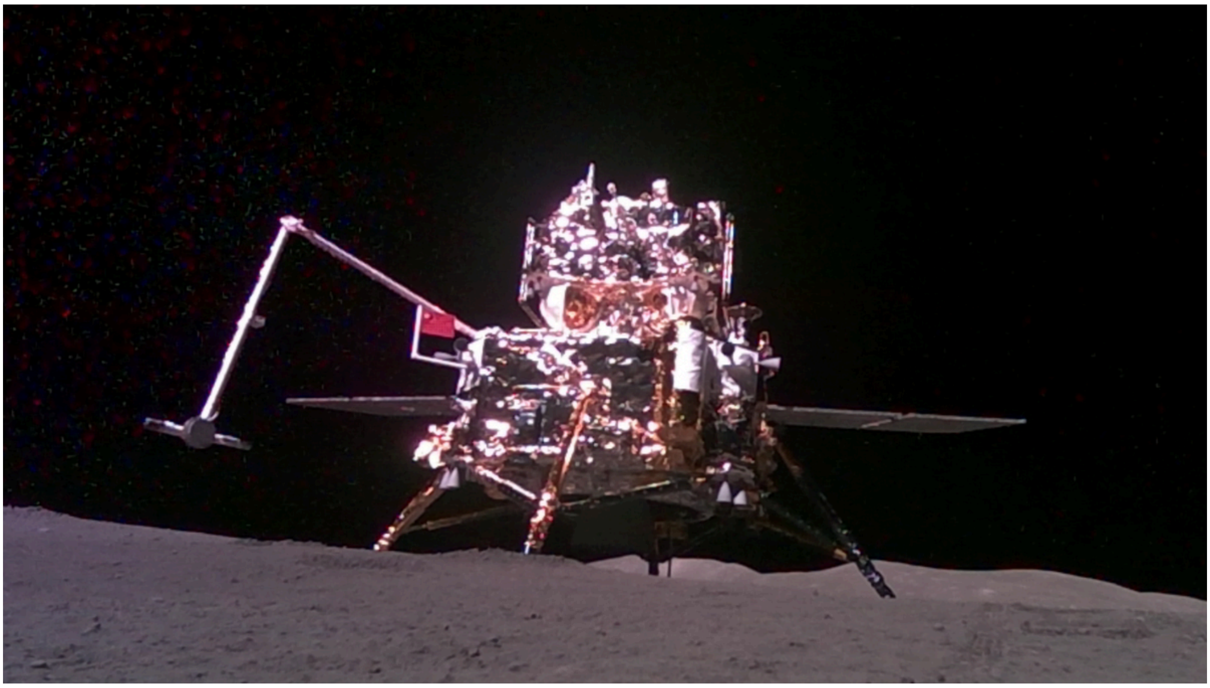

Lunar rover simulation research

31.01.2025

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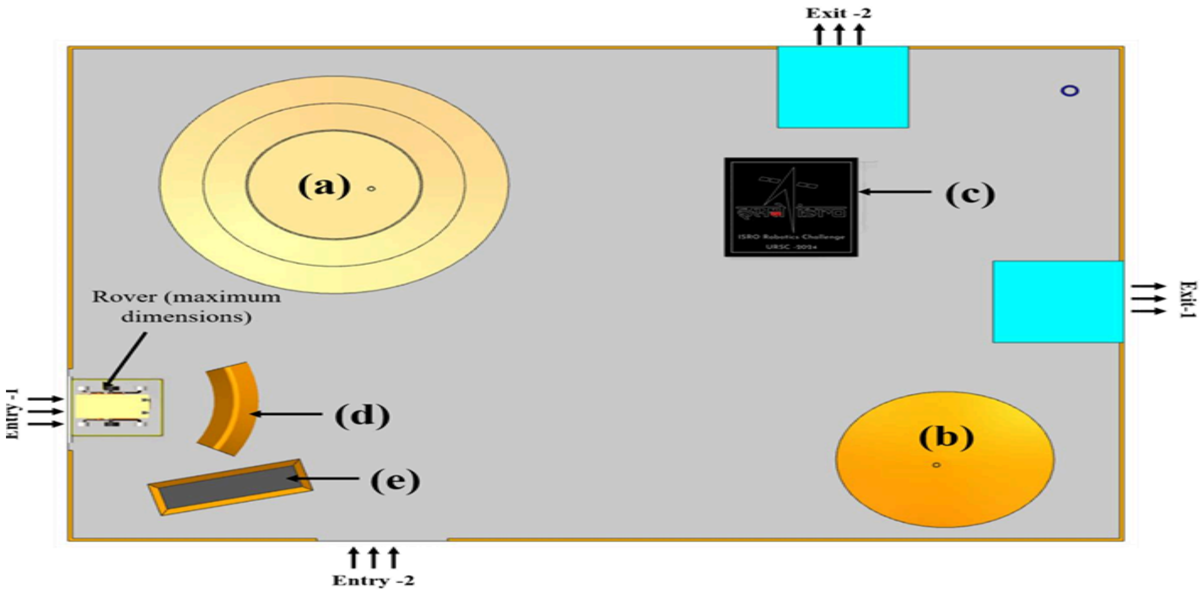
Stage 1: Mission & Arena Analysis

The rover will be made to navigate through a 12m x 9m arena with obstacles and craters, performing autonomous tasks as commanded and returning to an exit point. The challenges replicate those actually encountered in planetary exploration: navigation, sample collection, and marker identification

Arena Analysis



1) **Arena Dimensions**: The size is **12m x 9m**, filled with **100mm M-sand**

2) **Key elements**

- **Crater**: 4m diameter, 200mm depth, slope <15°. (Traversable)
- **Hump**: 2.5m diameter, 260mm height, made of M-sand. (Traversable)
- **Hard Terrain**: Solid surface, level with M-sand height. (Traversable)
- **Wall**: Non-traversable, 0.8m height.
- **Slot**: Length 1.8m, width 0.6m, depth 100mm. (Traversable)

3)**Entry Points**: Two options available, Entry-1 gives more points but is more difficult. Both are **1.5m wide**.

4)**Samples**: Three red samples at varying difficulty levels, which can be picked in any sequence.

5)**Bonus Markers**: Star-shaped, randomly placed, colored, and numbered for identification.

6)**Obstacles**
a)Traversable: Random shapes/sizes, ≤150x150x150mm.
b)Non-Traversable: Random shapes/sizes, ranging from 300x300x300mm to 800x800x800mm

7)**Exit Points**: Two options, Exit-1 offers more points but is harder.

8)**Boundaries**: Yellow-marked edges (200mm high) and white marks for entry/exit boxes.

9)**Obstacle Placement**: All non-traversable obstacles will have at least **1m separation**.

NOTE!!!
The diagram is the revealed elements in the area and number and coordinates of traversable obstacles, non-traversable obstacles and craters will not be disclosed

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Mission analysis

Field task

Task-1: Autonomous Navigation Task

We are required to demonstrate the performance of rover's navigation by traversing from entry point to sample collection point and subsequently to the container point and then exit from one of the identified locations. Rover can traverse in any path.

The teams are allowed to give maximum 4 commands if required in the total task at the following checkpoint which are as follows:

1. At the start of the task (at entry point-1 or 2)
2. After the drop of first sample
3. After the drop of second sample
4. After the drop of third sample

1. Entry Task

Teams can choose between Entry-1 and Entry-2, where:

+ Entry-1 fetches more points but could be more challenging.
+ Entry-2 is easier but scores fewer points.

Objective: Strategically decide the entry path based on rover capabilities.

2. Obstacle Identification Using Sensors

+ Requirement: The rover's sensors must:Detect dimensions of obstacles (height, width, and position).
+ Decide actions: Navigate around, over, or avoid the obstacles autonomously.

Key Sensors: Ultrasonic sensor, thermal sensor or camera

3. Crater Identification Using Sensors

+ Requirement: Sensors should:

    Detect and analyze the size (depth and diameter) of craters.
    Help the rover determine whether to navigate through, around, or avoid craters.

+ Key Sensors: Depth cameras or stereo vision sensors.

4. Sample Location Identification

Details: The rover must identify a red-colored sample with approximate dimensions
Outer Diameter (OD): 80 mm.
Length (L): 125 mm.
Requirement:

    Use vision-based sensors (camera with color detection) to locate the red sample.

    Implement object recognition algorithms to confirm size and shape.

5. Container Location Identification

Details: A cylindrical container with:
Diameter: 150 mm.
Height: 150 mm.
Requirement:

    Identify the container's location using cameras or sensors.

    Precisely navigate to the container and recognize its dimensions to confirm it as the target.

Task-2: Autonomous Sample Picking and Placing:

Key Challenges:

1. Target Identification (Tube Detection):
    - The rover must visually identify the red-colored hollow cylinder (ABS tube) lying on the surface.
2. Manipulator Arm Design:
    - A gripper system to securely pick up the tube without damaging or dropping it.
3. Mobility During Load:
    - The rover should be able to hold the tube securely during motion.
4. Placement Accuracy:
    - The tube needs to be dropped into a blue container with precision.

Table 3: Sample Tube specifications

1	Mass	~ 200 gm
2	Material	ABS
3	Shape	Hollow Cylinder with closed ends
4	Size	ID 67 mm & OD 80 mm, L 125 mm (Approx.)
5	Colour	Red

Table 4: Container specifications

1	Shape	Hollow Cylinder one side closed and other side with a flange
2	Cylinder Size	ID 140 mm, OD 150 mm, L 200 mm
3	Flange	ID 140 mm, OD 200 mm, Thickness 5 mm
3	Colour	Blue

Task-3: Repeat the Task-1 & Task-2 until all the samples are dropped in the sample container

Task-4: Identification of specific markers

Identification of bonus targets includes the following:

1. Capturing its images/shape with some sensor.
2. All the bonus targets are marked with distinctive number and the team also needs to identify the number
3. Coordinates of the particular bonus target to be identified with a variation of ± 0.5m

Table 5: Bonus marks specifications

1	No. of bonus marks	5 No's
2	Shape	5 pointed star with 72° angle between each 2 points
3	Size	Circle connecting 5 points of a star will have a dia. 100 mm
4	Positioning	Can be vertical or horizontal
5	Colour	Background – Green Number – Black

The full marks for the identification of bonus marks will only be allotted if a proof of detection and allotted number are provided along with coordinates. However, a partial mark will be given if all the requirements are not satisfied.

Task time:

Total time available to execute all the field tasks is 40 minutes and a 20 minutes slot will be provided for the team for setup their rover before the task.

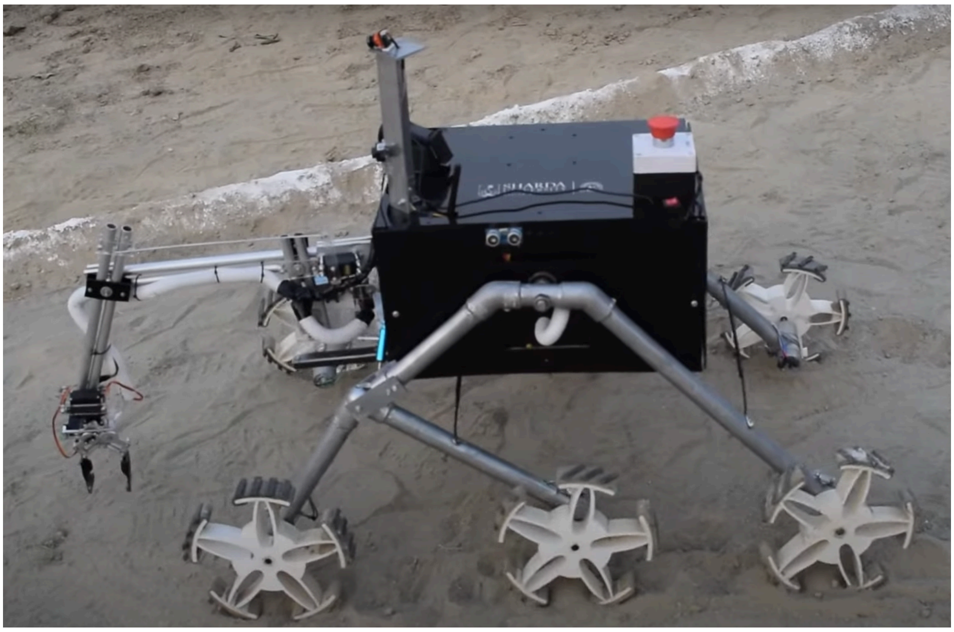
Scoring criterion

#	Evaluated Parameter	Max. Score	Description of evaluated parameter
1	System Architecture	10	• Illustration of the system architecture through a diagram. • Identification of interfaces among different sub-systems. • Inclusion of all essential sub-systems required in the system architecture.
2	Roving Mechanism	10	• Schematic representation of the roving mechanism. • Comprehensive understanding of the chosen mechanism. • Explanation for selecting the proposed mechanism.
3	Mechanism for Sample Pick-and-Place Activity	5	• Schematic representation of the chosen mechanism. • Thorough understanding of the selected mechanism. • Justification for selecting the proposed mechanism.
4	Emergency Response System	5	• Identification of emergency situations. • Description of the Response System.
5	Hardware Identification	10	• Sub-system-wise list of all required hardware for realizing the overall system. • Justification for selecting the type of hardware. • Estimated Bill of Material (BoM) for the system.
6	Software Identification	10	• Identification of software requirements for operating the realized system. • Algorithm selection for various computation tasks.
7	Hardware and Software Realization Plan	10	• Categorization of identified hardware into various sources of realization. • Specifications for purchased hardware. • Realization plans for fabricated hardware. • Implementation strategies for software.
8	Test Plan	10	• Identification of required tests. • Test plans for all identified tests.
9	System Specifications	5	• Generate table of specification for the proposed system
10	Project Management	5	• Identification of responsibilities among team members with a system breakdown structure. • Strategy for schedule management. • Cost estimation.
11	Novelty in the overall proposal	10	• Originality in terms of system design, hardware/software selection, etc.
12	Any Other Relevant Information	0	• Teams can include any additional information deemed necessary in the proposal.
13	Presentation	10	• Presentation file
14	Non-compliant Documentation Format	-20 as penalty	• Example of non-compliance: • Small font or margin • Exceeding the report length • Plagiarism exceeding 40%
Total		**100**	**Maximum Score**

Stage 2: Rover Performance Analysis

Here we analyse our competitors rovers and extract useful information out of them as well as rovers made by space agencies

Sharda university rover



This is a very basic design but has lots of issues

1)Center of gravity is too high due to boxy design which makes the rover unstable, the CoG should be kept as low as possible to reduce risk of tipping over and high CoG also goes against wheels and they might slip when climbing a crater which will mess up the navigation system as well

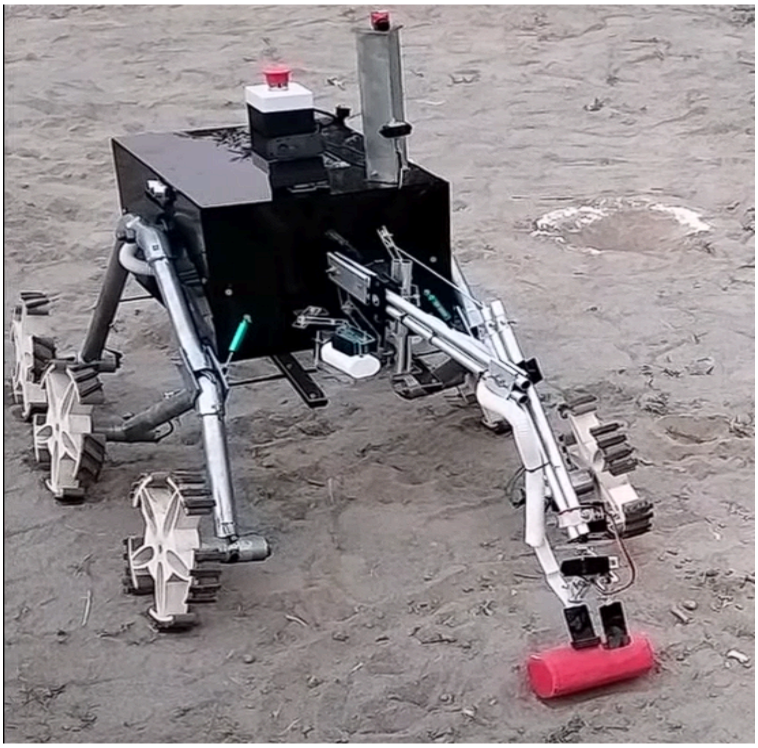
2)The Rocker bogie suspension is too tightly fixed giving it less freedom and looks more rigid decreasing its obstacle clearing capabilities

3) The wheel design is flawed, the width of wheels arent enough which makes it more probable to sink in sand (the rover struggles navigating in sand in the presentation video), a wide and complete wheel design should be incorporated instead, may even go with balloon wheels than this.

4)The mechanical arms rest in a very odd position very near to ground sometimes even touching it and the arm seems very weak around the joints and the joints dont have sophisticated enough system to come on a position very precisely and efficiently but rather takes a hit and trial approach due it its primitive design and the gripping mechanism is awful as well with not enough grip strength and that is clearly seen when it drops the object it picked instantly

Some of its strengths are

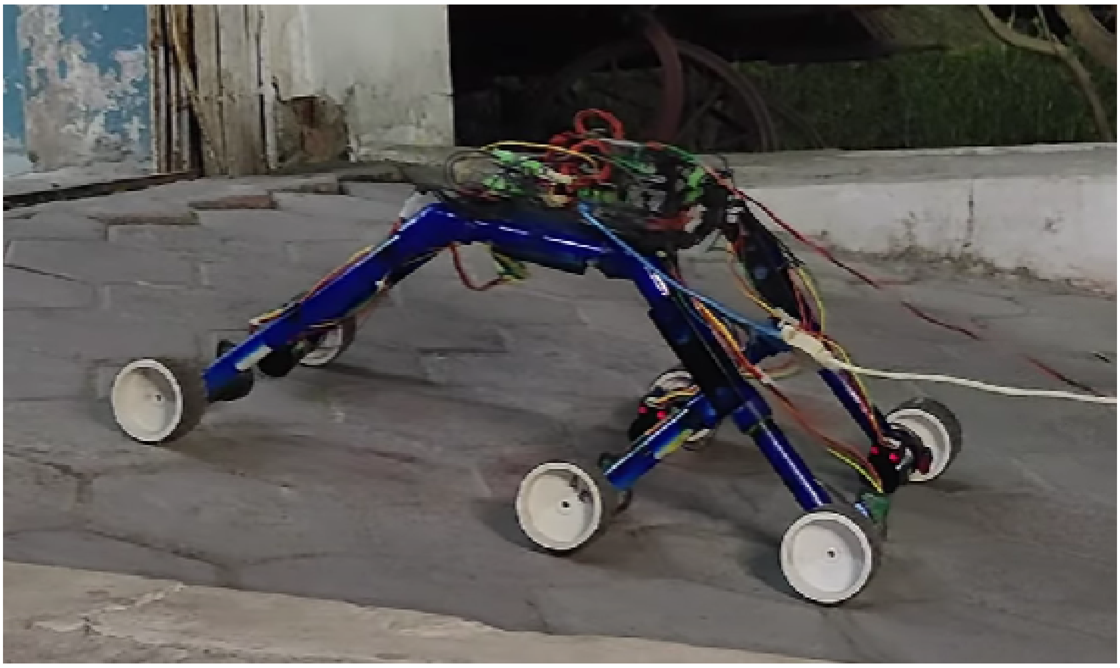
1) A great integration of openCV to check for coloured tubes and live video feed and the team claims to have LiDAR which is really advanced if true



Struggling to align properly dragging the tube but not holding it

Also has a kill switch

Team DHOOMKETU rover

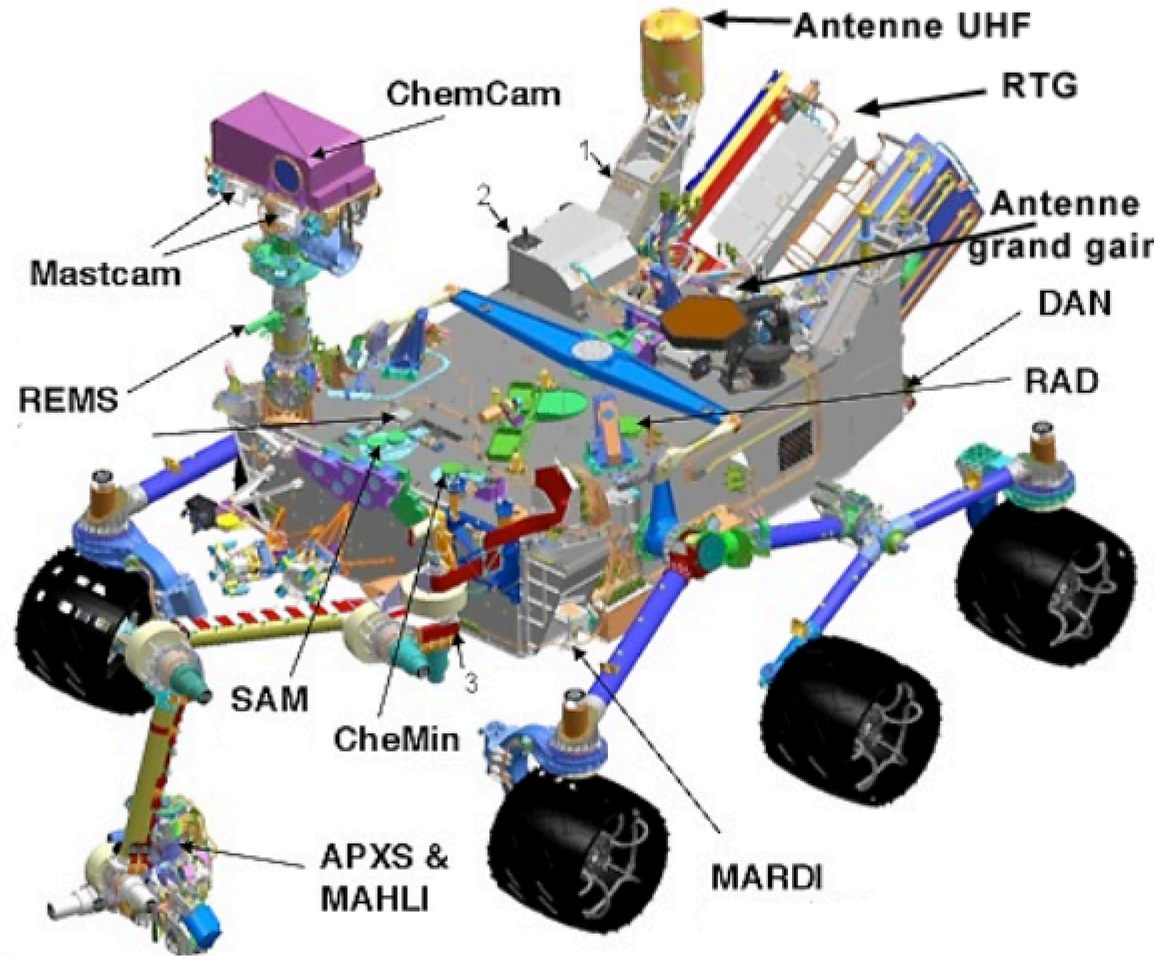


This rover again has some flaws (this design is prototype and we dont have finalised rover video in public)

1) The wheel seems too small which is not a good choice for a rover that needs to transverse obstacles, larger wheel provide a better approach angle so it rolls smoothly instead of straight up hitting them and also provide more stability

2) the electronics again seems to be high mounted which is not good for stability of rover

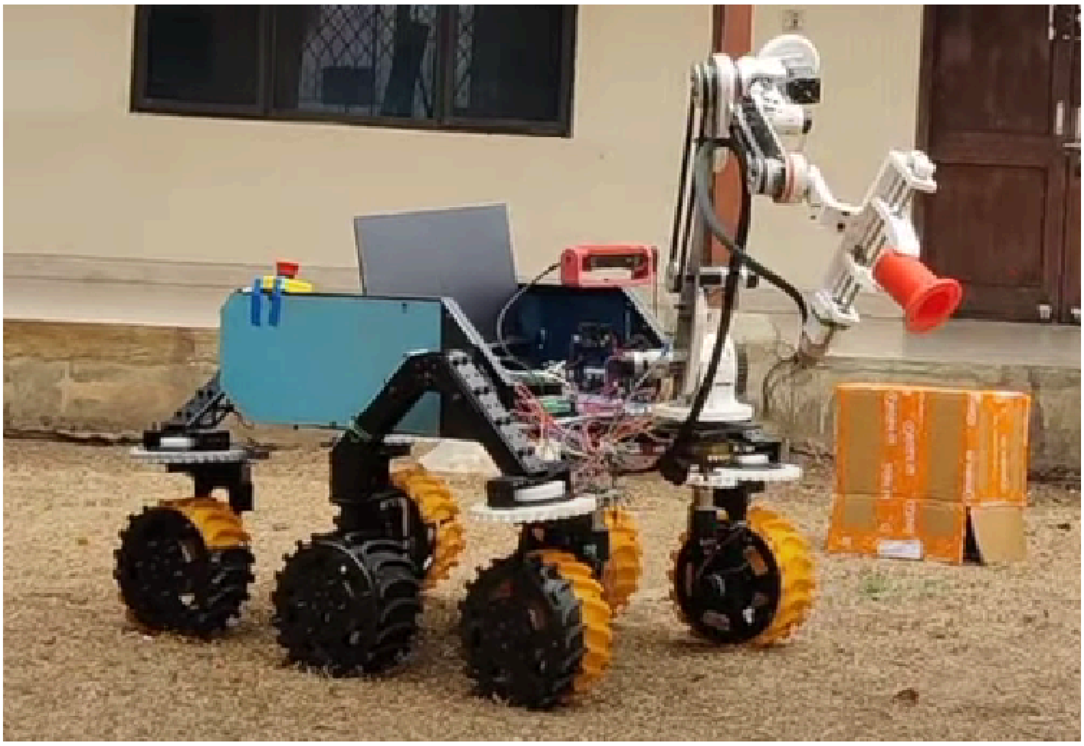
3) The rocker bogie system is also flawed, the angles are too low, its usually has a much larger angle in bogie side



We can see a much higher angle between the two legs of bogie side and also a much lower center of gravity in curiosity rover which were missed by most of the rovers in the competition,

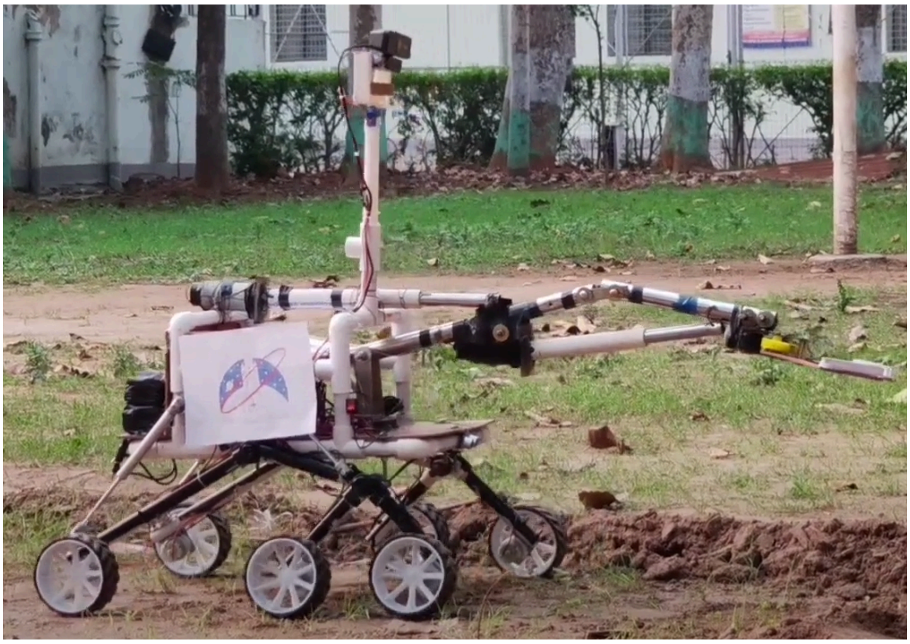
For the advantages, the software side is neatly done, it uses a LiDAR too and object detection and pathfinder software is really great

Team SHUNYA rover



Great rover overall, bigger wheels, improvement over others, really good mechanical arm but has some flaws in the wheel structure, the rocker wheel is really unstable and seems to use 1 motor for 2 wheels transferring power by gear

Team Talisha Space Research Organization



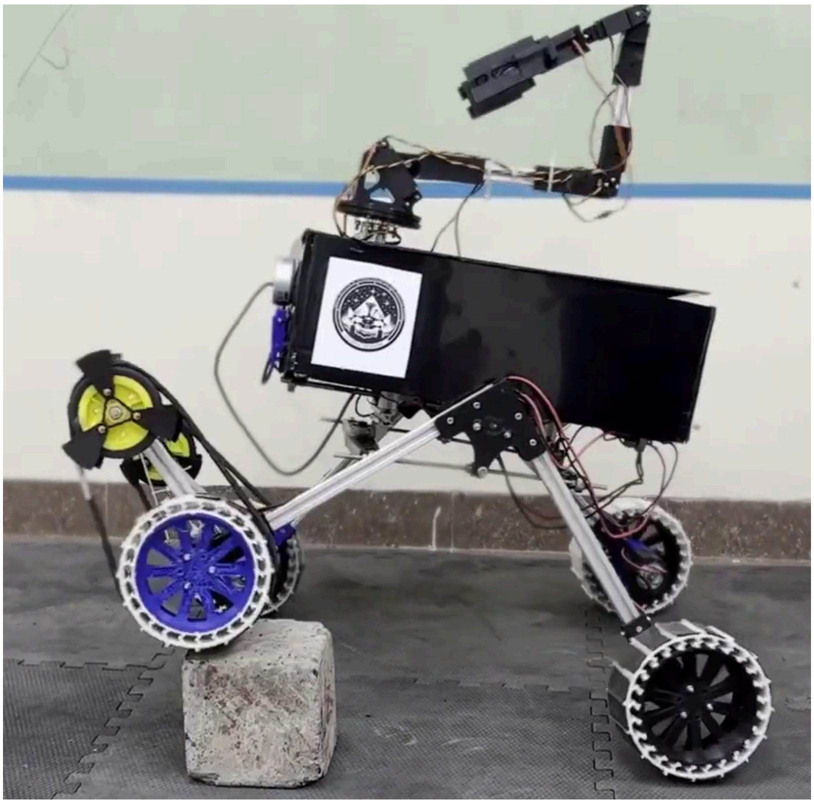
Loose wheels, its tilted so the wheel is with contact along a single line which is not good for sandy terrain and is gonna be stuck

The camera setup is really good with 360 degree rotatable axis

The structural integrity of rover is low, loose attachments and not good enough boxing of the electronics

The Arm looks not in good shape but works fine so it does its job.

Team IISER Bhopal rover



4 wheel design gives a disadvantage for traversing over obstacles

The CoG is gain really high, the system for running front wheels reduces its efficiency and the wheels slip on sand

Each movement and even the moving of robotic arm shakes the body (box) too much so too unstable of a rover it is.

No significant advantage found which can give them edge over other rovers

Team Dhristi

4 wheel setup is again worse and the arm joints are weak, they wobble in resting position increasing the

But this rover is the most stable one yet, the CoG is really good, the electronics box is low mounted, the arm is one the better ones with the stepper motor rod thing grabbing mechanism

And despite being 4 wheel structure it transverses the terrain fairly well

The wheels are broad enough and the rover has a kill switch

Stage 3) Improvement Proposal Challenge

Taking from what we have learned yet we can proceed building and improving our own rover for the competition

Let's break down each operation in multiple sections and suggest possible design elements one by one

1)Drive system- we should go with a 6 wheel rocker bogie suspension drive system, and the frame made out of carbon fiber, each wheel having independent actuators.

The drive system would be direct drive system with independent control over each wheel

The wheels can be made from Thermoplastic Polyurethane 3d printed tires (or any other available material if needed) the wheel pattern should be Tread Pattern inspired by curiosity rover by nasa.

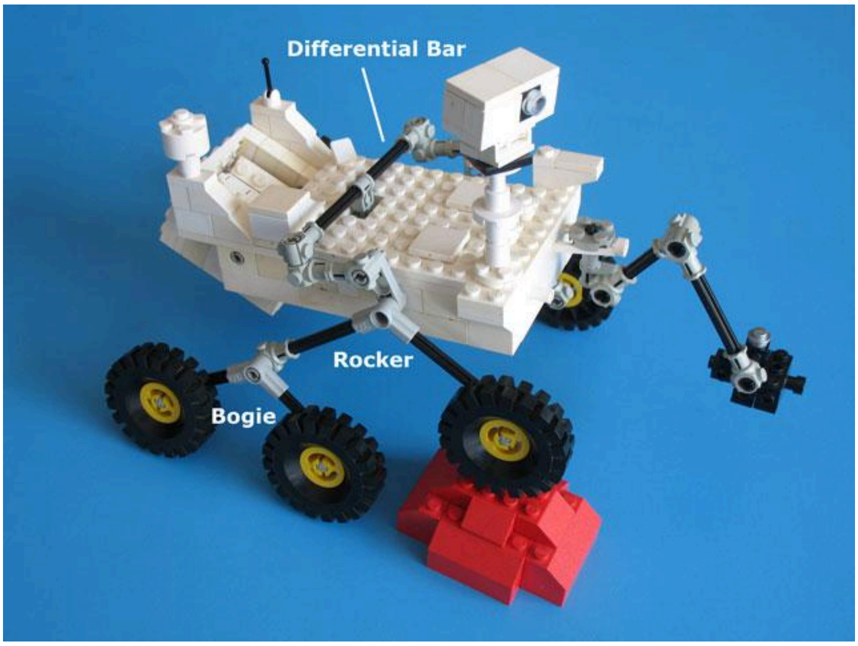
The motors should be Brushless DC motors for higher efficiency and wider speed range and control

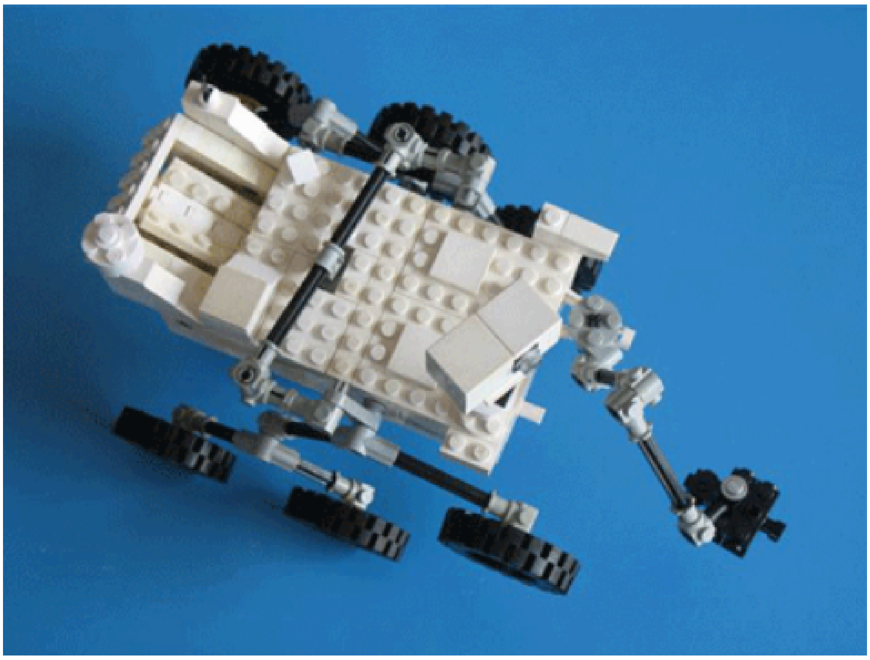
The wheel should be broad, 20-30 cm diameter (the craters in the arena will be of 20cm depth so the radius at max cant exceed 20 cm of the axel and motor would rub against the ground), wheels with 8 cm to 12 cm wide grip length, this can be updated in future with prototype testing to see if it faces any difficulty doing sharp turns in front of obstacles etc.

And a container behind the arm should be implemented to keep the tube in

Improvement proposal

Use of differential rod in rocker bogie mechanism, The mars rover curiosity uses a differential bar mechanism in rocker bogie system





Or a differential gear using 3 bevel gear

More info [Here]

2) Sensors:

We would need a series of sensors for object detection, obstacle detection, and crater and hill finding

a) For navigation we can use a RGB camera with ultrasound sensors and depending on budget can even go for a depth camera
b) Crater detection could also be done by the above sensors
c) IMU could be a great integration for orientation and motion measurement
d) Radio modules for telemetry
e) Sensors to confirm mechanical arm is in position to pick up items (Ultrasound or IR)

3) Control system:

The rover will use **Closed-Loop Control**: The arena is not fully shown and the rover is gonna have some errors so it should take continuous feedback and correct itself regularly based on its environment hence we choose a closed loop control over an open loop control used with a **PID control type** system for fixing errors

4) Algorithms:

a) For path planning we can use **Dynamic Window Approach (DWA)** as it don't require a global map and works with limited data (from the sensors) combined with **Visual Odometry**
b) If the rover is upgraded we can use Deep reinforcement learning and train the rover integrating ai ml into the path finding software
c) We can use **Template Matching** and **Contours detection** in openCV instead of Deep learning models like yolo or R-CNN since we already are in a controlled environment and we know the dimension of tubes and obstacle, openCV can be used to detect the colour of the tube as well using **HSV colour segmentation**

d) For robotic arm we will use **Inverse Kinematics Algorithm** for calculating the angles to reach combined with **PID**, then use a trajectory calculating algorithm like **Cubic Splines**, **Minimum-Jerk Trajectory** then **PID** will control the motion in real time of robotic arm and then a force control algorithm to apply enough force through the stepper motor grabber to hold the object

e) **Extended Kalman Filter** can be used to map out the area rover travelled for keeping track of its position and remembering previously tackled obstacle

f) These should be enough initially but we can incorporate some ML algorithms later on for better performance

5) Electronic Stack

a) **Processors and Development Boards:** We should use a powerful main processor, recommended one will be Jetson orin nano keeping in mind that there could be lots of AI integration and deep learning work later on paired with Aurdino

b) **Motor Driver ICs:** DRV8825 for stepper motor control on robotic arm and Sabertooth Motor Controllers for multiple motor closed control system, used in wheel motors

c) **LM2596** or **MP1584** can be used as power regulator in a wide range from high voltage (ex 12v) to low voltage (5-3.3v)

d) **ADS1115 (ADC)** for camera module and **HC-SR04** or **SRF05** ultrasound sensor

e) **SPI** for high speed data transfer between sensors and communication devices (wired type)

6) Materials:

The frame is supposed to be of carbon fibre tubes, the electronics box (main body) base can be made out of aluminium for heat dissipation and polycarbonate at the sides

Improvement proposal

We should do vibration damping in the rover, most competitors rover were shaking when going on rough terrain, this could be damaging to robotic arm and electronics so damping could be a huge improvement

7) Implementation of kill switch:

Between the batteries and the circuit we can put up a switch which directly breaks the connection with one terminal of battery

8) Failsafe system- in certain cases of failure rover should do actions which prevent further damage, some of them can be

In case of overheating a temperature sensor when exceeding a certain point should command immediate shutdown of those system to cool them off

In case of failure of Camera sensor (if the openCV cant detect arena and sees either black or any other solid colour feed from where it cant find out whats ahead, it should stop all the motors and call for a camera software reboot or checking old backups to fix the issue and if the issue doesnt get fixed then enter safe mode)

9) Batteries (SUGGESTION)

$LiFePO_4$ batteries will be better than Li ion or LiPo due to generally being safer and having more charge cycles altho if weight becomes a constraint Li ion can be used as it has a higher energy density

10)Mechanical Arm: We can go for a 6 DOF mechanical arm to grab tube in any orientation on any angle controlled by servo motors for higher precision and sensors to insure collection of sample tubes and 1D gripper operated by servo motor, the material could be 3d printed or aluminium (or even carbon fiber)

Improvement proposal

Implementation of mechanical locks so whenever the arm power is cut it does not slip off and shock absorbers on the joints, the grip could be made into a curve shape to accommodate the tube specifically since we already know the dimensions of the tube

More improvement suggestion

Incorporating a Flashlight in the rover to insure its steady work even if the lighting conditions turn out unexpected it would be a great redundancy without changing much of design and consuming high power

Keeping the rover as light as possible despite having a 50kg upper limit would be better, it would increase the battery life and would give a bigger buffer to add any other sensor or power intensive algorithm in the future so a complete carbon fibre body would be the best case scenario

Foldable radio antenna on the body

SOURCE AND CREDIT

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ChatGPT and Llama for electronics and algorithm research

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