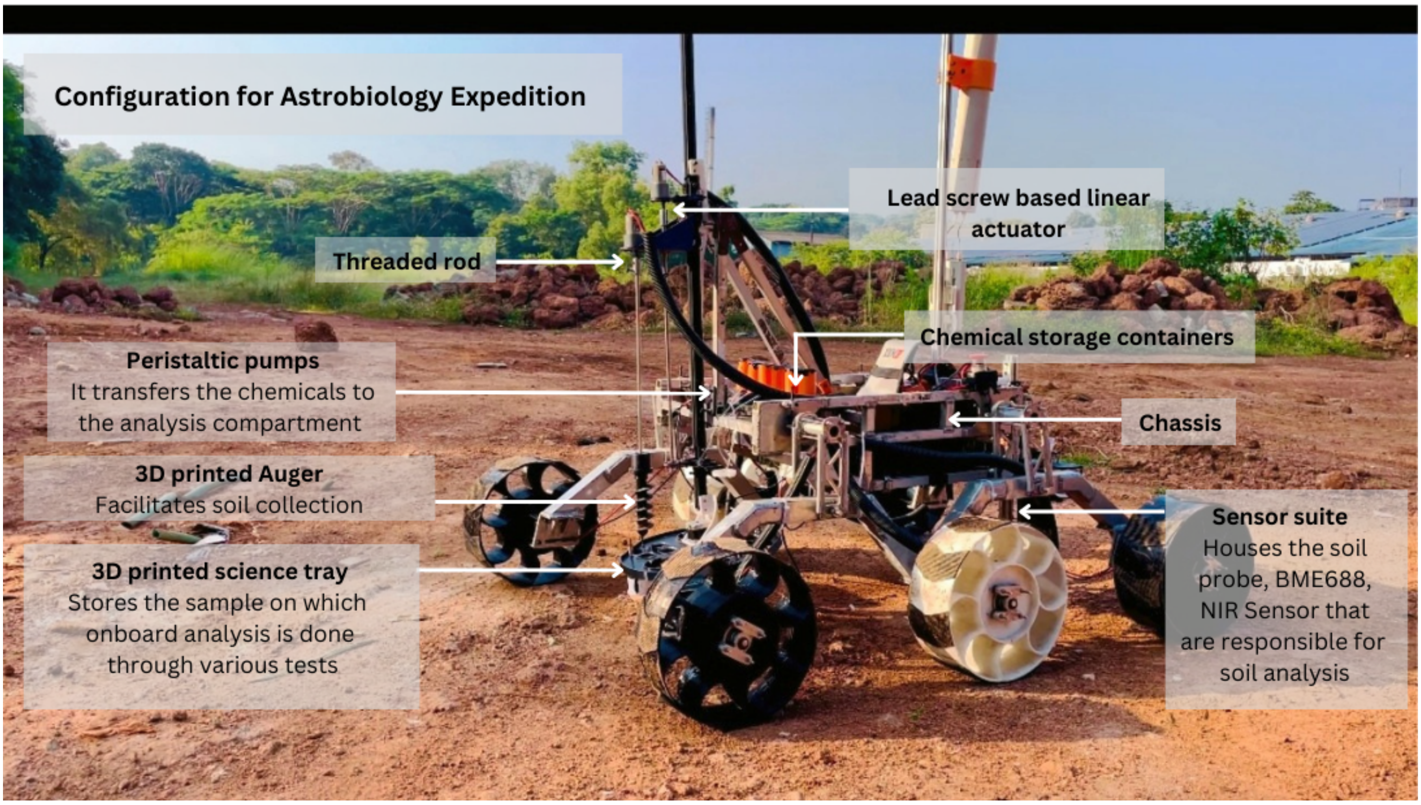


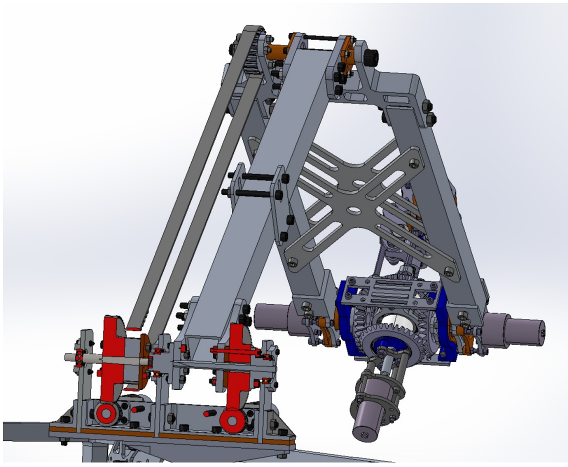
Figure 6: Rover configuration for AbEx

2 Mechanical Design

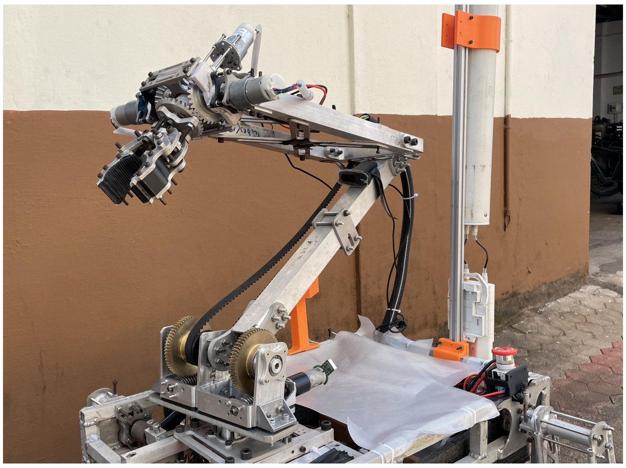
2.1 Robotic Arm

The robotic manipulator has undergone an extensive developmental cycle this year. The articulated arm actuates to provide six degrees of freedom (DoF); the first of which is the yaw motion facilitated by the swivel base. The base houses a custom, non-backdrivable worm gearbox with a reduction ratio of 40:1, this output is transferred via an Oldham coupling which accounts for shaft eccentricity. The arm also features coaxial worm screw assemblies atop the swivel base which power the first and second pitch. The output of the second worm gear is transmitted via a timing belt, the chosen belt allows for high precision and the teeth profile reduces the risk of slippage. The coaxial design allows for a compact assembly and the placement of the power transmission components at the base allows for a reduced rotational moment of inertia. The new design also accommodates a stow-away position for the arm that can be used during traversal. The links of the arm were manufactured using Aluminium 6063-T6 due to the material's high specific strength.

The 3 DoF end effector is equipped with 3 high torque motors, 2 of these motors are used in conjunction with a bevel differential in order to facilitate pitch and roll. The lead-screw powered gripper features treaded TPU gripping pads with an appropriate degree of conformability, thus providing a better grip. The unique orientation of the gripper allows for an enclosing and pinching grip based on the task at hand.



(a) Section View of the Coaxial Worm Assembly



(b) Robotic Manipulator Isometric View

Figure 7: Robotic Manipulator

2.2 Drive System

The drive system comprises an optimised space frame chassis, a novel multi-link suspension system based on a five-bar mechanism, and custom full-float wheel assemblies to drive our 3D-printed tyres.

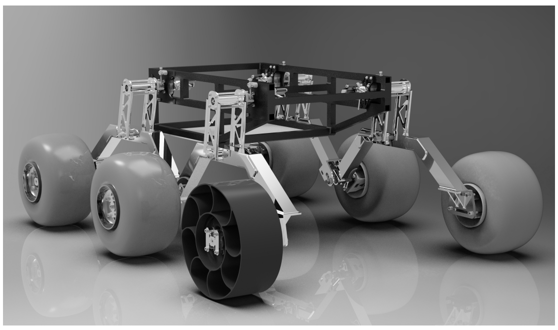


Figure 8: Rover Drive System

2.2.1 Chassis

The chassis is a robust space frame structure fabricated using Aluminium 6061 - T6 square cross-sectional tubes, which provide a high rigidity-to-weight ratio. The space frame has been designed and optimised through extensive finite element analysis simulations. The chassis serves as a mount for modular rover systems such as the robotic manipulator, electronics box and science module.

2.2.2 Suspension

The suspension design provides the rover with a low center of gravity, enhanced terrain adaptability and traversal capabilities along with improved chassis stability. The 2 DoF five-bar mechanism is constrained by adjustable torsion springs, which increase the suspension's mobility and provides passive dampening while ensuring no mechanical singularities. The suspension allows the rover to scale obstacles of 0.6m and descend a 1m deep ditch. The longitudinal dependency between wheels facilitates increased trafficability, allowing the rover to traverse rocky and uneven terrain effectively. The bogie's design and torsion spring values have been optimised via extensive simulation on Solidworks motion study.

2.2.3 Wheels

The current configuration of the wheels on the rover consists of 6 3D-printed wheels. The wheels are made from PLA and PETG, these materials offer good strength, durability and compliance. The motors powering the wheels are coupled with a high reduction ratio planetary gearbox for optimal torque delivery. A full float axle has been implemented to isolate the wheel motor shaft from external loads. We plan on implementing 3D-printed TPU and TPE wheels that would allow for better ground conformability and produce more traction. An iterative design process is being executed to ensure the wheels are competition ready.

3 Electronics and Control Systems

3.1 Communication

The rover uses a combination of omnidirectional (for the rover) and directional (for the base station) antennas that comply with FCC rules and regulations to operate on the 2.4GHz and 5.8GHz frequency bands. Using circular polarised Fatshark antennas at 5.8GHz significantly decreased the rover's weight. The 2.4GHz communication channel sends commands to the rover, and the 5.8GHz frequency range receives camera feed and sensor data. AirLink software will orient the antennas so that there are as few impediments as possible in the Fresnel zone, resulting in robust and reliable signal levels. The AirOS AirView spectrum analyser has been used to examine network data and get the best signal-to-noise ratio possible. The rover's communication ranges are up to 1 km in line of sight and 800 meters in non-line of sight conditions.

3.2 Hardware

The Electronics Box (E-Box) of the rover has been divided into 2 layers for ease of maintenance and replacement of parts. The first layer changes according to the requirements of the missions, and the second layer contains the electronic components common to all missions. The second layer is divided into multiple sections: A Battery storage compartment consisting of four 6C (22.2V) LiPo batteries with buck converters to get a 12V, 18V and a 5V output supply. A component compartment containing the rover's central PCB consisting of RPi and ESP32, motor driver PCBs to drive the motors, fuses and networking components. Also, a kill switch has been implemented to cease all functioning of the rover in case of an emergency.

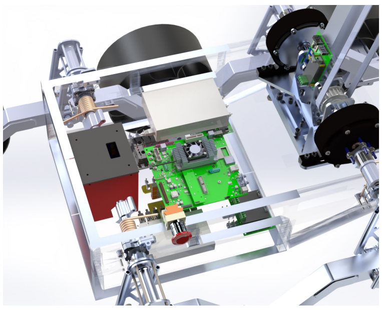


Figure 9: Electronics Box

3.2.1 Central and Power Distribution PCB

A central PCB has been fabricated to oversee control of the drive system and establish communication with the base station using an ESP32. Additionally, it has an RPi to access the video camera feed. The main power supply is stepped down to 5V, 12V and 18V using three 20A buck converters. Components are powered using different power distribution points provided on the PCB. Multiple safety points have been included in the PCB design including fuses before components, decoupling capacitors and low pass filters to reduce signal fluctuation. CAN protocol is used to establish communication between the central ESP32 which controls the drive system and the auxilliary ESP32s of the RM and Science Module.

3.3 Robotic Manipulator

Inverse Kinematics has been implemented on the 6 DoF Robotic Manipulator. The central ESP32 computes the required straight-line trajectory and joint value to reach the goal state provided by the operator, using the orientation data of each link and the swivel base, obtained using Inertial Measurement Units (IMUs). The Robotic Manipulator ESP32 computes the required actuation of gripper motors with the encoder data from each motor. A Proportional Integral Derivative (PID) controller is implemented on each joint for driving the motors to the computed angular value. The trajectory generated by the inverse kinematics enables the manipulator to avoid states of singularity. As a fail-safe, the operator can switch to Forward Kinematics and control the manipulator. Limit switches have been implemented for preventing over-actuation and to ensure the safety of the manipulator. For ease of operation, recurring manipulator configurations have been defined and preset which can be called with a simple push of a button.
The 6-DoF robotic manipulator comprises of three DC motors for the links and the swivel base and three DC motors with encoders for precise actuation of the gripper. It accommodates the PCBs consistsing of the BNO055 IMU modules, the six motor drivers, and the ESP32. The IMU data is relayed back to the central ESP32 via CAN communication.

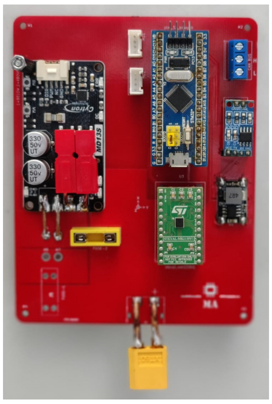


Figure 10: Robotic Manipulator PCB

3.4 Graphical User Interface (GUI)

Socket programming and PyQt are used to create a custom Graphical User Interface (GUI) that the base station uses to communicate with the rover and deliver commands for the drive system, robotic manipulator, and scientific module. Additionally, it aids in receiving feedback from the rover's camera and sensors.

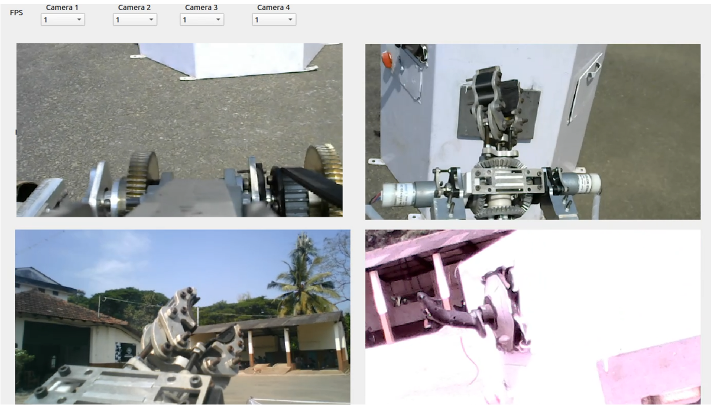


Figure 11: Robotic Manipulator GUI

4 Artificial Intelligence & Automation

4.1 Sensors and Processing

Various sensors are used for autonomous traversal in the AutEx mission. These are interfaced using the Nvidia Jetson AGX Xavier acting as the primary processing unit and the Raspberry Pi acting as the secondary processing unit. The Nvidia Jetson is a powerful processor with a dedicated GPU which helps in effective image and PointCloud processing through parallel computing, and also is responsible for most of the processing on the rover. The Raspberry Pi has the main purpose of providing additional PWM OUT pins which the Jetson lacks and also provide an additional boost in processing power. The ZED2 stereo camera provides high resolution images and PointClouds used for stereographic vision and obstacle detection. The SICK MRS 1000 3D LiDAR provides a 4-layered 3D PointCloud with a horizontal Field of View(FOV) of 270° and vertical FOV of 20° and is used to detect obstacles within a distance of 60 metres. An RTK based u-blox GPS module provides position data on a global frame with an accuracy of up to 10 centimetres using the principle of DGPS. The BNO080 IMU module provides orientation data as euler angles which along with the GPS module gives us the rovers pose.

4.2 Control structure

The drive system is based on a skid steer kinematic model, used to find the relation between velocity and PWM signals. A parabolic controller algorithm (for path planning) is used as the main control system of the rover. A software multiplexer has been implemented for decision making during the task. It switches from different states like cone detection, arrow detection, obstacle avoidance, and searching using clustered sensor data as select lines to obtain the GPS coordinates of the cones and arrows.

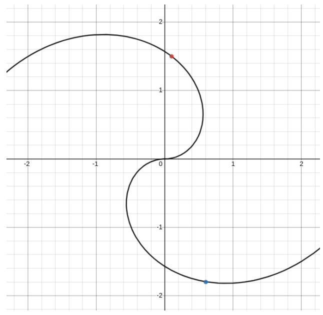


Figure 12: Parabolic Controller

4.3 Obstacle Avoidance

An iteration of the BUG 0 algorithm has been used for obstacle avoidance. The SICK MRS 1000 3D LiDAR provides accurate position of obstacles. Data from the LiDAR is passed into a controller which flags the rover to move into obstacle avoidance, altering from its initially planned path. Ground Planes in the PointClouds from the ZED2 stereo camera are eliminated using the PointCloud Library to confirm obstacle data coming in from the LiDAR. The stereo camera also acts as a direct substitute in case of loss of communication with the LiDAR.

4.4 Search Pattern

Each time an arrow is reached, its GPS coordinate is stored inside of a dictionary. Any arrow detected will then be compared to the stored dictionary to determine whether it is a novel arrow. A Radial Spiral-based Inverted search pattern has been developed for cases where the rover may not be able to detect a new arrow.

4.5 Arrow Detection

The direction of arrows is obtained using a Fully Convolutional Neural Network(FCNN) algorithm based on YOLOv7. A data set has been manually created using images from the ZED2 stereo camera, with arrows present in various directions and environments. The algorithm provides probabilistic weights for predicted direction of arrows and also creates bounding boxes around the arrows. ZED SDK's API has been used to find the distance of the centre of the bounding box from the rover. The data is then passed through a controller to effectively follow the arrow using a PD controller.

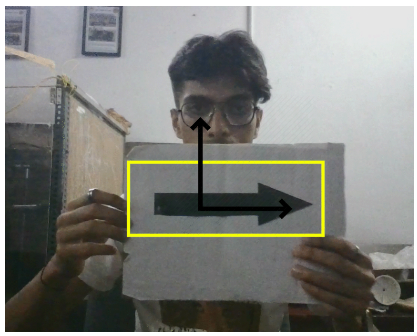


Figure 13: Arrow Detection

4.6 Cone Detection

Cone detection is carried out using the same YOLOv7 based FCNN algorithm and its pose estimation is also carried out using the ZED SDK's API. Masking and image processing is carried out using the OpenCV library to improve the accuracy of the FCNN module. However, cones are given precedence over arrows in the multiplexing controller, to ensure completion of the Autonomous Expedition mission.

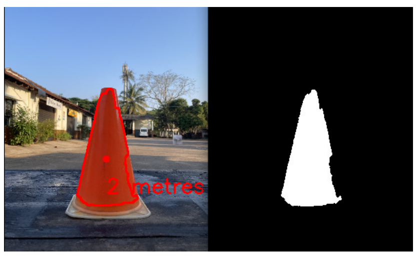


Figure 14: Cone Detection

5 Science Strategy

The Life Science Subsystem will study the atmospheric composition as well as the chemical and physical characteristics of soil at the mission site to determine whether the site comprises extinct or extant life, or is devoid of life.

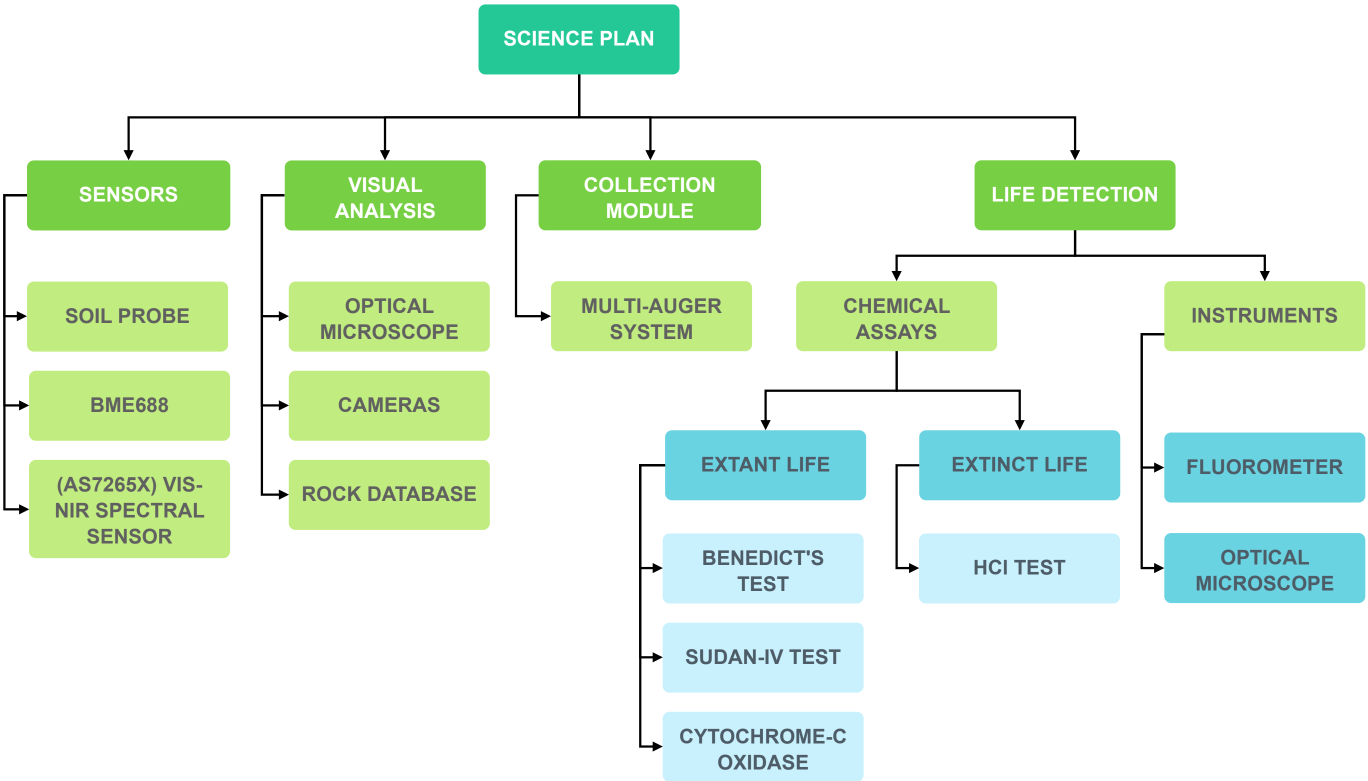
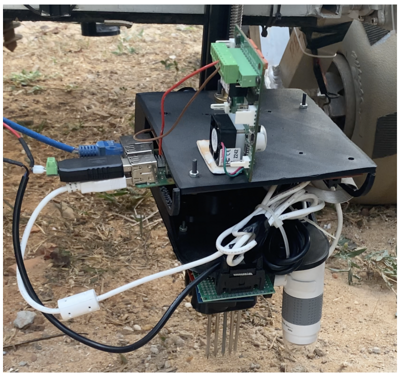


Figure 15: Science Strategy

5.1 Science Module

The science module is designed for the collection and analysis of the soil on board to detect the presence or absence of extinct and extant life in a particular sample. A separately actuated sensor suite will enable the digital microscope, soil probe, and the spectral sensor to closely analyze the terrain and collect vital information on the biological makeup of the soil. Additionally, a water bath has been implemented for the assays.

(a) Auger System



(b) Sensor Suite

Figure 16: Science Collection and Analysis Module

For sample collection, a custom 3D printed auger has been implemented to reduce the overall weight of the system. A multi-auger system with a multiplexer is used to allow a singular motor to actuate three augers. This facilitates sample collection from multiple sites while avoiding cross-contamination. A lead screw-based linear actuation mechanism has been implemented for the auger assembly and sensor suite to provide translatory motion. Limit switches have been implemented on the lead-screw which prevents over-actuation of the auger.
The science tray is being designed to abide by the no-spill policy and is actuated using the stepper motor to give precise movement. Cameras are mounted on the module to obtain visual inferences from the tests. Peristaltic pumps are being utilized to transport the chemicals from the chemical storage containers to the analysis chamber.
Motors are controlled using a combination of motor drivers (for DC and stepper motors) and relay modules (for peristaltic pump motors).
Robust science sensors like soil probe, BME688 and NIR Sensor have been interfaced with Raspberry Pi 4B. The science module is actuated using an auxilliary ESP32 which communicates with the central ESP32 using the industrial-grade CAN interface which provides robust and fast communication.
Automation of the sample collection and deposition mechanism is done using a VL53L4CD, Time of Flight (ToF) sensor mounted on the gantry plate which calculates the distance of the auger in real-time.
The Science Module PCB is powered by a 12V supply, which is stepped down to 5V by a micro-buck along with a glass fuse for current surge protection. It hosts an ESP32 module, a stepper motor driver, and headers to power the stepper motor on the science module. A ten-pin connector toggles the relays, and two Insulation-Displacement Connectors (IDC) actuate and rotate the auger on the science module, taking controls from the ESP32.

5.2 Chemical Assays

Four chemical tests will be implemented on the rover to classify the soil samples collected by the auger system into extant, extinct and no life. These will detect specific compounds and biosignature molecules to make the appropriate inferences. A 0.2N HCl solution will be tested on the soil to check for the presence of carbonates. Carbonates are indicative of calcareous remains and fossils which can provide evidence of ancient life. To detect reducing sugars, Benedict's assay has been implemented. Reducing sugars are essential in several biochemical reactions, because they function as reducing agents due to the aldehyde functional groups. Furthermore, they also act as a source of energy. The water bath ensures that the reaction takes place at the optimum temperature. Colour change of the solution from blue to green to orange and finally to red signifies a positive result, with increasing concentrations of sugars present in each stage. Lipids are strong biosignatures owing to the complexity of their structure and survivability. They are essential structural components in cells as well as functional components in metabolic reactions. They have very few abiotic sources, and are thus reliable in proving the presence of life. We have used the Sudan test to detect the presence of any lipid molecules. Since Sudan IV is a non-polar stain, the lipid molecules present in the sample will bind with it, retaining its red colour. Enzymes are robust signatures for extant life. Being easily degradable, their presence in a significant quantities would imply an active source of their production. They are also necessary for progression of metabolic reactions at rates sustainable to life. We have implemented a test to detect the presence of Cytochrome c Oxidase, which catalyses the final step in the electron transport chain for cellular respiration in all eukaryotes. A positive result is indicated when the filter paper strips with the reagent turn purple a few seconds after the sample is applied.

(a) Benedict's Test (b) Sudan IV Test

Figure 17: Chemical Assays

5.2.1 Water Bath

An on-board water bath on the science module enables us to carry out Benedict's test at the optimum temperature of 90°C. By providing a consistent and uniform heat distribution to the system, it minimises temperature fluctuations. The water bath eliminates contact between the heating elements, i.e. the nichrome wire, and the reagents, and eliminates the fire hazard.

5.2.2 Safety

All the reagents used for the chemical assays have diamond ratings ranging from 0 to 3. The storage containers, transport tubes and analysis containers have been tested thoroughly with the chemicals to ensure that they do not corrode or burn. The no-spill policy is maintained by sealing the water bath and providing walls on the module tray. The precise actuation of the stepper motor for the auger also prevents soil spillage.

5.3 Rock Database

We have formulated a database with parameters like colour, mineral, and elemental composition, biological inferences, origin, and formation along with the images of the specific rocks. The identification and analysis of the rocks observed on the site is a crucial aspect of the Astrobiology Expedition. The presence of certain rocks and minerals is conducive to life. Furthermore, biogenic rocks and minerals can be indicative of extinct or extant life. The rocks and minerals are identified by analysing the sample's physical features like colour, texture, and shape, using algorithms and filters in our database for efficiency.

5.4 Science Sensors

The sensor suite on the rover incorporates sensors which can quantify various biological and physical parameters of the environment. Factors such as moisture, pH and electrical conductivity of the soil, and presence of biosignature gases such as Volatile Organic Compounds (VOCs) and Volatile Sulfur Compounds (VSCs) will be detected. The data from these sensors will be used to plot graphs that will allow us to draw inferences and perform a thorough analysis.

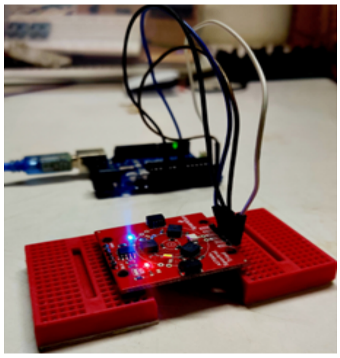


Figure 18: Spectral sensor

1. Soil Probe: We are incorporating a soil probe that can accurately measure soil moisture, pH, electrical conductivity and subsurface temperature. These can help us determine the habitability potential of the soil and determine the type of organisms that can survive in it.
2. BME688: This device has high accuracy temperature, pressure and humidity sensors. Its gas sensors can detect VOCs, VSCs and other gases such as carbon monoxide and hydrogen to resolutions in the range of parts per billion (ppb).
3. VIS-NIR spectral sensor (AS7265x): This triad sensor detects the reflectivity of the sample between the wavelength range of 350-1000nm. The data from the sensor can be used to plot a graph of intensity against wavelength that can help determine the chemical bonds present in the sample.

5.5 Fluorometer

We plan to implement a custom-built fluorometer on board the rover. It will help us conduct an in-depth analysis of the soil samples by means of addition of a specific agent. The addition of these compounds will help ascertain the presence of biomolecules such as nucleic acids and proteins, which fluoresce in their presence. The most reliable tests for fluorescence are being researched and appropriate intercalating fluorescent dyes are being narrowed down.

5.6 Optical Microscope

(a) Rocks (b) Growth on tree bark (c) Hypoliths

Figure 19: Microscope images

The microscope implemented onboard has a magnification of 75x to 300x. This provides a microscopic view of rocks and soil, which can help us identify textures, micro-fossils or formations in the samples. Furthermore, this microscope can also help us identify epiliths, endoliths, and hypoliths which can help us draw conclusions about the presence of active life on the site. We are developing a sliding mechanism near the mount of the microscope, which can adjust the focus. This will also allow us to look for smaller structures, such as fungi and microbial cells.

6 Prototyping

6.1 Mechanical Design and Manufacturing

Following up on the previous year's prototypes of a cycloidal drive system, a worm assembly was implemented in order to achieve precise motion, prevent backdrivability and provide the required reduction ratio suited to the current motors. The arm has also witnessed several upgrades, including a stowing mechanism, following the testing period. These upgrades were implemented using rapid prototyping via 3D printing. Over the course of the design phase, extensive prototyping was conducted on the 3D printed wheels, using materials such as PLA and PETG. Multiple designs, in combination with different materials, have been tested over a multitude of obstacles in order to achieve the optimum design that seeks a balance between compliance and rigidity. The five bar suspension has been redesigned in order to optimize weight while maintaining its load bearing capacity. Additionally the torsional spring values have been fine-tuned through extensive testing both on field and on Solidworks Motion Study. The new design of the five bar suspension is currently in its fabrication stage.

6.2 Electronics and Control Systems

The hardware prototyping of the ECS subsystem is initiated by a design idea, run in simulation software like proteus and LTSpice. Once the software successfully provides the expected results, the required corrections in the design are done. It is followed by arranging the required components and trying the circuit design on a breadboard. Finally, a PCB is designed on the idea that the circuit works as expected when implemented on a breadboard. The prototyping phase of the robotic arm started with simulating PID controls on MATLAB. After that, a simulation of forward and inverse kinematics was done respectively on MATLAB. Then testing of the PID controls was done on the dummy arm. After fine-tuning the PID, we implemented forward kinematics on the dummy arm. To achieve this, we used a BNO055 IMU to get feedback for the PID. We used two joysticks to control the robotic arm. A similar approach was implemented for testing inverse kinematics. We then extended the code with gripper control for the newly manufactured robotic arm. In order to prototype the GUI, data is sent from the server to the client via an ESP32. The PS4 dual shock controller is interfaced on the server side, and the motorcode is sent via the ESP32 to the client rover.

6.3 Artificial Intelligence and Automation

A temporary robot called "Martin" was made to help with preliminary testing of Global planner and the motor controller. "Martin" helped in the debugging of the motor control which calculates PWM signals from velocity and sends it to the motors. Sensors like a BNO055 for orientation data, GPS RTK for positional data, Realsense D435 depth camera for image output were interfaced using a Raspberry Pi microprocessor which provided the PWM pinout. Algorithm debugging and optimization was also carried out on the temporary bot which allowed us to test specific cases and increase our overall preparedness. To simulate arrow detection, an analogous mask for a frisbee was created using OpenCV, and the distance of the frisbee from the ZED2 stereo camera was obtained using stereographic projections and passed through a linear controller. The rover followed the frisbee imitating the arrow aspect of the AutEx mission.

6.4 Life Science

Multiple chemical assays for a range of biomolecules were performed on different soil samples. This helped us eliminate tests that generated a large number of false positives, could not be detected due to the colour of the soil, or were not sensitive enough to detect the desired biosignature. To interface our sensors, we worked with the Electronics and Control Subsystem. The sensors are interfaced and calibrated using an RPi 4B. In the process of selecting sensors, we found ones that did not generate accurate results, and these were thus discarded. The fluorometer is still in the prototype phase. It will use a laser as a light source, which causes the excitation in the sample, and a photoresistor to detect any fluorescence. Chemical stains and compounds, which will fluoresce only in the presence of the required biomolecules, are still being researched. For testing the chemical assays, sensors and rock database, a combination of both unknown and known samples will be used. The known samples will be the control sample, which will help us determine how accurately our plan works. The unknown samples will allow us to develop our analysis and interpretation skills. The entire science mission will be tested to ensure the science modules and the chemical assays work in tandem and any possible errors will be found and will undergo rectification.