Team Anveshak

System Acceptance Review

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For the URC 2022, we, at Team Anveshak, have developed our latest rover, Foresight. Our team is divided into three modules - Mechanical, Electronics & Software, and Science. These modules, in turn, are subdivided further into various submodules that focus on specific aspects of the rover.

Core Rover Systems

Traversal

Various traversal mechanisms were analyzed and the rocker-bogie was chosen for its lower component count and better performance. We have customized the conventional rocker-bogie with an offset between the bogie and rocker frame, introducing mechanical stoppers to prevent a 360-degree overturn. The link lengths and angle of the bogie are decided after optimizing for the stability of the chassis.

The rover uses a string differential mechanism developed to stabilize the chassis during traversal. Using pulleys, it uses strings connected to the shafts of the rocker-bogie on either side of the chassis. Using the strings, we have been able to drastically reduce the play that has been associated with the bar differential earlier. Thoroughly lubricated steel wires covered with a rubber casing have been used in the differential to have the least possible frictional losses.

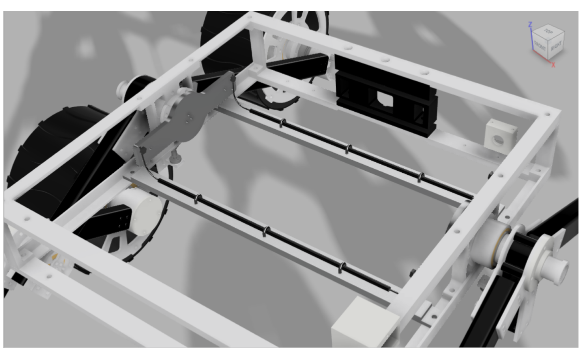

Fig 1: The string differential of rocker-bogie

The wheels of the rover were redesigned so as to be as light as possible without sacrificing robustness. The hubs were replaced in the current design with ones featuring a generative design with increased strength to weight ratio. The motor casing was replaced with a lighter version, and the 3-d printed parts were replaced with ones made out of abs plastic due to their superior material strength. out of polypropylene.

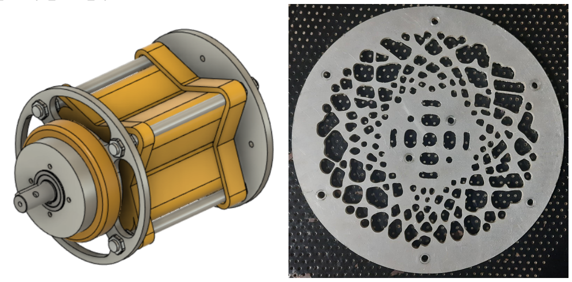

Fig 2: a)Motor setup b) Generative design of frame

Manipulator

The arm is a 5 DOF open-loop manipulator, designed keeping modularity in mind in order to reduce the setup time after the equipment servicing task. Maximizing workspace size and payload capacity were the primary factors considered during the design process.

The base of the manipulator uses a spur gear train with a high reduction ratio to minimize the required input torque. To ensure high output torque and non-back drivability of the joints, a worm gear and linear actuator have been chosen for the shoulder and elbow joints respectively.

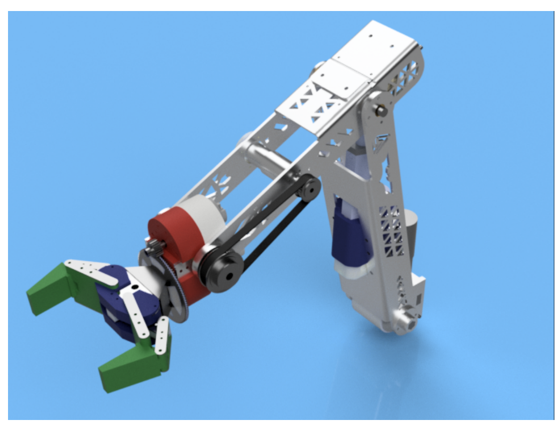

Fig 3: Manipulator

A preliminary analysis and simulation were carried out on MATLAB, followed by optimization keeping design goals and constraints in mind. A kinematic synthesis was carried out for the link lengths to obtain a larger workspace. In addition, the slider joint length has also been extended, and the linear actuator is replaced by one with a higher range. the whole robotic arm (manipulator) has been redesigned, and the changes in the manipulator have been focused on obtaining a larger workspace by increasing the joint.

The end effector of our manipulator is an underactuated gripper. It is capable of executing a *pinch grip* as well as an *encompassing grip*, depending on its point of contact with the object. This year, we have modified the link lengths of the 5 bar mechanism used in the fingers of the gripper and have adjusted the position of torsional springs to meet the force requirements more effectively.

Onboard Science Laboratory

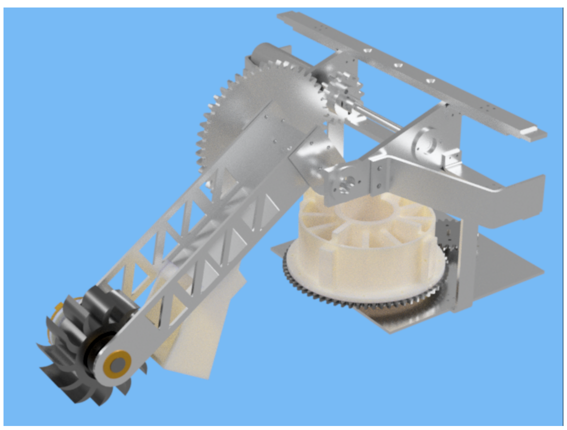

Fig 4: Automated Science Laboratory

The soil collection module is switched with the gripper module on the manipulator for the science task. It consists of a unique *bucket-wheel excavator* capable of excavating soil from very hard and rough surfaces in a short interval of time. The soil removed from the surface by the excavator is delivered into a collector box attached adjacent to it. The collected soil is transferred to the onboard laboratory using the manipulator.

The *onboard science laboratory* has a setup capable of preparing a suspension of soil collected from up to six different sites. The prepared soil suspension is pumped into the *2-DOF solution dropper*, controlled by solenoid valves.

The soil testing setup has test vials filled with chemicals for different tests arranged in a planar array. The *2-DOF solution dropper* drops the soil suspension into the vials as it moves from one vial to another sequentially.

Nichrome wires have been provided to enable heating of the reagents.

Control and Electronics

All the electronic components of the rover are housed in an electronic box that can be detached for maintenance. The box has provisions for sockets which makes it easier to connect external wires from the manipulator and drive actuators to the control systems inside the box. Nvidia Jetson Nano is used as the central processor and it interfaces the communication system to the controls of the rover. It is capable of performing computationally intensive tasks like object detection, path planning, and video compression algorithms.

The Nano runs ROS, which acts as an ideal framework to communicate between the various processes running on the rover while also enabling hardware abstraction. Improving upon our previous rover, we completely redesigned the PCBs to make them more compact and reduce the wiring. Optocouplers are used in PCBs to protect sensitive components from high voltages.

The Nano communicates with several STM32 (blue pill) microcontrollers, which use Pololu motor drivers to control all of the rover's motors and actuators. The drive motors are controlled by three STM32s, which are connected through an I2C connection. The STM32s that control the manipulator's actuators communicate with each other using a CAN bus, which was chosen for its high reliability and noise resistance.

Two 24 V LiPo batteries are used to power all the electronics of the rover, with power transfer managed by a custom-designed relay-based power distribution board. Buck converters are used in the power distribution board to convert the battery voltage into voltage outputs of 5V, 12V, and 24V. A killswitch has been incorporated to cut off the power to active components in case of emergencies.

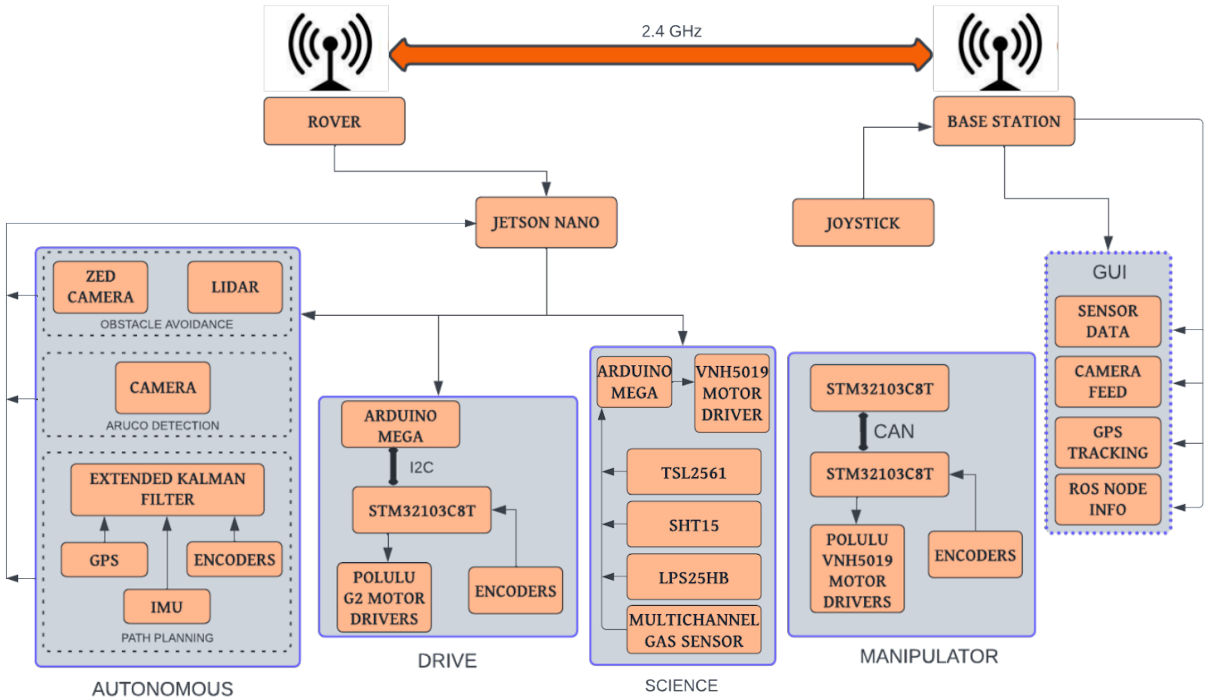

Fig 5: Electronics Systems Architecture

Communication

The 2.4Ghz band was chosen due to its ideal balance between bandwidth and range. Two Ubiquiti Rocket M2 routers are chosen due to their high degree of flexibility in configuring channel bandwidths. The routers are aided by a 13dBi omnidirectional antenna on the rover and a 15dBi sector antenna at the base station.

A continuous video feed provided by four Logitech cameras strategically placed around the rover gives information about the configuration of the rover, manipulator, and nearby objects. Video transmission is managed by a custom program built over GStreamer using UDP protocol, thereby greatly reducing latency. Control signals and other telemetry data are sent over TCP protocol which ensures error-free data transmission.

Software

A custom web-based GUI is used for visualization of the rover status. It allows us to start and stop ROS nodes with just one click of a button and also outputs status messages and video feed from the rover.

The frontend of the GUI is developed using React, a frontend framework. The backend runs on Flask, with an on-disk SQLite database to store information about topics and nodes.

Our model for autonomous navigation utilizes collective inputs from GPS and IMU sensors along with ZED odometry data to accurately locate and track the rover's position and motion. The combined input of laser scan messages from a 2D-LiDAR and point cloud messages from a ZED camera is utilized by the ROS navigation stack for path planning and obstacle avoidance. An algorithm is used for global path planning and the local planner is based on the dynamic window approach. We have implemented PID controls to get more precise control of the wheel velocity.

To detect ArUco tags, the arUco package of OpenCV is used. We have built a function that detects the distance between the rover and the arUco marker.

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Approach to competition tasks

Extreme retrieval

The Well-Built and reliable rocker-bogie system will enable the rover to traverse around rugged terrain easily. With different modes of speed, the rover will be able to complete the given tasks within the allotted time for each stage of the mission. In case of any signal loss, the rover is programmed to return to the last transmitted GPS coordinate to regain the signal.

Equipment servicing

The multi-purpose end-effector is capable of lifting loads of up to 6 kg with ease. Tasks like typing on a keyboard and Turning bolts using Allen heads can be done using the mechanism attached to the arm. The use of 720p cameras provides sharp feedback from various angles for ease of operation from the base station.

Autonomous navigation

Localization of the rover is achieved by using an Extended Kalman Filter to fuse the sensor data from the GPS, IMU, and wheel odometry data. The ROS navigation stack uses the combined input of a LiDAR and a ZED camera for path planning and obstacle avoidance. A wide-angle camera has been used to increase the field of view to make it easier to detect ArUco markers.

Testing operations

We found that the rover was capable of traversing rugged terrain with ease. The carbon fiber links also paid dividends in the rocker-bogie by making it lighter and more efficient. The PCBs were operated continuously for long periods of time to test stability and reliability. Communication range of the antennas was also tested under both LoS and NLoS conditions, which gave satisfactory results. Unit tests for software were performed to ensure the desired output, and affirm logical connections with other parts of the program. The sensors and I2C cables were made immune to electromagnetic interference by shielding.

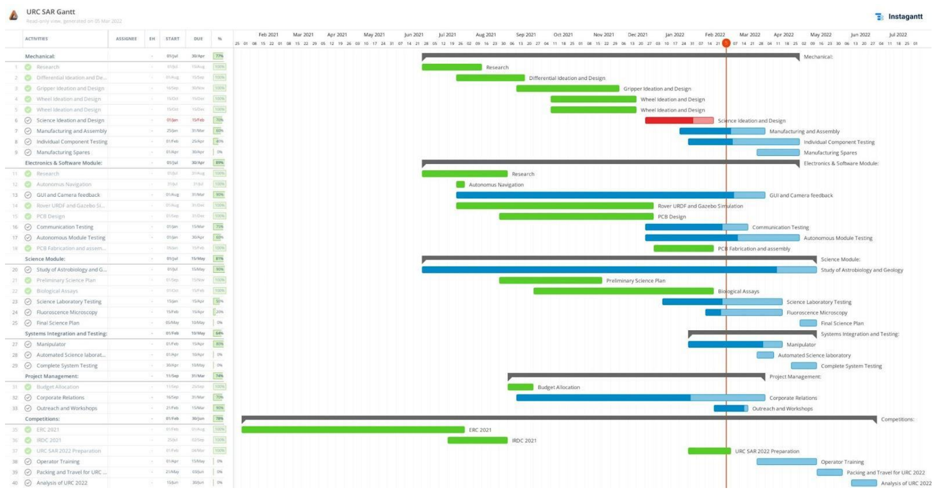
Upcoming phase of testing

We have planned a comprehensive procedure to test the complete rover, especially the redesigned subsystems.

A mock-up equipment servicing panel was built to explore the various capabilities of the manipulator and to gain control experience. Different inverse kinematics-based control algorithms will be tested for semi-automating control of the manipulator to enhance the speed and dexterity of manipulation. The automated science laboratory will be evaluated for its capability to collect soil from various terrains. The autonomous traversal capabilities of the rover will be assessed using the Gazebo simulation, as well as on the rover. ArUco detection will also be carried out under various lighting conditions to determine the optimum camera position. Operators will be trained extensively to ensure that the control of the traversal and manipulator systems is carried out effectively during the competition.

Project timeline

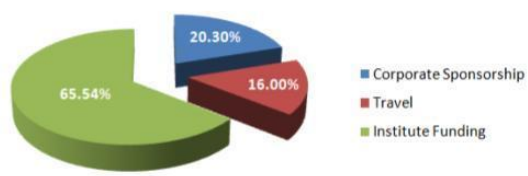
Due to the second wave of covid-19, we received permission to return to campus only in November 2021. Due to this our plans for fabricating and manufacturing components were delayed by a month. Currently, we have finished fabricating around 75% of the rover. Our primary focus is to draw insights from the drawbacks of the previous rover and make changes and modifications accordingly.

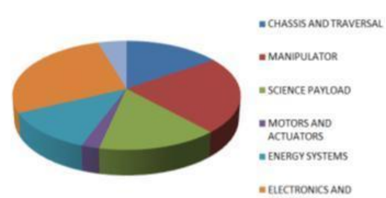


Expenditure overview

The rover for URC 2022 has a total cost of $15950, most of which was funded by our institute. Out of this, components worth $9750 are used from last year's rover. Additionally, we received $1,800 through corporate sponsorship. A detailed split up of the expenditure is given below. If we are selected for the URC 2022 finals, our institute will provide a grant of $7,000 for expenses related to travel and logistics to attend the competition. The additional travel expenses will be borne by the individual team members.

	Description	Budget allocated (USD) (June 2021 - June 2022)	Reused component cost (USD)	Expenditure till date (USD) (June 2021 - Feb 2022)	Upcoming expenditure (USD)	Total Rover Cost (USD)
	TOTAL ROVER COST					15949.62
	TOTAL	6550	9750.71	3860.86	2338.05	
1	CHASSIS AND TRAVERSAL	1000	3519.72	624.91	321.82	
1.1	Frame material and parts		977.14	350		
1.2	Differential			144	60	
1.3	Wheel		1571.15	130.91	261.82	
1.4	Manufactured Components		971.43			
2	MANIPULATOR	1500	400	326	1174	
2.1	Arm materials and parts		400	126	674	
2.2	Manufacturing			200	500	
3	SCIENCE PAYLOAD	1000	415.62	419.63	580.37	
3.1	Materials and parts		214.28	158.75	141.25	
3.2	Manufacturing		201.34	100.25	199.75	
3.3	Life detection chemicals			61.26	88.74	
3.4	Fluorescence microscopy			99.37	150.63	
4	MOTORS AND ACTUATORS	150	4375	130.95		
4.1	Drive motors		3600	0		
4.2	Other motors		100	0		
4.3	Actuators		675	130.95		
5	ENERGY SYSTEMS	800	0	523.73	261.86	
5.1	Batteries and other power components			523.72	261.86	
6	ELECTRONICS AND CONTROLS	1800	352.37	1559.97		
6.1	Processor			419.23		
6.2	Microcontrollers		52.37	130.93		
6.3	PCB Fabrication			382.79		
6.4	Sensors and Encoders			327.32		
6.5	Motor drivers		300	299.7		
7	COMMUNICATION	300	688	275.67		
7.1	Omni directional antenna		286			
7.2	Sector antenna		187			
7.3	Routers			235.67		
7.4	Cameras		215	40		





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Science Plan

The science plan has been formulated with the aim of gearing the rover to perform tests on the soil collected and distinguish between extant and extinct life with confidence.

Atmospheric Conditions

The rover is outfitted with sensors such as the SHT15 and DHT22 for temperature and humidity explicitly, TSL2561 and TSL2591 for luminosity, and LPS25HB for altitude and pressure. These sensors can detect the intensities of various wavelengths of light like *UV, far infrared,* and *ionizing radiations.* We're also using *Grove Multichannel Gas sensors* which can measure minimal concentrations of gasses.

Identifying Rock Samples

A wide-angle camera and onboard digital microscope are used for the analysis of soil and rock *texture, granularity, porosity, and color*, which is then used to identify the type of rock from a custom database. The database contains information about the *physical properties, composition, and origin of rocks*, from which the physical and atmospheric conditions that led to the formation of the rock can be predicted. The microscope also helps us *examine fossiliferous rocks* which might lead us to find structural or molecular evidence of extinct life. Besides, the pH of the soil is determined using pH strips.

Biological Assays

The major surface biomarkers that can be used to investigate the presence of life are *carbohydrates, lipids, proteins, amino acids, carbonates,* and *nucleic acids*.[1] The science subsystem onboard performs tests for these, and results are monitored using real-time camera feedback.

Benedict's reagent and *Bradford's protein assay* have been selected to test for the presence of reducing sugars and proteins respectively. While nucleic acids, proteins, carbohydrates, and intermediary metabolites are obviously potential molecular biosignatures, compounds in these classes are chemically fragile.[4] *Sudan (III) test has been selected to test for lipids*, a class of compounds renowned for their stability under harsh environmental conditions.[2] The difference in time taken by proteins (thousands of years) and lipids (millions of years) to decompose enables us to conclude how long ago life existed. *A test for $CaCO_3$ has been carried out using conc. HCl* to detect remains of extinct life forms. In addition to this, a test for NH_4^+ ions has also been carried out, since the presence of ammonium ions would indicate constant replenishment by microbes. NaOH is added to the sample, and the evolution of NH_3 *is quested by the gas sensor.* We are also using *bial's test for sugars* to detect the presence of pentoses and derivatives of pentose and *Nessler's reagent to identify the ammonium compounds* present in the sample.

We are in the process of building a custom fluorescence microscope using a multiline laser to assess the samples collected. *Cyanine and Rhodamine B* as fluorophores and *dichroic filters* are used to directly detect microbes in the given soil sample.[3] We are also looking into the possibility of conducting a test similar to the Viking landers' labeled release experiment, where *nutrients are injected* into the collected soil sample and a *change in the composition of gasses* released is tested.

Sugars	Proteins	Lipids	$CaCO_3$	Conclusion[3]
✓	✓	✓	✓	Extant (recent)
╳	✓	✓	✓	Extant (<1000 yrs)
╳	╳	✓	✓	Extinct (<Billion yrs)
╳	╳	╳	✓	Extinct (>Billion yrs)
╳	╳	╳	╳	No life

Chemical Hazard Protection

All chemicals are stored in separate slots of the collector box coated with a protective layer, thus preventing any leakage or contamination.

[1] Aerts et. al. (2014) *Biota and Biomolecules in Extreme Environments on Earth: Implications for Life Detection on Mars*

[2] *Biosignatures and Abiotic Chemistry*, An Astrobiology Strategy for the Exploration of Mars

[3] Tuovinen et. al. (2004). *Fluorescence microscopy for visualization of soil microorganisms - a review.*