Design and Development of an Intelligent Rover for Mars Exploration

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Abstract— **The paper describes various issues faced by rover in an alien environment and attempts to solve each of them using innovative design modifications. The rover features a bio-inspired eight-wheeled drive mechanism, an integrated robotic arm and a stereo vision technique for advanced image processing. The system control, for both the rover as well the robotic arm, is done using microcontrollers and microprocessors such as Arduino, Intel NUC, and Raspberry Pi. Inspired from nature, a reflex mechanism has also been integrated into the rover design to minimize damage, by automated safety reflexes. The arm is so designed to switch between three different end effectors depending upon the task to be performed. The 8-wheeled rover combines the rocker bogie mechanism and four rocker wheels and four spider-leg wheels. The spider-legs ensures that it can traverse over a considerable height greater than the chassis height which could be as much as thrice the diameter of the wheels ,whereas the current NASA`S curiosity rocker bogie system can only traverse over a height twice the diameter of the wheel. Additionally, as they are actuator-powered, the slope of the rover can be adjusted in such a way that it does not topple for a wide range of inclination and allows the rover to traverse over highly rugged terrain. It provides a large amount of traction with the ground even in terrains where there is a negative slope or vertical drop of around 1m using a spring-damper suspension mechanism whereas the rocker bogie mechanism provides traction only due to its body weight The Rover finds applications in the exploration of other planets, deep sea vents and other hostile environments. It offers a possibility of integrating numerous features such mineral collection and sampling, landscape mapping, moisture detection etc. Such an effort may even prove to be instrumental in detection and study of biological activity in worlds other than ours.**

I. INTRODUCTION

The Mars Rover is a vehicle that has been designed to traverse the rugged terrains of Mars and collect samples of various items on Mar's surface. Scientists over the years have tried to explore the possibility of life on Mars. Such explorations have been mostly done using rovers. Hence rovers need to be specially designed to traverse all kinds of terrains and must be equipped with state of the art technology. A common design element is most rovers over the years is the rocker bogie mechanism. The rocker bogie mechanism has quite a lot of advantages and is hence a well-established mechanism. The main advantage is that it ensures that all the wheels of the rover are in contact with the ground at all times. This advantage is key to creating a stable all terrain system. Consequently the traction of the rocker bogie provides is equal and reliable allowing a smooth running even on the uneven terrains.

The earliest notable Mars explorer, the *Pathfinder*, landed on Mars with a fully function rover on Mars on July 4, 1997.The rover carried a wide array of scientific instruments to analyze the Martian atmosphere, climate, geology and its rock and soil composition. Sojourner, the Pathfinder's rover, made observations that answered numerous questions about the origin of the rocks and other deposits on Mars. Following its stead, the *Opportunity* successfully investigated soil and rock samples and managed to take panoramic images of its landing site giving us valuable information about the Martian terrain and other site conditions. It is the data that was collected in these missions, using sampling technology, which allowed scientists at NASA to theorize about the presence of hematite and consider exploring the possibility of finding water on the surface of Mars. *Curiosity*, another historic milestone in the history of alien planet exploration, was assigned the role of investigating Martian climate and geology. It assessed whether the selected field site, Gale Crater, had ever offered environmental conditions favorable for microbial life and future investigated the role of water in planetary habitability as preparation for future human exploration [1-4]. In these types of rover's only 6-wheeled rocker bogie [5-12] suspension is used.

This paper proposes an 8-wheeled rover which combines four rocker wheels which form the rocker bogie mechanism along with four spider-leg wheels. The figure.1 shows the Solid Works model of the rover. The spider-legs ensures that it can traverse terrains with heights much greater than the chassis height. Additionally, since the wheels are actuator-powered, the slope of the rover can be adjusted in such a way that it does not topple for a wide range of inclination and allows the rover to traverse over highly rugged and uneven terrain, It provides a significant amount of supplemented traction with the ground even in terrains where there is a negative slope or vertical drop of around 1m using a spring-damper suspension mechanism.

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This is a significant improvement to the existing rocker bogie mechanism which provides traction using its body weight alone. Moreover this is done without compromising the strength of the chassis. The chassis has a factor of safety of 3.2 as per Finite Elemental Analysis. The leg, which is a combination of the four bar linkage, spring-damper and the linear actuator, provides assistance for the rover to traverse over small hindrances. A member is hinged to the chassis. One end of that member is pinned to the actuator and the outer end to a four bar linkage, making the system stable ad flexible at the same time. Thus the rover mechanism that has been described in this paper allows the rover to traverse all kinds of surfaces while maintaining stability and protecting the instruments that the rover carries.

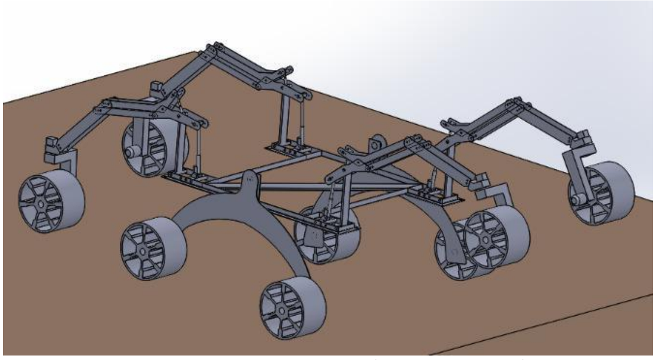

Figure 1. SOLIDWORKS model of the rover with front spider-legs elevated

To enable the rover to function in a semi-autonomous mode a number of sensors have been used in the system. To avoid catastrophic damage to the rover due to widely varying terrains, an ultra-sonic sensor is used. Much like the effect of a reflex action in the human body, the sensor detects the anomaly and sends the data to the microcontrollers for stopping the rover and averting any danger.

The mechanical system that controls the rover's motor system is quite complex but extremely efficient. The array of sensors combined with system containing a number of commonly available microcontrollers and microprocessors, makes the movement and the working of the rover extremely accurate and comfortably feasible. The motor drivers and the sensors used are interfaced with microcontrollers like the Arduino and is further controlled using state of the art microprocessors like Raspberry pi. The Rover has been design with a semi-autonomous control which allows for fast error correction as well as efficient control. This papers describes both the overall working as well as that of the individual subsystems present in the rover.

II. ROVER MECHANICAL DESIGN

The design of the rover is to allow it to traverse rough and rocky terrain which at present is not possible using conventional vehicle design. Therefore the major aim is to design a rover which has an effective mechanism removing the disadvantage of modern day rovers. The chassis designed is in accordance with the set of rules and requirements that have to be met in order to contest in the event. There are certain restrictions set on the length and width of the chassis, its overall weight, ground clearance etc. by the governing body of the "University Rover Challenge 2015" and it was made mandatory that the rules be followed by the competing teams.

A. Material Selection

Property	Value
Ultimate strength	310 MPa
Density	0.0975 lb/in^3
Strength to weight ratio	Moderate
Machinability	Highly machinable /weldable using TIG
Cost	Moderate
Availability	Available in Indian market

Table 1. Material Properties of Aluminum 6061 Alloy

Performance and strength are the major parameters which reflect the reliability of a vehicle. While designing and fabrication of the rover chassis, suitable low cost material had to be selected which maintained high strength to weight ratio thereby improving the performance of the rover. Considering various parameters like yield strength, material availability, density, strength to weight ratio and mainly the availability and cost of the material, various options were explored. The search narrowed down to either graded aluminum or composite materials. Composite materials like Carbon Fiber are mainly used in the conventional NASA designs of MARS rovers. Based on the factors in the table 1 we choose our material of construction as Aluminium-6061.

Aluminum 6061, a precipitation hardening alloy majorly comprises of Magnesium and Silicon. It was chosen for its good physical properties and great weldability. Being one of the most common alloys of Aluminum, it is easily available and cheap. Pre-tempered grades such as 6061-O (annealed) and tempered grades such as 6061-T6 (solutionized and artificially aged) and 6061-T651 (solutionized, stress-relieved stretched and artificially aged) are the commonly available types.

B. Chassis Model

Table 2. Channel Specifications

Material Specification	Al-6061 T6
Type of channel used	Rectangular channel
Channel size	2.5 in * .5 in
Thickness	3 mm
Chassis Dimensions	105cm * 80 cm
Weight	4.1 kg

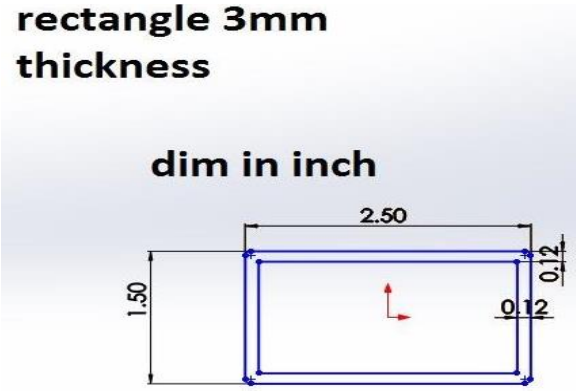

Figure 2. Dimensions of the channel used

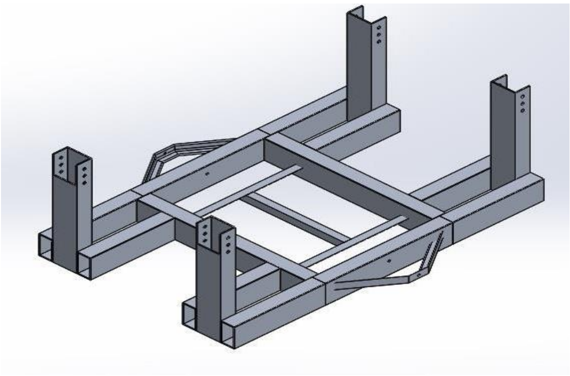

Figure 3. Final Design of the chassis

In order to design and manufacture the original chassis, continuous optimization had to be done. The FOS has to be higher and the deflection should be minimal. Hence, the careful selection of the channel type is required for further modelling. For minimal deflection and increased FOS, a rectangular channel of 3mm thickness was selected as the suitable channel. The rectangular channel of 3mm thickness is capable of withstanding both vertical and longitudinal load. The figure 2 shows the channel dimension and the table 2 shows channel specification. As most of the loads are exerted upon the mounting regions of linear actuators, the channel can now take fluctuating loads. The final design incorporates enough space which satisfies the component restraints and provides necessary strength for the rover. The chassis analysis was done after designing the final chassis. The figure 3 shows the final chassis design.

III. STATIC ANALYSIS OF MODEL

For the static analysis, the fixed supports were given as the support members of C arms. A force of 500N is given to each of the leg members. The figure 4 shows the distribution of forces and the fixed support whereas the figure 5 shows the meshing. The figure 6 and figure 7 shows the safety of factor and total deformation.

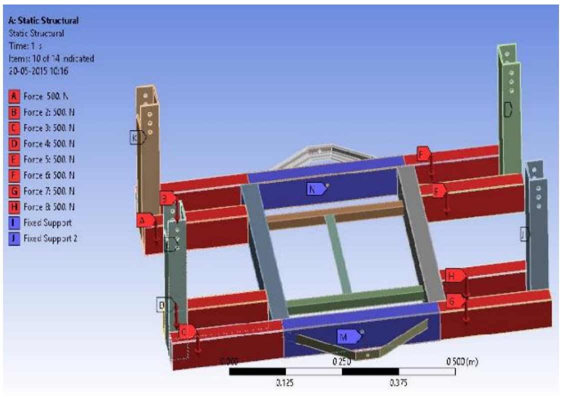

Figure 4 Distribution of forces and the fixed supports

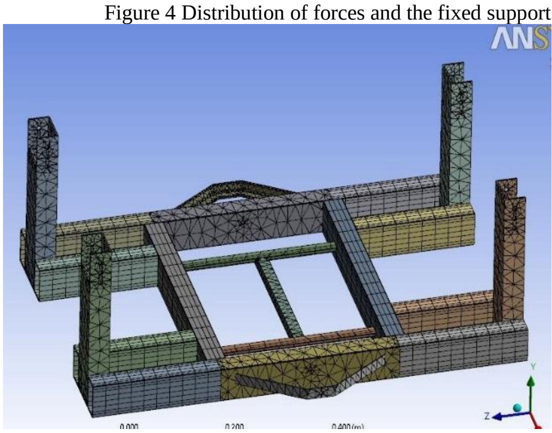

Figure 5. Meshing

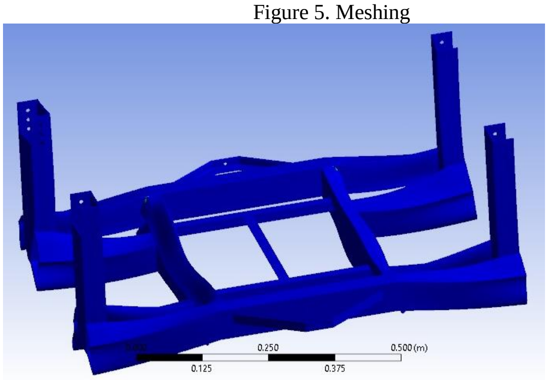

Figure 6. Factor of Safety

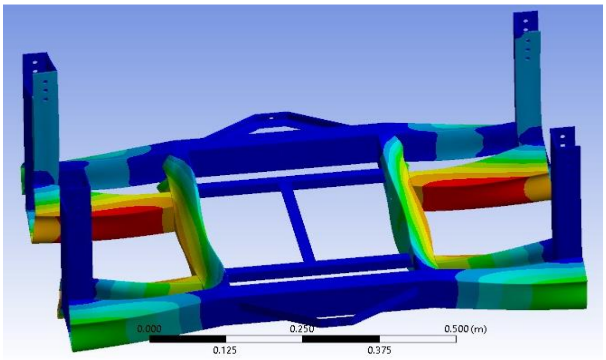

Figure 7. Total Deformation

The values obtained from the FEA analysis are: Factor of safety=5.8571(WithstandHighLoad),Deformation=0.001886cm (Little Deformation) and Max Equivalent Stress= $4.263*10^7$ Pa(Low Stress). Analyzing the data it can be concluded that the chassis is strong and can easily withstand high strength. Therefore the chassis need not be further optimized. The chassis is then built with real time boundary conditions. The figure 8 shows the real chassis model.

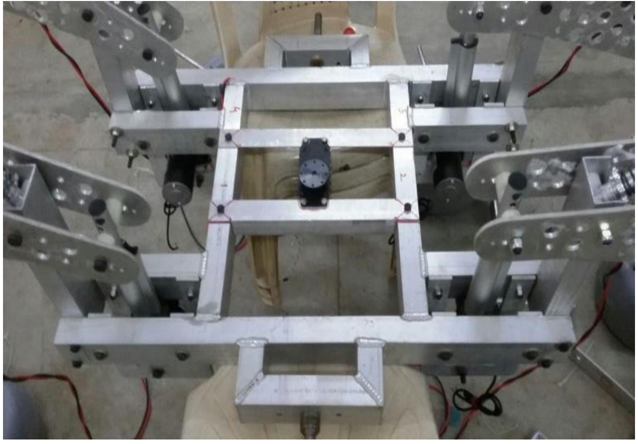

Figure 8. Real time chassis model

IV. MECHANICS DEVELOPMENT AND KINEMATIC ANALYSIS

For the chassis that has been built, a proper mechanism has to be developed which enables the legs of a vehicle to traverse up steps/rocks and still be able take the impacts of varying ground terrain. The primary motive of the mechanism is to allow the rover to a climb high stepped terrain and still have a suspension system in place to provide restoring force for the legs to come down and provide traction for the wheels over the ground terrain. Such a mechanism will allow rovers to travel rough and rocky terrain while at present is not possible for conventional rovers.

In currently used designs, there is a limit to the height that the rover can traverse and it is extremely difficult for these designs to climb up very high steps. Using suspension designs with very soft shocks can cover rough and rocky terrain to an extent but unfortunately it is impossible for it to climb up huge steps and rocks. It is well known that an unexplored terrain can have unexpected challenges. Thus it is essential for a mechanism to exist which can overcome such unexpected challenges. It is possible to test the conventional designs in unexplored areas, but these designs tend to suffer from disadvantages which would prevent them from prolonged use hence such designs are not feasible. Thus there is a need for a novel and innovative design which will enable rovers to face unaccounted landscape challenges and allow it to carry on with the unmanned exploration, without human intervention or repair issues.

A. *The Spider Mechanism*

The spider-leg mechanism ensures that the vehicle can traverse over a heights far greater than the chassis height. This could extend as far as thrice the diameter of the wheels. Additionally, since the mechanism is actuator-powered, the slope of the rover can be adjusted in such a way that it does not topple for a wide range of inclination and allows the rover to traverse over highly rugged or uneven terrain. It provides a large amount of traction with the ground even in terrains where there is a negative slope or vertical drop of around 1m using a spring-damper suspension mechanism and it achieves this without compromising on the strength of the chassis.

B. *Line Diagram Depiction Showing Initial Position*

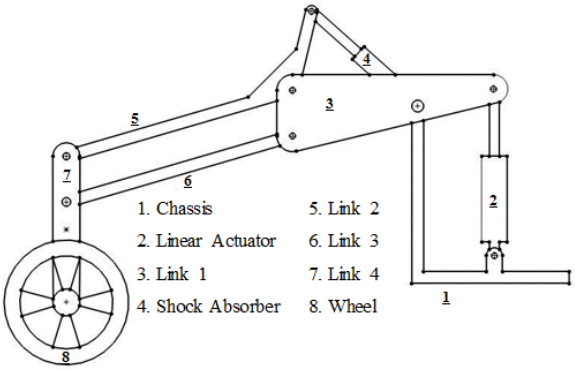

Figure 9. Wheel in ground level

Fig 9 and 10 depicts how the spider legs help to support the load when all the wheels are in ground. Notice that initially, all the linkages are pivoted at the center point of Sl no 3 in Figure 9. This pivot point moves only when the rover encounters an unexpected terrain. The springs are mainly involved in traction control and in supporting the weight.

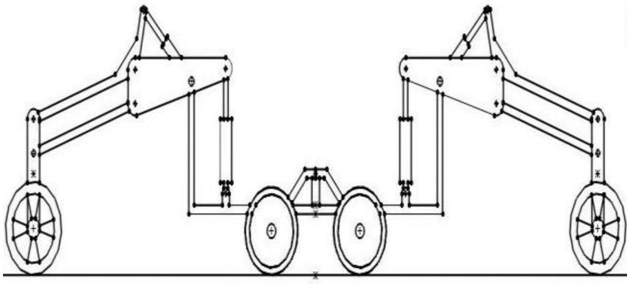

Figure 10. The complete side view of the spider legs

Figure 10 clearly depicts that the spider-leg, which is a combination of the four bar linkage, spring-damper and the linear actuator, provides assistance for the rover to traverse over small hindrances. As mentioned earlier, one link of the mechanism is hinged to the chassis. One end is pinned to the actuator and the other end to a four bar linkage.

C. *Line Diagram Depictions Showing the Movements of the Rover*

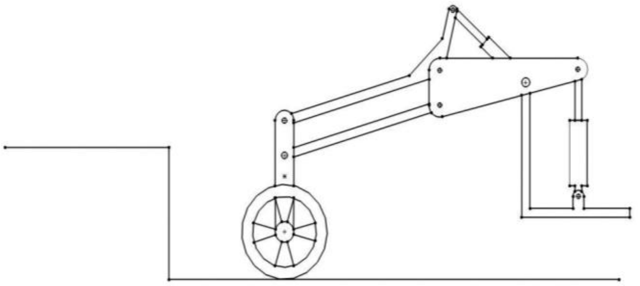

Figure 11. An example spider-leg mechanism approaching a stepped terrain

In figure 11, an example of the working of the spider-leg mechanism is shown at its mean position. At this position the links are able to transmit the shocks of varying terrain to the shock absorber. When the wheels of the spider-leg mechanism encounter a small obstacle relative to its wheel size it is able to easily overcome the obstacle as the shock absorber mounted on the top of the wheel's link gets compressed and the lift of the wheel is compensated this way.

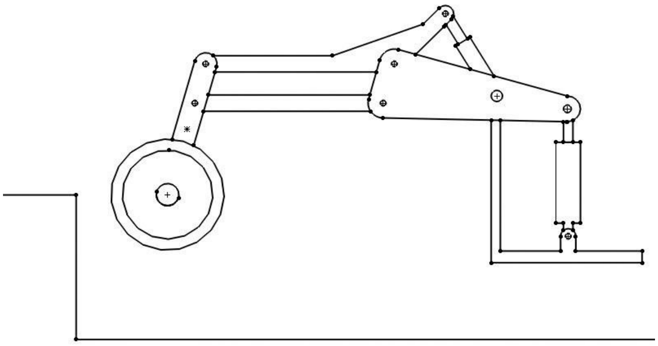

Figure 12. An example spider-leg mechanism raising itself.

In figure 12, as the spider-leg mechanism encounters a high obstacle the linear actuator is retracted wirelessly and this causes the link mechanism to extend out and reach a greater height, the shock on top of the mechanism is also compressed. However to get maximum reach and traction there needs to be 2 spider legs in front of the vehicle. Therefore 2 legs are raised. After this initial step, the vehicle rests on the middle 4 wheels and the 2 rear spider legs. The lifting of the front spider-legs allows the vehicle to reach terrain previously inaccessible and gain traction on top of the high terrain.

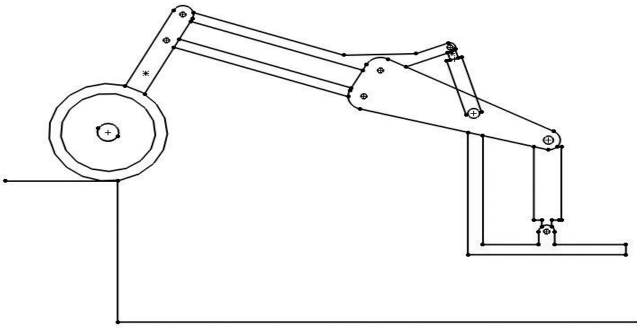

Figure 13. An example spider-leg mechanism overcoming a stepped terrain

In Figure 13, to effectively climb over a high obstacle a total of 4 spider-legs are required on a vehicle with individual drives, 2 spider legs at the front, which can be raised onto the high terrain and gain traction on the terrain and 2 spider legs at the rear of the vehicle. The legs at the rear lower onto the ground effectively lifting the vehicle and giving a push to the entire vehicle while the spider legs in front of the vehicle act to gain traction at the top of the obstacle and effectively pulls the entire vehicle up. This combination of the two forces allow the vehicle to overcome high stepped terrain.

C. *Software Design Depiction*

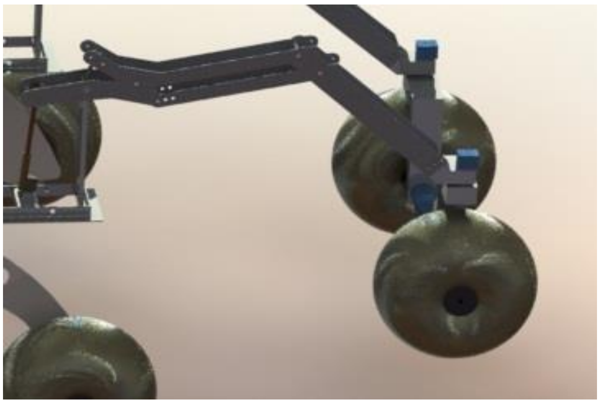

Figure 14.1 Solid works rendered image of the mechanism

A Solid works model was designed and the rover assembly was completed. This was essential for the manufacturing of the model. The figure 14.1 shows the solid works rendered image of the mechanism and figure 14.2 shows the isometric view of the entire rover making it easier to study the mechanism.

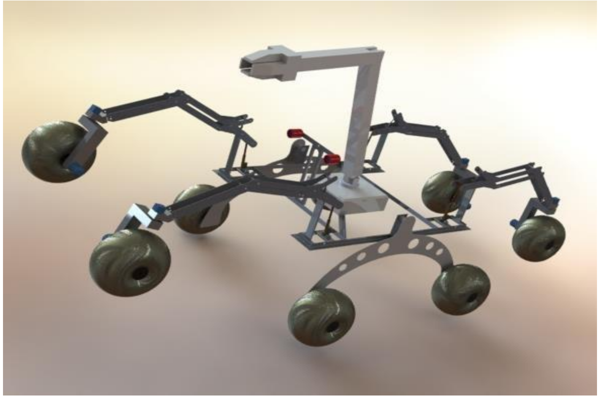

Figure 14.2 An isometric view of the overall rover

V. KINEMATIC ANALYSIS OF THE MECHANISM

Kinematic analysis is an integral part of the mechanism implementation. It helps us to study the trajectory of points, bodies (objects) and systems of bodies without considering the motion.

A. *Formulation of Velocity Polygon*

If a number of bodies are assembled in such a way that the motion of one causes a constrained and predictable motion to others, it is known as a mechanism. The function of a mechanism is to transmit and modify the associated motion.
The leg of the rover moves according to motion which constitutes a planar mechanism. For planer mechanism the degree of freedom of the mechanism can be calculated by Gruеblers Criterion.

$F=3(N-1)-2j$

Where $j= (1/2)(2N2+3N3)$

Where,

N= the total number of joints, $N2$= the number of binary joints, $N3$= the number of ternary joints

According to the Grubeler's criterion if for a planar linkage the degree of freedom is one, then it is called a mechanism.

A spring in a mechanism can be converted to a turning pair. This is because the action of a spring is to elongate or shorten as it gets subjected to in tension or compression. A similar variation is obtained by two binary link joined by a turning pair.

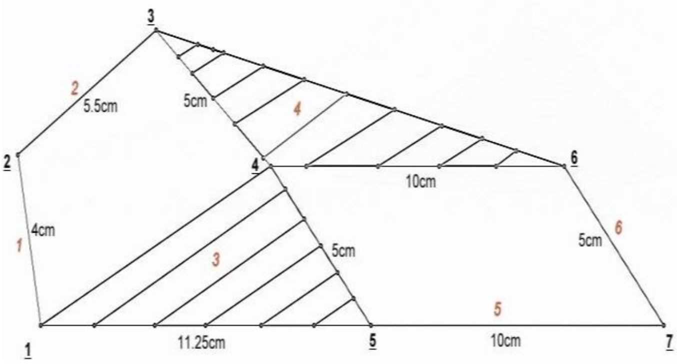

Figure 15 Mechanism Link Diagram

The validation of the mechanism is done as shown below. The mechanism consists of four binary links and two ternary links as shown in the figure 15.

Hence the total number of links are six.

F = 3(N-1) -2 J;

2J = 2* n_2 + 3*n_3

=2*4 +3*2 =14

F = 3(6-1) - 14

=1

Hence it is a mechanism.

The links move dependent of each other. Hence the velocities of each link maintain a relation. So once we experimentally find a velocity of a link, we can find out the absolute velocity as well as the relative velocity of other links with respect to reference links. To find out velocities this way, we must follow certain laws and constraints. They include laws like, the velocities of a joint are perpendicular to the direction of motion of a link and that the meeting points of line of action of velocity lines gives the velocity of the links with respect to ground.

Applying this method on the leg mechanism of the rover, the initial velocity given was found to be 7 cm/sec. This velocity was given at the wheel of the rover. An assumption was made that the velocity of the wheel will be the same as that of the legs of the rover while traversing the terrain. From the velocity polygon it was understood that the velocity with which the spring displaces is about one tenth of the velocity with which the wheel moves up. Figure 16.1 and 16.2 shows velocity diagram of links 5, 7 and 6, 7.

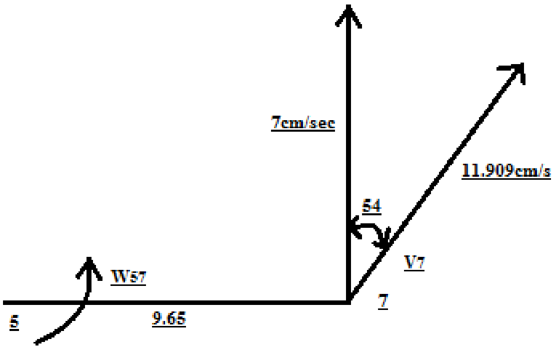

Figure 16.1 Velocity diagram of links 5, 7

Initially we assume the velocity of joint 7 to be 7 cm/sec. Later we have to find out the angular velocity of link 57 by the relation V = r ω.

$W_{57} = V_7 / L_{57}$

$W_{57} = 11.909/19.3 = 0.617$ rad/sec

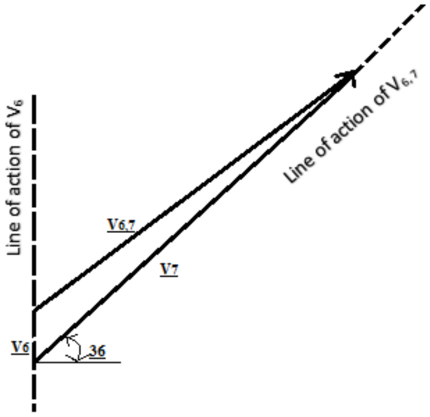

Figure 16.2. Velocity Diagram links 6,7

The known velocities are V_7 and the line of action of V_6 and line of action of $V_{6,7}$

$V_6 = 0.8$ cm/sec and $V_{6,7}=11.5$cm/sec

$W_6 = W_{6,7} = (V_{6,7} / L_{6,7}) = (11.5/7) = 1.15$ rad/sec

$W_3 = V_6/L_{4,6} = (0.8/20) = 0.04$ rad/sec

$V_3 = W_3 * L_{3,4} = 0.04*10 = 0.4$cm/sec

Now from the known v3 we find out v2.

$V_2=5.7$cm/sec and $V_{3,2}=6.3$cm/sec

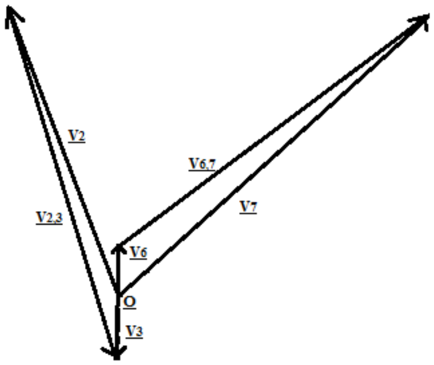

Figure 16.3. Velocity Polygon Diagram

Finally velocity polygon is drawn showing all the absolute velocities and relative velocities of each link with respect to other links as shown in figure 16.3.

VI. DYNAMIC ANALYSIS USING ADAMS

The various parameters for the newly developed mechanism is found out with the help of ADAMS software. The parameters that were to be found out include velocity of every joints and links, acceleration of the links and joints ,angular velocity, angular acceleration ,force and torque acting on various parts and finally the deformations of the spring, deformation velocity and the forces that act on the spring. These are important for validating the new design. The basic governing equations that govern the kinematic analysis in ADAMS are based on the Eulerian and Lagrangian dynamics.

The mechanism of the leg of our rover was analyzed in ADAMS and for the acceleration due to gravity 9.81, with the weight of the members the graphs were plotted for each link. The results for each part that was analyzed are given below.

A. *Simulation of the Spider Leg Using ADAMS*

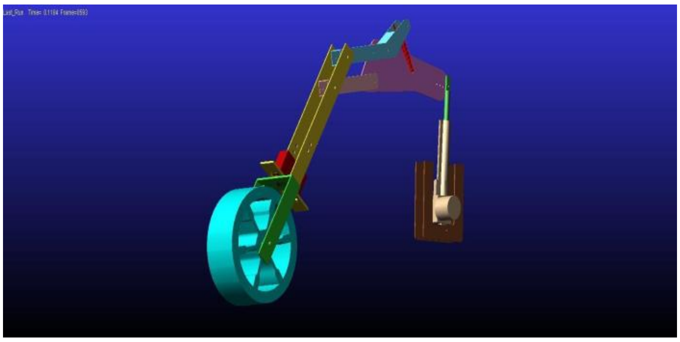

Figure 17. Simulation in ADAMS

The leg mechanism was kinematically analyzed in ADAMS software as shown in figure 17 by giving the center of gravity for each specific links and specifically giving the connectors to each link. Afterwards motions were assigned to each of the joints. Later graphs were plotted when simulated. Some of these are as shown below from18.1 to 18.5.

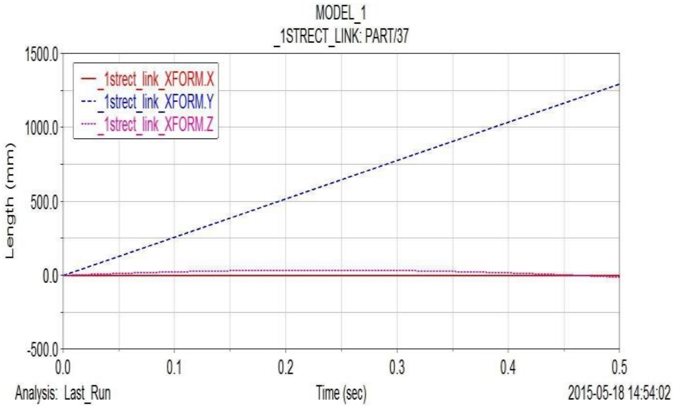

Figure 18.1. Length vs time graph of rectangular link 1

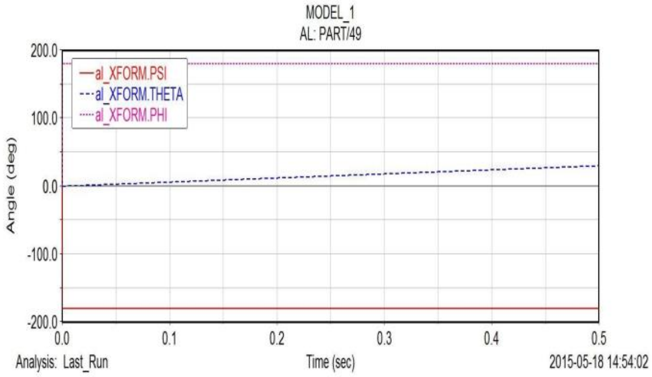

Figure 18.2. Angle Vs Time graph for wheel

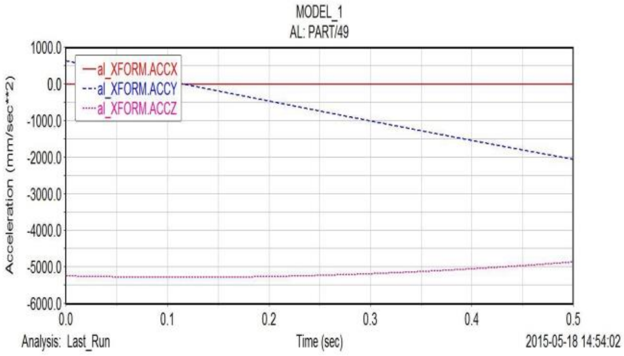

Figure 18.3.Acceleration Vs time graph for wheel

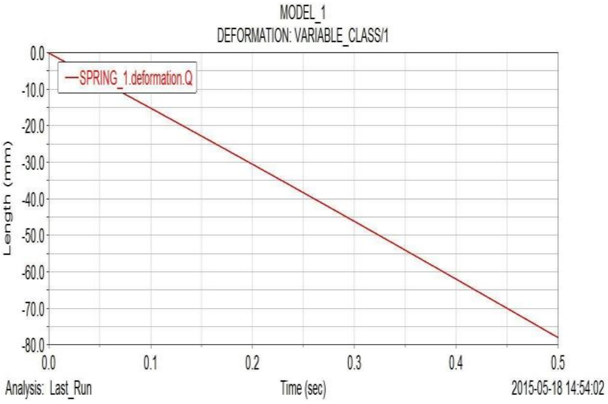

Figure 18.4 Deformation Vs time graph for spring

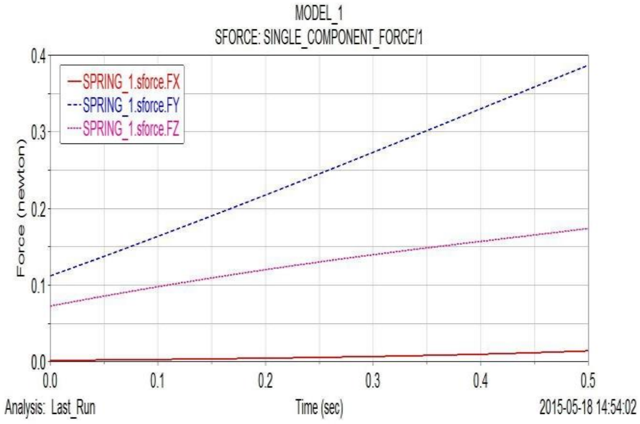

Figure 18.5Force Vs time graph for spring

VII. LINKAGE SPRING DESIGN

The linkage spring has to be carefully designed to support the weight while traversing a terrain in order in turn providing traction. For this, various parameters like spring rate (spring constant), spring material, free length etc. has to be considered, and number of coils etc. had to be fixed.

The cycle shock was the best available alternative for the shock absorption and maintaining traction. But the standard available cycle shocks have a very high stiffness rate. A spring has to be custom made for the specific purpose. So in order to do that, a spring had to be selected whose free length and the compressed length are known. The figure 19 shows the dimension of the spring used. But it is to be evaluated whether the spring can support prescribed weight. The load calculation for the spring is as follows.

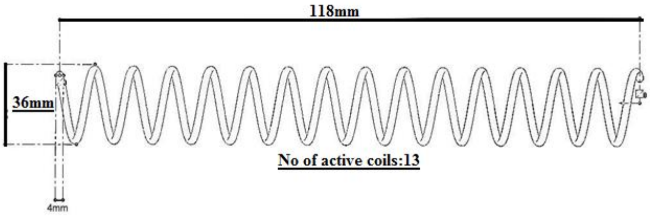

Figure 19 Spring Dimensions

To calculate the spring rate we know that,
Wire diameter = 4 mm
Free length = 118 mm
Compressed length = 80
No of active coils = 13
Outer diameter = 36 mm
Deflection = Free length – Compressed length
= 118 – 80 = 38 mm

Spring Rate =Spring Rate/ Stiffness = (Modulus of spring steel * (wire diameter) $^{4)}$/ (8*No of active coils*(mean coil diameter) ^{3}

Spring Rate= ((209*10^{9})*(4*10^{-3})^{4})/ (8*13*(36*10^{-3})^{3}
=5957N/m
Force which can compress 1” = spring rate * deflection
= 5957 Nm * (38 * 10^{-3})
= 226 N

Hence the load will be approx. 23kgf required for the spring to compress 1” which is the desired value.

VIII. WEIGHT DISTRIBUTION

The weight distribution is the apportioning of weight within a vehicle. Typically it is written in the form x: y where x is the percentage in front and y is the percentage in the back. In a vehicle which relies on gravity in some way, weight distribution directly affects a variety of the vehicle characteristics including handling, acceleration and traction. For this reason weight distribution varies with vehicle’s intended usage. The following section shows how the weight is distributed when the Mars Rover is in different position.

A. *The Rover is in Normal Position*

The figure 20.1 shows the rover in normal position with X=78cm, Y=396cm and Z=714cm.

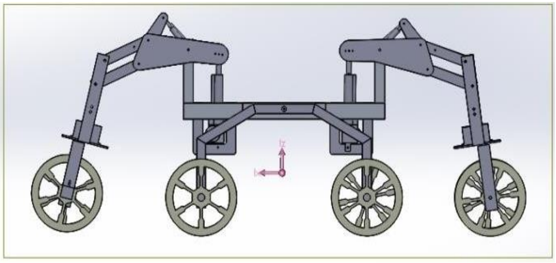

Figure 20.1 Normal Position

The calculation of weight distribution is as follows
Overall length = 230 cm
When four wheels are in ground the weight distribution is 50: 50, i.e. the center of gravity lies in the center as in Figure 20.1. The vehicle is stable as the CG lies in the center of the rover.

B. *The Rover’s One Leg is in the Lifted Position*

The figure 20.2 shows the rover in one leg lifted position with X=78cm, Y=400cm and Z=711cm

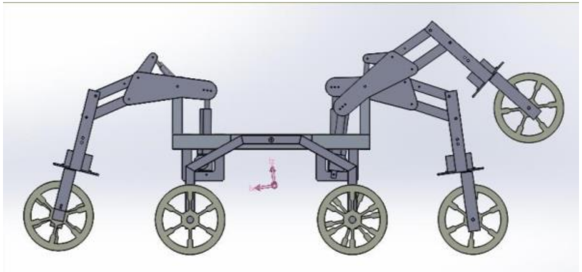

Figure 20.2 Rover’s One Leg Lifted Position

The calculation of weight distribution is as follows
Shift in length = 4 cm
Ratio = 230/ (115 + 4) = 1.932
Overall Weight Distribution = 25 * 1.932=48.3
Hence the weight distribution is 51.7: 48.3

C. *The Rover’s Both Legs are Lifted*

The figure 20.3 shows the rover in both legs lifted position with X=78cm, Y=401cm and Z=711cm

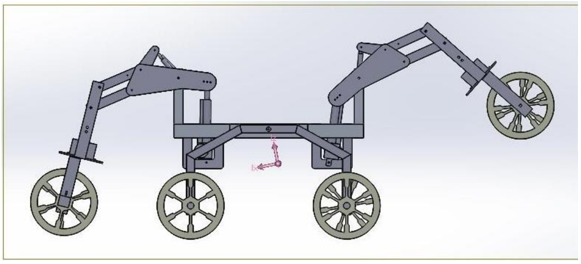

Figure 20.3 Rover’s Both the Legs are Lifted

The calculation of weight distribution is as follows
Shift in length = 5 cm
Ratio = 230/ (115 + 5) = 1.9166
Overall Weight Distribution = 25 * 1.9166 = 47.915
Hence the weight distribution is 52.1: 47.9

The weight distribution was well optimized when compared to previous versions. In the final model there is a significant difference in the weight distribution and in the CG value. After optimization, the CG shift is very low which makes the rover stable with the proper working of the mechanism. The figure 21 shows below shows the final prototype of the Mars Rover.

Figure 21. Final Prototype

IX. ROBOTIC ARM

This 3-linked robotic arm is an 8 degree of freedom inverse kinematic machine. Because of its rotational capability, the 3 degree of freedom base has maximum reachability around the rover, irrespective of the rover orientation. The arm is equipped with a gripper turret with 3 types of end effectors. One of them is a two link gripper mechanism. The second is a four link gripper mechanism for circular gripping and opening valves. The third end effector is an Archimedes screw that can be used for soil collection. The arm body as a whole has 2 additional degrees of freedom for linear movement across the rover body along a 100cm platform on a belt driven linear actuator. In addition, the linear actuator and arm can rotate on a DC stepper motor, fixed at the rover base to rotate the arm by 360 degrees on a horizontal platform. Figure 22 shows robotic arm and various end effectors used. This makes equipment servicing, sample collection and astronaut assistant tasks easier.

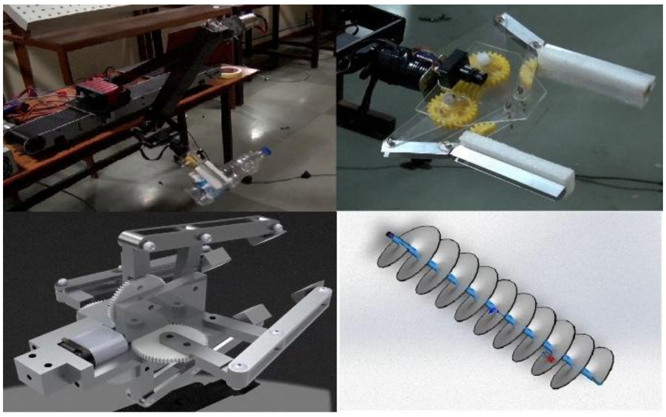

Figure 22: Robotic arm and different end effectors available on gripper turret

X. ROVER ELECTRONICS

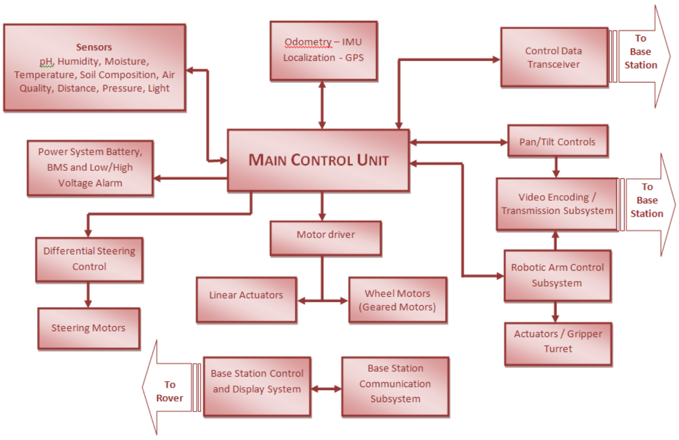

Figure 23: Block diagram of electronic system of the rover

The Figure 23 shows the electronics design block diagram of the main rover components. The electronic system includes the power system, sensors, camera, video transmission and reception, robotic arm system, navigation, driver system and radio frequency communication systems.

A. POWER SYSTEM

1. **Battery:** We use 16Ah 22.2V Lithium Polymer battery, as lithium polymer provides a light weight, reliable, reasonable current capacity, and form factor that is good for confined space.
2. **Battery Monitoring System:** We use battery monitoring circuits and low voltage alarm.

B. DRIVE SYSTEM

1. **Motors:** We use 18V brushed DC planetary gear motors, with gearing ratio 1:256 and 76 RPM, with Stall Torque of 300.8 kg-cm.
2. **Steering Actuators:** Our Rover Design uses high torque 30 RPM brushed DC gear motors as steering actuators, with shaft encoders, for making it faster and reliable actuators.
3. **Motor Driver:** We use a 120A motor driver, suitable for high powered robots. The driver allows us to control the motors with: analog voltage, radio controls, serial and packetized serial. Overcurrent and thermal protection are included in driver itself.

C. VIDEO SYSTEM

We use three cameras: pan/tilt camera, a camera along with robotic arm and a Stereo vision camera (for depth analysis and 3-dimensional view of the area)

1. **Main Camera:** We use a pan and tilt Night Vision CCTV wireless camera with 1 km range.
2. **Arm Camera:** We use a camera with 5.8 GHz AV receiver. This camera provides a decent vantage point of the arm end effectors and the arm objective. This allows for precision in

locating and orienting the end effector to perform various equipment servicing tasks such as opening valves, operating switches, etc.

D. MAIN CONTROL SYSTEM

We use INTEL-NUC processor and microcontrollers for controlling each subsystem. Image processing is done by Intel NUC. Other subsystems are controlled by Arduino Mega microcontrollers.

E. COMMUNICATION SYSTEM

1. **Control Radio:** We use 2.4 GHz Radio Frequency 9-channel Transmitter to control the rover. We use 2.4GHz XBee XBP24-AWI-001, for controlling the robotic arm.

2. **Video Transmission:** Main camera is a wireless camera with 2W transmission power and operating frequency of 2414-2468 MHz. The camera on the robotic arm has a transmitter frequency of 5645-5945MHz with 500mW power output.

3. **At Base Station:** We have 2.4GHz 9 channel transmitter, 5.8GHz 32 channel AV Receiver and 2.4 GHz AV receiver, 2.4 GHz XBee Transceiver to receive sensor data and send control signals.

F. NAVIGATION SYSTEM

Connected to an external antenna on the rover main control board, the Garmin GPS-15x receiver (with WAAS capability) is used to navigate and localize itself. This module provides functionality of abstracted navigation and is connected directly to the microcontroller, for parsing the NMEA navigation strings.

G. SENSORS

We use the below mentioned sensors for analyzing the following conditions:

1. Moisture Sensor: For identifying the water content in the soil sample, we use a soil moisture meter
2. Temperature, pressure and humidity Sensor
3. PH Sensor: To determine the PH of the soil sample using four buffer solutions
4. Distance Measurement
5. Air Quality Sensor: To determine the contents and quality of air at a location
6. Light Sensor: For determining the light intensity at the given location
7. Inertial Measurement Unit
8. Digital Compass: To increase the accuracy of localization and terrain traversing

XI. ADDITIONAL FEATURES

A. STEREO VISION AUTONOMOUS NAVIGATION SYSTEM

The rover is equipped with autonomous navigation unit that can help in reaching required destinations without the help of manual instructions. The heart of the system is Intel NUC Celeron processor, and main input sensors are stereo vision cameras and ultrasonic transducers. Stereo vision is based on Simultaneous Localization and Mapping (SLAM) algorithm to perform intelligent navigation. The SLAM unit takes the GPS coordinates of the destination as input and plans the shortest path from the current location. As it traverses along the planned path, the rover will generate the three-dimensional map of the environment and localize itself in the developed map.

B. SWARM ROBOTS

Swarm robots, using GPS and RF communication, are used for distributed sensing task. In order to investigate narrow, deep and risky areas, we use two four-wheeled swarm robots (ground vehicles) with stereo vision, which are kept in the main rover and can be deployed when required.

C. UNMANNED AERIAL VEHICLE

UAV based stereo vision system is used to determine the ground depth and perform obstacle mapping, and path planning. The drone has a payload capacity of 5kg.

XII. CONCLUSION

The mars rover has been designed with an improved mechanism when compared to existing versions and the final prototype has been built. The rover was built with aluminum 6061 and using various mechanical techniques like water jet cutting, TIG welding, drilling etc. The team's design had cleared the Critical Design Review of the University Rover Challenge 2015 conducted by Mars Society, USA. An innovative spider-leg mechanism has been implemented in which suitable kinematic linkage analysis and dynamic analysis were conducted to analyze and verify whether it is capable of traversing all terrains. The prototype manufacturing helped us to experimentally test the mechanism, so that we could bring necessary changes to the design. The present mechanism enables the vehicle to traverse up steps/rocks while still being able to take the impacts of varying terrain. In currently used designs, the height which the wheels of a vehicle can traverse, is limited and it is extremely difficult for these vehicles to climb up high steps. However a suspension mechanism with very soft shocks can cover rough and rocky terrain to an extent. Unfortunately it is impossible for them to climb up huge steps and rocks. Study and analysis has been done on the design and finally an optimized design in obtained. The final design is again tested experimentally using a fully functional prototype.

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