TEAM INFERNO DTU

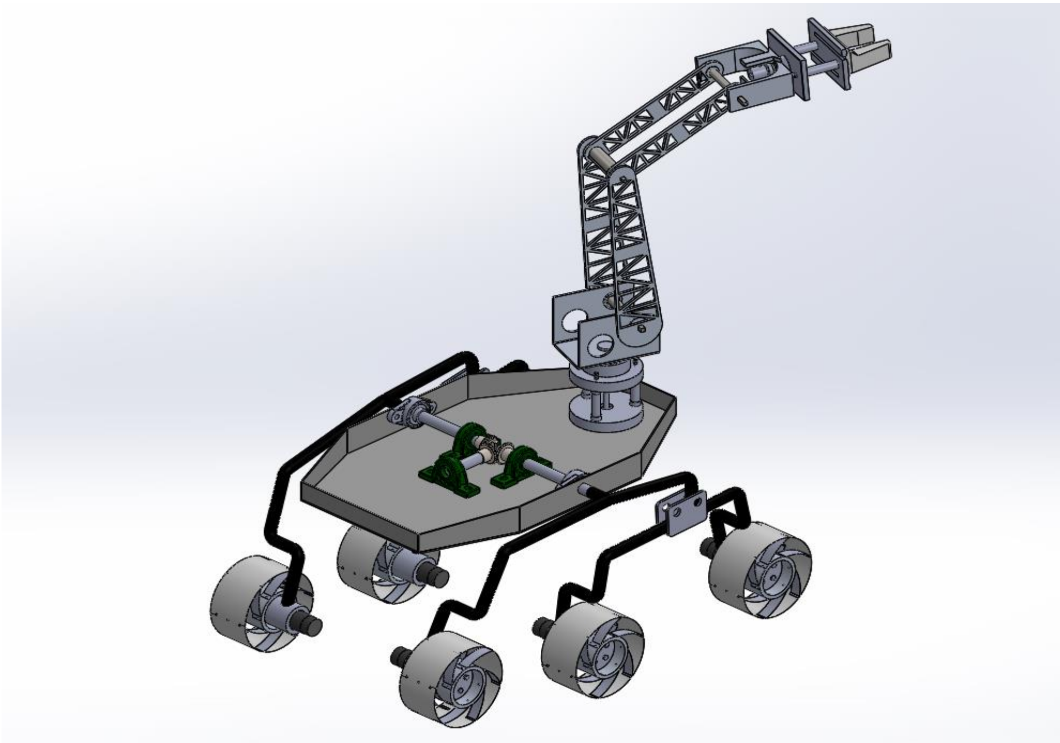
DESIGN REPORT

INDIAN ROVER CHALLENGE – 2019

College Name: Delhi Technological University

Team Captain: Geetanshu Ashpilya

Rover Name: A.R.G.U.S.



Team Inferno DTU

MECHANICAL

- Geetanshu Ashpilya (Team Captain)
- Deept Madhav (Vice Captain)
- Ashutosh Panpalia
- Annany Mohan
- Anish Bhalla
- Anmol Singh
- Sarthak Singh Rajput
- Shubham Singh
- Romesh Yadav
- Muskan Somani
- Mayank Dhawan
- Rahul

A) **Robotic Arm:** To design a robotic arm that is capable of performing the required competition tasks with ease.

B) **Rover Mechanics:** This department is responsible for the locomotion and stability of the rover vehicle.

ELECTRICAL

- Saksham Sangwan
- Karan Singh Bora
- Vishal Sharma
- Aman Singh Mann
- Madhur Gupta
- Arshiya Thukral

A) **Arm Control System**: The objective is to actuate links of the arm in a specific workspace for precise control through absolute feedback.

B) **Rover Drive System:** The department endeavors to achieve extensive maneuverability over tough terrains through accurate control of motors.

C) **Science Task:** To search sites and analyze for their likelihood to support microbial life from the data obtained through the on-board instrumentation.

D) **Communication System:** This subsystem aims to provide efficient and latency free wireless communication between rover and base station.

E) **Power System:** Forms the core to manage and feed different subsystems of the rover.

SOFTWARE

- Hitesh Kumar
- Avinash Kumar Chaudhary
- Vinayak

Autonomous Task: To identify potential obstacles in the path and navigate the rover to the final destination.

Corporate and PR

- Kunal Mathur
- Anushka Singh

The corporate team handles the administrative work and sponsorships.

Design Overview

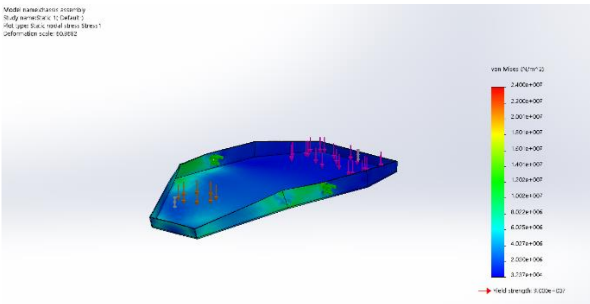
PARAMETERS	SPECIFICATIONS
VEHICLE WEIGHT	< 50kg
VEHICLE DIMENSIONS	0.85m*0.6m*0.6m
LIFT CAPACITY OF ROBOTIC ARM	3kg
MAXIMUM REACH OF ROBOTIC ARM	1m
COMMUNICATION SYSTEM	Wireless
SITE PARAMETERS DETECTION	Moisture, Temperature, Organic compounds, Humidity
VIDEO FEED	Wireless (5.8 GHz)
FREQUENCY BAND	2.4 GHz

Rover Mechanics

Rover Mechanics is the subsystem of mechanical department which deals with the locomotion and stability of the rover vehicle. The rover is designed such that it can traverse various difficult terrains and overcome large obstacles in its path while maintaining proper durability and avoiding any unnecessary tumbling in any direction. Most of the components have been made out of aluminium to reduce the overall weight. Our vehicle's structure has been primarily divided into three systems that enables easy identification and troubleshooting of failures and maintenance by enhancing accessibility to its various constituents. The three parts include: Chassis, Suspension system and Wheels.

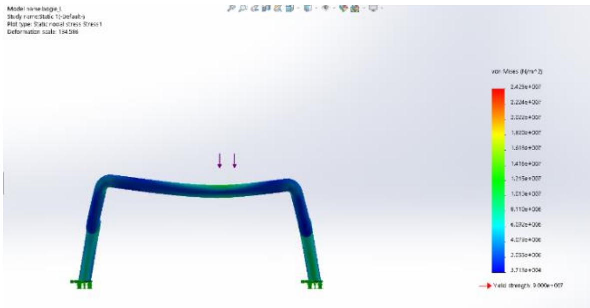
Chassis

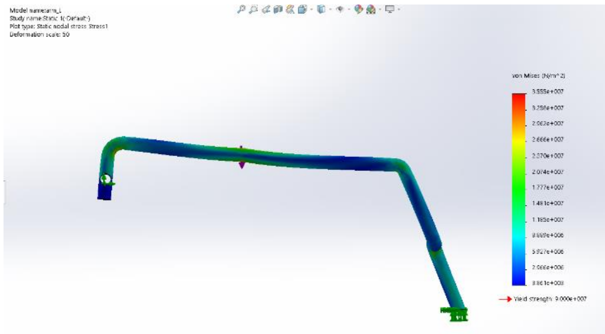
A robust octagonal structure has been chosen from various designs as it provides greater clearance for the movement of driving members and links and also a wider space for placing electrical components and differential mechanism also, walls of this structure provide a safer and dust free environment for electrical components by enveloping them under an acrylic sheet. A differential mechanism has been provided to distribute the various forces while traversing different terrains. The main advantage of this mechanism is that the pitch angle of chassis is the average of the pitch angles of right and left sides of suspension system.



Suspension System

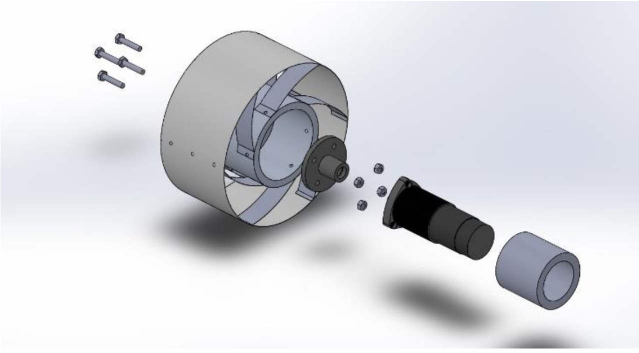
The suspension system of rover consists of Rocker Bogie mechanism. The rocker-bogie design has no springs or stub axles for each wheel, allowing the rover to climb over obstacles, such as rocks, that are up to twice the wheel's diameter in size while keeping all six wheels on the ground. Rocker Bogie suspension provides the purpose of stabilizing the rover at rough terrains. By virtue of rocker and bogie links, this suspension system provides optimal weight distribution as well as high climbing capacity while smoothly traversing through terrains. The system has been provided with two hinge point configurations that allow us to manually adjust between climbing capacity and magnitude of traction. As with any suspension system, the tilt stability is limited by the height of the center of gravity, therefore we have provided with heavy wheels and partially in-wheel drive motors to lower the center of gravity while maintaining high ground clearance. Also, to attain full traction on wheels, the links have been bent such that most of the rover's weight is concentrated on the wheels.





Wheels and hubs

Wheels have the important function to support the load of the rover and help navigate through different terrains, like sandy, non-cohesive soil as well as hard, dry terrain. In addition to these features, wheels also perform the function of providing an elastic behavior to increase contact force and flexibility as well as reducing overall vibrations and jerks. The wheel hubs are designed to partially contain motors within it so as to counteract the moment caused by the weight of motors. To accomplish these features different designs were studied and their features were compared. Considering all these factors, we have developed a hybrid design which encompasses all the constructive traits. The design consists of mainly three major parts: wheel hub, spokes, outer rim.



The hub is made up of aluminium to reduce unnecessary weight and the rest of the wheel components are made up of spring steel which provides the necessary elasticity that is required. Another important factor in deciding the final design was the cost, as self-manufacturing of wheels saved us almost 70% of money and resources that procurement of balloon wheels would have cost.

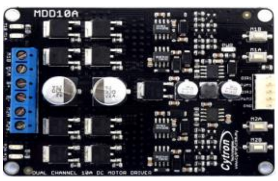
Specifications of rover mechanics

Chassis	Suspension System	Wheels and hubs
Aluminium frame	Rocker bogie	Spring steel wheels
Octagonal shape	High ground clearance, low center of gravity	Aluminium hubs
Includes bevel gear differential assembly	Bending of pipes for easy traversing	Partially in-wheel motors

Drive System

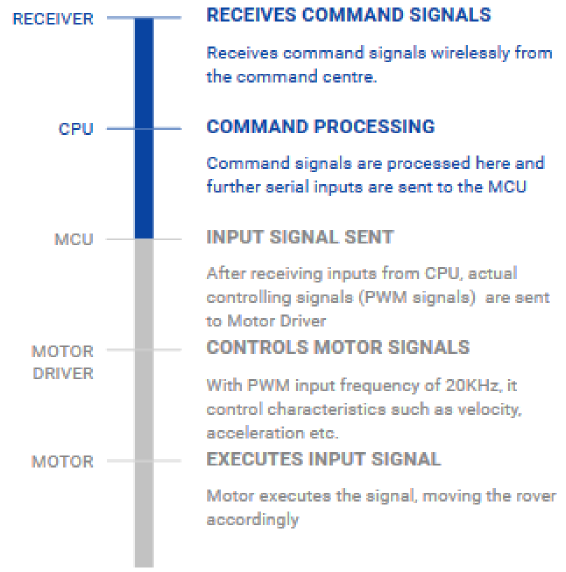
The drive system uses a distributed motor control of 6 individual motors, with 3 motor drivers to control the motors. The entire drive system is integrated with ROS framework.

The rover uses planetary geared DC Brushed motors. The intelligent drivers used in our Rover provide it with reasonable speed and torque to navigate through extreme terrains. The motors operate in the range of 12V to 24V, providing up to 5 N-m torque and an rpm of around 200. This compliment, in conjunction to the rocker bogie system, allows the Rover to climb steep slopes and travel tough terrains with ease. The motors have been controlled via pulse width modulation signals sent through the microcontroller unit, i.e. Arduino.



MD10A- Dual Channel Motor Driver

The motor driver boards feature dual NMOS H-Bridge circuits for efficient control over the direction of the motors. They support locked anti-phase and sign-magnitude pulse width modulation signals. Our drivers regenerate the battery when the motors accelerate or decelerates, increasing battery efficiency and reducing the heating of the motors. Full solid-state components are used which result in faster response time and eliminate the wear and tear of the mechanical relay.

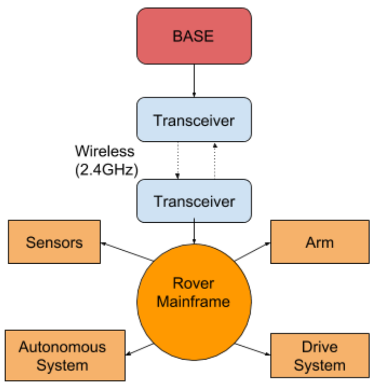


Resolutions for safety:

SL. NO.	FAILURE POINTS	RESOLUTON
1.	Improper PWM actuation to motors	A filter circuit of appropriate time constant can be installed.
2.	Jerk motion of the vehicle	PID constants need better tuning.
3.	Non-uniform current drawn by motors	A common ground rail for all the motors & MCUs.

Communication System

The wireless communication system uses two identical transceivers, where one is placed at the base station and other is placed on the Rover. The transceivers used operate at a frequency of 2.4GHz and 25+Mbps of throughput performance. It features 2x2 MIMO technology with the range crossing 1000 meters. In order to transfer data efficiently and without any latency 802.11g wireless distribution system has been implemented.



All communication between devices takes place over serial or USB. USB is used at the base station to interface with devices because of its ease of use in a desktop environment. The serial communication between Arduino and Raspberry Pi results into reliable and fast communication.

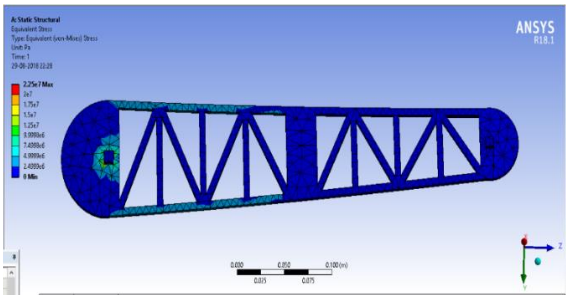
Robotic Arm

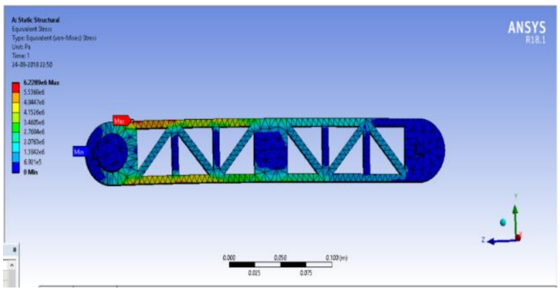
Definition and Purpose

Robotic arm is a medium through which the rover interacts with its environment. In the actual Martian atmosphere, the rover will not have any human assistance and thus, the arm will facilitate the rover to explore its surroundings. The robotic arm has been designed considering the capabilities to pick and drop, flip switches and open & close of drawers over a large workspace and up to a height of 1m. Our arm also has a potential of handling objects up to 5 kg weight along with a detachable gripper assembly for soil sample collection and on-board scientific analysis.

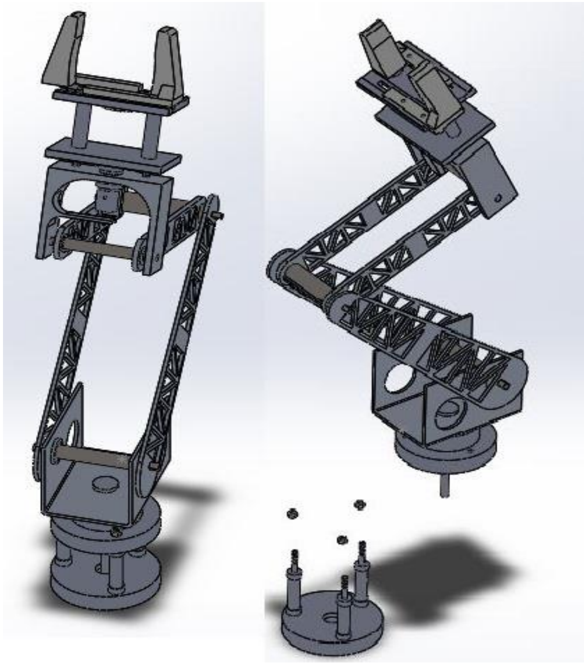
Mechanical Design

After detailed research and analysis, the initial design assumption of parallel links and orientation capability of 5- DOF has been finalized. Shear tests have been made the primary criteria for selecting the link design and material; for high strength and minimum possible weight, high grade Aluminium has been used. The verification and validation of design is done using FEA software.





The base plate is designed in such a way that, it facilitates spherical nature of the arm into any coordinate system desired. The shoulder joint is planned to such an extent that it gets segregated from rover effortlessly by means of three nuts.



Gripper and Drill Assembly

The gripper has been manufactured through 3-D printing technique. The mechanism of our gripper is based on rack and pinion to increase the object gripping capabilities. Two-separate and detachable end-effectors are designed, one for soil sample collection as well as on-board scientific analysis and other for various tasks such as equipment servicing task. The soil collecting gripper is capable of collecting soil from a depth of 5-8 cm. The feedback is considered to evaluate whether the soil is fit for collection and suitable soil is then collected by using hollow claws.

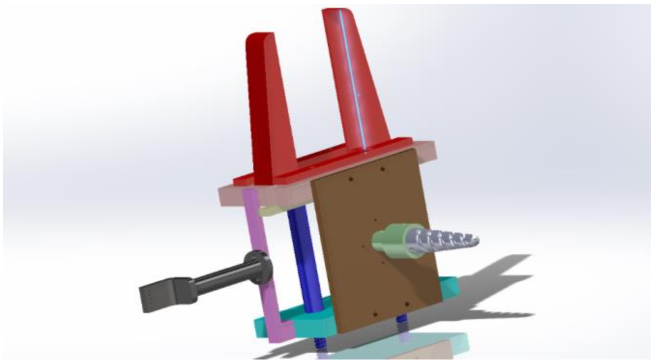
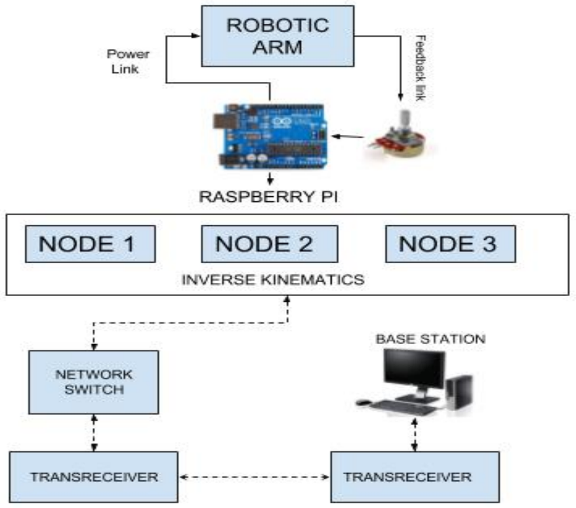


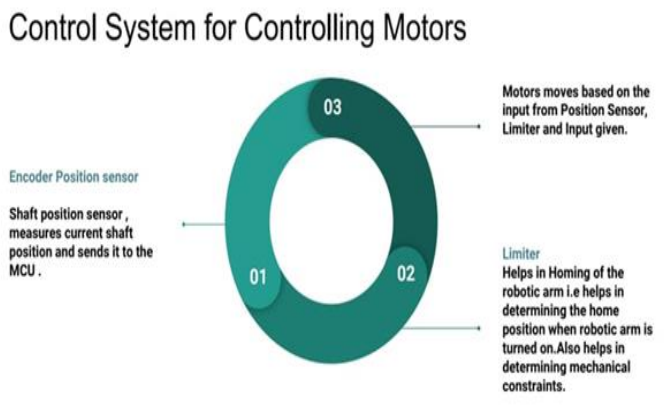
Fig.: Soil collection end-effector

Arm control system

We have chosen Inverse Kinematics unique analytical solution in top-down orientation to determine the various joint parameters that provide a desired position of the arm’s end-effectors. The analytical inverse kinematics solutions are significantly faster than numerical solvers.



We have designed our own feedback loop for controlling the respective shafts for wrist, base and elbow joint of the robotic arm. This has been achieved by using multi-turn potentiometers that provide absolute positional feedback of the motor shaft. The shoulder motor comes preinstalled with optical encoder and has high torque with accuracy of 0.25 degrees.



Safety measures have been taken in the robotic arm by implementing limiters which assist in determining the home position when the arm is turned on (i.e. homing process). The limiters also decide the mechanical limits and stop the movement at the extreme/ default position chosen.

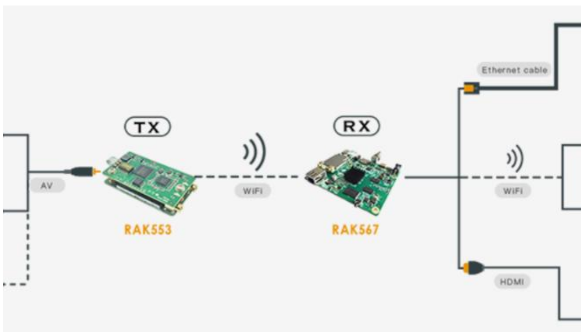
ROS is used for taking input from joystick connected to the user's CPU at base and send respective commands to the CPU on the rover over the air and thus control the Arduino.

Drive System

For drive system of various joints, DC brushed motors and servos are used. The motors have been controlled via pulse width modulation signals sent through the microcontroller unit, i.e. Arduino. The motor driver boards feature dual NMOS H-Bridge circuits for efficient control over the direction of the motors. Encoders are used for positional control. Gear-train has been designed and manufactured to meet the desired torque requirements. The shafts are designed in order to obtain a feasible relative motion between various links.

Video Subsystems

The video transmission is implemented by FlyLink video modules and FPV cameras are used for video feed. We have utilized analog cameras and video TX/RX modules which encode video signals using the H264 format. A maximum video resolution of 640x480@30 fps is obtained. The video modules are operating at a frequency of 5.8 GHz. The encoded video is directly streamed from the server created by the video module itself.



The TX/RX modules used support IEEE802.11 a/b/g/n and AV input. FPV PAL cameras are used to capture the video feed. The cameras support aspect ratio of 16:9 and 4:3 and have 5 MP sensitivity.

Autonomous and Navigation Control

Overview

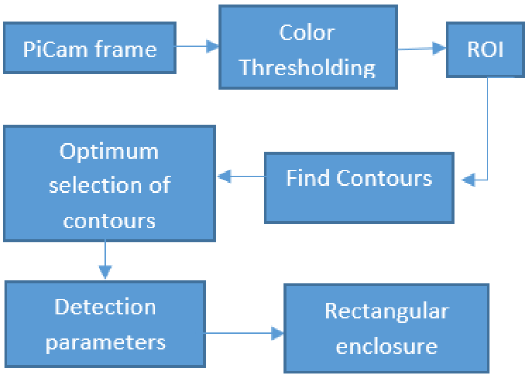
Autonomous system has been developed to replete the IRC'19 tasks requirement efficiently. It is divided into several subsystems: Detection & path planning, steering system, sensor fusion, SLAM etc. All the system works together to corroborate successful incisive decision making.

Software Strategy

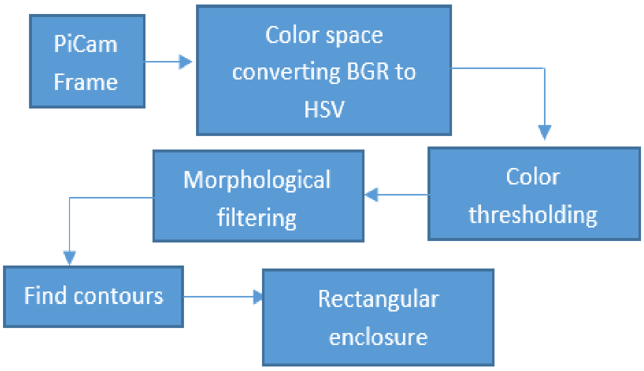
The software is developed using Robot Operating System (ROS) framework which enables us to concurrently design several components of the software and test in isolation.

Obstacle Detection

For rover in autonomous mode, it gets crucial to avoid obstacles which precludes the possibility of getting bumped into one. This has been achieved by using OpenCV & Python. Pi Cam is mounted on chassis which ensures symmetrical frame for vision perception. Obstacle node would publish message to steering node, which steers the rover to eschew the detected obstacle.



Markers detection: This system is capable of detecting blue bottle, yellow disk, and red box simutaneously and can discern the number of markers spotted in the frame. It can also detect obstacle and markers in a single window frame. This is achieved using OpenCV image processing libraries in Python. Morphological filtering is used to nullify the pixel noises and enhance the output to greater extent. Detection was visible even from a distance. The shrewd use of of contours saves our time from training of complicated machine learning algorithms.



Sensor Fusion

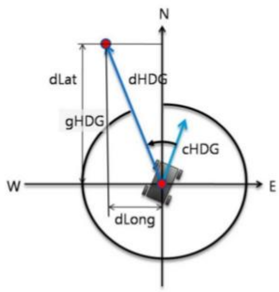
The rover has been equipped with many sensors hence, acknowledging the fact ROS node can only be executed once in an Arduino resulting in numerous constraints. In this scenario, sensor fusion is really helpful, combining data from different sensors for the purpose of improving system performance.

Rover Localization & Navigation Planning

Ardupilot acts as the base of control and coordination between different hardwares. The ardupilot chosen for the rover is the Pixhawk. It incuperates data from acclerometer, magnetometer, gyrometer, GPS, sonar sensors, etc. and provides a wide range of functionability.

How does navigation algorithm work?

The idea of finding designated waypoint and follow the heading was based on very simple geometry. If I know where I am and where my heading is then I can determine whether I should turn to right or left. **GPS & Navigation:** GPS provides coordinates of rover that are fed to *navsat_transform* node which determines the rover location helps in further navigation through the waypoints and mapping them. If obstacle shows up, the *auto_navi* node acts as intermediate to overcome the obstacle based on bypassed contour location. Terrains are overcome using gyroscope and accelerometer of Pixhawk, which feeds pitch data. The more difficult the terrian, more is the value of varying pitch. This is used to control the steering system efficiently.



Case 1 gHDG-cHDG > 180

Power Distribution Systems

Batteries

The rover is fed by Lithium Polymer battery. Lithium polymer was chosen over other chemistries because it is cost effective, provides excellent power density, offers low internal resistance so as to get low drops and exceptionally less toxicity as compared to other available battery types.

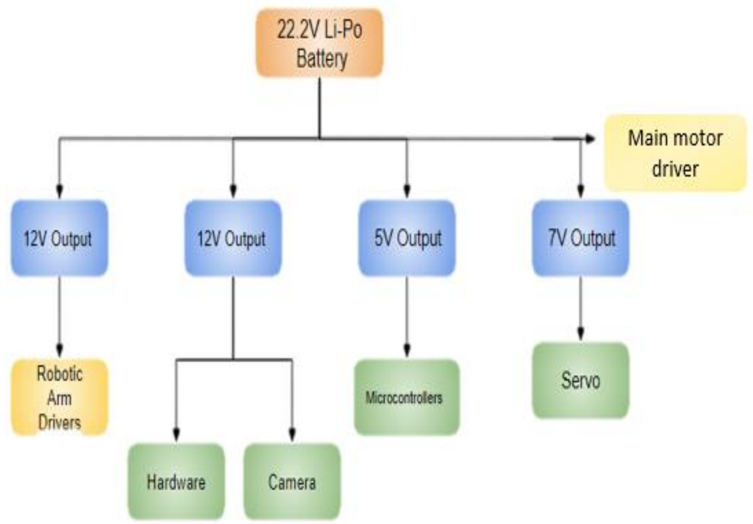
For the purpose at hand, three Li-Po batteries are chosen of 22.2 Volts and providing a capacity of 10Ah each; for meeting the proper power demands and run time requirements of the rover. The battery is connected to rest of the power system through an emergency disconnect switch acting as a *kill switch,* easily visible and reachable in case of an emergency or power failure. Batteries are also connected to low voltage buzzer alarm for notifying low levels.

DC – DC Conversion

The drive motor controllers are connected directly to the 22.2V rail. However, most of the electronic systems in the rover do not operate at this voltage. For accommodating the power requirements of other systems, UBEC's (universal battery eliminator circuit) are used to convert the fed voltage to required voltage levels i.e. DC – DC Conversion to two 12V rails, 5V rails, 7V rails. The two 12V rails are used to isolate the 12V motors from any of the 12V electronics as they may experience malfunctions due to electromagnetic interference from the motor. UBEC's are used for their high efficiency, easy handling and low rise in temperature while in use for a prolonged time.

Power Distribution Board

Power Distribution becomes a complex task with several devices being connected with their respective power needs on the circuit making it a complex task to be accomplished. For minimizing the complexity and effort, power distribution boards are being utilized in the system. The task at hand required designing of special PDB's, printed and crafted to meet the needs. The PDB's are able to be operated at maximum voltage of 30V and are able to withstand current of 50A.

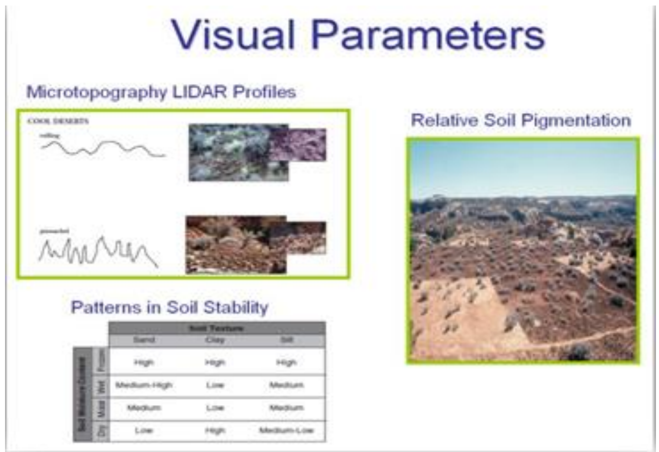


Science Department

For developing a science platform, special focus is given to the study of earth science along with sensing studies and chemical studies. In order to locate and analyze a site with the potential to support extremophilic life, the team researched the nature of various desert microbes and fungi, the process of biological crust formation, and methods used to study desert soils both in the field and from remote surveyors.

Site Selection Parameters

The field results were obtained in a two-part procedure:
Firstly, assessment of macroscopic features displayed on camera feed, and secondly analysis of the returned sample by using different sensors.
The objective for the team is to investigate several sites using minimally-invasive measurements for evidence of photosynthetic microorganisms, bacterial colonies, or other microbial extremophiles. At each site, at least two pictures will be required: one, a close-up high-resolution picture and the other, a wide-angle panorama.



The team will look for sites that will exhibit clear Micro topographical features and erosion patterns, particularly the pinnacle surfaces common to biological crusts. These features signify the soil's ability to retain moisture. The color and texture of the soil will also be examined as possible indicators of the ability of the soil to absorb light and maintain the structural support necessary for colonization by microbes and fungi.
The sample is collected from the site and several tests are run on the soil for different properties of soil necessary for the living and breeding of microbes and fungi or in all; Life.
Firstly, Site is tested for its moisture and organic content using a SEN 13322 and MQ4 sensor which senses the soil for the content mentioned above.
Secondly, Temperature and Humidity of the soil will be recorded so as to ensure optimum conditions for supporting life. The sensor to be used for this purpose is DHT11 sensor.

Budget Allocation and Planning

MECHANICAL PORTION	NET COST
Robotic arm	₹40,604/-
Rocker Bogie	₹20,514/-
Fabrication Cost	₹50,700/-
Subtotal	**₹1,11,458/-**
ELECTRICAL PORTION	**NET COST**
Science Task	₹5,015/-
Rover Drive System	₹43,550/-
Robotic Arm	₹39,250/-
Video Transmission	₹46,600/-
Autonomous	₹11,280/-
Battery	₹44,950/-
Subtotal	**₹1,90,645/-**
OTHERS	**NET COST**
IRC-2019 Registration	₹3,000/-
Subtotal	**₹3,000/-**
Total estimated cost of the project	**₹3,05,103/-**

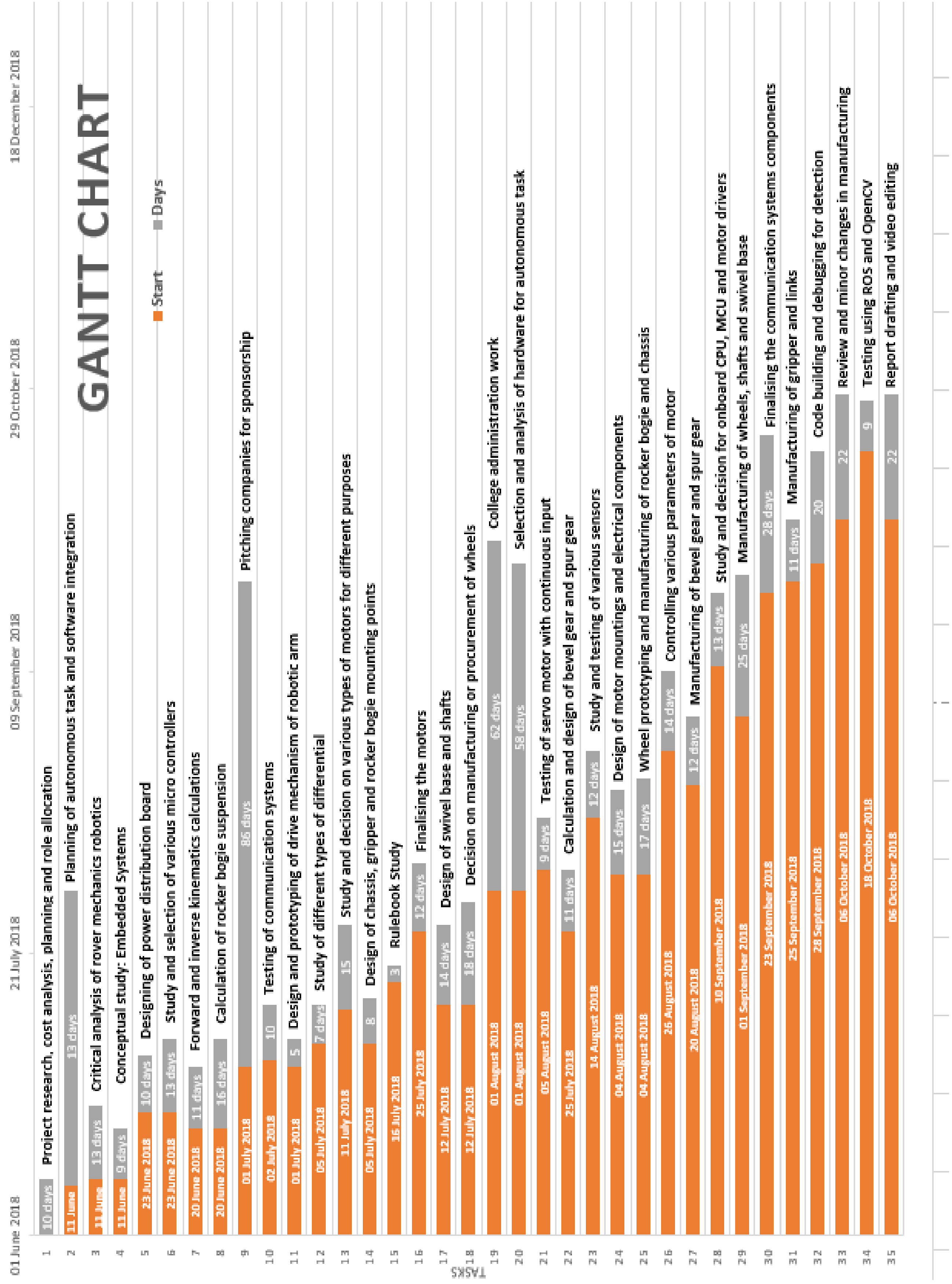
For clarity in the budget allocation and to foster further planning, the cost report has been divided into the above subsystems. The team estimates the total cost of the project to be **₹ 3,05,103**/-

The required funds were gathered by the team from the following sources:

- **Previous Go-Karting Competitions**: Since we were a go-karting team before, we had a net prize money of **₹1,20,000/-** available with us.
- **Sponsors:** We got a net sponsorship amount of ₹25,000/- from our sponsors of the current competitive season.
- **Team Contributions:** The remainder of the budget was met by contributions by all the team members.

Project Timeline

The following is the detailed timeline report of the team followed for the project.



Team Motivation

Team Inferno DTU is a project based technical team, founded in September 2013, with the sole focus on innovation. Earlier, the team used to design and manufacture Go karts to take part in multiple national level racing competitions. Since then the team has come a long way in building a strong reputation for itself by winning numerous awards. Recently we secured the first rank in the Innovation Round for implementing lane and object detection using machine vision in the kart, at the International Go Kart Championship (IGC) 2018. After innovating a lot in the field of Go karting, the team felt the need to shift towards the domain of mechatronics, that has a much wider scope for innovation as compared to our previous project.

Modern robotics has a key role in automation and has enhanced assembling operations around the globe. Robotics spans across multiple scientific and engineering disciples, leading to ease in programming and promotes creativity. The primary purpose for the advent of artificial intelligence was to eliminate the chances and adverse effects of human error, enhance precision and reliability, reduce human effort and create better technologies for tomorrow. Robots are dexterous and also function without any limitations.

All these key essential factors make this dynamic field essential for our country's budding engineers to gain practical knowledge and insight in enabling them to innovate and enhance upon the country's technological front. Henceforth, the team has now taken up this project as its primary goal, involving the designing and fabrication of a Martian Rover Prototype Vehicle that is subjected to negotiate difficult terrain, requiring the implementation of multiple electrical components and control systems within the vehicle for basic functioning. This project challenges the mechanical members of our team to deal with advanced manufacturing techniques and designing of sensitive components, as well as enabling the electrical members to develop complicated control systems to link the various subsystems. In the near future, our vision is to fully automate the vehicle and be able to compete with the top rover teams around the world. Moreover, this type of vehicle has its major utility in space exploration and similar regions that are inaccessible by humans. Since there is an absence of human operators in such regions, the rover vehicles are made fully automated. There is a great symphony of various disciplines such as mechanical, electrical, software and chemical engineering that function together to make the field of space exploration and sample testing much easier and efficient. This further enticed our team's urge and curiosity, motivating us towards taking this specific project as the team's new domain, after a series of extensive team discussions and meetings.