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Recent Developments in the Robotic All Terrain Lunar Exploration Rover (RATLER) Program

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P. R. Klarer

Advanced Vehicle Development Department
Robotic Vehicle Range
Sandia National Laboratories
Albuquerque, New Mexico

Abstract

The Robotic All-Terrain Lunar Exploration Rover (RATLER) is a four wheeled all-wheel-drive dual-body vehicle. A uniquely simple method of chassis articulation is employed which allows all four wheels to remain in contact with the ground, even while climbing over step-like obstacles as large as 1.3 wheel diameters. The RATLER design concept began at Sandia National Laboratories in late 1991 with a series of small, proof-of-principle, working scale models. The models proved the viability of the concept for high mobility through mechanical simplicity, and eventually received internal funding at Sandia National Laboratories for full scale, proof-of-concept prototype development. Whereas the proof-of-principle models demonstrated the mechanical design's capabilities for mobility, the full scale proof-of-concept design currently under development is intended to support field operations for experiments in telerobotics, autonomous robotic operations, telerobotic field geology, and advanced man-machine interface concepts. The development program's current status is described, including an outline of the program's work over the past year, recent accomplishments, and plans for follow-on development work.

Introduction

Sandia National Laboratories' Robotic Vehicle Range (SNL/RVR) has been developing mobile robotic systems for a variety of DOE and DoD applications since 1984. In 1989 President George Bush called for the establishment of a U.S. Space Exploration Initiative (SEI) with the goals of returning to the Moon to stay and a manned mission to Mars. Subsequent national studies such as NASA's 90-Day Study [1] and the Synthesis Report [2] have led to significant renewed interest in robotic precursor missions for exploration of the Moon. Beginning in 1991, in response to the President's announcement of the SEI, an innovative concept for a simple, agile lunar rover vehicle was developed and evaluated at Sandia National Laboratories in the form of several scale models [3,4]. The Robotic All-Terrain Lunar Exploration Rover (RATLER) is a four wheeled all-wheel-drive platform with twin body compartments connected by a hollow central pivot. The uniquely simple method of chassis articulation by means of the hollow central pivot is employed to allow all four wheels to remain in contact with the ground while traversing uneven terrain. This central pivot, as well as the vehicle center of mass, is located as close to the axle line and the geometric center of the vehicle as possible to ensure maximum stability while climbing over large obstacles. Figure 1 shows one of the early models of the RATLER during field testing at Death Valley National Monument in late spring of 1992.

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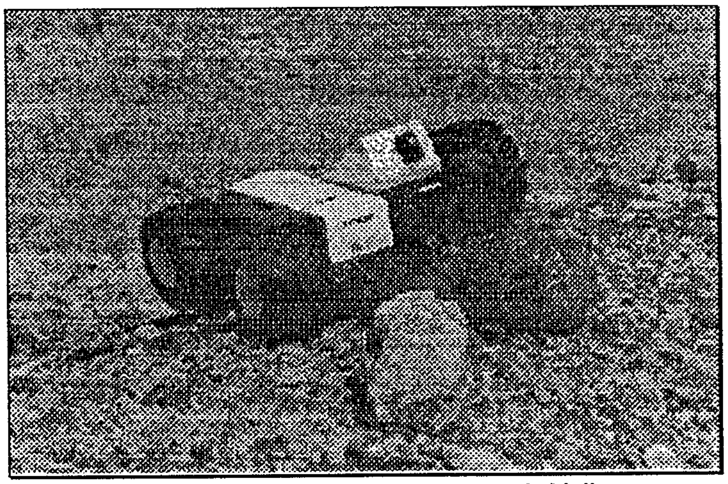

Figure 1. RATLER Testing at Death Valley

Over the summer of 1992, two summer students employed at the SNL/RVR designed, constructed, and tested a more robust version of the scale model RATLER, called RATLER-A. RATLER-A and the original models provided additional testing opportunities at the White Sands National Monument, where the RATLER design concept showed promise for very good mobility and agility characteristics in very dry, loose gypsum sand. Two additional models were built to support demonstration of the concept to NASA, DOE, and the public at the National Air and Space Museum's Planetary Rover EXPO in September 1992. Figure 2 shows the RATLER-A being operated over a simulated Mars terrain at the Planetary Rover EXPO.

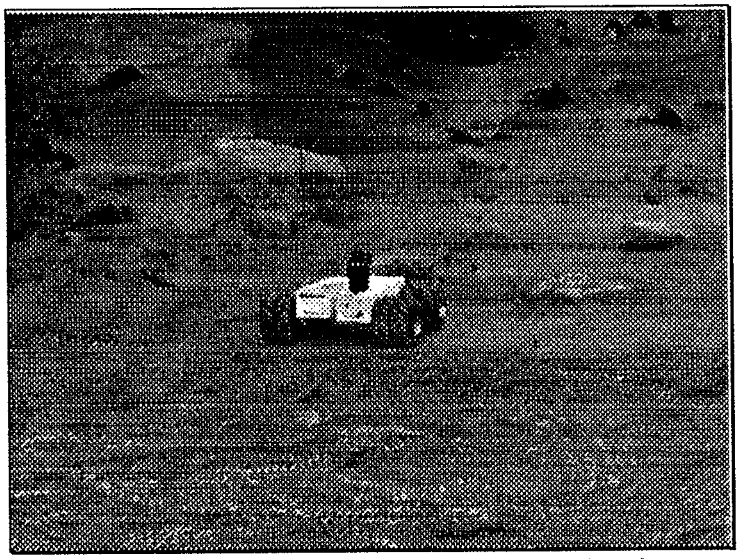

Figure 2. RATLER-A in Simulated Mars Terrain

As a result of the work with the scale models, a Laboratory Directed Research and Development (LDRD) program was initiated to develop a full scale RATLER vehicle. The LDRD project was originally proposed for a period of two years, beginning in October 1992, and was recently approved for the second year of development. The remainder of this paper focuses on the LDRD program for development and testing of the full scale RATLER, called RATLER II.

RATLER II Development Program

The goals for the RATLER II development program are to develop a 1-meter scale RATLER vehicle using off the shelf technology, and to demonstrate a capability commensurate with stated or inferred requirements for a lunar exploration rover vehicle. In conjunction with the actual vehicle platform, a compact, portable Control Driving Station (CDS) is also under development to support field operations. Both the CDS and the RATLER II incorporate multiple processors on a 32 bit communication bus, and implement a real-time, event-driven multitasking software architecture.

Upon initiation of the RATLER II program in October 1992, the first task was to determine the performance requirements or specifications existing in the literature for a lunar exploration rover. Although examples of lunar roving vehicles were found [5,6,7], a contemporary set of requirements for future missions to the Moon were not found. A trade-off study [8] was performed to attempt to derive requirements that could then be used by the project team to design and build the RATLER II. Results of that study led to a RATLER II design that could be constructed using off the shelf technology, and which was expected to meet a reasonable set of performance criteria in terms of mobility and payload capacity. The current RATLER II configuration was sized to meet the mass and volume constraints imposed by the ARTEMIS Common Lunar Lander [9], and to provide a significant science payload capacity. Figure 3 shows the current RATLER II configuration.

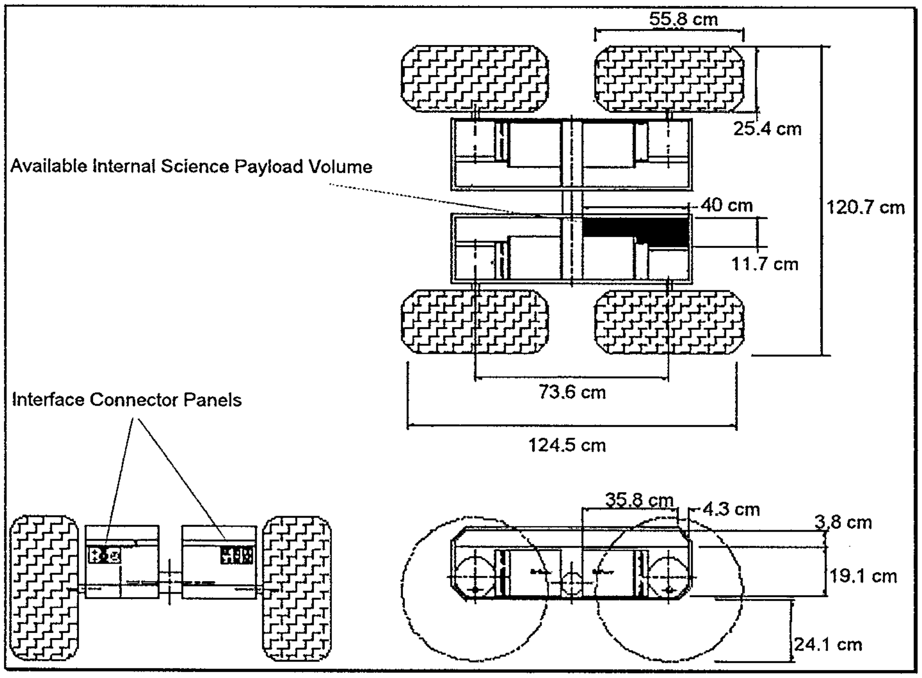

Figure 3. RATLER II Configuration

Based on the trade-off study results, a RATLER II pathfinder was constructed and tested at both the SNL/RVR, and at the White Sands Missile Range (WSMR) during November and December of 1992. Those field trials and additional analysis led to a few minor changes in the vehicle's configuration, which should result in improved mobility and an increase in mechanical strength of the structure. The changes included the addition of aluminum skid plates to protect the under-sides of the carbon composite chassis, larger wheels, increased drive motor torque, and a slight increase in the vehicle's lateral stance. The RATLER II prototype currently under construction is shown in Figure 4.

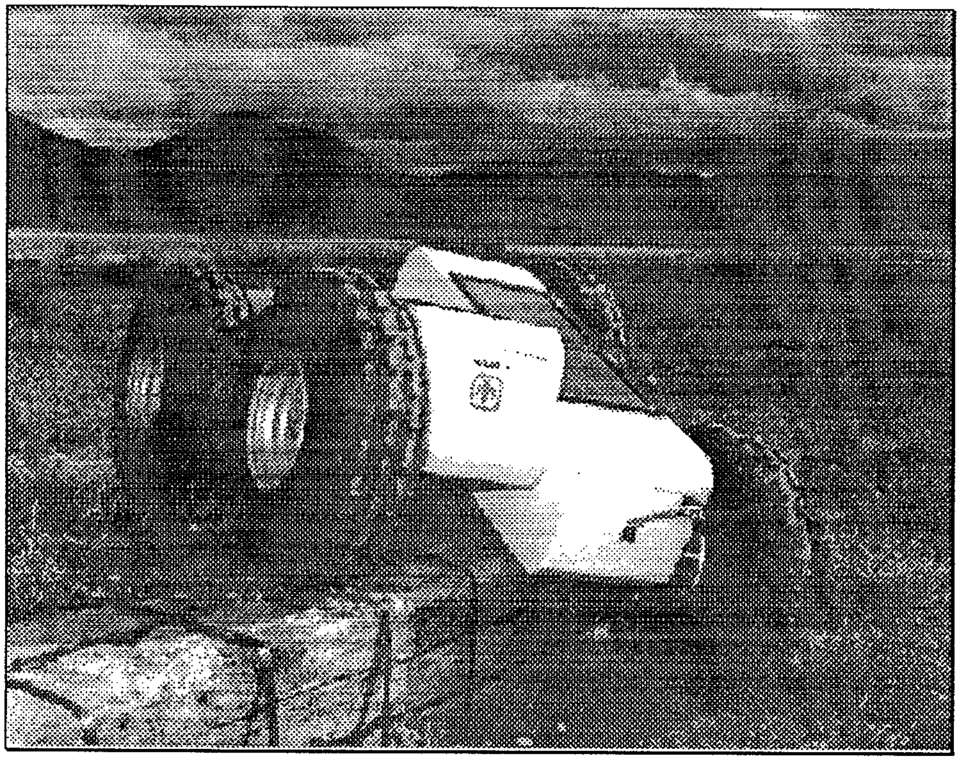

Figure 4. RATLER II Prototype

The RATLER II chassis consists of two bodies, connected by a passive central pivot aligned along the lateral axis of the vehicle. The bodies are constructed of an inner and outer skin of carbon fibers embedded in an epoxy matrix, laid over a cellulose honeycomb inner core. Each body is approximately 25 centimeters wide by 25 centimeters deep by 92 centimeters long, and masses approximately 3.2 kilograms empty. The complete system (not including science instruments) is projected to mass ~70 kilograms, including four lead-acid batteries and four rubber tires on steel rims. Table 1 lists the RATLER II's specifications and expected performance parameters.

Table 1. RATLER II Specifications

Parameter	Value	Units
Wheel Radius	28	cm
Wheel Width	25	cm
Wheelbase	72.4	cm
Stance (to center of contact patch)	81	cm
Total Vehicle Mass (TVM, no payload)	70	kg
Total Stored Volume (TSV)	0.6	$meters^3$
Maximum Single Dimension of TSV	174	cm
Maximum Speed	0.6	meters/second
Slope Stability	>45	degrees
Slope Climbing	~30	degrees
Obstacle Climbing	~75	cm
Maximum Payload Mass (additonal to TVM)	18	kg
Maximum Payload Power (planned)	100	watts (electric)
Maximum Palyload Internal Volume	9600	cm^3

The drive system uses four wheel independent electric drive from four 24 volt DC permanent magnet gearhead motors, each of which provides ~22 Newton-meters of torque, and should provide a maximum speed of ~60 centimeters per second. The battery system is augmented with commercial photovoltaic arrays to provide a trickle charge capability, and is expected to provide ~6 hours of operation assuming a 50% duty cycle on the drive system. An internal payload space of ~9600 cubic centimeters and a maximum of 18 kilograms additional mass budget is provided for scientific instruments, which are allowed a total of up to 100 watts of on-board power.

The computing system being implemented on RATLER II is a commercial STD-32 system, which is based on the popular STD 80 backplane design but has been expanded to allow 32 bit data transfers. The STD-32 system supports multiple processors using a master/slave arrangement with bus arbitration and shared peripheral support. The master processor is an Intel 80486 based machine equipped with 8 Mbytes of RAM and 1 Mbyte of EEPROM. The single slave processor is an NEC V53 (80286/80386 clone) equipped with 1 Mbyte of RAM. Extra card slots have been provided to allow additional slave processors for future expansion. Shared peripheral devices on-board include a high speed, 12 bit, 32 channel Analog to Digital (A/D) converter, a 12 bit, 8 channel Digital to Analog (D/A) converter, Ethernet adapters, and a custom designed, 12 channel digital quadrature encoder board. Each of the two CPU's have on-board I/O ports which give the system a total of 5 serial (RS-232) ports and 72 Parallel I/O lines, of which 24 are optically isolated. On-board sensors and instrumentation include a magnetic fluxgate compass, a Global Positioning System (GPS) receiver, pitch and roll axis inclinometers, an angular rate sensor for the yaw axis, a body-pivot angle encoder, individual wheel odometers, drive motor tachometers, drive motor temperature sensors, drive motor current monitors, battery voltage sensor, and a computer module temperature sensor. All of the internal components are mounted on removable payload module base plates, to allow easy access for maintenance or repair. Communications with the CDS during field operations are handled through a 4800 BAUD, full duplex digital RF modem, and an RF video/audio transmitter.

The Ethernet ports are used for development, and access a LAN at the SNL/RVR for software development tools and source code, so that code development can be accomplished directly on the target CPUs on-board the vehicle. The software architecture for each CPU incorporates a real-time, event driven, multitasking system, is written in C and C++, and accomplishes inter-CPU communications through dual ported RAM. The software system has been designed to allow future expansion of autonomous capabilities, and rapid prototyping of new experimental configurations for robotic control. Current program plans call for an initial operational capability demonstration of teleoperation in September 1993, with future work in FY94 to include the addition of autonomous navigation features.

Future Work

A major focus of the project team's efforts in FY94 will be the conduct of field trials with the RATLER II and its CDS. As noted above, a payload bay area has been allotted to carry scientific instruments weighing up to 18 kilograms and requiring up to 100 watts of power. The RATLER II program is intended to be a testbed for robotic lunar exploration, and as such provides mobility for the true focus of such a mission, i.e. the science package. Although the SNL/RVR is not developing any science packages for lunar exploration, we are offering a 'free ride' during our ongoing field trials to developers of such instruments. We will provide the appropriate interface information to qualified instrument developers, to allow them access to RATLER II's support systems. With proper planning and coordination between the developer and the RATLER II project team, integrating the science package should be a relatively straightforward 'strap-down' process, and should allow several different science packages to be operated on-board the RATLER II during field operations over the course of FY94 (through September 1994). Each proposed payload will be evaluated on an individual basis, and support funding (if any) will be negotiated as required between the SNL/RVR and the instrument developer. As long as no significant modifications to the RATLER II hardware or software is required to support the instrument, no support funding to the SNL/RVR will be required from the instrument developer.

As noted above, one of the major efforts beginning in October of 1993 will be the extension of the RATLER II's navigation capabilities to include some autonomous features. Current plans call for a configuration similar to Brooks' subsumption architecture [10,11], which will necessitate the addition of obstacle detection sensors. Various configuration options are under consideration, and it is hoped that at least two different implementations will be developed and evaluated over the course of the RATLER II program.

A six degree-of-freedom manipulator is planned for FY94, and will be among the first tasks undertaken beginning in October 1993. A dedicated slave CPU will allow coordinated motion of the manipulator while the vehicle is in motion, with virtually no impact on other on-board processing tasks taking place. This capability will allow the entire system to act as a multi-degree-of-freedom (redundant) mobile manipulator, and should provide a useful platform for field trials and testing of planetary exploration mission scenarios. An initial payload lift capacity of ~2 kilograms at full arm extension is planned, as is a small suite of interchangeable end effectors.

The current video RF transmitter incorporates two sideband audio channels, which may be used to bring back stereo audio from the RATLER II to the CDS. Although the Moon has no atmosphere and therefore sound does not travel beyond the surface (however it does travel through the Lunar interior), potential terrestrial applications for the RATLER II could make use of such a feature and we plan to incorporate it. In addition, a set of stereo video cameras will be installed along with a duplexing system to allow stereo vision over a single RF transmitter. Duplexing has been implemented previously at the SNL/RVR for this purpose, and has proven to be quite effective in improving perception without incurring the penalty of increased bandwidth requirements for transmission of the real-time images.

Another item of interest for future work in the RATLER II program will be multi-vehicle control. A second vehicle, identical to the RATLER II prototype, will be constructed and will be used to explore the advantages and disadvantages of simultaneously controlling more than one rover from a common control station, by a single operator. The results of this testing may help determine the economic and technical feasibility of using robotic vehicles for lunar missions.

Obviously, the wheels, solar panels, computers, and batteries being used on the RATLER II are not types which would be suitable for a space qualified system. Conceptual designs for lunar-type wheels will be explored to the extent that at least one set of wheels will be constructed and evaluated, but a comprehensive program of wheel design is not currently planned. The subject of wheel design for lunar roving machines has been explored in some detail [12], and if incorporated in this development program might easily consume the entire budget. Trade studies may be performed with regard to batteries, solar cells, and computing technologies, to identify space qualified (or qualifiable) systems, but the RATLER II prototype currently under development will remain Earthbound. It is intended that a space qualified, flight-ready system could be developed based on the RATLER II, if such a program was determined to be in the national interest, but that is beyond the scope of the RATLER II program as it is currently defined.

Summary

Sandia National Laboratories' Robotic Vehicle Range has brought the Robotic All Terrain Lunar Exploration Rover (RATLER) program from an initial concept to a full scale working prototype in ~19 months. The RATLER II is designed to provide mobility characteristics and payload capacity that are sufficient to realistically demonstrate lunar exploration activities by a mobile robotic vehicle, and is sized to be compatible with payload constraints imposed by the ARTEMIS Common Lunar Lander. The RATLER II prototype itself is not intended to be a space qualified system, but should provide design and engineering data which could be used in the future for a flight qualified lunar exploration rover. The RATLER II will be operational by the end of September 1993 in a teleoperation mode, and will begin field trials in October 1993. Activities planned for the remainder of 1993 and through September 1994 include the addition of a manipulator arm, additional sensing capabilities, autonomous behavioral control software, and field demonstrations of the system in a realistic environment. Developers of science instruments that could make constructive use of the RATLER II's mobility and manipulation characteristics are invited to contact the author to discuss cooperative field trials and demonstrations of their systems, carried as a payload on the RATLER II.

Acknowledgments:

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