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Design and Analysis of Mars Rover

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Abstract

This paper explains various tasks which have to be performed by a mars rover. This rover is designed to participate in the University Rover Challenge (URC) hosted by The Mars society, USA. Hence, the Mars rovers is designed keeping in mind all the constraints imposed by the URC guidelines. The basic features of this rover are divided into three sub-modules i) the robotic arm part iizz) the mobile base or rover mobility system and iii) the science mission module.

A SCARA (Selective Compliance Assembly Robot Arm) configuration arm is used in this rover, since an articulated arm would require more powerful motors to carry the load, compared to a SCARA configuration arm. The rover's mobility system consist of a chassis and a suspension system. The chassis is designed in such a way that it can be able to withstand the weight of the robotic arm placed over it without tripping over when moving through rough terrains. The suspension system is chosen as Rocker-Bogie. The Rocker-Bogie suspension system has several advantages over the other suspension systems. It can climb the rocks which are twice the diameter of the size of its wheel. There are six-wheels each connected to a DC motor which can be independently controlled. The last sub-module is the science mission module. It has a soil sample collecting mechanism a camera and various other sensors to study the characteristic of the rocks and soil. The main objective of this rover is to find the presence of life in the surface of Mars. Each of these sub-modules are designed and modelled separately and finally put together to form the whole rover. This rover is designed in a way such that it can be able to perform all the tasks efficiently, as required by the URC competition, besides keeping the cost of the rover to a minimum.

Keywords— *Mars rover, SCARA arm, rocker-bogie suspension system, science mission module, soil sample collecting mechanism.*

I. Introduction

The University Rover challenge (URC) is a robotics competition hosted by the Mars society for university students. This is held annually at the Mars Desert Research station, outside Hanksville, Utah in the United States. The main goal of this competition is to promote student in developing skills in robotics, improving the state-of-the-art in rovers, and learn to work in a multidisciplinary teams in collaboration with engineers and scientists. The solution proposed in this competition, if feasible, may one day be deployed in actual Mars rovers which will be built in the future. This paper focuses on the mechanical design related aspect of the rover, which will be used for the preliminary Design Review for participating in the competition. The rover is designed after rigorous study of existing rovers. The study began by going through the history of planetary rovers from the initial concepts to the present ones used. Their general characteristics and evolution were also studied [1]. The Perseverance rover built by the NASA which is the most advanced rover till date was also studied for better understanding of state-of-the-art in rover technology. It was launched from Florida’s space coast on July 30, 2020, using the United Launch Alliance Atlas V rocket. After understanding all the technologies used in the existing rovers, our rover is designed taking into consideration the constraints imposed by the competition which is given in the rules and guidelines for the competition [2]. After reading the rules carefully and the tasks to be carried out by the rover, the whole design is split in to tree sub-modules i) the robotic arm, ii) The rover mobility/ suspension system iii) the science mission module. This rover is primarily designed for the exploration operation to identify the presence of life on the Mars [3]. The robotic arm has to perform several manipulation tasks for astronaut assistance, so it is designed according to that [4]. For this rover SCARA configuration is chosen considering the advantages it offers over other configuration. The suspension system is studied for choosing the best one optimal for navigation in rough and rocky terrain [5]. The design optimization techniques were also studied [6] for this purpose. This technology used for navigation in difficult terrain was also studied [7] for better understanding the navigation challenges. The rocker-bogie suspension was chosen after taking into consideration the advantage it offers over other suspension system. And finally, the science mission which has to be carried out by the rover is studied [8] for getting the overall insights of the tasks to be carried out before going into actual design process. The primary task includes the analysis of soil sample. The soil is collected and studied for determining the presence of life [9]. The science mission module also has a camera for taking panoramic images, which can also be used for navigation in addition to the LIDAR present on the front of the rover. The material used for building the frame of the rover is chosen as Aluminium 6061 T6, considering its low cost and strength to weight ratio. A chassis is designed to accommodate the robotic arm, the science mission module, an antenna, the soil sample collecting mechanism and electronic circuits. The rocker-bogie suspension system is attached on either side of the chassis. The design process of the rover is carried out as mentioned in the methodology section. Mesh analysis is carried out for ensuring the reliability of the proposed design.

Fig 1. Rover

II. METHODOLOGY

First, the tasks which needed to be performed by the rover is completely analysed. Literature survey is done to arrive at the target specifications. As this rover is divided into three sub-modules such as robotic arm, rover mobility system and science mission module, each module is analysed separately. After brainstorming several conceptual designs were generated and concept screening was done to select the optimum model for our design. After fixing the design and dimensions, each and every part of the rover was designed in Solidworks. In each, sub-modules, first part are created in “part module” and assembled together using proper mates and constraint in “assembly module”. Finally, the three modules are put together and the whole rover is formed. Stress analysis carried on the parts to reassure the designed pars are reliable and motion study is performed to ensure the proper movement of joints and mechanisms.

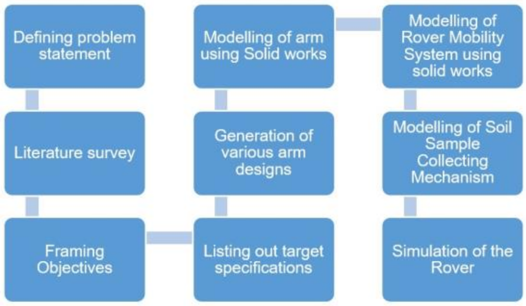

Fig 2. Methodology

III. TORQUE CALCULATION

Torque Calculation is crucial, since it helps in choosing the motor for our application.

Before torque calculation it is important to discuss the significance of our SCARA configuration. It can lift a lot of weight, since all the weights acts along the direction of gravity, so it is enough for the arm to lift the weight vertically, it can be achieved by turning the link 6 at -90 degree which makes the gripper face downwards along the link5 axis. (Here the link 6 is perpendicular to link 5 assumed as 0degree).This is not the case for articulated arm has to lift the weight it will require a lot of powerful motors along all the joints, since it has to lift the weight at an angle against the gravity. So, using a SCARA configuration gives the benefit in cost reduction. But the gripper cannot always be kept -90degree angle since the arm has to perform several other manipulation takes like using spanner, screw driver etc. so it has to carry same load of approximately 150-250 grams. So the arm has to at 0 degree to perform these actions. So, when the gripper is at 0 degree that is perpendicular to the link 5, the maximum load acts on the gripper.

The total torque of the arm is stall torque and rated torque,

Total Torque = Stall torque + Rated Torque

Stall torque can be calculated by the formula,

Stall torque = F x d

F – Force in Newton (N)

d – Distance in Meter (m)

Rated Torque due to the angular acceleration is calculated using the equation,

$$T_{rated} = I \times \alpha$$

I = Moment of Inertia (Kg-m^2)

α = Angular Acceleration (rad/s ^{2})

IV. MECHANSIMS

Each of the mechanisms which place a crucial part in the rover are explained below.

A. *Robotic Arm*

A SCARA configuration robot is designed to perform the manipulation tasks. It is a 6kg payload arm, the arm has a reach of about 1 meter. It has 1 prismatic joint and 4 revolute joints. The gripper is attached at the end of the robotic arm. This arm has 6 links and 5 joints.

To reduce the weight and cost of the robotic arm hollow aluminium 6061 T6 is used. It has a power to weight ratio of 8:1. This robotic arm is placed in front of the rover chassis. A prismatic joint is used which is driven by belt drive. Two rollers are used on each side of the bar which moves to and fro, where a belt drive is moved by a stepper motor. Pulley is used on the top for the support.

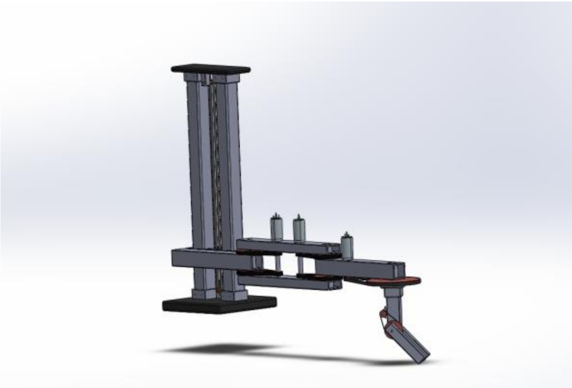

Fig 3. Robotic Arm

The second link is attached to the roller mounted on the bar. The link 3 is attached to link 2 and link 4. There are two motors placed on top of the link 3. The motors are placed in such a way that the weight of the motors on the link doesn't shift the centre of mass/gravity to right side towards the gripper side. The two motors are connected via belt drivers which have a timing pulley. So, the motor rotates the joint 2 and motor 2 rotates the joint 3. The shaft of the motor is elongated. The shaft of the motor is elongated. The tip of the shaft is connected to ball bearing so that one motor rotation doesn't affect the other motor's rotation.

The revolute joint on the link 2 and link 4 are connected to the link 3 with ball bearing to ensure smooth rotation of each of the joints. The link 4 is attached to link 3 and link 4. A DC motor is placed on this link 4. This motor has a belt drive attached to link 5. The link 5 is placed perpendicular to link 4 such that when the DC motor on link 4 rotates, it rotates the link 5. A small DC motor is placed in link 5. The link 6 is placed perpendicular to the link 5. The link 6 has two hollow tubes placed on either side of the link 5. So, when the small DC motor rotates these two bars move simultaneously. The gripper is attached to the link 6. The gripper is designed to hold objects and perform manipulation tasks. The high torque DC motor at the base of the gripper initiates the actuation. The gripper is designed with rail cuts at the tip to have proper grip to hold objects.

B. *Gripper*

It is a two finger gripper to perform picking tools, toggling switches, rotating valves and other manipulation tasks. In this gripper a screw (M60x1.5) is attached to provide linear movements. Also the thread (pitch 2mm) on the link makes the gripper hold objects. The gripper is designed such that it can expand and contract when the lead screw attached to it moves. It is a two-finger gripper, the tasks it need to perform are picking and using the tools such as spanner, screw driver, wire cutter etc. which constitutes the astronaut assistance tasks which will help the astronauts to repair the space vehicles.

The gripper can hold objects which are up to 5cm. The curvy part of the gripper's finger provides right amount of space and force to hold the tools at right position. It provides additional grip. When the lead screw placed in the middle moves the gripper opens or closes corresponding to direction of the rotation of the motor. In addition to the earlier function it can also toggle switches, type in the keyboard, open and close the drawer, pick and place a tool box, pull a rope etc…

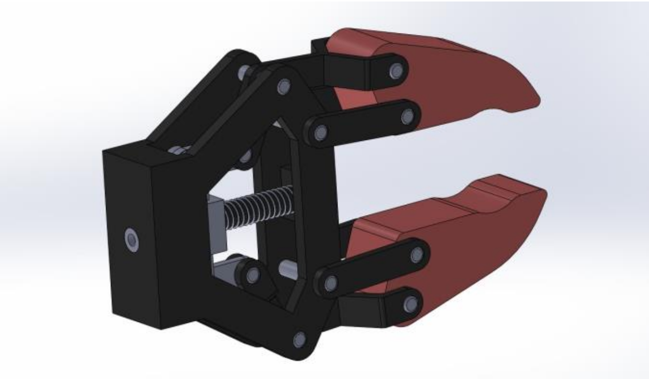

Fig 4. Gripper

C. Chassis

The chassis is designed in such a way that it will be able to withstand the weight of the robotic arm placed over it, the weight of the electronics part and the science mission module such as the camera, it also provides the space to place the antenna.

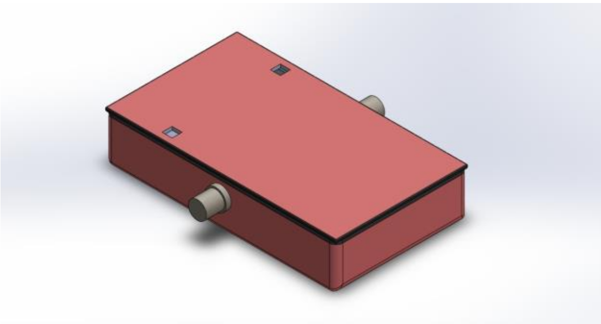

Fig 5. Chassis

TABLE I. SPECIFICATION OF CHASSIS

Specification of Chassis	
Chassis length	660 mm
Chassis width	394 mm
Chassis Height	108 mm
Material used	Aluminium 6061
Chassis weight	5 kg
Number of Chambers	2

D. *Science Mission Module*

To analyse the geographic properties, soil samples are collected with the help of scooper. During the sample collection process the two lead screws will lower the science mission module. When it stoops lower enough to touch the soil, the motor is actuated which then scoops the soil and keeps them in it. There are three such slots to take samples from three different places. It is later taken to the bio-chemistry lab on-site to preform various analyses on the soil.

Fig 6. Science Mission Module

This module carries some sensors to analyse various parameters such as temperature, moisture and PH. For the measurement of temperature LM35 is used. For the measurement of the moisture FC-28 a soil moisture sensor is used. PH of the soil will be analysed in the on-board chemistry lab which is placed on the rover. The chassis box then goes inside where the test are done to study the soil.

TABLE II. SPECIFICATION OF SCIENCE MISSION MODULE

Specification of Science Mission Module	
Length	300 mm
Width	150 mm
Height	26 mm
Activation type	Lead Screw
Lead Screw Length	420 mm
Lead Screw Diameter	15 mm

E. *Camera Module*

This is a part of science mission module. The camera module consists of a panoramic camera. This camera aids in the navigation part as well an in the manipulation tasks. This camera can be rotated 360° degrees. Pictures of the terrain can also be taken to perform some image analysis.

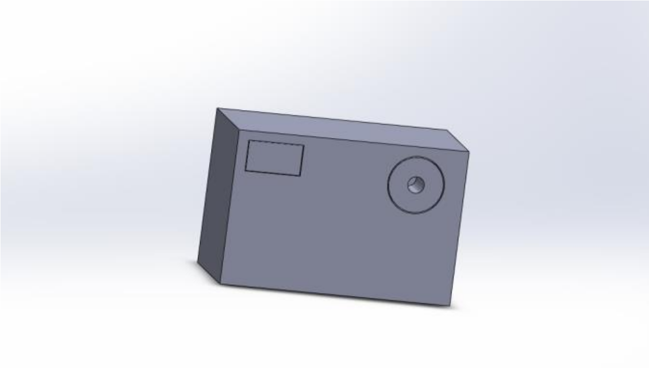

Fig 7. Camera Module

In addition to these, a laser blaster is added to the camera. This performs the chemical composition analysis of the rocks and soil.

F. *Rocker Bogie Suspension System*

Rocker bogie suspension system is used for the mobility of the rover. It has six wheels each of which are connected to a DC motor. The main advantages of this mechanism are that the rover can have 360° rotation, it can cross slopes without slipping and can move over rocky terrain efficiently compared to the other suspension mechanism. This mechanism is designed in such a way that the focal point of gravity of the entire rover is kept upwards, when one rocker goes up, the alternate part moves downwards.

the locomotion in rough terrain of mars is achieved by this simple but efficient mechanism, this mechanism is implemented in curiosity mars rover and also the latest perseverance rover. Two bars placed at an angle of about 108 degree is connected with another pair of bars at one end, the other pair have an angle of about 137° degree between their links. The dimensions of the link are scaled down version of the perseverance rover. The length of the link is calculated as suitable for our chassis dimension. Each motor is connected at each end of the mechanism, the first link needs to be lengthier than other two in order to maintain stability for the chassis, and also this helps the chassis to climb a rocky area and balance in a down slope. The independent movement of each side of the rocker bogie allows the rover to stabilise in uneven terrain, the joint here, acts as a pivot point which allows free rotation of the 1st pair, and the joint here also acts as a pivot point so that another free rotation is possible

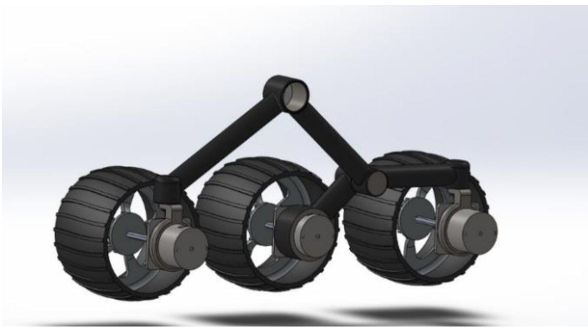

Fig 8. Rocker Bogie Mechanism

This mechanism is capable of climbing the obstacles which are twice the diameter of the wheel size. In this mechanism all the six wheels will be touching the ground all the time and each wheels can be independently controlled. This is the most efficient suspension, it is still used in advanced rover like perseverance. It is also designed in such a way that it has better tractive performance, since it will be required to navigate through rough terrain.

V. DRAWINGS OF THE MECHANSIMS

2D drawings are generated for each parts, since it will be used for the fabrication purpose in the future.

A. *Robotic Arm*

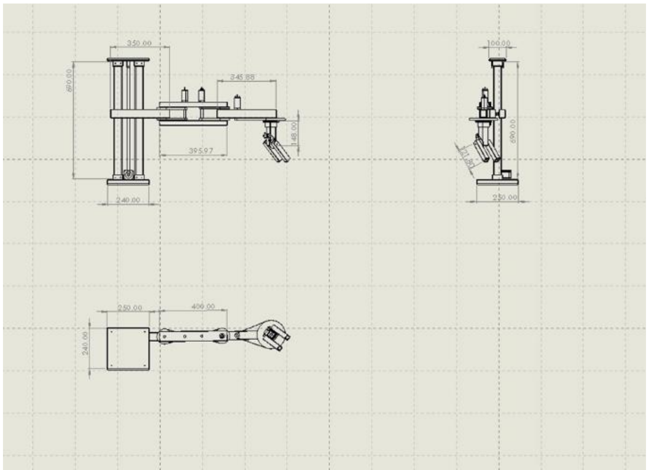

Fig 9. Orthographic projection of Robotic Arm

B. *Gripper*

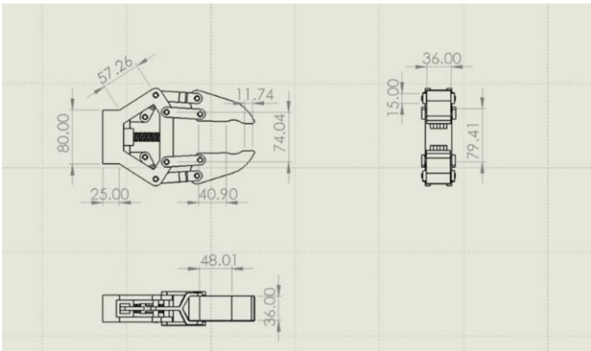

Fig 10. Orthographic projection of Gripper

C. *Rocker Bogie Mechanism*

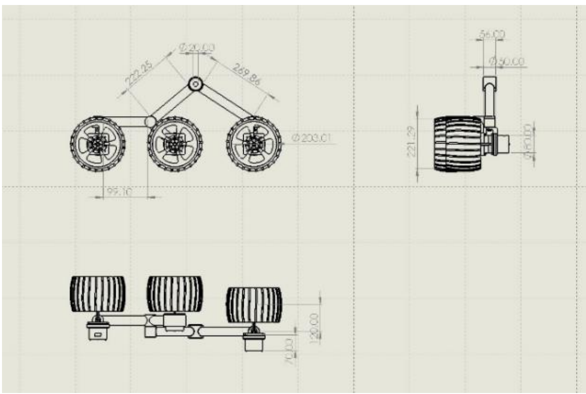

Fig 11. Orthographic projection of Rocker Bogie Mechanism

D. *Chassis*

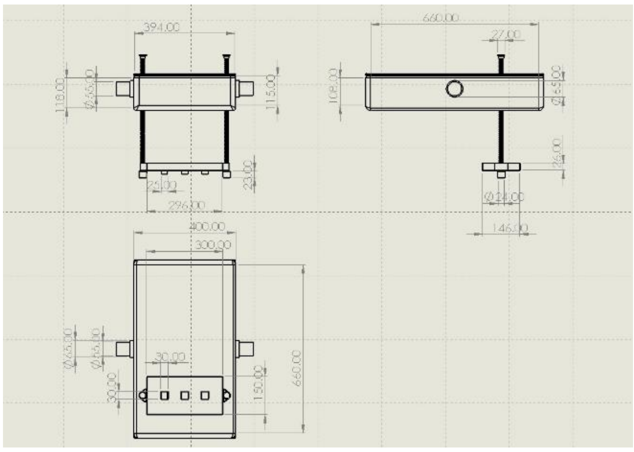

Fig 12. Orthographic projection of Chassis

VI. Mesh Analysis

Meshing or mesh generation is the process of breaking an object into many small shapes to properly define the physical shape of the object. If the mesh is more detailed, the 3D CAD model will be more accurate.

One of the significant roles when it comes to engineering simulation process, is creating a high-quality mesh, which ensures the simulation accuracy. Computers cannot solve simulations on CAD model's original geometry shapes as the equations associated with cannot be applied to an arbitrary shape. Creating a proper mesh contributes to the accuracy, speed and convergence of the simulation. The equations are generally partial differential equations and the calculations are iterative. CFD (Computational Fluid Dynamic) and FEA (Finite Elemental Analysis) are employed to perform this analysis.

Arbitrary polyhedron mesh is carried out in this analysis. The mesh analysis is done for the whole rover which is shown below

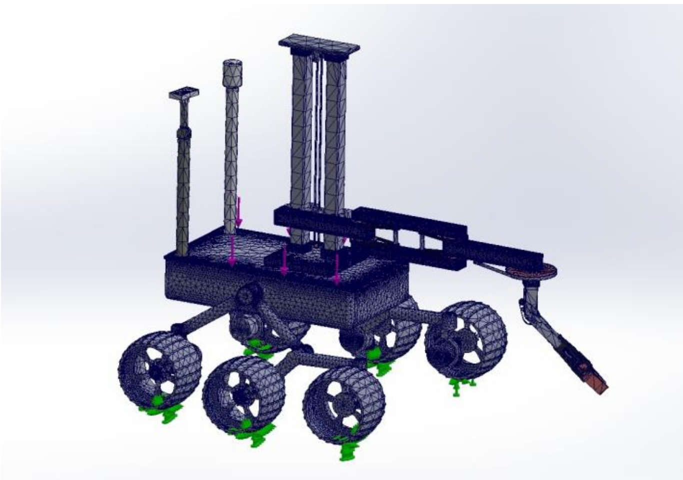

Fig 13. Mesh analysis of rover

A 40N force is applide on the chassis to find if it can with hold that kind of load.

VII. Conclusion

As mentioned in methodology section, each and every step is carried out sequentially to meet all the requirements mentioned in the target specifications. Beginning with the generation of conceptual designs after brainstorming, the one that meets the target specifications is selected after concept screening. After fixing the final design, each and every part is designed with utmost precision and joined with appropriate mates using Solidworks 2020. Mesh analysis is carried out to ensure that the simulation works flawlessly. Then, motion study is done to check if all the joint and mechanisms works properly. After ensuring the proper working of all mechanisms an artificial terrain one resembling the competition conditions is created virtually in Solidworks. Then, the rover is allowed to perform all the functions in this virtual space. The rover was able to go through a downward slope which is one meter is depth and suspension system was able to travel over a rock which is twice the diameter of the wheel and the arm is able to perform all the tasks mentioned in the competition. The rover is ready for preliminary design review.

VIII. Future Work

The future work of the project includes the electronic circuit design, PCB(Printed Circuit Board) designing, fabrication of the components, integration of all the modules, developing algorithms for autonomous navigation building a base station to communicate with the rover. And finally testing, validation and refinements will be done so as to ensure that the rover will be able to perform all the intended functions at the full of its capacity.

References

1. B.K. Muirhead, “Mars Rovers, Past And Future,” 2004 IEEE Aerospace Conference Proceedings, March 2004.
2. “University Rover Challenge – Requirements And Guidelines”, https://urc.marssociety.org/home/requirements-guidelines
3. Balakrishnan Shankar, Ganesha Udupa, Praveen Basil, Aswath Suresh, “Design and Development of an Intelligent Rover for Mars Exploration,” The Mars Society with permission. January 2015.
4. Ravi kiran Bollineni, Sidharth S.Menon, Ganesha Udupa, “Design of Rover and Robotic Arm,” materialstoday: Proceedings, vol. 24, pp. 1340-1347, January 2020.
5. Fırat Barlas “Design of A Mars Rover Suspension Mechanism,” Izmir Institute of Technology, January 2004.
6. Nayar, Hari and Kim, Junggon and Chamberlain-Simon, “Design Optimization of A Lightweight Rocker–Bogie Rover for Ocean Worlds Applications,” International Journal of Advanced Robotic Systems., vol.16, pp. 1-20, November 2019.
7. Simmons, Reid and Krotkov, Eric and Chrisman, Lonnie and Cozman, “Experience with Rover Navigation for Lunar-Like Terrains,” International Conference on Intelligent Robots and Systems, April 19

8. Volpe Richard, "Rover Technology Development and Infusion for The 2009 Mars Science Laboratory Mission" 2009 NASA/ESA Conference on Adaptive Hardware and Systems, November 2009.
9. Richard Volpe, Eric T. Baumgartner, P. Scheaker, Samad Hayati "Technology Development and Testing for Enhanced Mars Rover Sample Return Operations," Aerospace Conference Proceedings, 2000 IEEE, vol.7, February 2000.
10. Zakrajsek, James and McKissock, David and Woytach, Jeffrey, "Exploration Rover Concepts and Development Challenges," First AIAA Space Exploration Conference., vol.1, pp. 1-23, April 2005