Lunar Rover Technology Demonstrations with Dante and Ratler

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Eric Krotkov, John Bares, Lalitesh Katragadda, Reid Simmons, Red Whittaker

Robotics Institute, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, Pennsylvania

Krotkov tel (412) 268-3058 fax (412) 621-1970 email: epk@cs.cmu.edu

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INTRODUCTION

Carnegie Mellon University has undertaken a research, development, and demonstration program to enable a robotic lunar mission. The two-year mission scenario is to traverse 1,000 kilometers, revisiting the historic sites of Apollo 11, Surveyor 5, Ranger 8, Apollo 17 and Lunokhod 2, and to return continuous live video amounting to more than 10 terabytes of data. Our vision blends autonomously safeguarded user driving with autonomous operation augmented with rich visual feedback, in order to enable facile interaction and exploration. The resulting experience is intended to attract mass participation and evoke strong public interest in lunar exploration.

The encompassing program that forwards this work is the Lunar Rover Initiative (LRI). Two concrete technology demonstration projects currently advancing the Lunar Rover Initiative are:

- The Dante/Mt. Spurr project, which at the time of writing is sending the walking robot Dante to explore the Mt. Spurr volcano, in rough terrain that is a realistic planetary analogue. This project will generate insights into robot system robustness in harsh environments, and into remote operation by novices.
- The Lunar Rover Demonstration project, which is developing and evaluating key technologies for navigation, teleoperation, and user interfaces in terrestrial demonstrations. The project timetable calls for a number of terrestrial traverses incorporating teleoperation and autonomy including natural terrain this year, 10 km in 1995, and 100 km in 1996.

This paper will discuss the goals of the Lunar Rover Initiative and then focus on the present state of the Dante/Mt. Spurr and Lunar Rover Demonstration projects.

LUNAR ROVER INITIATIVE

The programmatic goals of this initiative include conducting terrestrial demonstrations, and forming a consortium of partners and technical providers. The principal purpose of the demonstrations is to evaluate the readiness for lunar missions of key rover technologies such as teleoperation interfaces and on-board perception and planning.

Key participants to date include Carnegie Mellon, NASA, LunaCorp, and Sandia National Laboratories. LunaCorp is a commercial entity whose purpose is to foster commercial lunar exploration. The partners are negotiating with technical service providers and with potential customers.

An important participant in the initiative is the NASA Robotics Engineering Consortium, formed in 1994 to commercialize advanced robot technology. The consortium is providing large-scale indoor test tracks and an umbrella for the process of rover development and integration by industrial participants. These facilities will support extensive testing of lunar mission scenarios with different emphases on entertainment and science.

The Lunar Rover Initiative will substantially advance such planetary exploration technologies as high-bandwidth mobile communications, teleoperation, autonomous perception and planning, robotic safeguarding, and durability in harsh environments. By driving and demonstrating these technologies, the initiative provides a path to a lunar launch within the millennium.

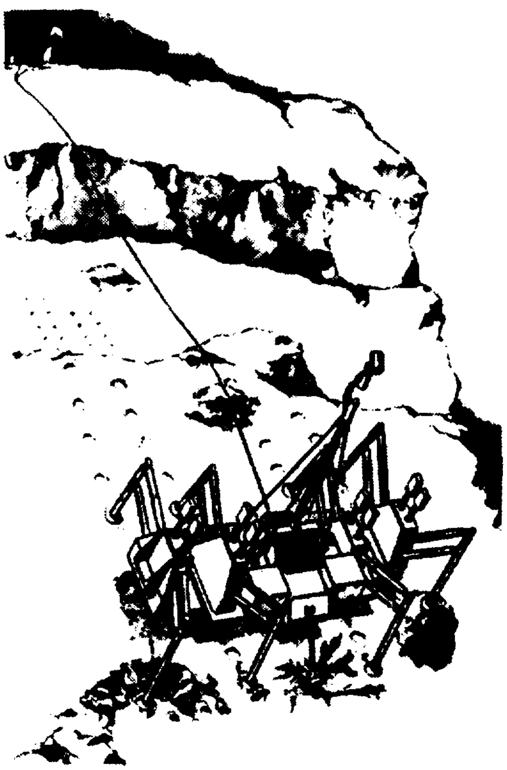

Figure 1 Dante

DANTE/MT. SPURR

Dante II (Figure 1) is an eight-legged, walking and rappelling robot for active volcano exploration. Following Dante I's attempt to explore the active Mount Erebus volcano in Antarctica in 1993, the robot has been reconfigured and further developed for a 1994 mission to Mount Spurr, Alaska. One of the primary objectives of the 1994 Mt. Spurr program is to demonstrate robotic exploration of harsh, barren, and steep terrain such as those found on the Moon and planets.

Presently, the robot is being used to explore and collect gas samples from the crater floors of active volcanos. High-temperature fumarole gas samples are prized by volcanologists. However, collecting the samples is very dangerous and poses many challenges for scientists. For example, in two separate events in 1993, eight volcanologists were killed while collecting samples and monitoring volcanoes. Without jeopardizing human safety, creation of robots such as Dante allow scientists to collect gas samples and examine crater floors from safe and remote locations.

Dante combines tether and leg motion to rappel up and down steep slopes and sheer cliffs. Dante's eight pantographic legs are organized in two groups of four, which alternately support and advance the robot. Similar to a mountain climber rappelling on a mountain cliff, the tether cable provides a reactive force to gravity and assists in maintaining equilibrium as the robot rappels up and down steep slopes or cliffs. Dante can also walk over obstacles as large as one meter high.

Dante receives power and telemetry through the tether cable, making it an ideal deployment platform for remote, multi-day explorations. Mounted on top of Dante is a laser rangefinder that perceives and maps the terrain around the robot within a six meter radius. An on-board computer then uses the terrain information to determine safe paths and adjusts its gait to overcome or avoid obstacles.

For the Mt. Spurr mission, Dante will operate in a self-reliant wireless mode, interacting with operators 130 kilometers from the volcano. During the expedition, Dante will demonstrate that it is capable of traversing escarpments and exploring craters in challenging environments. Dante will also demonstrate competent ascent and descent of steep and rough terrain as well as withstand environmental challenges from cold, high winds, high humidity, and exposure to acid gas. Other principal objectives for this mission are to demonstrate:

- key ingredients of teleoperation and control;
- autonomous control for certain segments;
- remote operation of a robotic walking system with interfaces appropriate for novices;
- ability to deploy scientific equipment and gather real-time data.

Dante has successfully completed a mission rehearsal totalling 400 m on a 35 degree slope, a critical part of its mission readiness review. At the time of writing, the robot is in Alaska, ready to begin its mission in the unforgiving environment of an active volcano.

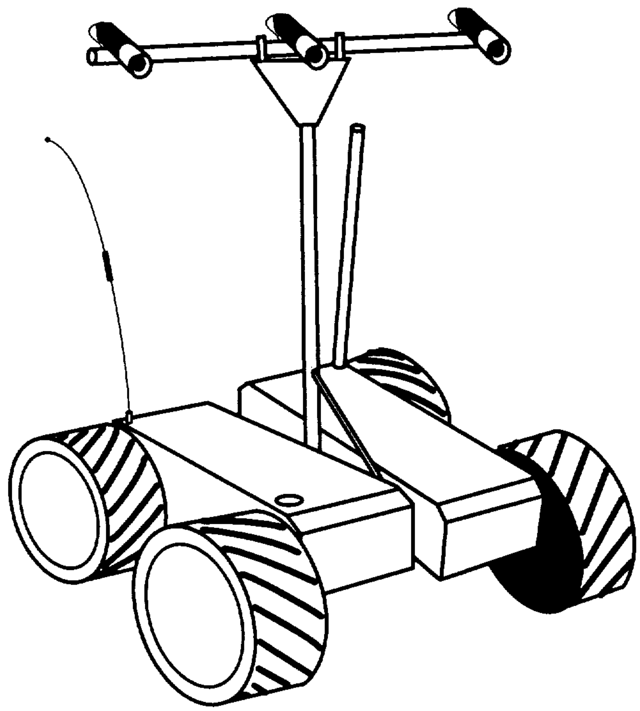

Figure 2 Ratler

LUNAR ROVER DEMONSTRATION

The Lunar Rover Demonstration (LRD) robot system is designed to competently and reliably traverse lunar-like terrain. This section describes the central system components: the rover mechanism and real-time controller, a perception system using trinocular stereo, local and global planning algorithms, and a task-level controller.

Mechanism and Controller

The Ratler (Figure 2) is a four-wheeled platform developed by Sandia National Laboratory. (The name is an acronym for Robotic All-Terrain Lunar Exploration Rover.) The skid-steered vehicle features an articulated chassis in which the body is divided into two halves, with two wheels on each side. The halves are joined together such that they may rotate along the lateral axis to enhance the mobility and stability of the platform.

Control of the Ratler may be directed from a local pendant, a remote command station, or on-board processors. An RF serial link and a microwave video link provide telemetry. State sensors include encoders on drive motors, a compass, three inclinometers, and a turn-rate gyro.

To estimate the position and attitude of the vehicle as it travels, we have formulated and implemented a dead reckoning algorithm that maintains an estimate of the robot's position and orientation in a fixed, external reference frame. To improve both reliability and accuracy, in addition to the conventional inputs from motor encoders, attitude inputs from the state sensors have been incorporated.

Perception

The perception system consists of a stereo mapping module that derives terrain information from stereo images. The hardware consists of three CCD cameras mounted on a mast 1.5 meters tall. To maximize image stability as the rover traverses surface irregularities, a motion-smoothing linkage averages the pitch of the two Ratler bodies.

The mapping software consists of a stereo matching module that computes disparities from trinocular images using normalized correlation, and a mapping module converting image-space disparities into camera referenced Cartesian coordinates.

Planning

Ranger is a local path planner that takes three-dimensional sensor data as input and produces viable driving commands as output. It is concerned neither with controlling actuators (that is the job of the vehicle controller) nor with generating strategic goals (that is the job of the global path planner).

The Ranger system is an intelligent, predictive, state-space controller: intelligent because it uses three-dimensional scene data; predictive because it reasons from its knowledge of its capability to react to hazards; state-space because it explicitly forms an expression of the vehicle dynamic state vector as the primary signal upon which decisions are based.

The D* algorithm is a global path planner that provides a means to evaluate terrain paths coupled with vehicle constraints to arrive at an optimum path given available information. D* is also efficient and can provide real-time replanning capabilities of the global path with incoming sensor data.

Task-Level Control

One effective way to interact with the Lunar Rover is in a semi-autonomous mode. The idea is for a human operator to use a virtual reality interface, such as the one developed at NASA Ames [1], to view the area surrounding the rover and to indicate preferred directions for the rover to follow. This type of interface has been implemented using topographic site maps, in order to facilitate planning and commanding large-scale routes for the rover to follow, and monitoring rover progress over terrain.

LUNAR ROVER CONFIGURATION

Although the Ratler has served as an effective testbed for terrestrial demonstrations, its configuration does not address a number of central concerns for operating on the Moon. We have confronted these issues in the preliminary configuration of a next-generation rover, to be operational in 1995.

The study focussed on the mechanism, power, thermal, and communication link [3]. The result is a six-wheeled 250 kg class rover (Figure 3) with active, two-axis pointing of the solar array to the Sun and the antenna to Earth, providing 400 W of power, and about 1.5 Mb/s downlink to Earth. The rover will hibernate during the night. The primary challenges in lunar rover design have proven to be

- Return continuous video with minimal interruption
- Accomplish an unprecedented 1000 km traverse spanning two years of operation in the extreme conditions on a surface of fine electrostatic dust.
- Survival in radiation, -180 deg C cold, vacuum, and operations in the heat of +130 deg C

A second stage of configuration is currently focussing on software requirements, computing, visualization, and mechanism analysis.

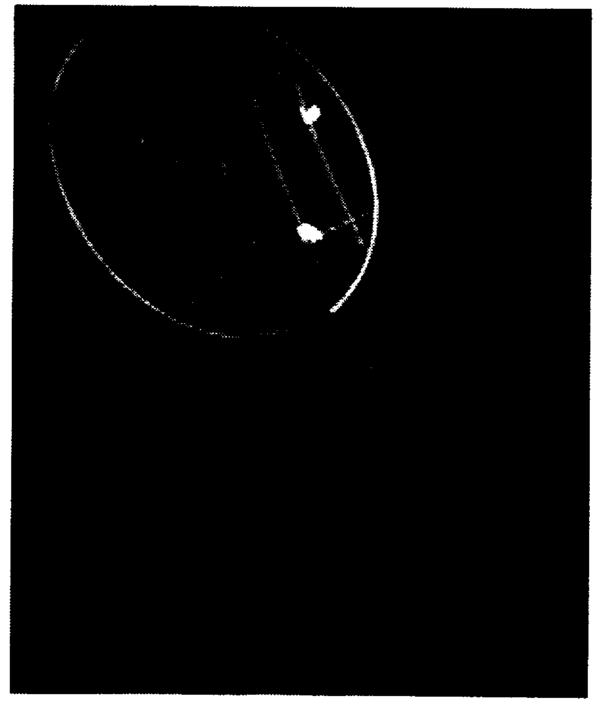

Figure 3 Scale model of preliminary configuration

SUMMARY

In this paper, we have described the Lunar Rover Initiative as a broad-based activity aiming to launch a lunar mission within the millennium. We have concentrated on two concrete technology demonstration projects advancing the initiative: the Dante/Mt. Spurr project emphasizing planetary analogue terrain and remote operation, and the Lunar Rover Demonstration project emphasizing large-scale navigation.

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SESSION RP

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