PROJECT MANAGEMENT

ORGANISATIONAL STRUCTURE

CRISS (Consortium for Research In Space Systems) is a 45+ member team with undergraduate students in their second and third years across multiple departments of BITS Pilani, Pilani Campus. The team is advised by a group of 15+ professors across a multitude of disciplines such as Mechanical Engineering, Electrical and Electronics Engineering, Biological Sciences, Department of Chemistry, Computer Science Engineering etc. Our Faculty-in-charge is **Dr Mani Sankar Dasgupta**, HOD, Mechanical Engineering. While setting up the organisational structure of the team, care was taken to ensure that communication channels were efficient. On the technical side, the team is divided into 4 subteams, viz. **Mechanical, Electrical, Software, and Science.**

The MECHANICAL Subteam is responsible for building the mechanical backbone of the rover. To ensure proper delegation of tasks, the team is divided into 3 subdivisions: **Mobility Subdivision**, which builds the wheels, suspension and chassis, **Robotic Arm Subdivision**, which is responsible for designing, fabrication and programming of the robotic arm and **Science Mechanism Subdivision**, which designs and assembles the components needed for soil collection and analysis mission. **The ELECTRICAL Subteam** has been tasked with designing and assembling all the electrical and electronic components that will be required on the rover. The subteam has been further divided into 3 subdivisions: **Powers subdivision**, which builds the battery pack, power distribution architecture and its wiring, **Embedded Subdivision**, which is responsible for all the embedded electronics in the arm, drive motors and science module. The third subdivision is **Communications,** which works on intra-rover as well as base station communication.

The SOFTWARE Subteam is responsible for the algorithm development and coding that will enable the rover to complete its missions. It is further divided into **Navigation** for path planning, motion planning and vision integration, **Perception** for the development of computer vision, Visual SLAM and Reinforcement Learning and **Hardware**, which is responsible for choosing the optimum hardware components keeping in mind performance as well as financial feasibility. **The SCIENCE Subteam** is responsible for the strategic planning and implementation of its approach to the SCAM task in conjunction with the science-mechanism team. It has 2 subdivisions: **Life Detection** that focuses on biochemical, optical and habitability analysis on soil and **Rock Analysis** which is responsible for geological analysis as well as life detection on rock samples.

The team is led by a Team Lead and a Vice Lead, followed by Subteam Leads for their respective subteams. The Subteam Leads along with the Team Lead and Vice Lead form the **EXECUTIVE COMMITTEE**. Within these subteams, we have established Points of Contact with respect to each subdivision. Furthermore, the team has a few handpicked **SYSTEM ENGINEERS** who resolve inter-team dependency issues, as mentioned above. Such an organisational structure enables an efficient flow of information while keeping the communication channels flexible. The different strata of roles also encourage greater accountability. Apart from this, the **OPERATIONS Team** consists of 6 subdivisions, viz. Treasury, Fundraising and Sponsorship, Website development, Content Writing, Graphic Designing, and Social Media outreach.

PROJECT PLANNING

Setting the Foundation: Since the team was newly established by a bunch of robotics enthusiasts completely from scratch at the beginning of 2021, the team didn't have any legacy of knowledge nor experience for rover design or manufacturing. Hence, the fundamental task executed by the initial team members was to study different state-of-the-art rover systems in the space industry and rover challenger series (eg. University Rover Challenge). It helped the team to interpret different components and modules of our rover, the level of complexity as well as autonomy needed for the IRC Challenge missions. The team paid close attention to regulations mentioned in the rulebook to make sure the rover is designed as intended, with a major focus on modularity and robustness.

Stages of Development: The four subteams viz. Mechanical, Electrical, Software and Science then began with a more specific study of deliverables to devise problem statements to be solved under each subteam. These problem statements were then divided among further subdivisions and subsections within the subteam to assign tasks to each individual. The deliverables are then arranged in a proper timeline with proper time buffers to respect deadlines and milestones. Since its inception, the team divided the rover development process into 5 phases: **(1) Rover Study (2) Skill Development (3) IRDC Challenge 2021 (4) Rover Design for IRC 2022 (5) Manufacturing & Assembly.**

(1) helped the team to gain proficiency in mechanisms, electronics, science and autonomous systems study. (2) was responsible to help members learn about different tools needed for designing, electrical interfacing and software development. After setting up the foundation of the team through (1) and (2), it participated in IRDC 2021 and gained major experiences in overall rover design and collaboration among different subteams. The most important outcomes were a better understanding of rover development in stages and inter-subteam dependencies. The team then started to apply its knowledge gained through (3) for our most important milestone till then, i.e. (4). The team took care to decode the actual mechanisms and electrical architecture, as well as science tests and apparatus needed till last-point detail to be manufacturing-ready right after designing. The team has finally plunged into (5) to implement and execute the deliverables. All five phases are roughly consecutive, but not mutually exclusive in terms of timeline. All of them merge with each other with a few parts always running in parallel eg. prototyping and designing to improve the final design and then getting into manufacturing of actual components.

Subteam-wise Strategy: The Mechanical team leveraged designing and simulation tools to develop suspension, chassis, wheels, arm and science modules. It prototyped several components for studying mechanisms and manufacturing such as 3D printing or suspension links using PVC pipes as a feedback system for improved mechanisms. The electrical team also interfaced with several actuators, sensors and visual apparatus to understand its working and needed electronics & processor requirements for each of them for optimum performance. The Science team did extensive research analysis on biology and geology for arriving at appropriate wet and dry tests along with science instruments and apparatus. Finally, the software team did algorithm implementation for autonomous navigation and perception, followed by current prototype bot testing and actual rover in January.

RESOURCES MANAGEMENT

The team recognises the importance of managing all of the numerous aspects that contribute to the smooth operation of the team and project progress. The team handles the resources in 5 sections: **(1) Human skills (2) Inventory (3) Financial resources (4) Production resources (5) Information technology**

Human Skills: This is the most important resource we have and will continue to have. Hence, the team focuses on developing a conducive collaboration environment to nurture the skill as well as the enthusiasm of members to make sure they are delivering and contributing at their optimum level. The team has thus collaborated with 3 Institutes for accessing technical guidance and resources: **BITS Pilani, CEERI Pilani and NTNU Trondheim research group.**

At BITS Pilani, we have our own 3 workspaces allotted for 24*7 where members can avail themselves of good sitting and brainstorming facilities at their own time and pace. We also have connections with Innovation Hub, Library, Labs, Faculty and Workshop inside the campus which help us provide electronics, computational resources and consumables on a temporary or permanent basis. At CEERI, the team collaborates with a pool of scientists to work directly under the projects relevant to our team. NTNU research group especially collaborates with the software team to develop the autonomous systems of our rover. Collaborations with these entities help the team keep continuing the research in spite of financial constraints. Apart from these connections, the team invests considerable time in brainstorming sessions and subteam level meetings, along with constant communication with system engineers and team leads to keep the development process in a feedback loop. The team members also work among each other very efficiently, with senior and experienced members helping new and junior members to acquire skills and understand concepts better

Inventory: Since the team has its own workspaces allotted by the institute, it avails the spaces to properly store the different components safely and in proper maintenance. It keeps the electronic components, sensors, actuators, etc. in lockers with naming conventions and an inventory placing system for rapid localisation and to avoid dust settling on components. Consumables such as channels, rods, sheets, 3D printing spools, fixtures, mounts, etc and tools needed for manufacturing are stored separately at a common place or directly procured through Workshop on a loan/purchase basis. Prototypes for testing (eg. Arm prototype, Rover Prototype Bot for software testing, Science mechanisms, etc.) are usually maintained and stored at the lab allotted to us since the environment is more isolated from the outside environment with ample lighting and electricity facilities. Finally, the operations team maintains thorough frequent documentation to tally components against their working conditions and possession by members.

Financial and Production Resources: Since the budget of the rover is huge, it is of grave importance to maintain funds, responsibly conduct financial transactions and avail facilities available to us through labs, centres and manufacturing workshops. Since the team has an official bank ledger account under Institute, all the funds are stored safely and all transactions are conducted by the Accounts Department on a high priority basis for the team. This ensures the team doesn't spend much time on transaction and shipping time. The team also has a separate bank account in which it stores money contributions from team members and utilises to order components urgently without any hassle of Institute involvement. A well-developed finance team helps in keeping a tally of all purchases made or to be made and provides analysis about vendor choices and price options. Due to the team's connections with different entities as mentioned above, the team can freely experiment with different components without any money investment and purchases, to make the optimum purchase choices later. This helps in saving a lot of money for the team in terms of prototyping and learning. The team can also avail manufacturing facilities at workshops and centres such as Additive Manufacturing, CNC, Welding, Consumables, etc. free of cost or at a subsidised rate.

Information Technology: Owing to the complexity of the project and team strength, it's of importance to have a well-maintained database of information arising from different subteams. The team uses Slack and Messaging Apps for communications and official notices, Github for software development, Fusion Team Hub-Dropbox-Google Drive combination for design and simulations files, Valispace for engineering data, Notion for collaboration and task assignment and Google Drive for file storage. These tools help us inefficient collaboration among team members.

FUNDRAISING AND SPONSORSHIP PLANS

Bank Account and Institute funds: Since our team was founded recently (January 2021) by a group of undergraduate students, fundraising and sponsorship were of utmost priority for us. To kickstart our fundraising campaign, our first step was to establish a bank account under the supervision of our institute's Dean through a provision provided for teams like ours. This enabled us to not only generate legitimacy but also provided us with the means to advertise and attract potential donors. The team collectively applied for our institute's first-degree research funding program and that helped us with our purchase of equipment for our prototyping phase, which provided us with a sum of **₹ 6,00,000**.

BITS Fundraising Portal: By using the institute's official fundraising portal and with the help of the Alumni Association of BITS Pilani to guide us, we were able to successfully establish a channel for donors to contribute to our team. We are constantly trying to appeal to those who wish to encourage technical research on our campus. The same portal is also being used for crowdfunding as well, which we advertise using digital flyers, pamphlets and posters. Our fundraising team is constantly on the lookout for BITS Pilani Alumni in top corporate positions across the world who would be willing to donate or sponsor the team. Our future fundraising plans include selling institute-approved merchandise as well as organising workshop and skill development events based on our line of research, all of which will be concluded within the current academic session.

Sponsors: With regards to sponsorships, the operations subteam is constantly reaching out to corporations through mediums like emails, website portals and social media accounts. With the help of professors and industry experts, the team is in talks with vendors and retailers who are willing to sponsor it through discounts or Corporate Social Responsibility funds. Using a tier-based system, the team intends to provide its sponsors with perks such as advertising on banners, flyers and our website, social media coverage and organising specialized workshops in our institute. At the moment, CRISS' sponsors are Autodesk, who have generously granted the team a sum of **₹ 1,00,000**, PCB Power Market, who has agreed to fabricate PCBs for free of cost, Ansys and Valispace who have provided the team with their licensed software for free and Altem Technologies who have agreed to manufacture 3D printed wheels for free while also providing their much needed technical guidance. We also encouraged our team members to contribute to the team as per their willingness to do so for a total of **₹2,00,000** and we are grateful to say that this was able to solve many of our urgent needs.

Budget and Funds: The team's current funds exceed its required budget which puts it in a comfortable position to take part in future competitions. We wish to develop a sustainable model that will last in the institute for many years and for that, the team needs strong financial support, which the Operations Team has successfully garnered. This will also help cover any unforeseen costs while allowing the financial freedom to experiment with new ideas.

EDUCATIONAL & PUBLIC OUTREACH & RECRUITMENTS

The sole purpose of the founding of our team was to foster interest in the field of robotics and astrobiology among the students of our college. Hence, the team is actively involved in various public outreach activities. Through the use of our social media platforms, we post informative and graphical explanations for many of the concepts that we find interesting. This way, we aim to generate interest and excitement among the new students who wish to try something new in this field. The team also conducts various technical workshops for teaching skills to campus students and collaborates with on-campus technical teams to create a combined repository of knowledge accessible to students.

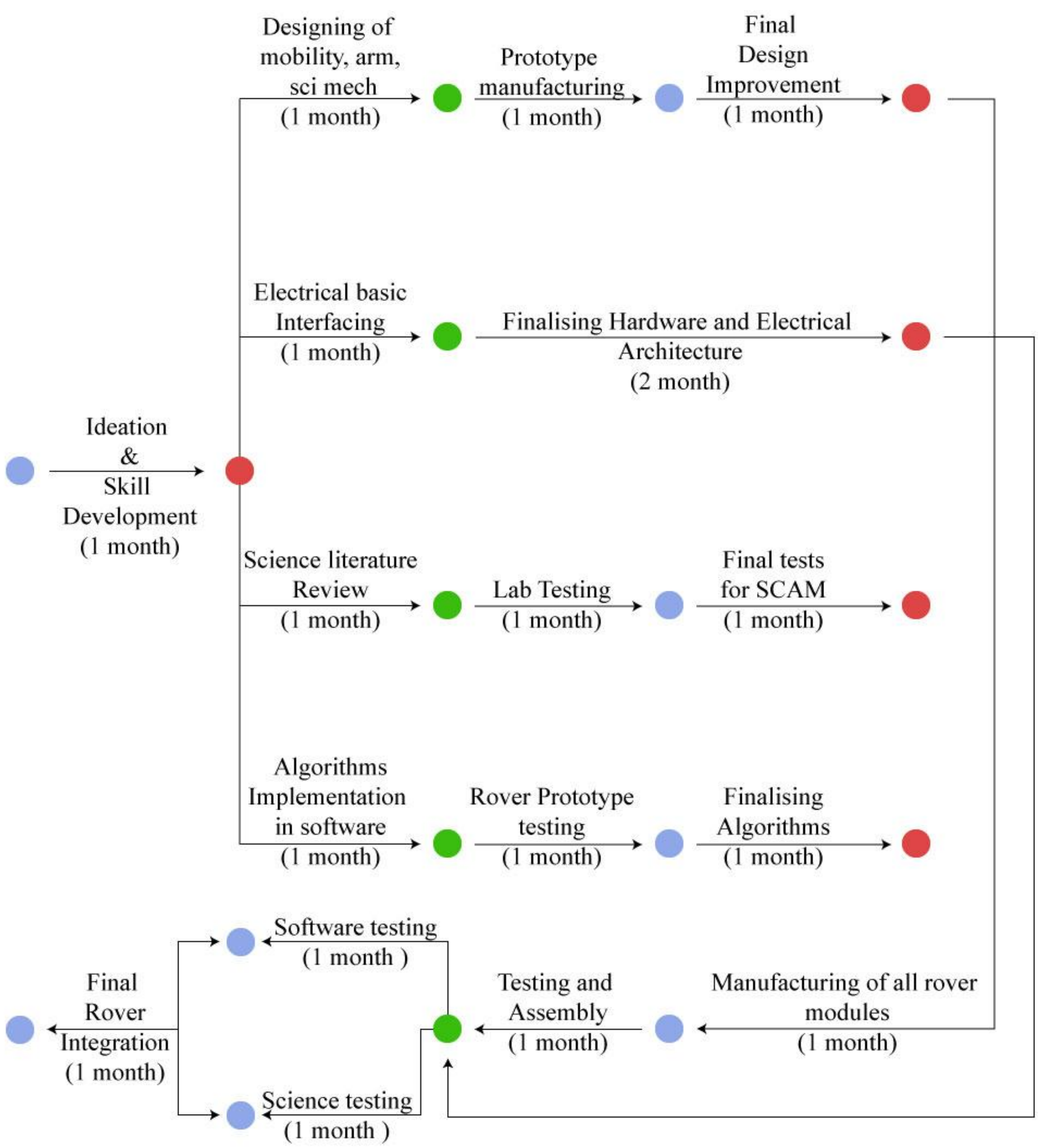
The team conducts month-long recruitments to select highly motivated and talented students from campus that can commit fully to the team's works and vision. It consists of 5-6 stages with tasks in each subteam and subdivisions, with increasing difficulty and knockouts to select just 1-2 students in each subdivision by the end of recruitments after 2 interviews rounds followed by final HR round to gauge time commitment and personal motives of members joining the team. At the end of recruitments, we have a total of 20-25 students.

BUDGET

COMPONENTS	PRICES	COMPONENTS	PRICES
MECHANICAL		**SOFTWARE**	
Consumables	30000	StereoVision camera & Cameras	56,000
Machining & Manufacturing	30000	IMU & GPS	9,500
Bearings, Fixtures & Joints	20000	On-Board Computer	37,000
Drive Motors	20000	**SCIENCE**	
Linear Actuators	30000	Digital Handheld Microscope	5000
Science module and arm motors	20000	Raspberry Pi Camera sensor	4000
Motor Drivers	25000	16mm Telephoto Lens	4000
ELECTRICAL		Filter	7000
2.4 GHz transceiver	14200	Gas Sensors	10000

2.4 GHz antenna (Rover)	18000	Habitability sensors	3000
2.4 GHz antenna (Base station)	12000	7 in 1 sensor probe	6000
Base Station Control Hardware	10000		
LiPo Batteries & BMS	28,500	**Miscellaneous**	50000
Power Converters	4000	**Prototyping Costs**	50000
Raspberry Pis 8 GB RAM	20000	**Contingency**	50000
Microcontrollers	10000	**Logistics & Travel**	50000
Wires & Cables	5000	**Extras**	50000
CAN Hardware	5000		
General-purpose electronics	10000	**TOTAL**	**7,00,000**

DEVELOPMENT TIMELINE (PERT CHART)



MECHANICAL

MOBILITY

Chassis: The chassis has been designed keeping in mind structural strength and the physics involved in the calculation. The weight of the total rover is estimated to be 48 kg which is well below the 75 kg limit. Also, keeping in mind the 1.5 m × 1.2 m dimension limit, the rover will be around 1.2 m × 1 m. To protect the electrical module from dust, rain, and other environmental factors, it will be housed inside a plastic covering of approx 70 cm × 30 cm. To facilitate wiring, USB ports will be installed on the electric module.

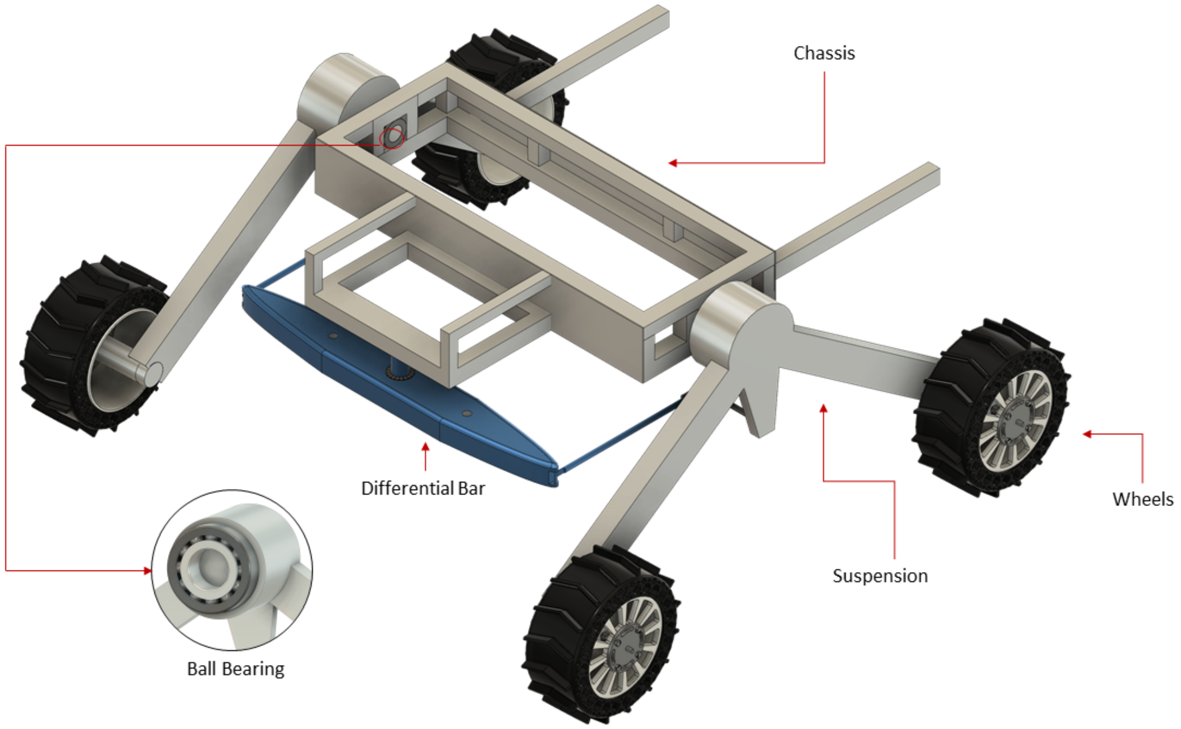


Fig 1: Complete Mobility System

Suspension: For the suspension, a simple 4-wheel double rocker suspension design has been implemented. This decision is taken based on the current time and other resources available. Being the team's first attempt at the competition, this type of suspension would be ideal considering the manufacturing options as well as time for designing and testing. The suspension, in unison with the differential bar, will support the chassis and help maintain it horizontally parallel to the ground. The differential bar will be placed under the chassis in order to leave ample space for other modules above. At the same time, it will help us bring the centre of mass of the rover closer to the ground. Torsion bearings are used to pivot the bar with respect to the chassis and ball joints to support the triaxial motion at the ends of the differential bar. The team is currently in the prototyping stage and iterating over a few versions to get the most optimal design. All corresponding simulations and calculations have already been done, and we are now eagerly looking forward to real-life manufacturing and testing of our rover suspension.

Wheels: Considering all aspects of manufacturing, assembly processes, the time of development and expenses with respect to wheels, it was concluded that 3D printing a custom design is a more economical and viable option. The wheel design has been completed and is in the final phase of simulations and testing. The team has implemented a TPU based honeycomb structure for the tyre since this structure cuts down the weight without compromising on strength and can absorb energy better than most other structures. The aluminium-based rim is kept as simple as possible with a simple spoke design. A source of 3D printing of required dimensions and for required materials, for prototyping has already been established in the university itself. The prototype will be made in the first half of December and field tests will be done using the same, changes will be made on the design if required after the field test, after the design is finalized it will be sent to Altem for 3D printing.

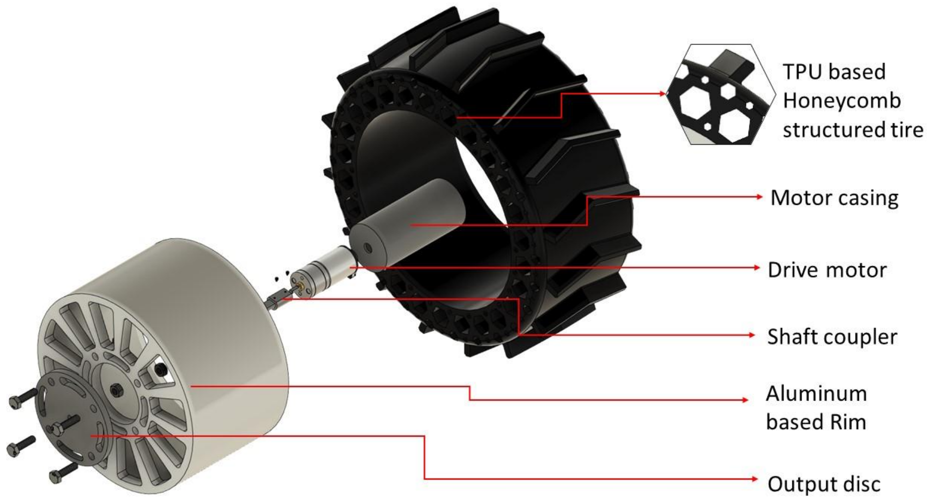


Fig 2: Exploded view of the wheel and wheel hub design

ROBOTIC ARM

Design: We have designed a 1.3 m long 5 Degree of Freedom articulated robotic arm that can pick up a payload of 8 kg. After detailed kinematic study optimum pivot positions were derived for the linear actuators of 6" stroke which rotates the first two joints. For smooth rotation between the links, flange ball bearings are used to support the connecting shaft. The pitching and rolling motion of the wrist assembly are attained by a set of angled double-helical gears. A zero backlash 1:40 reduction worm gear drive is used in the swivel base for the base rotation which will be fixed with the chassis. With the vision of modularity in mind, we have designed the entire arm into a principal module that can be disconnected from the base assembly at any point. The Arm will be coupled with the vertical shaft of the base assembly at the time of attachment of the arm. The end effector comprises a lead screw actuated 4 bar mechanism made using additive manufacturing. The gripping action is actuated by the motion of the lead in the assembly.

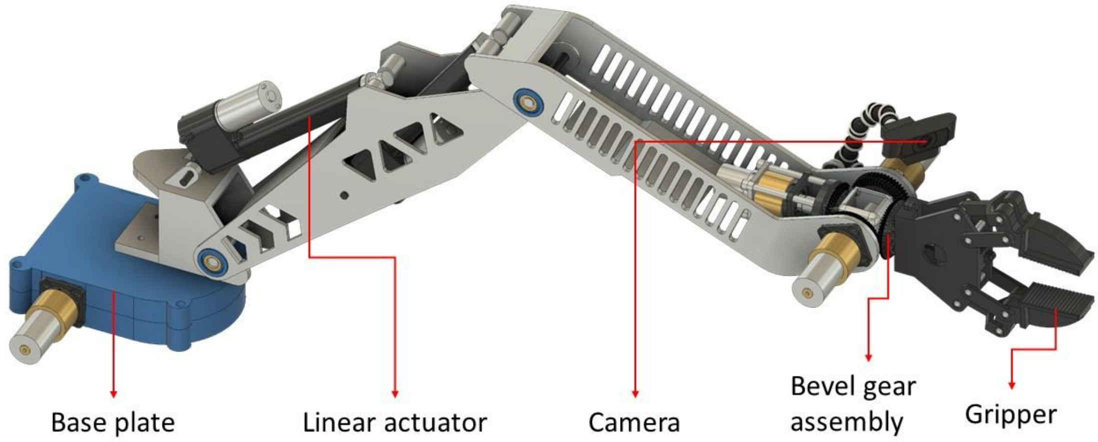


Fig 3: Robotic Arm Assembly

Manufacturing Plan: We intend to manufacture the robotic arm as multiple modular components. We will be creating our base assembly from a standard worm gearbox, customising it to fit our requirements and attaching it with our motor. We will be 3D printing multiple prototypes of the wrist assembly and the end effector iteratively to the design flaws and finally optimise the design choices. The links are to be cut out from aluminium sheet metals using a laser cutting process which will be held together by spacers. We plan to mount two normal web cameras over the arm, one will go on top of the end effector and one on the second link both with flexible mounts. A small scale working robotic arm prototype was made using servo motors and 3d printed links in order to implement the Forward and inverse kinematics algorithms.

Arm Programming: We plan to take in feedback from the motor from the base plate assembly, and the two linear actuators to perform an inverse kinematics algorithm. The wrist assembly will be controlled manually using an xbox controller/joystick. First 3 DoF will be controlled using an inverse kinematics algorithm followed by individual control of the remaining 2 DoF of the wrist. Arm simulations will be carried out in ROS and Gazebo using MoveIt and RViz libraries to assist in the motion planning of the arm. 3 and 5 Degree of Freedom inverse kinematics mathematical models have been developed and tested in MATLAB. A 3 DoF prototype has been fabricated to test the inverse kinematics algorithm. It utilises 3D printed links along with servo motors to test the algorithms developed. Multiple motion planning algorithms with increasing autonomy, and hence complexity are currently being developed and tested on the prototype

Testing Methodology: We will be constructing a lander with a vertically mounted keyboard, switches, joystick, USB ports and drawers which will be used to analyse the flexibility, accuracy and reachability of the robotic arm. Apart from that structural testing will also be carried out on the 3D printed wrist and end effector. Back drivability of the motors and actuators will also be studied.

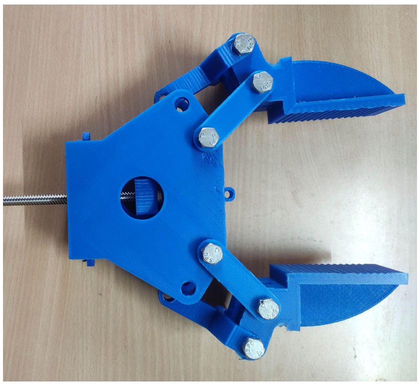


Fig 4: 3D Printed End Effector

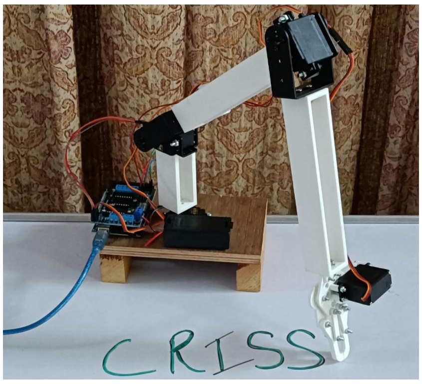


Fig 5: Arm Prototype for Programming

SCIENCE MECHANISM

Introduction: The SCIENCE MECHANISM designed by the team performs tasks related to the sample collection and analysis mission (SCAM). It consists of a collection mechanism, filtration, storage, testing and analysis. It is a modular system that can be attached and detached quickly.

Soil Collection: The collection mechanism consists of an auger that collects the soil sample from at least 8cm depth to satisfy the requirement of a minimum 5cm depth and 10g of sample. Three augers have been used to avoid cross-contamination across the sample collected in different sites, and they are used one after the other. To provide linear actuation to the augers, a lead screw has been used. A collection bucket collects and stores up to 50g of soil. The bucket can be rotated to pour some of its contents into the filtration chamber by using a servo motor. Rock samples are collected using the robotic arm.

Filtration & Storage: The filtration chamber has a 2 level strainer+filter paper setup which allows fine soil particles and gives a colloidal solution when mixed with water. Water is stored in a reservoir and is pumped to the filtration chamber. The filtrate is then stored in the testbed. Flow control of water is achieved using valves wherever necessary. The reagents for testing are stored in three syringes, releasing the reagents when the plunger is actuated using a lead screw mechanism. Its advantage is that a controlled flow of reagents is released for testing in 3 stages.

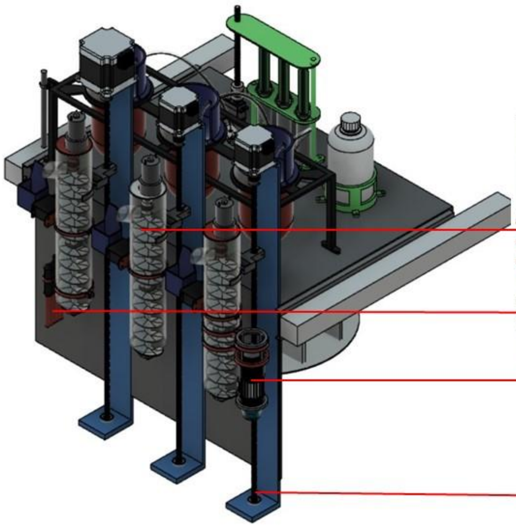


Fig 6: Orthographic view of science module

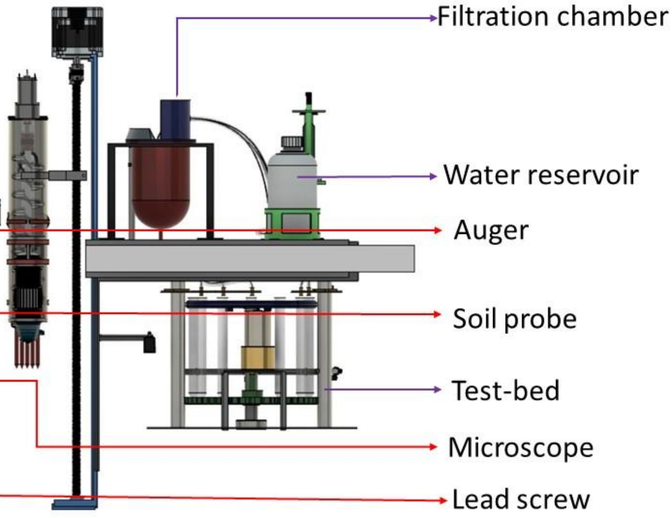


Fig 7: Side view of the science module

Testing & Analysis: The testbed has 12 test tubes arranged in a circular fashion and rotates using a stepper motor to align with the pipe outlets from the filtration chamber, and 4 test tubes are used per site. The reagents are poured into the test tubes with the sample, and multiple cameras observe the reaction happening, which relays back to the base station for analysis. A multifilter camera is also used which is mounted on the robotic arm to study the spectroscopy of soil and rocks. A Handheld microscope and 7 in 1 sensor probe are mounted on the auger system, which observes and relays back information regarding the sample.

Manufacturing & Assembly: The platform, motors, supporting rods, augers are metallic, while the mounts for a few components like syringes, water reservoirs are 3D printed. Some of the fixtures are welded to platforms and supporting rods, while a few others are clamped to support. At the final stage of assembly, a railing system is used to slide the entire module into the chassis. This makes it a highly modular system.

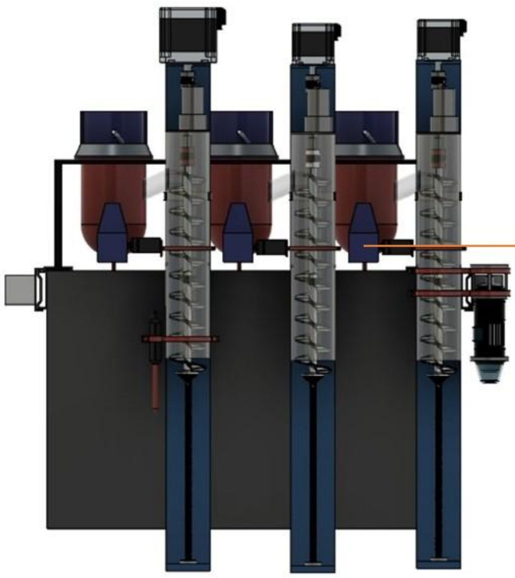


Fig 8: Lead Screw & Auger System

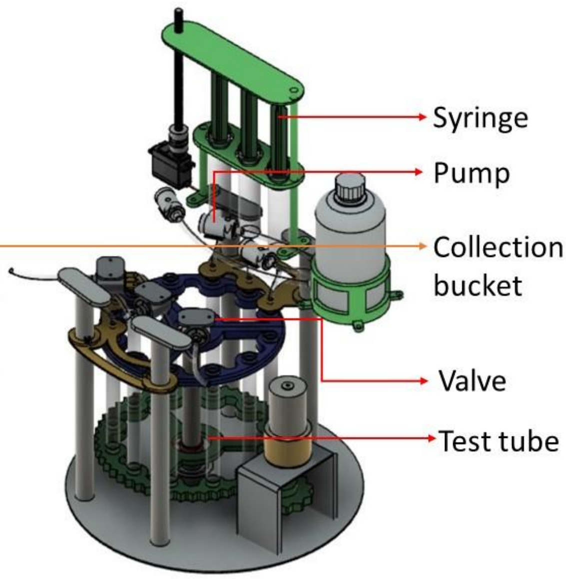


Fig 9: Storage & Testbed

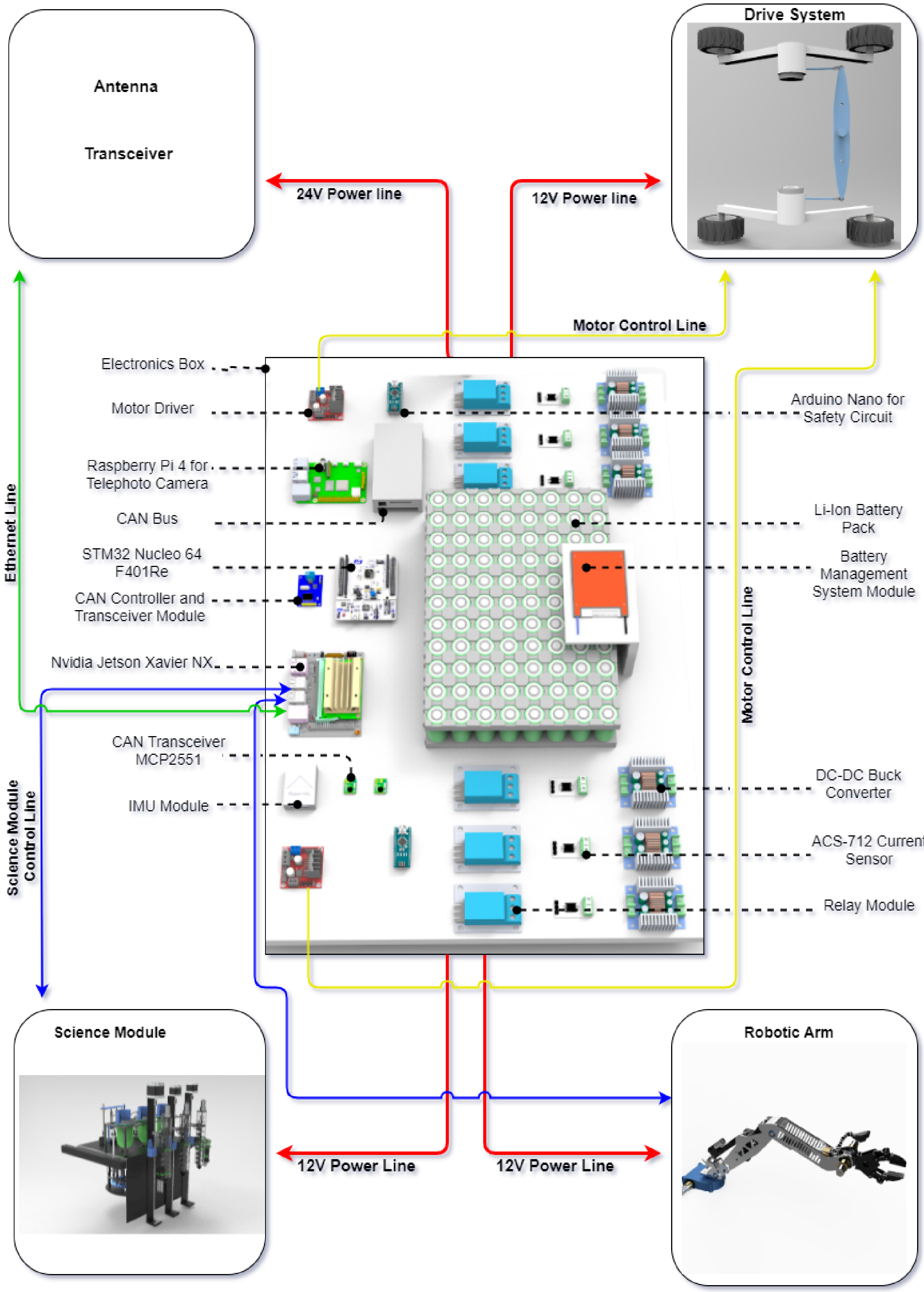


Fig 10: Electrical Architecture

ELECTRICAL

POWERS

Battery pack: Power requirements are met with Vipow 18650 8S11P Li-ion Battery. Each cell provides 3.7V and has a capacity of 3000 mAh. With the 8S11P combo we will reach upto 29.6V which will be enough to meet the motor and communications requirement. This battery also results in a total capacity of 264 Ah while the maximum continuous current will go upto 99 A. A BMS is also integrated into this Battery system which deals with various features like balance charging, protection from overcharge, over-discharge and SoC calculations. The battery will be placed on the lower floor of the electronic box towards a wall and will have dimensions of 16cm X 22cm X 8cm and will weigh up to 3.08 Kg. The battery will be encased inside a special wrapping material.

Power distribution: To maintain constant voltage lines across the rover, a total of 6 buck converters are used. 2 converters are used for powering the drive motors of 12V, one converter is used to power the motors and linear actuators of robotic arm and auger, motors and valves of the science mechanism and other miscellaneous components which operate in a range of 10-15V, one converter is used to provide 19V power supply to the Jetson, one converter will be used to provide 5V power supply the microcontrollers like Raspberry Pi and STM 32 nucleo-F401RE, one converter will be used to provide 24V power supply for the antenna.

Safety circuit: For overcurrent protection a safety mechanism is built using ACS 712 current sensor and a relay and arduino NANO. Current sensor is used in the circuit after each converter which can detect and read current upto 30 Ampere, relay is connected after the current sensor in the circuit which when open breaks the flow of current, arduino NANO reads the data from current sensor, if the current in the branch is more than safety limit then it signals the relay to break the circuit.

CONTROLS

The control system of the rover is decentralised for modularity and ease of intra-rover communications. It is divided into Electronics' box, Science box and Robotic arm. Science Box and Robotic Arm are equipped with Raspberry Pi-4 Model B+ owing to the good availability of I/O ports, as well as Bluetooth and WiFi connectivity. The RasPis are connected to the multiple onboard cameras and sensors. Its powerful video compression capabilities will be used for efficient transmission of video feeds coming from the multiple webcams on board. The Science box, apart from microcontrollers, contains electro-mechanical components such as pumps, valves and motors essential for collection and testing of soil samples.

Considering the Autonomous navigation capabilities required for the rover,the Nvidia Jetson Xavier NX is chosen for its exceptional computational power, 40 pin GPIO expansion header and versatile array of I/O ports. The Jetson will also be connected to the rover antenna, and will be the mediator to send/receive data to/from the RasPis and other microcontrollers across the system.

To control the drive system consisting of 4 DC motors, two Sabertooth 25A dual channel motor drivers are utilised. The STM32 Nucleo64-F401RE dev-board is used for interfacing the motor drivers considering its high accuracy owing to its 10bit PWM which is necessary for the precision required for the Autonomous Mission. Furthermore, feedback from quadrature wheel encoders will be used for more precise control of both the motors and the rover as a whole.

Other microcontrollers like Arduino Mega and Uno are used for their compact size and adequate number of pins for controlling the various motors and sensors. Similarly, RasPys are used wherever heavier processing is required, or video feed is involved. Arduino Nanos are used for handling lower level tasks in the systems.
The intra rover communications are handled through a CAN bus. All microcontrollers are interfaced with the same using the MCP2515 CAN controller, and/or MCP 2551 transceiver, depending on the microcontroller at hand. The microcontrollers are programmed to acquire information from the CAN bus, allowing for plug-and-play level integration, and eases the addition of microcontrollers to the system. The CAN_H, CAN_L Lines coming from different microcontrollers will be integrated on a PCB for tidiness.

All systems were designed for modularity at every level. Every module has its own microcontroller, and connects to CAN. Similarly, every module has designated ports on the electrical box for connecting with components outside without letting in dust. For last minute additions, rubber wire hole plugs are used, so as to put wires through without letting in dust. Ports like USB Type A, Type B, RJ45 as well as dust proofed holes for all other wires are present on the box walls for quick disconnection of the Science and Arm modules as well as the Stereo Cameras and Webcams.

COMMUNICATIONS

The communication system planned for the rover entails a 2.4 GHz link (using the 802.11 standard) from the base station to the rover. The rover is equipped with the omnidirectional Ubiquiti AMO 2G13 Air Max Omni antenna along with the Ubiquiti AM-2G15-120 sector antenna at the base station. Both antennas are fed by the Ubiquiti Rocket M2 transceivers which allow for seamless plug and play integration. These transceivers are fed using a 24V Power over Ethernet line through the Ubiquiti's PoE adapter.

The various microcontrollers present on the rover will be connected to the CAN bus via multiple CAN transceiver modules. Additionally, ethernet cables will be used for relaying bandwidth-intensive data like the camera feeds. Camera feeds will be compressed using the H264 algorithms and then transmitted. Due to the minimal number of ethernet ports available on the OBC, attempts for interfacing some of the microcontrollers wirelessly using Bluetooth is also being explored.

Along with the antenna and transceiver mentioned above, the base station is equipped with a joystick, controller and keyboard input methods to allow for rover control remotely. Rover tracking using GPS is to be implemented coupled with a compatible antenna rotating mechanism at the base station to allow for minimal pointing losses. The bottleneck of interference due to other sources using the same band is tackled by changing the primary channel of operation (facilitated by the Ubiquiti AirOS interface). Non Line of Sight conditions set to be tackled empirically using the data gathered from extensive testing. Figure 1 shown below depicts the block diagram of the entire communication system.

SCIENCE

Introduction

For the Soil Collection and Analysis Mission, we have developed a semi-autonomous science module equipped with testing methods and sensors to analyze the habitability of the surroundings. The science module is well equipped with various chemical tests, optical analysis techniques, and soil and gas sensors. For better results and space management, each piece of equipment has been placed in the most suitable places throughout the rover. We have divided the SCAM into two sub-missions for ease of performing, Life Detection and Mineral Analysis and Habitability analysis. We have carefully chosen the techniques to be used for each sub-mission and have also planned out the progress of SCAM in the form of individual progress of each sub-mission and have carefully picked the equipment to be utilized for each.

Life Detection and Mineral Analysis

The LDMA sub-task comprises analyzing the soil to detect different biomarkers with the help of chemical analysis and analytical techniques such as Raman Spectrometer so as to determine if life is present in the soil or not. It also involves the usage of optical analysis to detect rocks and determine their mineral composition. The positive test of all the chemical tests along with the detection of ribose sugar through Raman spectrometer can be indicative of an extant form of life where the ribose sugar comprising NA molecules encodes for proteins which help in the production of glycogen/starch the energy-storing molecules with all of these process being carried out inside of a cell with plasma membrane comprising lipids, thus covering the central dogma of life. A positive test for some biomarkers would indicate the presence of an extinct or inactive form of life.

Chemical Tests: A suite of carefully chosen tests has been incorporated in the science module for the detection of essential biomarkers of life. The tests cover all the basic building blocks of life - proteins, lipids, and fats, energy-storing carbohydrates (e.g., starch, glycogen), and ammonia strip test. The Biuret test detects the presence of peptide bonds by the formation of pale purple-coloured coordination compounds, thus covering up most of the proteins. Sudan IV test detects the presence of lipids, triglycerides, and lipoproteins by using the Sudan dye to stain the lipid molecules; the presence of lipid can be easily identified by observing the stained lipid ring formed above the soil sample. Lugol's Iodine test detects the presence of starch and glycogen by the formation of blue-black colored amylose-iodine complexes. Ammonia strip test detects the presence of ammonia which is essential for many biological processes and serves as a precursor for amino acid and nucleotide synthesis. In combination with other molecules, these biomarkers can provide a conclusive differentiation between extant, extinct, and no life samples.

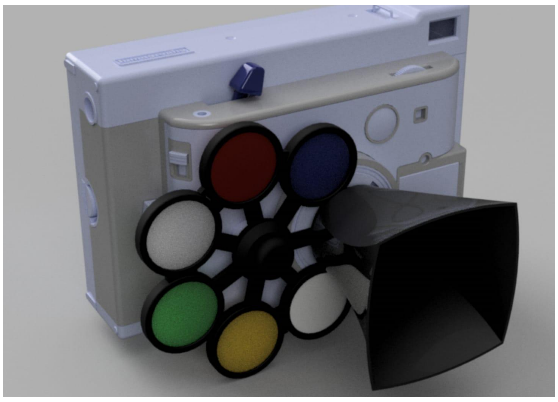


Fig 11: Filtered HRC

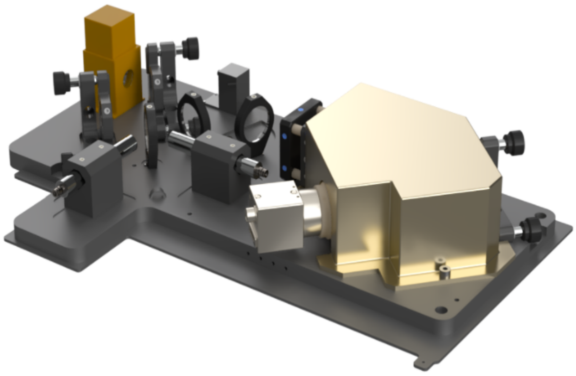


Fig 12: Raman Spectrometer

Handheld Microscope: We will be implementing a handheld digital microscope for rock analysis. The handheld digital microscope has a digital camera with LED illumination points to provide live video to the base station and capture images. It will be attached to the linearly actuating auger. It will be used to study the texture and surface mineral composition of the rocks. Once the image is processed to the base station, intelligent data interpretation models will be applied to the photos to compare the same with the existing dataset and determine its mineral composition. These models are developed using deep learning and machine learning techniques.

Raman Spectrometer: A custom dual-laser Raman spectrometer is implemented to detect key biomarkers and minerals such as nucleic acids, carbohydrate molecules, saccharides, and minerals. The instrument will be mounted on a linear actuator that will actuate to go close to the sample, which can either be a soil sample or a rock sample. The primary purpose of the Raman spectrometer would be to obtain the composition of the rock or soil sample under study. The shift in wavelength of the Raman scattered particles generates a fingerprint by which molecules can be identified. Raman spectrometer has been implemented as it does not require sample preparation, and it could be utilized for soil analysis and rock analysis as well. A multi-laser system (532nm and 785 nm) is used to obtain Raman spectra at both wavelengths and detect as many molecules as possible. An onboard processor uses the output of the CMOS detector to produce graphs. The analysts at the base station would study these graphs to identify the minerals and biomarkers necessary for detection. To analyze the graphs obtained from the Raman spectrometer, the entire team of analysts would undergo training and practice reading the Raman Spectrometer graphs under the guidance of experts and with the help of known samples.

Filtered HRC: The Filtered HRC(High-Resolution Camera) is being used to know the element composition and mineralogical composition of a sample under study. This technique has two main components: a 1080p high-resolution camera and a wheel containing low band-pass filters, each corresponding to a particular wavelength. One is a complete pass filter to get the standard image of the rock sample. A specific rock sample is photographed using all the filters to know the mineral composition. The elemental and mineral composition obtained from these pictures can also help us in understanding if there is life present in the sample or not. A high concentration of biotic minerals can indicate the presence of life. The image captured through this filter gives the spatial distribution of the minerals and elements in the rock sample under study. The on-site analysts will be trained to understand the difference between reflection from the sample and that from the surroundings; a standard image without any filters will be captured at the beginning to ease the job.

Deep Learning: The rock analysis will also be assisted by Deep Learning (DL) Neural Networks pre-trained on a database collected before the competition. The NNs will provide the human operator with reasonably accurate rock classification and the associated degree of certainty for the various classes in the database. This will allow the operator to cross verify the classification with the properties of the rock in the database, based on the image sent back. The database will be acquired in two phases, accompanied by the simultaneous development of the DL models and networks to improve their performance. The first phase will include the acquisition of images of rocks from the internet and the training of a model on this data. In the second phase, we will enhance the real-world performance of this model by capturing and using real-world images of rocks from our imaging equipment. The model may have to be modified by varying degrees subject to the availability of ample training data of all image classes.

Habitability Analysis

For Habitability analysis, we will be using a suite of sensors. These sensors will help us to determine whether the environmental conduction at a particular place is favourable for life or not. For atmospheric analysis, we would be using sensors that will detect the presence of oxygen, carbon dioxide, methane, carbon monoxide, ammonia, UV intensity, and other nitrogenous gases. Other than this, we would also incorporate a soil sensor which will provide us with the moisture content, pH value, temperature, humidity, and NPK concentration of the soil sample. The presence of water is a significant indicator of life. Thus we are also using a humidity sensor, which will provide us with the relative humidity at a particular place. If the relative humidity is in the range of 90% to 100% in an area, the probability of the presence of life will be maximum. As the percentage of relative humidity will decrease, the likelihood of life will also decrease proportionally. Other than this, we are also using an atmospheric pressure sensor. The range of atmospheric pressure suitable for life is around 0.01-10 MPa.

Fig 13: Handheld Microscope

Fig 14: 7 in 1 probe sensor

SOFTWARE

Base-station Interface for Rover Control: The control interface for the operators at the base station will be set up on a workstation computer. It will include a graphical user interface (GUI) that will provide the operator with the access necessary to manipulate all the equipment present on the rover remotely. This will be accompanied by a robust command-line interface (CLI) for reliable and swift control and feedback of the signals sent to and received from the rover. While it will function as a fallback input, it will also function as a primary feedback interface and will also have the capability to override the GUI in case of a malfunction. The GUI will provide the operator with an intuitive way to operate the rover remotely, while the CLI can be used to give predefined line-interpreted humanly readable commands, or alternatively using pre-programmed keyboard shortcuts for specific functions.

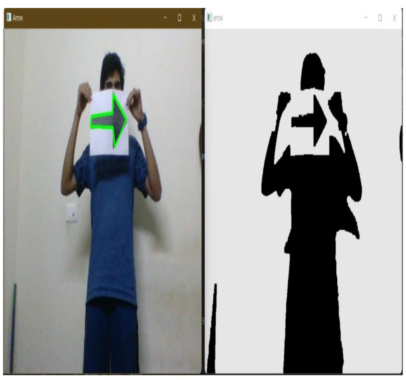
The robotic arm and the drive will be controlled separately by an Xbox controller for each, in order to provide the operator with more intuitive control for their manipulation. However, the GUI and CLI will also have options to control the arm and drive, as both fallback options with the capability to override the Xbox controller if and when needed.

Arrow & Cone Detection: A DL model is used to detect any arrows present in the field of view. The team uses state-of-the-art CNN fine-tuned by a custom dataset of images of arrows & cones of the set dimensions under specified conditions. Post detection pre-DNN CV is used for error correction. Arrows will be detected using CV and using pose estimation the rover will try to stand within the 2-meter radius vicinity of the arrow and stop there for 10 seconds. As soon as the orange traffic cone is detected, the rover stops within the 2-meter radius vicinity of the cone.

Next, the rover will get equally spaced repeated hypothetical goals until an actual arrow/cone is detected.
The traffic cone will be detected using the Yolo object detection algorithm. The model was trained using transfer learning along with custom training using images taken manually of cones to fine-tune the model's detection. Once the cone is detected the rover will estimate the pose of the cone and upon reaching the appropriate distance end of the task is declared.

Autonomous Traversal: Global planning algorithm consists of turning the rover to the current set goal and planning straight paths towards it. Using the direction information of the current/last visible real arrow, the planning algorithm will make use of repetitive hypothetical goals until an actual arrow/cone is detected. As soon as the rover sees a real arrow, the current hypothetical goal is discarded and the goal is set to the real arrow/cone Local planning will be done using state of the art local obstacle avoidance algorithms like Artificial Potential Field, Trajectory Rollout or Time Elastic Band, being done on real-time sensor data. Once the rover is near enough the goal the local planning algorithm will shift from APF to DWA to help the rover stand within the 2-meter radius of the arrow using Carrot Global Planner with a straight-line path, and stay put there for 10 seconds. As soon as an orange traffic cone is detected, the rover stops within the 2-meter radius vicinity of the cone.

Hardware for Software: For the purpose of testing and further development of our computer vision and autonomous traversal algorithms, the team has developed a prototype rover. The rover's dimensions are approximately 90cm x 80cm x 50 cm. It is a 4 wheeled rover, with each 30cm wheel being controlled by a 12 V DC motor, enabling skid-type steering. The Prototype bot has a Zed stereo camera, an Asus webcam and a PixHawk IMU and GPS sensor mounted on it. The stereo cam will be needed for the navigation tasks, The IMU and GPS would help us in localization. A webcam to help us out in increasing the field of view. The On Board Computer will be Nvidia's Xavier NX, as we would be requiring computational power that can handle all the communications and the algorithms with almost no lag. The software tools that we have used are the ROS middleware for communicating between the algorithms and the data flow from the sensors to the outputs to the actuators. OpenCV library for the perception needs, ROS packages for navigation algorithms, Zed Camera SDK for developing custom computer vision stack and perception capabilities.



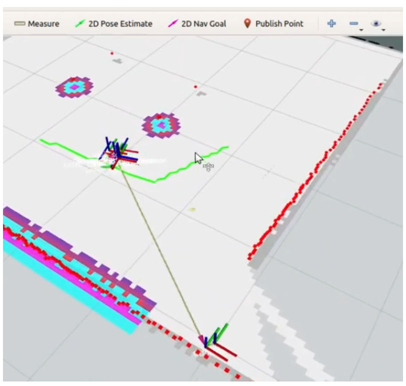


Fig 15: Arrow detection **Fig 16: Custom global path planner** **Fig 17: Rover prototype**

Why we opted for the Autonomous Task: As we are a research-oriented team that is interested in Robotics and Space Systems, the autonomy of mobile robots is an extremely relevant topic for our study. Keeping this in mind and the fact that we are also targeting the University rover challenge, in which the autonomous task is not optional, it was obvious for us to opt for the autonomous task for the International rover challenge. It will serve as a really important benchmark of how our research compares to other competing teams and how prepared we are for URC's autonomous task.

****** THE END ******