

A Long Range Science Rover for Future Mars Missions

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ABSTRACT

This paper describes the design and implementation currently underway at the Jet Propulsion Laboratory of a long range science rover for future missions to Mars. The small rover prototype, called Rocky 7, is capable of long traverse, autonomous navigation, and science instrument control, carries three science instruments, and can be commanded from any computer platform and any location using the World Wide Web. In this paper we describe the mobility system, the sampling system, the sensor suite, navigation and control, onboard science instruments, and the ground command and control system.

1. INTRODUCTION

Even prior to the recent discovery of the possibility of past life on Mars by a research team of scientists at the Johnson Space Center and at Stanford University, NASA had planned six missions to Mars for 2001, 2003, and 2005. Currently NASA is replanning its Mars exploration strategy to develop strategies that lead to one or more sample return missions. Since samples must be examined using onboard science instruments and collected from a variety of sites, rovers will play a crucial role in these missions. These rovers will traverse to sites separated by several kilometers and place instruments against outcrops or loose rocks, search an area for a sample of interest, and collect rocks and soil samples for return to Earth. Our research objectives are to develop technologies that enable such scenarios within the mission constraints of mass, power, volume, and cost.

Our goal is to develop technologies that overcome limitations detailed above as well as to introduce new capabilities currently not supported. These are:

- Increase rover autonomy so that the number of science experiments per uplink command is increased, resulting in more science data. This involves increased autonomy for rover navigation to reach science targets, autonomous confirmation of reaching such targets, and use of sensory information to autonomously perform manipulation and science instrument placement and pointing.
- Develop the ability of the microrover to traverse long distances by integrating a celestial sensor (e.g., sun sensor) to determine rover's orientation; and by developing a deployable mast mounted camera system to send panoramic images of the surrounding area to the ground control personnel.
- Integrate representative science instruments on to the rover and develop intelligent data reduction techniques to maximize the useful science return.
- Develop onboard resource analysis and decision making capability so that maximum science is returned for the available resources.
- Develop a distributed Internet based rover interface so that scientists can provide science experiment requests and the general public can view return images immediately.
- Test and validate these technologies in realistic settings and with planetary scientist participation.

This paper provides an overview of our prototype rover called Rocky 7 and describes our near-term goals. Section 2 gives a description of the mobility system, the sampling arm, sensors, the perception system, the navigation technique, and the science instruments. Section 3 describes a new operator interface development that allows a

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rover to be commanded from any location using the World Wide Web. Conclusions are given in Section 4. References are provided in Section 5.

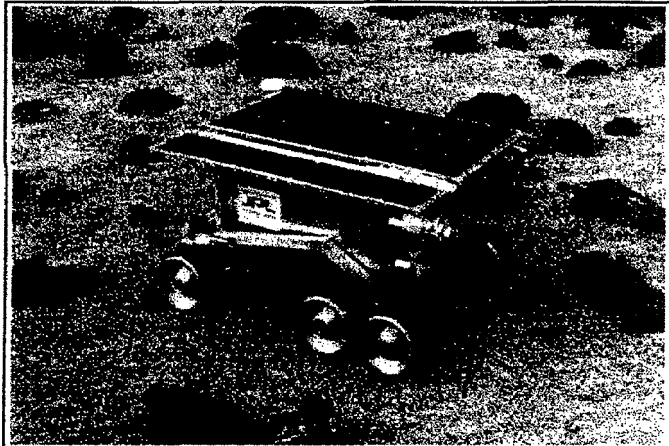


Figure 1. Rocky 7 rover in JPL Mars Yard shown with stowed mast and sampling arm

2. ROCKY 7 ROVER

In this section we provide the Rocky 7 rover configuration and detail the constituent components. Figure 1 shows Rocky 7 in the JPL Mars Yard. Mars Yard is a 15X25 meter outdoor test area that closely simulates Mars like terrain constructed based on statistical analysis of images taken by Viking Landers I and H.

One important consideration in developing Rocky 7 has been its flight relevance. This has severely constrained its size, mass, and power. The size of the rover is dictated by the size of the payload envisioned for future missions. Rocky 7 measures 48 cm wide, 64 cm long, and 32 cm high.

2.1 Mobility System

The mobility system is a modified Rocker-Bogie design used in previous rovers at JPL [2]. It consists of two rockers (hence the name "Rocky") hinged to the sides of the main body attached to six wheels two of which are steerable. This configuration requires two fewer actuators (total of eight) than previous version. Each rocker has a steerable wheel at one end and a smaller rocker at the other end. Two wheels are attached at the end of each of these small rockers. The main rockers are constrained in motion via a lever which is hinged at the end of the main body and its two ends are attached to the end of main rockers. This mechanism provides two important mobility characteristics for the rover. First, a wheel can be lifted vertically while other wheels remain in contact with the ground. This feature provides rock climbing capability to the rover. Rocky 7 can climb rocks 1.5 times its wheel diameter. Second, the vehicle can climb over rocks that span the width of the vehicle, using the smaller rocker and the two-wheel arrangement on the main rocker, even if a rock almost fits snugly between the front and middle wheels.

2.2 Sampling System

One significant improvement over previous Rocky series rovers is the incorporation of a sampling device on Rocky 7. The savings in actuators achieved by reducing the number of steerable wheels are used to develop the sampling system. This light weight (650 gm) sampling arm consists of a two-DOF manipulator (32 cm long) that is attached to the front of the rover and can reach 10 cm below the ground surface. When folded, it is in a horizontal position against the front of the rover. The arm has a two-DOF scoop mechanism and is designed to both dig and carry the samples. When scoops are rotated 180 degree backward the arm can grasp objects using the back side of the scoops. Figure 2 shows that sampling arm with acquired soil sample.

In addition to sampling function, the arm is used to deliver light to an optical fiber via a pair of mirrors. This is accomplished by configuring the scoops to a position and exposing a normally closed hole. The optical fiber carries the light (image) to a point spectrometer located inside the rover chassis,

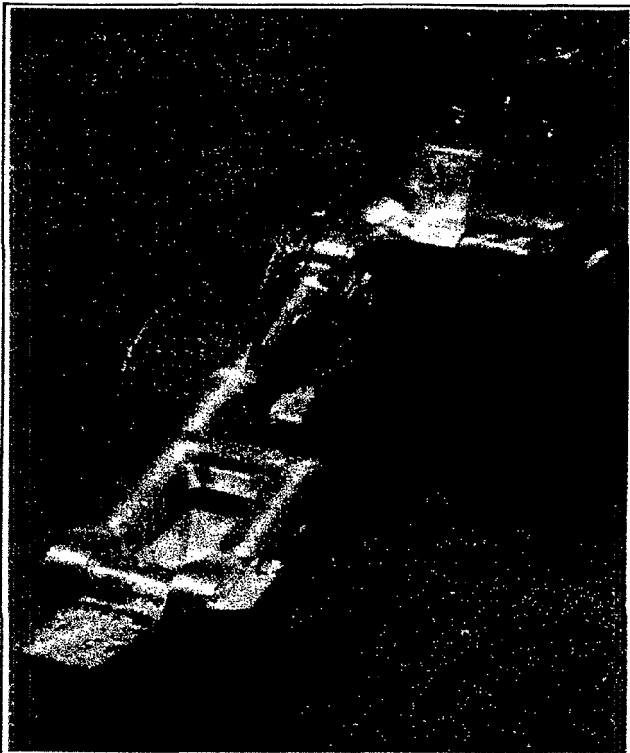


Figure 2. Rocky 7 sampling arm and scoops

The arm is deployed for three different operations: digging, dumping, and spectrometer data acquisition. Before each deployment the rover checks for possible collision of the arm with the obstacles (rocks) using its on board stereo vision system and automatically positions itself to avoid them. For a dig operation, the vision system also processes the images of the area in front of the rover to determine if the ground is soil-like by analyzing the image texture and elevation information. It then deploys the arm and lowers it until contact is made with the surface by monitoring the arm motor current. After the dig operation, it positions the scoop that collected the sample and takes its image. It then compares this image against the one taken just before the dig operation. If it detects enough difference between these two images, the rover reports success and completes the dig operation by closing the scoops and stowing the arm. Otherwise it does an automatic dump, stows the arm, and reports failure. Similar autonomous checks are performed for a dump operation.

2.3 Sensors

Several sensors are used for navigation. A sun sensor developed by Lockheed Martin, called the Wide Angle Sun Sensor (WASS), provides heading information as a function of the rover's location and the time of day

using an onboard real-time software module. In addition, an accelerometer is installed to provide pitch and roll information. The wheels are equipped with encoders for precise servo control and to estimate the rover's position. The rover is equipped with seven (extendible to eight) CCD cameras. Two at each end, for the perception system discussed in the next section, two at the end of a deployable mast and one in a close-up imager.

2.4 Perception System

To simplify the perception system hardware, Rocky 7 uses only a passive stereo vision [3] for hazard detection unlike its predecessor that used a laser striping system in conjunction with multiple monocular cameras to detect obstacles. The stereo vision system uses a pair of cameras with wide angle lenses to allow viewing of both the manipulator and its actions as well as to permit imaging of rocks and other hazards extending from near the rover to a little above the horizontal. Rocky 7 is equipped with six cameras that can be used for navigation: two in front of the rover, two in the back, and two on the mast.

One advantage of the stereo vision system is that it is easy to extend the system capability by adding additional cameras to the back side of the rover and use the existing infrastructure (i.e., frame grabbers and software) to perform collision avoidance.

2.5 Navigation System

Rocky 7 navigation strategy is based on operator waypoint designation and autonomous behavior based navigation to move to the specified targets [4, 5]. Operation starts with a command issued to the rover to take a panoramic image of the scene by obtaining several overlapping images. These images are then processed by a stereo vision software to obtain terrain maps on the ground. An interactive software allows one to select specific points (locations) on one of these images using a mouse. The software returns the position of this location as calculated by the stereo vision system and displays the coordinates of the point. If no valid coordinate exists for the particular point, the software indicates this to the operator. The operator continues this operation and builds a path which deems to be safe for the rover to traverse through in moving from its initial position to the target location.

Before each move, the rover takes a set of images and process them onboard and determines if there are obstacles that it must avoid. If there is no obstacle it moves a short distance and then stops and repeats the same operation.

If it determines that there is an obstacle, then it turns away by a fixed amount to the right or to the left depending where the obstacle is.

2.6 Science Instruments

An important objective of our research in developing rovers is to understand not only the mobility, navigation, and control issues, but to also consider problems associated with the integration of science instruments, their on board operation and data reduction. Currently Rocky 7 has three science instruments: a point reflectance spectrometer, a wide field of view spectral imager, and a close-up spectral imager.

The point reflectance spectrometer is on-board the rover chassis and its fiber optic path is integrated into the rover manipulator. This allows the spectrometer to be pointed at rock/soil targets from many different angles. Also included on the manipulator is a calibration target for taking reference data for the current illumination. In the near future a laser will be added to the fiber optic path so that the point of the spectra data can be illuminated and imaged to confirm exactly where the spectral data was taken,

The wide field of view spectral imager is developed by adding motorized filter wheels to the mast cameras. This filter wheel system is used to gather broad band spectral data enabling color images to be constructed. The mast is a three degrees of freedom torso/shoulder/elbow articulated robotic arm enabling the cameras on the end to be positioned 1.4 meters above the ground as well as being able to pan and tilt the cameras to get the desired imagery. The cameras are shown in Figure 3.

The third instrument is a close-up imager that uses a monochrome camera and active lighting source. This is packaged as a 500g "dummy" instrument representing an APX or Moessbauer spectrometer which would have to be placed against a designated target. The instrument is mounted at the end of the mast and the mast degrees of freedom are utilized to position instrument against rocks in front of the rover. Passive compliance is used to allow the instrument to orient itself normal to the target surface and contact sensors used to confirm placement.

2.7 Long Traverse

Rocky 7's mast and the sun sensor allow the rover to traverse long distances. The scenario for the operation of the rover consists of traversing in the indicated direction, using the sun sensor, and periodically (e.g., -100m to 200 m) transmitting panoramic images to the ground station. These panoramic images are obtained by a pair of cameras mounted on a stowable mast that is carried by the rover. The ground station provides new commands to either to continue to traverse in the same direction or to change direction. If the site is of interest to scientists, site survey commands will be issued. For each site survey, a panoramic image is used to designate science targets and to specify science experiment parameters (such as angle of pointing a science instrument relative to a target, instruments distance from a target, and duration of data acquisition, etc.). The rover then autonomously performs the requested science experiment. Success of each science experiment is confirmed by the rover autonomously via executing specific tests for that experiment.

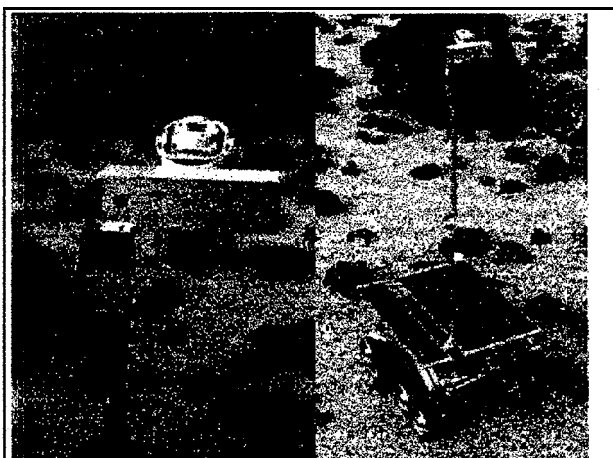


Figure 3. Rocky7 mast shown in the upright position (right) Spectral and Close-up imagers (left)

designation successfully. This Web based version of the allows a scientists to select science targets in his or her home institution using any computer platform. He/she is also be able to describe the nature of a particular science

3.0 Advanced Operator Interface

We have developed a ground control station to remotely command the rover and receive data from it. The operational scenario is based on the rover down-linking science data and stereo panoramic image pairs. This data along with camera parameter information is used to develop terrain maps.

The interface is based on a World Wide Web (WWW) which consists of viewing an image taken by a rover camera. Through a mapping between this image and an elevation map discussed earlier an operator can point and click on any point on the image and obtain the coordinates of the point. This technique has been used before at JPL for target selection and waypoint

experiment to be performed at that point (pointing requirements, time required for data collection, data compression, etc.), This information is then sent electronically to a central station at JPL for consolidation and verification for flight rules for next day's mission and for uplinking to the rover. Figures 4 and 5 show the interface for remote target and waypoint selection.

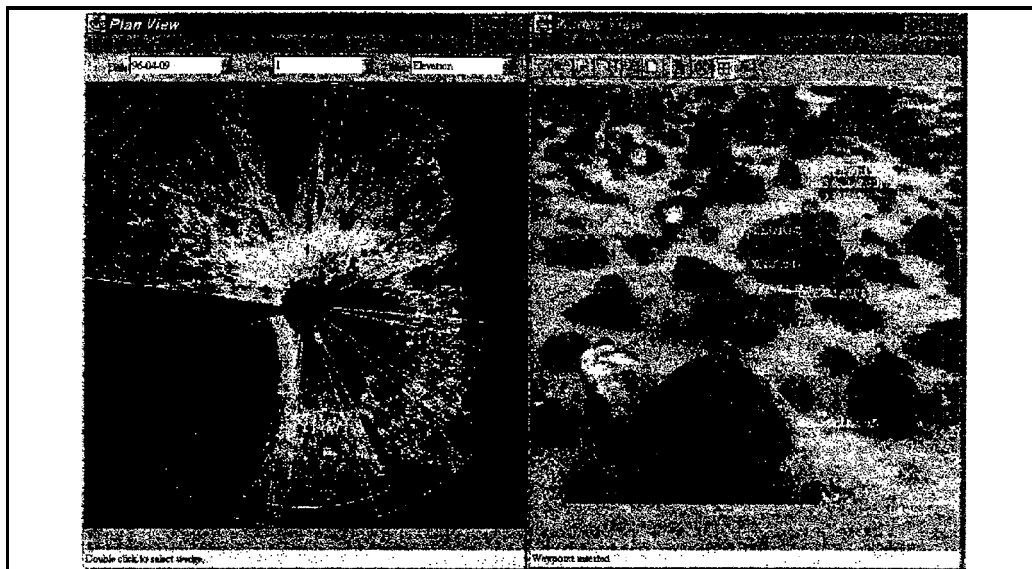


Figure 4. WEB based interface. Right image shows waypoints selected. The left image hews a top view of the elevation map generated from panoramic images. The right image corresponds to one of the wedges shown in the left image. This interface can be accessed from: <http://robotics.jpl.nasa.gov/tasks/scirover/operator/wits/index.html>

Plans are also underway to provide panoramic elevation maps to clearly show the camera image in the context of the panoramic elevation map, The operator control station will also be able to show these in the context of descent imagery which is very important for scientists planning their global exploration strategy.

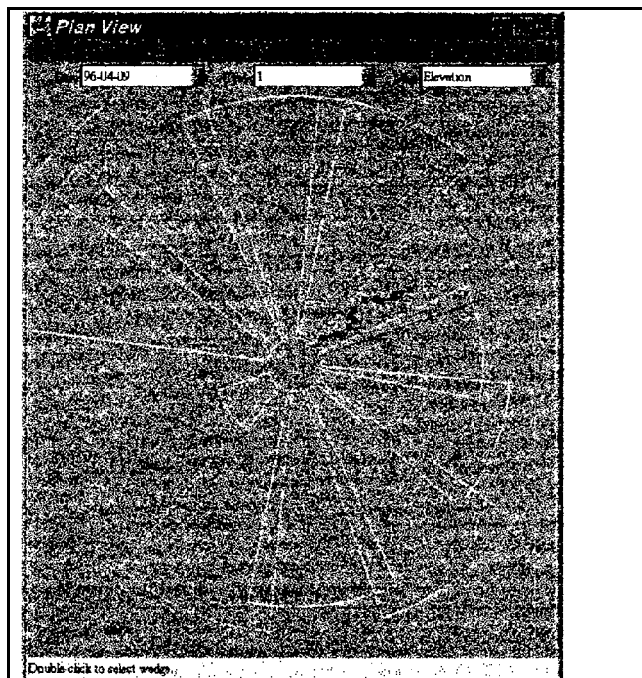


Figure 5. This image is the same image as shown in Figure 5 without the elevation map. The operator has an option of looking at the left image of Figure 5 with or without the elevation map.

In the future, we will perform feature segmentation and provide feature maps to identify landmarks for rover localization autonomously.

4. CONCLUSIONS

This paper has provided an overview of research on future Mars rovers covering navigation, perception, science instrument pointing and placement, and operator interface issues.

Although this research program covers many essential elements of Mars rovers, research related to materials, space qualified computers, communication hardware, thermal insulation, advanced mobility systems, and structures are being address by other tasks at JPL [6].

ACKNOWLEDGMENTS

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