Roving Vehicles for Lunar and Planetary Exploration

A Special Bibliography From the
NASA Scientific and Technical Information Program

Includes the design, development, and application of lunar and Mars rovers; vehicle instrumentation and power supplies; navigation and control technologies; and site selection.

January 2004

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A Special Bibliography from the NASA Scientific and Technical Information Program

JANUARY 2004

20030112606 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Lithium Ion Batteries on 2003 Mars Exploration Rover
Bugga, Ratnakumar; Smart, Marshall; Whitcanack, Larry; Knight, Jennifer; Ewell, Richard; Surampudi, Rao; Puglia, Frank; Curran, Tim; The 2002 NASA Aerospace Battery Workshop; April 2003; In English; Original contains color illustrations; No Copyright; Avail: CASI; A03, Hardcopy; Available from CASI on CD-ROM only as part of the entire parent document

The 2003 Mars Exploration Rovers (MER) have Li-SO2 primary batteries on the Lander to support the EDL operations, Li-FeS2 thermal batteries on the back shell for firing pyros during cruise stage separation and Li ion rechargeable batteries on the Rover to assist in the launch, TCM and surface operations. The Rover is about ten times bigger in size, pay load and traversing capability than the previous Sojourner rover and will have a longer mission life with the rechargeable batteries. Lithium ion batteries fabricated by Yardney Technical Products for the MER mission show adequate performance in the operating range, in the MER environments, under steady state and pulse currents and, also in conjunction with a battery charger designed and built in-house.
Derived from text
Electric Batteries; Lithium; Metal Ions; Mars Exploration; Roving Vehicles

20030111177 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Rock Size-Frequency Distributions at the Mars Exploration Rover Landing Sites: Impact Hazard and Accessibility
Golombek, M. P.; Matijevic, J. R.; DiMaggio, E. N.; Schroeder, R. D.; Lunar and Planetary Science XXXIV; 2003; In English; Copyright; Avail: CASI; A01, Hardcopy; Available from CASI on CD-ROM only as part of the entire parent document

The Viking and Mars Pathfinder landing sites and a wide variety of rocky locations on the Earth show size-frequency distributions that follow an exponential when expressed in cumulative fractional area covered by rocks of a given diameter or larger versus diameter plots. Mars lander rock distributions have been fit by an equation of the form: $Fk(D) = k \exp[-q(k) D]$, where $Fk(D)$ is the cumulative fractional area covered by rocks of diameter D or larger, k is the total area covered by all rocks, and an exponential $q(k) = 1.79 + 0.152/k$, which governs how abruptly the area covered by rocks decreases with increasing diameter. These distributions form a family of noncrossing curves that flatten out at small rock diameter at a total rock abundance of 5-40%. Model rock size-frequency distributions indicate a low probability of impacting hazardous rocks during MER landing. Rocks large enough to analyze and abrade by the rover should be plentiful within an easy Sol's drive.
Derived from text
Frequency Distribution; Landing Sites; Rocks; Viking Mars Program; Size Distribution; Mathematical Models; Mars Roving Vehicles; Mars Exploration

20030111172 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Selection of the Final Four Landing Sites for the Mars Exploration Rovers
Golombek, M.; Grant, J.; Parker, T.; Kass, D.; Crisp, J.; Squyres, S.; Carr, M.; Adler, M.; Zurek, R.; Haldermann, A., et al.; Lunar and Planetary Science XXXIV; 2003; In English; Copyright; Avail: CASI; A01, Hardcopy; Available from CASI on CD-ROM only as part of the entire parent document

Engineering constraints developed for the Mars Exploration Rovers (MER), their translation into ~185 potential landing sites and their downselection to 6 high priority science sites have been described [1, 2]. These 6 sites (Meridiani-previously referred to as Hematite, Gusev, Isidis, Melas, Eos, and Athabasca) were evaluated in detail as to their science potential and safety, relative to specific engineering constraints, at the 3rd MER Landing Site Workshop held March 26-28, 2002 in Pasadena, CA. This abstract describes: (1) the evaluation of these 6 sites, (2) the removal and reprioritization of sites following this workshop, (3) the identification of a low-wind site in Elysium, (4) the final 4 sites being considered for landing the 2 MER

and (5) their evaluation at the 4th MER Landing Site Workshop held January 8-10, 2003 in Pasadena, CA [3].
Author
Mars Exploration; Landing Sites

20030110749 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Ten-Meter Scale Topography and Roughness of Mars Exploration Rovers Landing Sites and Martian Polar Regions
Ivanov, Anton B.; Lunar and Planetary Science XXXIV; 2003; In English; Copyright; Avail: CASI; A01, Hardcopy; Available from CASI on CD-ROM only as part of the entire parent document

The Mars Orbiter Camera (MOC) has been operating on board of the Mars Global Surveyor (MGS) spacecraft since 1998. It consists of three cameras - Red and Blue Wide Angle cameras (FOV=140 deg.) and Narrow Angle camera (FOV=0.44 deg.). The Wide Angle camera allows surface resolution down to 230 m/pixel and the Narrow Angle camera - down to 1.5 m/pixel. This work is a continuation of the project, which we have reported previously. Since then we have refined and improved our stereo correlation algorithm and have processed many more stereo pairs. We will discuss results of our stereo pair analysis located in the Mars Exploration rovers (MER) landing sites and address feasibility of recovering topography from stereo pairs (especially in the polar regions), taken during MGS 'Relay-16' mode.
Author
Mars Surface; Topography; Mars Roving Vehicles; Surface Roughness; Mars Landing Sites

20030110724 Saint Louis Univ., MO, USA
Students Work Alongside Scientists to Test Mars Rover
Fuchs, M. P.; Green, T. J.; Levant, J. M. S.; Nunez, J. I.; Bowman, C. D.; Sherman, D. M.; Lunar and Planetary Science XXXIV; 2003; In English; Original contains color and black and white illustrations; Copyright; Avail: CASI; A01, Hardcopy; Available from CASI on CD-ROM only as part of the entire parent document

NASA's 2003-2004 Mars Exploration Rovers and associated Athena Science Payload will provide an exciting opportunity to get students and the public involved in Mars exploration. One outreach component, the Athena Student Interns Program, will directly engage high school students in scientific discovery on Mars by incorporating the students into the mission s science team. The Athena Student Interns Program, based on the successful LAPIS program, was prototyped during the FIDO rover field trials that took place in the Arizona desert and at the Jet Propulsion Laboratory (JPL) in August 2002 (http://mars.jpl.nasa.gov/mer/fido). Use of a participatory evaluation process allowed mid-course corrections to be made to the program and provided the model for mission-related outreach.
Derived from text
Mars Exploration; Mars Surface; Roving Vehicles

20030078476
Optomechanical design of ten modular cameras for the Mars exploration Rovers
Ford, Virginia; Karlmann, Paul; Hagerott, Ed; Scherr, Larry; Proceedings of SPIE - The International Society for Optical Engineering; 2002; ISSN 0277-786X; Volume 4771; In English; Optomechanical Design and Engineering 2002, Jul. 7-9, 2002, Seattle, WA, USA; Copyright; Avail: Other Sources

The 2003 mission to Mars includes two Rovers, which will land on the Martian surface. Each Rover carries 9 cameras of 4 different designs. In addition, one similar camera is mounted to each lander assembly to monitor the descent and provide information for firing the control jets during landing. This paper will discuss the mechanical systems design of the cameras, including fabrication tolerances of the lenses, thermal issues, radiation shielding, planetary protection, detector mounting, electronics, the modularity achieved, and how the 10 different locations were accommodated on the very tight real estate of the Rovers and Landers.
EI
Aerospace Sciences; Cameras; Design Analysis; Lenses; Optical Equipment; Roving Vehicles

20030066805 Los Alamos National Lab., NM, USA
Development and Testing of Laser-induced Breakdown Spectroscopy for the Mars Rover Program: Elemental Analyses at Stand-Off Distances
Cremers, D. A.; Wiens, R. C.; Arp, Z. A.; Harris, R. D.; Maurice, S.; Sixth International Conference on Mars; 2003; In English; Original contains color and black and white illustrations; Copyright; Avail: CASI; C01, CD-ROM; A01, Hardcopy; Available on CD-ROM as part of the entire parent document

One of the most fundamental pieces of information about any planetary body is the elemental composition of its surface materials. The Viking Martian landers employed XRF (x-ray fluorescence) and the MER rovers are carrying APXS (alpha-proton x-ray spectrometer) instruments upgraded from that used on the Pathfinder rover to supply elemental composition information for soils and rocks to which direct contact is possible. These in- situ analyses require that the lander or rover be in contact with the sample. In addition to in-situ instrumentation, the present generation of rovers carry instruments that operate at stand-off distances. The Mini-TES is an example of a stand-off instrument on the MER rovers. Other examples for future missions include infrared point spectrometers and microscopic-imagers that can operate at a distance. The main advantage of such types of analyses is obvious: the sensing element does not need to be in contact or even adjacent to the target sample. This opens up new sensing capabilities. For example, targets that cannot be reached by a rover due to impassable terrain or targets positioned on a cliff face can now be accessed using stand-off analysis. In addition, the duty cycle of stand-off analysis can be much greater than that provided by in-situ measurements because the stand-off analysis probe can be aimed rapidly at different features of interest eliminating the need for the rover to actually move to the target. Over the past five years we have been developing a stand-off method of elemental analysis based on atomic emission spectroscopy called laser-induced breakdown spectroscopy (LIBS). A laser-produced spark vaporizes and excites the target material, the elements of which emit at characteristic wavelengths. Using this method, material can be analyzed from within a radius of several tens of meters from the instrument platform. A relatively large area can therefore be sampled from a simple lander without requiring a rover or sampling arms. The placement of such an instrument on a rover would allow the sampling of locations distant from the landing site. Here we give a description of the LIBS method and its advantages. We discuss recent work on determining its characteristics for Mars exploration, including accuracy, detection limits, and suitability for determining the presence of water ice and hydrated minerals. We also give a description of prototype instruments we have tested in field settings.
Author
Mars Exploration; Planetary Geology; Planetary Composition; Chemical Analysis; Laser-Induced Breakdown Spectroscopy

20030066722 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Mars Exploration Rover Landing Site Selection
Golombek, M.; Grant, J.; Parker, T.; Kass, D.; Crisp, J.; Squyres, S.; Adler, M.; Haldemann, H.; Carr, M.; Arvidson, A., et al.; Sixth International Conference on Mars; 2003; In English; Copyright; Avail: CASI; C01, CD-ROM; A01, Hardcopy; Available on CD-ROM as part of the entire parent document

Selection of the landing sites for the Mars Exploration Rovers has involved over 2 years of research and analysis effort that has included the participation of broad sections of the planetary sciences community through a series of open landing site workshops. The effort has included the definition of the engineering constraints based on the landing system, mapping those engineering constraints into acceptable regions and prospective sites, the acquisition of new information from Mars Global Surveyor and Mars Odyssey orbiters, the evaluation of science and safety criteria for the sites, and the downselection and final site selection based on the sites science potential and safety. The final landing sites (Meridiani Planum and Gusev crater) were selected by NASA Headquarters on April 11, 2003, prior to launch in June. This paper presents engineering requirements, and potential landing sites for Mars Exploration Rovers.
Derived from text
Mars Exploration; Mars Landing Sites; Mars Surface; Mars Roving Vehicles; Site Selection

20030066682 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Pancam: A Multispectral Imaging Investigation on the NASA 2003 Mars Exploration Rover Mission
Bell, J. F., III; Squyres, S. W.; Herkenhoff, K. E.; Maki, J.; Schwochert, M.; Dingizian, A.; Brown, D.; Morris, R. V.; Arneson, H. M.; Johnson, M. J., et al.; Sixth International Conference on Mars; 2003; In English; Original contains color illustrations; Copyright; Avail: CASI; C01, CD-ROM; A01, Hardcopy; Available on CD-ROM as part of the entire parent document

One of the six science payload elements carried on each of the NASA Mars Exploration Rovers (MER; Figure 1) is the Panoramic Camera System, or Pancam. Pancam consists of three major components: a pair of digital CCD cameras, the Pancam Mast Assembly (PMA), and a radiometric calibration target. The PMA provides the azimuth and elevation actuation for the cameras as well as a 1.5 meter high vantage point from which to image. The calibration target provides a set of reference color and grayscale standards for calibration validation, and a shadow post for quantification of the direct vs. diffuse illumination of the scene. Pancam is a multispectral, stereoscopic, panoramic imaging system, with a field of regard provided by the PMA that extends across 360 of azimuth and from zenith to nadir, providing a complete view of the scene around the rover in up to 12 unique wavelengths. The major characteristics of Pancam are summarized.
Derived from text
Imaging Techniques; Mars Exploration; Multispectral Photography; Panoramic Cameras; Mars Roving Vehicles; NASA Space Programs

20030066557 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA

Mars Exploration Rovers as Virtual Instruments for Determination of Terrain Roughness and Physical Properties

Arvidson, R. E.; Lindemann, R.; Matijevic, J.; Richter, L.; Sullivan, R.; Haldemann, A.; Anderson, R.; Snider, N.; Sixth International Conference on Mars; 2003; In English; Original contains black and white illustrations; Copyright; Avail: CASI; C01, CD-ROM; A01, Hardcopy; Available on CD-ROM as part of the entire parent document

The two 2003 Mars Exploration Rovers (MERs), in combination with the Athena Payload, will be used as virtual instrument systems to infer terrain properties during traverses, in addition to using the rover wheels to excavate trenches, exposing subsurface materials for remote and in-situ observations. The MERs are being modeled using finite element-based rover system transfer functions that utilize the distribution of masses associated with the vehicle, together with suspension and wheel dynamics, to infer surface roughness and mechanical properties from traverse time series data containing vehicle yaw, pitch, roll, encoder counts, and motor currents. These analyses will be supplemented with imaging and other Athena Payload measurements. The approach is being validated using Sojourner data, the FIDO rover, and experiments with MER testbed vehicles. In addition to conducting traverse science and associated analyses, trenches will be excavated by the MERs to depths of approximately 10-20 cm by locking all but one of the front wheels and rotating that wheel backwards so that the excavated material is piled up on the side of the trench away from the vehicle. Soil cohesion and angle of internal friction will be determined from the trench telemetry data. Emission spectroscopy and in-situ observations will be made using the Athena payload before and after imaging. Trenching and observational protocols have been developed using Sojourner results; data from the FIDO rover, including trenches dug into sand, mud cracks, and weakly indurated bedrock; and experiments with MER testbed rovers. Particular attention will be focused on Mini-TES measurements designed to determine the abundance and state of subsurface water (e.g. hydrated, in zeolites, residual pore ice?) predicted to be present from Odyssey GRS/NS/HEND data.

Author

Mars Roving Vehicles; Terrain Analysis; Surface Roughness; Mars Surface; Terrain

20030065170 NASA Langley Research Center, Hampton, VA, USA

Mars Exploration Rover Six-Degree-Of-Freedom Entry Trajectory Analysis

Desai, Prasun N.; Schoenenberger, Mark; Cheatwood, F. M.; [2003]; In English; AAS/AIAA Astrodynamics Specalits Conference, 3-7 Aug. 2003, Big Sky, MT, USA

Report No.(s): AAS Paper 03-642; Copyright; Avail: CASI; A03, Hardcopy

The Mars Exploration Rover mission will be the next opportunity for surface exploration of Mars in January 2004. Two rovers will be delivered to the surface of Mars using the same entry, descent, and landing scenario that was developed and successfully implemented by Mars Pathfinder. This investigation describes the trajectory analysis that was performed for the hypersonic portion of the MER entry. In this analysis, a six-degree-of-freedom trajectory simulation of the entry is performed to determine the entry characteristics of the capsules. In addition, a Monte Carlo analysis is also performed to statistically assess the robustness of the entry design to off-nominal conditions to assure that all entry requirements are satisfied. The results show that the attitude at peak heating and parachute deployment are well within entry limits. In addition, the parachute deployment dynamics pressure and Mach number are also well within the design requirements.

Author

Degrees of Freedom; Trajectory Analysis; Atmospheric Entry; Mars Roving Vehicles; Mars Exploration; NASA Space Programs

20030034825 Massachusetts Univ., Amherst, MA, USA

Self-Directed Cooperative Planetary Rovers

Zilberstein, Shlomo; Morris, Robert, Technical Monitor; April 2003; In English

Contract(s)/Grant(s): NAG2-1463; No Copyright; Avail: CASI; A02, Hardcopy

The project is concerned with the development of decision-theoretic techniques to optimize the scientific return of planetary rovers. Planetary rovers are small unmanned vehicles equipped with cameras and a variety of sensors used for scientific experiments. They must operate under tight constraints over such resources as operation time, power, storage capacity, and communication bandwidth. Moreover, the limited computational resources of the rover limit the complexity of on-line planning and scheduling. We have developed a comprehensive solution to this problem that involves high-level tools to describe a mission; a compiler that maps a mission description and additional probabilistic models of the components of the rover into a Markov decision problem; and algorithms for solving the rover control problem that are sensitive to the limited computational resources and high-level of uncertainty in this domain.

Author

Roving Vehicles; Space Exploration; Autonomy; Networks; Decision Theory

20030034817 Massachusetts Univ., Amherst, MA, USA
Reinforcement Learning for Weakly-Coupled MDPs and an Application to Planetary Rover Control
Bernstein, Daniel S.; Zilberstein, Shlomo; [2003]; In English
Contract(s)/Grant(s): NAG2-1463; NAG2-1394; NSF IRI-96-24992; NSF IIS-99-07331; No Copyright; Avail: CASI; A02, Hardcopy

Weakly-coupled Markov decision processes can be decomposed into subprocesses that interact only through a small set of bottleneck states. We study a hierarchical reinforcement learning algorithm designed to take advantage of this particular type of decomposability. To test our algorithm, we use a decision-making problem faced by autonomous planetary rovers. In this problem, a Mars rover must decide which activities to perform and when to traverse between science sites in order to make the best use of its limited resources. In our experiments, the hierarchical algorithm performs better than Q-learning in the early stages of learning, but unlike Q-learning it converges to a suboptimal policy. This suggests that it may be advantageous to use the hierarchical algorithm when training time is limited.
Author
Decision Making; Markov Processes; Mars Surface; Roving Vehicles

20030034662 Massachusetts Univ., Amherst, MA, USA
Decision-Theoretic Control of Planetary Rovers
Zilberstein, Shlomo; Washington, Richard; Bernstein, Daniel S.; Mouaddib, Abdel-Illah; Morris, Robert, Technical Monitor; [2003]; In English; Original contains black and white illustrations
Contract(s)/Grant(s): NAG2-1463; Copyright; Avail: CASI; A03, Hardcopy

Planetary rovers are small unmanned vehicles equipped with cameras and a variety of sensors used for scientific experiments. They must operate under tight constraints over such resources as operation time, power, storage capacity, and communication bandwidth. Moreover, the limited computational resources of the rover limit the complexity of on-line planning and scheduling. We describe two decision-theoretic approaches to maximize the productivity of planetary rovers: one based on adaptive planning and the other on hierarchical reinforcement learning. Both approaches map the problem into a Markov decision problem and attempt to solve a large part of the problem off-line, exploiting the structure of the plan and independence between plan components. We examine the advantages and limitations of these techniques and their scalability.
Author
Roving Vehicles; Unmanned Ground Vehicles; Decision Theory; Markov Processes; Mathematical Models; Control Theory

20030014741 NASA Ames Research Center, Moffett Field, CA USA
The Mars Exploration Rover/Collaborative Information Portal
Walton, Joan; Filman, Robert E.; Schreiner, John; Koga, Dennis, Technical Monitor; Oct. 31, 2002; In English; 10th International Conference on Human-Computer Interaction, 22-27 Jun. 2003, Crete, Greece; Copyright; Avail: CASI; A02, Hardcopy; Distribution as joint owner in the copyright

Astrology has long argued that the alignment of the planets governs human affairs. Science usually scoffs at this. There is, however, an important exception: sending spacecraft for planetary exploration. In late May and early June, 2003, Mars will be in position for Earth launch. Two Mars Exploration Rovers (MER) will rocket towards the red planet. The rovers will perform a series of geological and meteorological experiments, seeking to examine geological evidence for water and conditions once favorable for life. Back on earth, a small army of surface operations staff will work to keep the rovers running, sending directions for each day’s operations and receiving the files encoding the outputs of the Rover’s six instruments. (Mars is twenty light minutes from Earth. The rovers must be robots.) The fundamental purpose of the project is, after all, Science. Scientists have experiments they want to run. Ideally, scientists want to be immediately notified when the data products of their experiments have been received, so that they can examine their data and (collaboratively) deduce results. Mars is an unpredictable environment. We may issue commands to the rovers but there is considerable uncertainty in how the commands will be executed and whether what the rovers sense will be worthy of further pursuit. The steps of what is, to a scientist, conceptually an individual experiment may be scattered over a large number of activities. While the scientific staff has an overall strategic idea of what it would like to accomplish, activities are planned daily. The data and surprises of the previous day need to be integrated into the negotiations for the next day’s activities, all synchronized to a schedule of transmission windows . Negotiations is the operative term, as different scientists want the resources to run possibly incompatible experiments. Many meetings plan each day’s activities.
Author
Mars Exploration; Space Exploration; Roving Vehicles; Geology

20030012639 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA

Visible to Short Wavelength Infrared Spectroscopy on Rovers: Why We Need it on Mars and What We Need to do on Earth

Blaney, D. L.; Mars Infrared Spectroscopy: From Theory and the Laboratory To Field Observations; 2002; In English; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

The next stage of Mars exploration will include the use of rovers to seek out specific mineralogies. Understanding the mineralogical diversity of the locale will be used to determining which targets should be investigated with the full suite of in situ capability on the rover. Visible to Short Wavelength Infrared (VSWIR) spectroscopy is critical in evaluating the mineralogical diversity and to validate the global remote sensing data sets to be collected by Mars Express and the Mars Reconnaissance Orbiter. However, spectroscopy on mobile platforms present challenges in both the design of instruments and in the efficient operation of the instrument and mission. Field-testing and validation on Earth can be used to develop instrument requirements analysis tools needed for used on Mars.

Author

Infrared Spectroscopy; Roving Vehicles; Mars Surface; Mars Exploration; Design Analysis; Mars Landing Sites; Data Processing

20030006804

Design Concept for a Nuclear Reactor-Powered Mars Rover

Elliott, John O.; Lipinski, Ronald J.; Poston, David I.; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, no. 1; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

A study was recently carried out by a team from JPL and the DOE to investigate the utility of a DOE-developed 3 kWe surface fission power system for Mars missions. The team was originally tasked to perform a study to evaluate the usefulness and feasibility of incorporation of such a power system into a landed mission. In the course of the study it became clear that the application of such a power system was enabling to a wide variety of potential missions. Of these, two missions were developed, one for a stationary lander and one for a reactor-powered rover. This paper discusses the design of the rover mission, which was developed around the concept of incorporating the fission power system directly into a large rover chassis to provide high power, long range traverse capability. The rover design is based on a minimum extrapolation of technology, and adapts existing concepts developed at JPL for the 2009 Mars Science Laboratory (MSL) rover, lander and EDL systems. The small size of the reactor allowed its incorporation directly into an existing large MSL rover chassis design, allowing direct use of MSL aeroshell and pallet lander elements, beefed up to support the significantly greater mass involved in the nuclear power system and its associated shielding. This paper describes the unique design challenges encountered in the development of this mission architecture and incorporation of the fission power system in the rover, and presents a detailed description of the final design of this innovative concept for providing long range, long duration mobility on Mars. [copyright] 2003 American Institute of Physics

Author (AIP)

Mars Missions; Mars Surface; Mass; Nuclear Power Reactors; Nuclear Reactors; Radiation Protection; Research Projects; Roving Vehicles

20030006784

Active Heat Rejection System on Mars Exploration Rover -- Design Changes from Mars Pathfinder

Ganapathi, Gani B.; Birur, Gajanana C.; Tsuyuki, Glenn T.; McGrath, Paul L.; Patzold, Jack D.; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, no. 1; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

The active Heat Rejection System designed for Mars Pathfinder was modified for the Mars Exploration Rover (Mars ‘03) mission and will be used to remove excess heat from the Rover electronics during the cruise part of the mission. The Integrated Pump Assembly design from MPF remained essentially intact; changes were primarily made to reduce weight. However, the cooling loop was significantly redesigned to service totally different requirements for the MER rovers. In addition, the vent design was readdressed to alleviate potentially excessive nutation as was induced on the MPF spacecraft in the process of dumping the CFC-11 overboard prior to Entry/Descent/Landing. The current vent design was based on a better understanding of the flow characteristics during the blowdown process. This paper addresses some of the key design changes. This paper also

addresses lessons learned from the performance testing, and potential changes to improve the HRS performance (e.g. temperature oscillations). [copyright] 2003 American Institute of Physics
Author (AIP)
Cooling; Mars (Planet); Mars Exploration; Mars Missions; Mars Pathfinder; Roving Vehicles; Systems Engineering; Temperature Control; Ventilation

20030006783
Development of a Thermal Control Architecture for the Mars Exploration Rovers
Novak, Keith S.; Phillips, Charles J.; Birur, Gajanana C.; Sunada, Eric T.; Pauken, Michael T.; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, no. 1; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

In May and June of 2003, the National Aeronautics and Space Administration (NASA) will launch two roving science vehicles on their way to Mars. They will land on Mars in January and February of 2004 and carry out 90-Sol missions. This paper addresses the thermal design architecture of the Mars Exploration Rover (MER) developed for Mars surface operations. The surface atmosphere temperature on Mars can vary from 0[deg]C in the heat of the day to -100[deg]C in the early morning, prior to sunrise. Heater usage at night must be minimized in order to conserve battery energy. The desire to minimize nighttime heater energy led to a design in which all temperature sensitive electronics and the battery were placed inside a well-insulated (carbon-opacified aerogel lined) Warm Electronics Box (WEB). In addition, radioisotope heater units (RHU's, non-electric heat sources) were mounted on the battery and electronics inside the WEB. During the Martian day, the electronics inside the WEB dissipate a large amount of energy (over 710 W*hrs). This heat energy raises the internal temperatures inside the WEB. Hardware items that have similar temperature limits were conductively coupled together to share heat and concentrate thermal mass. Thermal mass helped to minimize temperature increases in the hot case (with maximum internal dissipation) and minimize temperature decreases in the cold case (with minimum internal dissipation). In order to prevent the battery from exceeding its maximum allowable flight temperature, wax-actuated passive thermal switches were placed between the battery and an external radiator. This paper discusses the design philosophies and system requirements that resulted in a successful Mars rover thermal design. [copyright] 2003 American Institute of Physics
Author (AIP)
Control Theory; Launch Vehicles; Mars (Planet); Mars Exploration; NASA Programs; Packaging; Roving Vehicles; Temperature Control

20020091882 NASA Ames Research Center, Moffett Field, CA USA
Instrument Deployment for Mars Rovers
Pedersen, Liam; Bualat, Maria; Kunz, C.; Lee, Susan; Sargent, Randy; Washington, Rich; Wright, Anne; Clancy, Daniel, Technical Monitor; Sep. 17, 2002; In English; IEEE 2003 International Conference on Robotics and Automation, 12-17 May 2003, Taiwan, Province of China; No Copyright; Avail: CASI; A02, Hardcopy

Future Mars rovers, such as the planned 2009 MSL rover, require sufficient autonomy to robustly approach rock targets and place an instrument in contact with them. It took the 1997 Sojourner Mars rover between 3 and 5 communications cycles to accomplish this. This paper describes the technologies being developed and integrated onto the NASA Ames K9 prototype Mars rover to both accomplish this in one cycle, and to extend the complexity and duration of operations that a Mars rover can accomplish without intervention from mission control.
Author
Deployment; Mars Surface; Roving Vehicles; Technology Utilization; Mars (Planet); Systems Engineering

20020091830 QSS Group, Inc., Moffett Field, CA USA
Science Target Assessment for Mars Rover Instrument Deployment
Pedersen, Liam; Clancy, Daniel, Technical Monitor; Sep. 17, 2002; In English; 2002 IEEE/RSJ International Conference on Intelligent Robots and Systems, 30 Sep. - 4 Oct. 2002, Switzerland; No Copyright; Avail: CASI; A02, Hardcopy

This paper introduces the system being developed at NASA Ames Research Center, intended for the Mars '09 Smart Lander, to robustly place sensors or tools against rocks in a single communications cycle. Science targets must be assessed prior to instrument placement in order to segment them from the background and determine where, if possible, to position the

instrument. An initial result of this research effort is a novel Bayesian based method for segmenting rocks from the ground using 3D data.
Author
Mars Surface; Roving Vehicles; Targets; Instrument Orientation

20020083006 NASA Ames Research Center, Moffett Field, CA USA
Rovers for Mars Polar Exploration
Stoker, Carol; DeVincenzi, Donald, Technical Monitor; [1998]; In English; Conference on Mars Polar Processes, 18-22 Oct. 1998, Houston, TX, USA; No Copyright; Avail: Other Sources; Abstract Only

Mobility is a generic capability needed for Mars exploration. Requirements for mobility range from those to get observations of individual rocks all the way to getting high resolution observations of regional areas. Table 1 shows the required-range of mobility to achieve various tasks. The Pathfinder mission and field experiments simulating rover missions [1, 2, 3, 4, 5] provide guidance as to rover capabilities that can reasonably be expected in the next decade. Rover mobility can be accomplished in a variety of ways, the most common being wheels or tracks and legged-walkers. Wheeled vehicles can traverse over rocks smaller than 1/2 wheel diameter, and with path planning to avoid larger rocks, can traverse terrains comparable to those seen on Mars in the Viking and Pathfinder landing sites. Slopes of 45 deg can be easily negotiated by wheeled rovers. Walking vehicles can negotiate even more complex terrain but requires computation capability to select each leg placement. Extremely complex terrain was traversed by the Nomad II walker which descended into (and most of the way out of) an active volcanic caldera (Mount Spur, AK) in 1995, although a slope failure eventually resulted in broken legs. The traverse range of a rover is limited by its science objectives, performance capabilities, and operational lifetime. The speed of rover traverse is a relative minor factor. With a different communication system, and no stops for science experiments, Sojourner could probably have traveled a kilometer. But, achieving land speed records is not a major objective of a science mission. Achieving science objectives requires targeting particular objects and studying them in detail, and the associated operational requirements will likely limit rover traverse range significantly. Traversing from target to target requires relatively few command cycles provided the traverse is over a short enough distance that it can be adequately planned. An operational goal of 100 m traverse per command cycle, arriving at a predetermined target, seems achievable. Investigating science targets requiring manipulator or instrument placement and sample collection will likely take several command cycles per target. Mission simulations [6] have demonstrated that traverse dI stances of 100-300 m, with detailed investigation of 5-10 targets take 50-100 command cycles, not unlike the Pathfinder experience in spite of the use of larger, faster, more capable rovers. Significant advances in rover autonomy will be needed to improve this Situation and it is not clear how much improvement will be brought to flight programs in the next decade. Dust accumulation on solar panels degrades power over time and, without dust removal, rover operational lifetimes may be limited to 90 sols.
Derived from text
Roving Vehicles; Mars Exploration; Mobility; Trajectory Planning; Mars Pathfinder

20020078203 NASA Ames Research Center, Moffett Field, CA USA
Contingency Planning for Planetary Rovers
Dearden, Richard; Meuleau, Nicolas; Ramakrishnan, Sailesh; Smith, David; Washington, Rich; Clancy, Daniel, Technical Monitor; [2002]; In English; 3rd International NASA Workshop on Planning and Scheduling for Space, 27-29 Oct. 2002, Houston, TX, USA; No Copyright; Avail: CASI; A02, Hardcopy

There has been considerable work in AI on planning under uncertainty. But this work generally assumes an extremely simple model of action that does not consider continuous time and resources. These assumptions are not reasonable for a Mars rover, which must cope with uncertainty about the duration of tasks, the power required, the data storage necessary, along with its position and orientation. In this paper, we outline an approach to generating contingency plans when the sources of uncertainty involve continuous quantities such as time and resources. The approach involves first constructing a 'seed' plan, and then incrementally adding contingent branches to this plan in order to improve utility. The challenge is to figure out the best places to insert contingency branches. This requires an estimate of how much utility could be gained by building a contingent branch at any given place in the seed plan. Computing this utility exactly is intractable, but we outline an approximation method that back propagates utility distributions through a graph structure similar to that of a plan graph.
Author
Contingency; Roving Vehicles; Mars Surface; Planning; Approximation

20020070287 NASA Ames Research Center, Moffett Field, CA USA

Autonomous Rovers for Human Exploration of Mars

Bresina, John; Dorais, Gregory; Golden, Keith; Washington, Richard; Lau, Sonie, Technical Monitor; [1998]; In English; No Copyright; Avail: Other Sources; Abstract Only

Autonomous rovers are a critical element for the success of human exploration of Mars. The robotic tasks required for human presence on Mars are beyond the ability of current rovers; these tasks include emplacement and maintenance of a habitat, fuel production facility, and power generator, landing-site scouting, and mining. These tasks are required before and also during human presence; the ability of rovers to offload work from the human explorers will enable the humans to accomplish their mission. The capacity for these tasks will be realized by significant advancement toward full rover autonomy and, in particular, by overcoming current rover mission limitations in the areas of robust operation, resource utilization, and failure recovery. The Pathfinder mission demonstrated the potential for robotic Mars exploration, but at the same time indicated clearly the need for more rover autonomy. The highly interactive, ground-intensive control with significant downtime limited the effectiveness of the Sojourner rover. Advances in rover offer increased rover productivity without risk to rover safety. We are developing an integrated on-board executive architecture that incorporates robust operation, resource utilization, and failure recovery. This work draws from our experience with the architecture for the Deep Space One autonomy experiment, with enhancements in the area of ensuring robust operation in the face of unpredictable, complex environments, such as what a rover encounters on Mars. Our ultimate goal is to provide a complete agent architecture for rover autonomy. The complete architecture will include long-range mission and path planning, self-diagnosis and fault recovery, and continual monitoring and adjustment of execution resources. The architecture will enable robust operation over long ranges of time and distance, performing complex tasks in a planned and opportunistic manner, and serving as an intelligent, capable tool for human explorers.

Author

Diagnosis; Ground Based Control; Interactive Control; Mars Exploration; Robotics; Roving Vehicles; Trajectory Planning

20020061268 NASA Ames Research Center, Moffett Field, CA USA

Testing Planetary Rovers: Technologies, Perspectives, and Lessons Learned

Thomas, Hans; Lau, Sonie, Technical Monitor; [1998]; In English; IEEE Conference on Robotics and Automation, 16 May 1998, Leuven, Belgium; No Copyright; Avail: Other Sources; Abstract Only

Rovers are a vital component of NASA's strategy for manned and unmanned exploration of space. For the past five years, the Intelligent Mechanisms Group at the NASA Ames Research Center has conducted a vigorous program of field testing of rovers from both technology and science team productivity perspective. In this talk, I will give an overview of the the last two years of the test program, focusing on tests conducted in the Painted Desert of Arizona, the Atacama desert in Chile, and on IMG participation in the Mars Pathfinder mission. An overview of autonomy, manipulation, and user interface technologies developed in response to these missions will be presented, and lesson's learned in these missions and their impact on future flight missions will be presented. I will close with some perspectives on how the testing program has affected current rover systems.

Author

Roving Vehicles; Manned Mars Missions; Planetary Surfaces

20020052585 NASA Ames Research Center, Moffett Field, CA USA

Mars Rovers: Past, Present, and Future

Bualat, Maria; Lau, Sonie, Technical Monitor; [2001]; In English; AIAA Dinner Meeting, 19 Jul. 2001, Moffett Field, CA, USA; No Copyright; Avail: CASI; A03, Hardcopy

This viewgraph presentation provides information on the exploration of Mars through the use of rover vehicles. Mars is considered an interesting planet because it is the most like Earth of all known planets, and it may have or have had water on or below its surface. There are many different engineering design challenges for roving vehicles intended for Mars. These include: communications time delay, narrow communications bandwidth, extreme temperatures, rough and rocky terrain, the lack of a global positioning system, and dust. The Sojourner Rover specifications are provided including wheel diameter and instruments. There are prototypes being tested at NASA's Ames Research Center of the next generation Mars rovers.

CASI

Roving Vehicles; Mars Exploration; Mars (Planet); Research Vehicles; Systems Engineering

20020046334 Hawaii Univ., Honolulu, HI USA

A Rover's-Eye View in the Thermal Infrared: Spectral Adjacency Effects

Horton, K. A.; Moersch, J. E.; Lucey, P. G.; Ruff, S. W.; Lunar and Planetary Science XXXIII; April 2002; In English; CD-ROM contains the entire conference proceedings presented in PDF format

Contract(s)/Grant(s): NAG5-10635; No Copyright; Abstract Only: Available from CASI only as part of the entire parent document

Due to the unique perspective of thermal infrared spectral measurements of geologic targets taken obliquely from a planetary rover or fixed lander, we have conducted several series of experiments designed to explore the various interferences which may arise from the local environment. Additional information is contained in the original extended abstract.

Derived from Text

Spectrum Analysis; Infrared Radiation; Infrared Spectra; Planetary Surfaces

20020045783 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA

Downselection of Landing Sites for the Mars Exploration Rovers

Golombek, M.; Grant, J.; Parker, T.; Schofield, T.; Kass, D.; Knocke, P.; Roncoli, R.; Bridges, N.; Anderson, S.; Crisp, J., et al.; Lunar and Planetary Science XXXIII; April 2002; In English; CD-ROM contains the entire conference proceedings presented in PDF format; No Copyright; Abstract Only: Available from CASI only as part of the entire parent document

Six landing sites that show evidence for processes involving water have been selected from a possible 185 for the Mars Exploration Rovers. These sites are being imaged by orbiting spacecraft and evaluated for science potential and safety before selection of two in May 2002. Additional information is contained in the original extended abstract.

Derived from Text

Mars Landing Sites; Mars Exploration

20020011683 NASA Ames Research Center, Moffett Field, CA USA

VIPER: Virtual Intelligent Planetary Exploration Rover

Edwards, Laurence; Flueckiger, Lorenzo; Nguyen, Laurent; Washington, Richard; [2001]; In English; No Copyright; Avail: CASI; A02, Hardcopy

Simulation and visualization of rover behavior are critical capabilities for scientists and rover operators to construct, test, and validate plans for commanding a remote rover. The VIPER system links these capabilities. using a high-fidelity virtual-reality (VR) environment. a kinematically accurate simulator, and a flexible plan executive to allow users to simulate and visualize possible execution outcomes of a plan under development. This work is part of a larger vision of a science-centered rover control environment, where a scientist may inspect and explore the environment via VR tools, specify science goals, and visualize the expected and actual behavior of the remote rover. The VIPER system is constructed from three generic systems, linked together via a minimal amount of customization into the integrated system. The complete system points out the power of combining plan execution, simulation, and visualization for envisioning rover behavior; it also demonstrates the utility of developing generic technologies. which can be combined in novel and useful ways.

Author

Virtual Reality; Computerized Simulation; Roving Vehicles

20020004189 NASA Ames Research Center, Moffett Field, CA USA

A Framework for Distributed Rover Control and Three Sample Applications

McGuire, Steve; [2001]; In English; No Copyright; Avail: CASI; A01, Hardcopy

In order to develop quality control software for multiple robots, a common interface is required. By developing components in a modular fashion with well-defined boundaries, roboticists can write code to program a generic rover, and only require very simple modifications to run on any robot with a properly implemented framework. The proposed framework advances a Generic Rover that could be any rover, from Real World Interface's All Terrain Robot Vehicle Jr. series to the Fido-class rovers from the Jet Propulsion Laboratory to any other research robot. Using these generic hardware interfaces, software designers and engineers can concentrate on the actual code, and not have to worry about hardware details. In addition to the hardware support framework, three sample applications have been developed to demonstrate the flexibility and extensibility of the framework.

Author

Distributed Parameter Systems; Roving Vehicles; Software Development Tools; Human-Computer Interface

20020002861 Research Inst. for Advanced Computer Science, Moffett Field, CA USA

Particle Filters for Real-Time Fault Detection in Planetary Rovers

Dearden, Richard; Clancy, Dan; Koga, Dennis, Technical Monitor; [2001]; In English; ESA Workshop on On-Board Autonomy; No Copyright; Avail: CASI; A02, Hardcopy

Planetary rovers provide a considerable challenge for robotic systems in that they must operate for long periods autonomously, or with relatively little intervention. To achieve this, they need to have on-board fault detection and diagnosis capabilities in order to determine the actual state of the vehicle, and decide what actions are safe to perform. Traditional model-based diagnosis techniques are not suitable for rovers due to the tight coupling between the vehicle's performance and its environment. Hybrid diagnosis using particle filters is presented as an alternative, and its strengths and weakeners are examined. We also present some extensions to particle filters that are designed to make them more suitable for use in diagnosis problems.

Author

Fault Detection; Robotics; Roving Vehicles

20010114481 NASA Ames Research Center, Moffett Field, CA USA

Rovers as Geological Helpers for Planetary Surface Exploration

Stoker, Carol; DeVincenzi, Donald, Technical Monitor; [2000]; In English, 13 Nov. 2000, Reno, NV, USA; No Copyright; Avail: Other Sources; Abstract Only

Rovers can be used to perform field science on other planetary surfaces and in hostile and dangerous environments on Earth. Rovers are mobility systems for carrying instrumentation to investigate targets of interest and can perform geologic exploration on a distant planet (e.g. Mars) autonomously with periodic command from Earth. For nearby sites (such as the Moon or sites on Earth) rovers can be teleoperated with excellent capabilities. In future human exploration, robotic rovers will assist human explorers as scouts, tool and instrument carriers, and a traverse 'buddy'. Rovers can be wheeled vehicles, like the Mars Pathfinder Sojourner, or can walk on legs, like the Dante vehicle that was deployed into a volcanic caldera on Mt. Spurr, Alaska. Wheeled rovers can generally traverse slopes as high as 35 degrees, can avoid hazards too big to roll over, and can carry a wide range of instrumentation. More challenging terrain and steeper slopes can be negotiated by walkers. Limitations on rover performance result primarily from the bandwidth and frequency with which data are transmitted, and the accuracy with which the rover can navigate to a new position. Based on communication strategies, power availability, and navigation approach planned or demonstrated for Mars missions to date, rovers on Mars will probably traverse only a few meters per day. Collecting samples, especially if it involves accurate instrument placement, will be a slow process. Using live teleoperation (such as operating a rover on the Moon from Earth) rovers have traversed more than 1 km in an 8 hour period while also performing science operations, and can be moved much faster when the goal is simply to make the distance. I will review the results of field experiments with planetary surface rovers, concentrating on their successful and problematic performance aspects. This paper will be accompanied by a working demonstration of a prototype planetary surface rover.

Author

Roving Vehicles; Planetary Surfaces; Geology

20010089410 Smithsonian Institution, Washington, DC USA

A Rover Deployed Ground Penetrating Radar on Mars

Grant, J. A.; Campbell, B. A.; Schutz, A. E.; Conference on the Geophysical Detection of Subsurface Water on Mars; August 2001; In English

Contract(s)/Grant(s): NAG5-9658; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

Radar is a fundamental tool capable of addressing a variety of geological problems on Mars via collection of data suitable for interpreting variations in surface morphology and reflectivity. Surface-deployed ground penetrating radar (GPR) can help further constrain the geology and structure of the near surface of Mars by directly measuring the range and character of in situ radar properties. In recognition of this potential, a miniaturized, easily modified GPR is being developed for possible deployment on a future Mars rover and will enable definition of radar stratigraphy at high spatial resolution to depths of 10-20 meters. Ongoing development of a Mars impulse GPR with industry partners at Geophysical Survey Systems, Inc., focuses on design and testing of a prototype transducer array (with both high frequency bistatic and low frequency monostatic components) in parallel with fabrication of a low power, mass, and volume control unit. The operational depth of 10-20 meters is geared towards definition of stratigraphy, subsurface blocks, and structure at the decimeter to meter scale that is critical for establishing the geologic setting of the rover. GPR data can also be used to infer the degree of any post-depositional pedogenic alteration or weathering that has subsequently taken place, thereby enabling assessment of pristine versus secondary

morphology at the landing site. As is the case for most remote sensing instruments, a GPR may not detect water unambiguously. Nevertheless, any local, near-surface occurrence of liquid water will lead to large, easily detected dielectric contrasts. Moreover, definition of stratigraphy and setting will help in evaluating the history of aqueous activity and where any water might occur and be accessible. Most importantly perhaps, GPR can provide critical context for other rover and orbital instruments/data sets. Hence, GPR deployment along well positioned transects in the vicinity of a lander should enable 3-D mapping of stratigraphy and could serve to guide direct subsurface sampling. Additional information is contained in the original extended abstract.
Author
Ground Penetrating Radar; Roving Vehicles; Electronic Transducers; Remote Sensing; Mars Exploration

20010045056 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
Preliminary Engineering Constraints and Potential Landing Sites for the Mars Exploration Rovers
Golombek, M. P.; Parker, T.; Schofield, T.; Kass, D.; Crisp, J.; Haldemann, A.; Knocke, P.; Roncoli, R.; Lee, W.; Adler, M., et al.; Lunar and Planetary Science XXXII; 2001; In English; CD-ROM contains the entire conference proceedings presented in PDF format; No Copyright; Abstract Only: Available from CASI only as part of the entire parent document

Preliminary engineering constraints on Mars Exploration Rover landing sites are derived, mapped into remote sensing criteria, and used to identify potential landing sites. High-priority sites via an open request to the science community and future plans are described. Additional information is contained in the original extended abstract.
Derived from Text
Landing Sites; Mars Exploration; Roving Vehicles; Mars Surface

20010045045 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
FIDO Prototype Mars Rover Field Trials, May 2000, Black Rock Summit, Nevada
Seelos, F. P.; Arvidson, R. E.; Squyres, S. W.; Baumgartner, E. T.; Schenker, P. S.; Jolliff, B. L.; Niebur, C. S.; Larsen, K. W.; Snider, N. O.; Lunar and Planetary Science XXXII; 2001; In English; CD-ROM contains the entire conference proceedings presented in PDF format; No Copyright; Abstract Only: Available from CASI only as part of the entire parent document

Results of May 2000 field testing of the FIDO prototype Mars rover are summarized. Tests included remote science operations and simulated aspects of the Athena payload for 2003 MER (Mars Exploration Rovers). Additional information is contained in the original extended abstract.
Derived from Text
Field Tests; Environmental Tests; Performance Tests; Prototypes; Roving Vehicles

20010023135 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
Exploring Mars with Balloons and Inflatable Rovers
Jones, Jack A.; Cutts, James A.; Kerzhanovich, Viktor V.; Yavrouian, Andre; Hall, Jeffrey L.; Raque, Steven; Fairbrother, Debbie A.; Concepts and Approaches for Mars Exploration; July 2000, Part 1; In English; No Copyright; Avail: CASI; A01, Hardcopy

Until now, the exploration of Mars has taken place with global coverage of the planet by satellites in orbit or with landers providing very detailed coverage of extremely limited local areas. New developments in inflatable technology, however, now offer the possibility of in situ surface and atmospheric global studies of Mars using very lightweight rovers and balloons that can travel hundreds or even thousands of kilometers relatively quickly and safely. Both systems are currently being tested at JPL; preliminary results show great promise. One of the balloon technologies offers the additional bonus of being able to land payloads on Mars much more gently than parachutes, yet with considerably less mass.
Derived from text
Roving Vehicles; Inflatable Structures; Mars Exploration; Balloons

20010023042 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
FIDO Field Trials in Preparation for Mars Rover Exploration and Discovery and Sample Return Missions
Arvidson, R. E.; Baumgartner, E. T.; Schenker, P.; Squyres, S. W.; Concepts and Approaches for Mars Exploration; July 2000, Part 1; In English; No Copyright; Avail: CASI; A01, Hardcopy

The Mars 2003 Mission may include a rover to acquire remote sensing and in-situ measurements of surface materials, including rock surfaces that have been cleared of dust and coatings by use of an abrasion tool. Mars Sample Return Missions for 2005 and beyond may include rovers with remote sensing and in-situ measurement capabilities. Further, these mobility

platforms may have systems to drill into rocks and collect cores, acquire soil samples, and place the rock and soil samples in ascent vehicles. The point of this abstract is to document that these operations have already been shown to be tractable based on continuing field trials of the FIDO Mars prototype rover.
Derived from text
Mars Sample Return Missions; Mars Surface; Roving Vehicles

20010020520 NASA Ames Research Center, Moffett Field, CA USA
Field Experiments with Planetary Surface Rovers: Lessons for Mars Mission Architecture
Stoker, Carol; Concepts and Approaches for Mars Exploration; July 2000, Part 2; In English; No Copyright; Avail: CASI; A01, Hardcopy

Over the last decade, a variety of field experiments have been performed that simulate operations of a rover on Mars. These, in combination with the Pathfinder experience, lead to a realistic assessment of rover mission capabilities and to recommendations for rover technology and mission architecture to improve the science return of Mars exploration. A table summarizes field experiments that represent a range of possible mission designs and operational strategies. The experiments varied by the type and quality of imaging systems and other instrumentation, the use of orbital and aerial imaging and spectroscopy, the communcation bandwidth and command strategy, and the distance traveled. All mission simulations were blind field tests operated by science teams whose interpretations were compared to field ground truth providing an assessment of the accuracy of remote science interpretations and a better understanding of where improvements are needed.
Author
Mars Missions; Mars Exploration; Mission Planning; Roving Vehicles; Simulation

20010019295 NASA Ames Research Center, Moffett Field, CA USA
Potential Mars Exploration Rover Landing Sites West and South of Apollinaris Patera
Gulick, Virginia C.; First Landing Site Workshop for the 2003 Mars Exploration Rovers; 2001; In English; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

Apollinaris provides an exceptional site for astrobiological, geological, and climatalogical purposes. Fluvial (including ground water sapping) and associated processes were likely pervasive from the late Noachian, through the Hesperian, and into the Amazonian. Long-lived and large scale hydrothermal systems were certainly present throughout much if not all of this period. Thermal springs likely persisted for long periods. Water from the highlands via Ma'adim Valles and other smaller valley networks deposited highland-derived material in the area. In short, Apollinaris provides an excellent variety of rock types and ages and may preserve evidence of biologic or pre-biologic processes in associated thermal spring deposits.
Derived from text
Mars Exploration; Mars Volcanoes; Landing Sites; Roving Vehicles

20010019285 NASA Johnson Space Center, Houston, TX USA
The TES Hematite-Rich Region in Sinus Meridiani: A Proposed Landing Site for the 2003 Rover
Christensen, Philip R.; Bandfield, Joshua; Hamilton, Victoria; Ruff, Steven; Morris, Richard; Lane, Melissa; Malin, Michael, et al.; First Landing Site Workshop for the 2003 Mars Exploration Rovers; 2001; In English; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

The Thermal Emission Spectrometer (TES) instrument on the Mars Global Surveyor (MGS) mission has identified an accumulation of crystalline hematite (alpha-Fe2O3) that covers an area with very sharp boundaries approximately 350 by 750 km in size centered near 2 S latitude between 0 and 8 W longitude (Sinus Meridiani). The depth and shape of the hematite fundamental bands in the TES spectra show that the hematite is relatively coarse grained (greater than 5-10 micrometers). The spectrally-derived areal abundance of hematite varies with particle size from approximately 10% for particles greater than 30 micrometers in diameter to 40-60% for unpacked 10 micrometer powders. The hematite in Sinus Meridiani is thus distinct from the fine-grained (diameter less than 5-10 micrometers), red, crystalline hematite considered, on the basis of visible and near-IR data, to be a minor spectral component in Martian bright regions. A global map of the hematite abundance has been constructed using TES data from the MGS mapping mission.
Derived from text
Landing Sites; Spectrometers; Thermal Emission; Roving Vehicles; Hematite; Mars Surface

20010019278 Lunar and Planetary Inst., Houston, TX USA
First Landing Site Workshop for the 2003 Mars Exploration Rovers
2001; In English; 1st Landing Site Workshop for the 2003 Mars Exploration Rovers, 24-25 Jan. 2001, Mountain View, CA, USA
Contract(s)/Grant(s): NASW-4574
Report No.(s): LPI-Contrib-1079; No Copyright; Avail: CASI; A05, Hardcopy; Abstracts Only

This volume contains abstracts that have been accepted for presentation at the First Landing Site Workshop for the 2003 Mars Exploration Rovers, January 24-25, 2001.
Author
Mars Exploration; Roving Vehicles; Landing Sites; Mars (Planet); Mars Surface; Conferences

20010018838 Stanford Univ., Stanford, CA USA
Development and Demonstration of a Self-Calibrating Pseudolite Array for Task Level Control of a Planetary Rover
Rock, Stephen M.; LeMaster, Edward A.; January 2001; In English
Contract(s)/Grant(s): NAG2-1330; No Copyright; Avail: CASI; A03, Hardcopy

Pseudolites can extend the availability of GPS-type positioning systems to a wide range of applications not possible with satellite-only GPS. One such application is Mars exploration, where the centimeter-level accuracy and high repeatability of CDGPS would make it attractive for rover positioning during autonomous exploration, sample collection, and habitat construction if it were available. Pseudolites distributed on the surface would allow multiple rovers and/or astronauts to share a common navigational reference. This would help enable cooperation for complicated science tasks, reducing the need for instructions from Earth and increasing the likelihood of mission success. Conventional GPS Pseudolite arrays require that the devices be pre-calibrated through a Survey of their locations, typically to sub-centimeter accuracy. This is a problematic task for robots on the surface of another planet. By using the GPS signals that the Pseudolites broadcast, however, it is possible to have the array self-survey its own relative locations, creating a SelfCalibrating Pseudolite Array (SCPA). This requires the use of GPS transceivers instead of standard pseudolites. Surveying can be done either at carrier- or code-phase levels. An overview of SCPA capabilities, system requirements, and self-calibration algorithms is presented in another work. The Aerospace Robotics Laboratory at Statif0id has developed a fully operational prototype SCPA. The array is able to determine the range between any two transceivers with either code- or carrier-phase accuracy, and uses this inter-transceiver ranging to determine the at-ray geometry. This paper presents results from field tests conducted at Stanford University demonstrating the accuracy of inter-transceiver ranging and its viability and utility for array localization, and shows how transceiver motion may be utilized to refine the array estimate by accurately determining carrier-phase integers and line biases. It also summarizes the overall system requirements and architecture, and describes the hardware and software used in the prototype system.
Author
Global Positioning System; Robotics; Roving Vehicles; Transmitter Receivers

20010003945 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
Loop Heat Pipe Applications for Thermal Control of Martian Landers/Rovers
Birur, Gaj; Rodriquez, Jose; Nikitkin, Michael; [1999]; In English; 10th 10th Spacecraft Thermal Control Technology Workshop, 24-26 Feb. 1999, El Segundo, CA, USA; No Copyright; Avail: CASI; A03, Hardcopy

In early nineties Mars was designated as the planet to be explored. The present results of Mars program include the following: Background of Mars program. Thermal control design for Martian spacecraft. Loop heat pipe for Lander and Rover. Test results. and LHP applications for future Martian Lander and Rover.
Derived from text
Temperature Control; Heat Pipes; Mars Exploration

20000112987 NASA Ames Research Center, Moffett Field, CA USA
The Athena Mars Rover Science Payload
Squyes, S. W.; Arvidson, R.; Bell, J. F., III; Carr, M.; Christensen, P.; DesMarais, D.; Economou, T.; Gorevan, S.; Klingelhoefer, G.; Haskin, L., et al.; Mars Surveyor 2001 Landing Site Workshop; [1998]; In English; No Copyright; Avail: CASI; A01, Hardcopy

The Mars Surveyor missions that will be launched in April of 2001 will include a highly capable rover that is a successor to the Mars Pathfinder mission's Sojourner rover. The design goals for this rover are a total traverse distance of at least 10 km and a total lifetime of at least one Earth year. The rover's job will be to explore a site in Mars' ancient terrain, searching for materials likely to preserve a record of ancient martian water, climate, and possibly biology. The rover will collect rock and soil samples, and will store them for return to Earth by a subsequent Mars Surveyor mission in 2005. The Athena Mars rover science payload is the suite of scientific instruments and sample collection tools that will be used to perform this job. The specific science objectives that NASA has identified for the '01 rover payload are to: (1) Provide color stereo imaging of martian surface environments, and remotely-sensed point discrimination of mineralogical composition. (2) Determine the elemental and mineralogical composition of martian surface materials. (3) Determine the fine-scale textural properties of these materials. (4) Collect and store samples. The Athena payload has been designed to meet these objectives. The focus of the design is on field operations: making sure the rover can locate, characterize, and collect scientifically important samples in a dusty, dirty, real-world environment. The topography, morphology, and mineralogy of the scene around the rover will be revealed by Pancam/Mini-TES, an integrated imager and IR spectrometer. Pancam views the surface around the rover in stereo and color. It uses two high-resolution cameras that are identical in most respects to the rover's navigation cameras. The detectors are low-power, low-mass active pixel sensors with on-chip 12-bit analog-to-digital conversion. Filters provide 8-12 color spectral bandpasses over the spectral region from 0.4 to 1.1 micron Narrow-angle optics provide an angular resolution of 0.28 mrad/pixel, nearly a factor of four higher than that of the Mars Pathfinder and Mars Surveyor '98 cameras. Image compression will be performed using a wavelet compression algorithm. The Mini-Thermal Emission Spectrometer (Mini-TES) is a point spectrometer operating in -the thermal IR. It produces high spectral resolution (5 /cm) image cubes with a wavelength range of 5-40 gm, a nominal signal/noise ratio of 500:1, and a maximum angular resolution of 7 mrad (7 cm at a distance of 10 in). The wavelength region over which it operates samples the diagnostic fundamental absorption features of rockforming minerals, and also provides some capability to see through dust coatings that could tend to obscure spectral features. The mineralogical information that Mini-TES provides will be used to select from a distance the rocks and soils that will be investigated in more detail and ultimately sampled. Mini-TES is derived from the MO/MGS TES instrument, but is significantly smaller and simpler. The instrument uses an 8-cm Cassegrain telescope, a Michelson interferometer, and uncooled pyroelectric detectors. Along with its mineralogical capabilities, Mini-TES can provide information on the thermophysical properties of rocks and soils. Viewing upward, it can also provide temperature profiles through the martian atmospheric boundary layer. Elemental and Mineralogical Composition: Once promising samples have been identified from a distance using Pancam/Mini-TES, they will be studied in detail using up to three compositional sensors that can be placed directly against them by an Instrument Arm. The two compositional sensors, presently on the payload are an Alpha-Proton-X-Ray Spectrometer (APXS), and a Mossbauer Spectrometer. The APXS is derived closely from the instrument that flew on Mars Pathfinder. Radioactive alpha sources and three detection modes (alpha, proton, and x-ray) provide elemental abundances of rocks and soils to complement and constrain mineralogical data. The Athena APXS will have a revised mechanical design that will cut down significantly on backscattering of alpha particles from martian atmospheric carbon. It will also include a target of known elemental composition that will be used for calibration purposes. The Athena Mossbauer Spectrometer is a diagnostic instrument for the mineralogy and oxidation state of Fe-bearing phases, which are particularly important on Mars. The instrument measures the resonant absorption of gamma rays produced by a Co-57 source to determine splitting of nuclear energy levels in Fe atoms that is related to the electronic environment surrounding them. It has been under development for space flight for many years at the Technical University of Darmstadt. The Mossbauer Spectrometer (and the other arm instruments) will be able to view a small permanent magnet array that will attract magnetic particles in the martian soil. The payload may also include a Raman Spectrometer. If included, the Raman Spectrometer will provide precise identification of major and minor mineral phases. It requires no sample preparation, and is also sensitive to organics. Fine-Scale Texture: The Instrument Arm a also carries a Microscopic Imager that will obtain high-resolution monochromatic images of the same materials for which compositional data will be obtained. Its spatial resolution is 20 micron/pixel over a 1 cm depth of field, and 40 micron/pixel over a 1-cm depth of field. Like Pancam, it uses the same active pixel sensor detectors and electronics as the rover's navigation cameras. The Instrument Arm is a three degree-of-freedom arm that uses designs and components from the Mars Pathfinder and Mars Surveyor '98 projects. Its primary function is instrument positioning. Along with the instruments noted above, it also carries a brush that can be used to remove dust and other loose coatings from rocks. Sample Collection and Storage: Martian rock and soil samples will be collected using a low-power rotary coring drill called the Mini-Corer. An important characteristic of this device is that it can obtain intact samples of rock from up to 5 cm within strong boulders and bedrock, Nominal core dimensions are 8xl7 mm. The Mini-Corer drills a core to the commanded depth in a rock, shears it off, retains it, and extracts it. It can also acquire samples of loose soil, using soil sample cups that are pressed downward into loose material. The Mini-Corer can drill at angles from vertical to 45' off vertical. It has six interchangeable bits for long life. Mechanical damage to the sample during drilling is minimal, and heating is negligible. After acquisition, the sample may be viewed by the arm instruments, and/or placed in one of 104 compartments in the Sample Container. A subset of the acquired samples may be replaced with other samples obtained later if desired. The Sample Container has no moving parts, and is mounted external to the rover for easy removal by the Mars Surveyor 2005 flight system. Operation of the rover

will make extensive use of automated onboard navigation and hazard avoidance capabilities. Otherwise, use of onboard autonomy is minimal. Data downlink capability is about 40 Mbit/sol, and the use of the Mars Surveyor '01 orbiter for data relay imposes a limit of at most two command cycles per sol. Because of the significant amount of time available between command cycles, all payload elements will be operated sequentially, rather than in parallel.; this approach also significantly simplifies operations and minimizes peak power usage. The landing site for the '01 rover has not been selected yet. Site selection will make as full use as possible of Mars Global Surveyor data, and will involve substantial input from the broad Mars science community. Summary: The following table describes the mass, power, providers, and key scientific objectives of all the major elements of the Athena payload. Additional Athena payload information may be found at: http://astrosun.tn.cornell.edu/athena/index.html. Additional information contained in the original.
Author
Mars (Planet); Mars Surface; Mars Surface Samples; Mineralogy; Onboard Equipment; Planetary Geology; Roving Vehicles; Soils; Planetology; Mars Missions

20000112922 NASA Ames Research Center, Moffett Field, CA USA
On-Board Real-Time State and Fault Identification for Rovers
Washington, Richard; [2000]; In English; Robotics and Automation, 2000; No Copyright; Avail: CASI; A02, Hardcopy

For extended autonomous operation, rovers must identify potential faults to determine whether its execution needs to be halted or not. At the same time, rovers present particular challenges for state estimation techniques: they are subject to environmental influences that affect senior readings during normal and anomalous operation, and the sensors fluctuate rapidly both because of noise and because of the dynamics of the rover's interaction with its environment. This paper presents MAKSI, an on-board method for state estimation and fault diagnosis that is particularly appropriate for rovers. The method is based on a combination of continuous state estimation, wing Kalman filters, and discrete state estimation, wing a Markov-model representation.
Author
Error Analysis; Fault Detection; Real Time Operation; Roving Vehicles; State Estimation; Autonomy

20000112898 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
Performance Characteristics of Lithium Ion Prototype Cells for 2003 Mars Sample Return Athena Rover
Ratnakumar, B. V.; Smart, M. C.; Ewell, R.; Surampudi, S.; Marsh, R. A.; The 1999 NASA Aerospace Battery Workshop; May 2000; In English; No Copyright; Avail: CASI; A03, Hardcopy

A viewgraph presentation outlines the mission objectives and power subsystem for the Mars Sample Return (MSR) Athena Rover. The NASA-DOD (depth of discharge) Interagency Li Ion program objectives are discussed. Evaluation tests performed at JPL are listed, and test results are shown for the Li-Ion cell initial capacity, charge/discharge capacity, voltage and ratio, specific energy, watt-hour efficiency, and cell voltage at various temperatures.
CASI
Lithium Batteries; Electrolytic Cells; Temperature Effects

20000110302 NASA Ames Research Center, Moffett Field, CA USA
Results of the First Astronaut-Rover (ASRO) Field Experiment: Lessons and Directions for the Human Exploration of Mars
Cabrol, N. A.; Kosmo, J. J.; Trevino, R. C.; Thomas, H.; Eppler, D.; Bualat, M. G.; Baker, K.; Huber, E.; Sierhuis, M.; Grin, E. A., et al.; The Fifth International Conference on Mars; July 1999; In English; CD-ROM contains the entire conference proceedings presented in PDF format; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

The first Astronaut-Rover Interaction field experiment (hereafter designated as the ASRO project) took place Feb. 22-27, 1999, in Silver Lake, Mojave Desert, CA. The ASRO project is the result of a joint project between NASA Ames Research Center and Johnson Space Center. In the perspective of the Human Exploration and Development of Space (HEDS) of the Solar System, this interaction - the astronaut and the rover as a complementary and interactive team - in the field is critical to assess but had never been tested before the Silver Lake experiment. Additional information is contained in the original extended abstract.
Author
Solar System; Roving Vehicles; Mars Surface

20000102369 NASA Ames Research Center, Moffett Field, CA USA

State Identification for Planetary Rovers: Learning and Recognition

Aycard, Olivier; Washington, Richard; [1999]; In English; Robotics and Aeronautics, 2000; No Copyright; Avail: CASI; A02, Hardcopy

A planetary rover must be able to identify states where it should stop or change its plan. With limited and infrequent communication from ground, the rover must recognize states accurately. However, the sensor data is inherently noisy, so identifying the temporal patterns of data that correspond to interesting or important states becomes a complex problem. In this paper, we present an approach to state identification using second-order Hidden Markov Models. Models are trained automatically on a set of labeled training data; the rover uses those models to identify its state from the observed data. The approach is demonstrated on data from a planetary rover platform.

Author

Education; Roving Vehicles; Planetary Surfaces

20000095579 NASA Ames Research Center, Moffett Field, CA USA

Autonomous Onboard Science Image Analysis for Future Mars Rover Missions

Gulick, V. C.; Morris, R. L.; Ruzon, M. A.; Roush, T. L.; [1999]; In English, 1999, Padova, Italy; No Copyright; Avail: Other Sources; Abstract Only

To explore high priority landing sites and to prepare for eventual human exploration, future Mars missions will involve rovers capable of traversing tens of kilometers. However, the current process by which scientists interact with a rover does not scale to such distances. Specifically, numerous command cycles are required to complete even simple tasks, such as, pointing the spectrometer at a variety of nearby rocks. In addition, the time required by scientists to interpret image data before new commands can be given and the limited amount of data that can be downlinked during a given command cycle constrain rover mobility and achievement of science goals. Experience with rover tests on Earth supports these concerns. As a result, traverses to science sites as identified in orbital images would require numerous science command cycles over a period of many weeks, months or even years, perhaps exceeding rover design life and other constraints. Autonomous onboard science analysis can address these problems in two ways. First, it will allow the rover to transmit only ‘interesting’ images, defined as those likely to have higher science content. Second, the rover will be able to anticipate future commands. For example, a rover might autonomously acquire and return spectra of ‘interesting’ rocks along with a high resolution image of those rocks in addition to returning the context images in which they were detected. Such approaches, coupled with appropriate navigational software, help to address both the data volume and command cycle bottlenecks that limit both rover mobility and science yield. We are developing fast, autonomous algorithms to enable such intelligent on-board decision making by spacecraft. Autonomous algorithms developed to date have the ability to identify rocks and layers in a scene, locate the horizon, and compress multi-spectral image data. Output from these algorithms could be used to autonomously obtain rock spectra, determine which images should be transmitted to the ground, or to aid in image compression. We will discuss these and other algorithms and demonstrate their performance during a recent rover field test.

Author

Design Analysis; Manufacturing; Downlinking; Field Tests; High Resolution; Spectrometers; Waterproofing; Detection; Water; Mars Missions; Roving Vehicles

20000094522 NASA Ames Research Center, Moffett Field, CA USA

1999 Marsokhod Field Experiment: A Simulation of a Mars Rover Science Mission

Stoker, C.; Cabrol, N.; Roush, T.; Gulick, V.; Hovde, G.; Moersch, J., et al.; [1999]; In English; 30th Lunar and Planetary Sciences; No Copyright; Avail: CASI; A01, Hardcopy

A field experiment to simulate a rover mission to Mars was performed in February 1999. This experiment, the latest in a series of rover field experiments, was designed to demonstrate and validate technologies and investigation strategies for high-science, high-technology performance, and cost-effective planetary rover operations. Objectives: The experiment objectives were to: (1) train scientists in a mission configuration relevant to Surveyor program rover missions at a terrestrial analog field site simulating the criteria of high-priority candidate landing-sites on Mars; (2) develop optimal exploration strategies; (3) evaluate the effectiveness of imaging and spectroscopy in addressing science objectives; (4) assess the value and limitation of descent imaging in supporting rover operations; and (5) evaluate the ability of a science team to correctly interpret the geology of the field site using rover observations. A field site in the California Mojave Desert was chosen for its relevance to the criteria for landing site selection for the Mars Surveyor program. These criteria are: (1) evidence of past water activity;

(2) presence of a mechanism to concentrate life; (3) presence of thermal energy sources; (4) evidence of rapid burial; and (5) excavation mechanisms that could expose traces of life.
Author
Excavation; Imaging Techniques; Mars Missions; Mars Surface; Marsokhod Mars Roving Vehicles; Planetary Surfaces; Simulation

20000081752 NASA Ames Research Center, Moffett Field, CA USA
1999 Marsokhod Field Experiment: A Simulation of a Mars Rover Science Mission
Stoker, C.; Cabrol, N.; Roush, T.; Gulick, V.; Hovde, G.; Moersch, J.; [1999]; In English; 30th 30th Lunar and Planetary Science Conference, 15-19 Mar. 1999, Houston, TX, USA; No Copyright; Avail: CASI; A01, Hardcopy

A field experiment to simulate a rover mission to Mars was performed in February 1999. This experiment, the latest in a series of rover field experiments, was designed to demonstrate and validate technologies and investigation strategies for high-science, high-technology performance, and cost-effective planetary rover operations.
Author
Marsokhod Mars Roving Vehicles; Planetary Surfaces; Mars Exploration; Mars Missions; Simulation

20000081627 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
FIDO Rover Trials, Silver Lake, California, in Preparation for the Mars Sample Return Mission
Arvidson, R. E.; Squyres, S. W.; Baumgartner, E. T.; Blaney, D. L.; Haldemann, A. F.; Klingelhoefer, G.; Lunar and Planetary Science XXXI; March 2000; In English; CD-ROM: CD-ROM contains entire conference proceedings presented in PDF format; No Copyright; Available from CASI only as part of the entire parent document

During field trials in the Mojave Desert, the Mars Sample Return (MSR) prototype rover, FIDO, simulated sampling and exploration activities with a science payload similar to what will be on the MSR rover, validating the mission operations approach.
Author
Mars Sample Return Missions; Roving Vehicles

20000080944 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
Student Participation in Mars Sample Return Rover Field Tests, Silver Lake, California
Anderson, R. C.; Arvidson, R. E.; Bowman, J. D.; Dunham, C. D.; Backes, P.; Baumgartner, E. T.; Bell, J.; Dworetzky, S. C.; Klug, S.; Peck, N.; Lunar and Planetary Science XXXI; March 2000; In English; CD-ROM: CD-ROM contains the entire conference proceedings presented in PDF format; No Copyright; Available from CASI only as part of the entire parent document

An integrated team of students and teachers from four high schools across the country developed and implemented their own mission of exploration and discovery using the Mars Sample Return prototype rover, FIDO, at Silver Lake in the Mojave Desert.
Author
Field Tests; Students; Education; Mars Surface; Roving Vehicles

20000080936 State Univ. of New York, Buffalo, NY USA
Development of a Rover Deployed Ground Penetrating Radar
Grant, J. A.; Schutz, A. E.; Campbell, B. A.; Lunar and Planetary Science XXXI; March 2000; In English; CD-ROM: CD-ROM contains the entire conference proceedings presented in PDF format
Contract(s)/Grant(s): NAG5-4569; No Copyright; Available from CASI only as part of the entire parent document

Development of a rover deployable Ground Penetrating Radar (GPR) involves: the nearly finished design and testing of a transducer array with high frequency (bistatic) and low frequency (monostatic) components; and design and development of a complete impulse GPR system.
Author
Ground Penetrating Radar; Roving Vehicles; Planetary Surfaces; Planetary Geology; Space Exploration

20000064074 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
Mars Rover Navigation Results Using Sun Sensor Heading Determination
Volpe, Richard; [1998]; In English; No Copyright; Avail: CASI; A02, Hardcopy

Upcoming missions to the surface of Mars will use mobile robots to traverse long distances from the landing site. To prepare for these missions, the prototype rover, Rocky 7, has been tested in desert field trials conducted with a team of planetary scientists. While several new capabilities have been demonstrated, foremost among these was sun-sensor based traversal of natural terrain totaling a distance of one kilometer. This paper describes navigation results obtained in the field tests, where cross-track error was only 6% of distance traveled. Comparison with previous results of other planetary rover systems shows this to be a significant improvement.
Author
Mars Surface; Roving Vehicles; Surface Navigation; Robots; Solar Sensors

20000057424 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
The Mars Surveyor '01 Rover and Robotic Arm
Bonitz, Robert G.; Nguyen, Tam T.; Kim, Won S.; [1999]; In English; No Copyright; Avail: CASI; A03, Hardcopy

The Mars Surveyor 2001 Lander will carry with it both a Robotic Arm and Rover to support various science and technology experiments. The Marie Curie Rover, the twin sister to Sojourner Truth, is expected to explore the surface of Mars in early 2002. Scientific investigations to determine the elemental composition of surface rocks and soil using the Alpha Proton X-Ray Spectrometer (APXS) will be conducted along with several technology experiments including the Mars Experiment on Electrostatic Charging (MEEC) and the Wheel Abrasion Experiment (WAE). The Rover will follow uplinked operational sequences each day, but will be capable of autonomous reactions to the unpredictable features of the Martian environment. The Mars Surveyor 2001 Robotic Arm will perform rover deployment, and support various positioning, digging, and sample acquiring functions for MECA (Mars Environmental Compatibility Assessment) and Mossbauer Spectrometer experiments. The Robotic Arm will also collect its own sensor data for engineering data analysis. The Robotic Arm Camera (RAC) mounted on the forearm of the Robotic Arm will capture various images with a wide range of focal length adjustment during scientific experiments and rover deployment
Author
Mars Surface; Mars Surveyor 2001 Mission; Robot Arms; X Ray Spectrometers; Mars (Planet); Roving Vehicles

20000056903 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
Die Attachment for -120 C to +20 C Thermal Cycling of Microelectronics for Future Mars Rovers: An Overview
Kirschman, Randall K.; Sokolowski, Witold M.; Kolawa, Elizabeth A.; [1999]; In English; InterPACK, 1999; No Copyright; Avail: CASI; A02, Hardcopy

Active thermal control for electronics on Mars Rovers imposes a serious penalty in weight, volume, power consumption, and reliability. Thus, we propose that thermal control be eliminated for future Rovers. From a functional standpoint there is no reason that the electronics could not operate over the entire temperature range of the Martian environment, which can vary from a low of approximately equal -90 C to a high of approximately equal +20 C during the Martian night and day. The upper end of this range is well within that for conventional electronics. Although the lower end is considerably below that for which conventional--even high-reliability electronics is designed or tested, it is well established that electronic devices can operate to such low temperatures. The primary concern is reliability of the overall electronic system, especially in regard to the numerous daily temperature cycles that it would experience over the duration of a mission on Mars. Accordingly, key reliability issues have been identified for elimination of thermal control on future Mars Rovers. One of these is attachment of semiconductor die onto substrates and into packages. Die attachment is critical since it forms a mechanical, thermal and electrical interface between the electronic device and the substrate or package. This paper summarizes our initial investigation of existing information related to this issue, in order to form an opinion whether die attachment techniques exist, or could be developed with reasonable effort, to withstand the Mars thermal environment for a mission duration of approximately I year. Our conclusion, from a review of literature and personal contacts. is that die attachment can be made sufficiently reliable to satisfy the requirements of future Mars Rovers. Moreover, it appears that there are several possible techniques from which to choose and that the requirements could be met by judicious selection from existing methods using hard solders, soft solders, or organic adhesives. Thus from the standpoint of die attachment. it appears feasible to eliminate thermal control for Rover electronics. We recommend that this be further investigated and verified for the specific hardware and thermal conditions appropriate to Mars Rovers.
Author
Active Control; Temperature Control; Thermal Cycling Tests; Microelectronics; Electronic Equipment; Component Reliability

20000056888 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
Advanced Design and Implementation of a Control Architecture for Long Range Autonomous Planetary Rovers
Martin-Alvarez, A.; Hayati, S.; Volpe, R.; Petras, R.; [1999]; In English; Artificial Intelligence, Robotics and Automation for Space, 1999, Noordwijk, Netherlands; No Copyright; Avail: CASI; A03, Hardcopy

An advanced design and implementation of a Control Architecture for Long Range Autonomous Planetary Rovers is presented using a hierarchical top-down task decomposition, and the common structure of each design is presented based on feedback control theory. Graphical programming is presented as a common intuitive language for the design when a large design team is composed of managers, architecture designers, engineers, programmers, and maintenance personnel. The whole design of the control architecture consists in the classic control concepts of cyclic data processing and event-driven reaction to achieve all the reasoning and behaviors needed. For this purpose, a commercial graphical tool is presented that includes the mentioned control capabilities. Messages queues are used for inter-communication among control functions, allowing Artificial Intelligence (AI) reasoning techniques based on queue manipulation. Experimental results show a highly autonomous control system running in real time on top the JPL micro-rover Rocky 7 controlling simultaneously several robotic devices. This paper validates the sinergy between Artificial Intelligence and classic control concepts in having in advanced Control Architecture for Long Range Autonomous Planetary Rovers.
Author
Design Analysis; Control Systems Design; Automatic Control; Autonomy; Feedback Control; Control Theory

20000056091 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
Long Range Navigation for Mars Rovers Using Sensor-Based Path Planning and Visual Localisation
Laubach, Sharon L.; Olson, Clark F.; Burdick, Joel W.; Hayati, Samad; [1999]; In English; No Copyright; Avail: CASI; A02, Hardcopy

The Mars Pathfinder mission illustrated the benefits of including a mobile robotic explorer on a planetary mission. However, for future Mars rover missions, significantly increased autonomy in navigation is required in order to meet demanding mission criteria. To address these requirements, we have developed new path planning and localisation capabilities that allow a rover to navigate robustly to a distant landmark. These algorithms have been implemented on the JPL Rocky 7 prototype microrover and have been tested extensively in the JPL MarsYard, as well as in natural terrain.
Author
Mars Surface; Navigation; Robotics; Roving Vehicles; Trajectory Planning; Position Sensing; Mars Sample Return Missions

20000054886 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
A Comparison of Two Path Planners for Planetary Rovers
Tarokh, M.; Shiller, Z.; Hayati, S.; [1999]; In English; No Copyright; Avail: CASI; A02, Hardcopy

The paper presents two path planners suitable for planetary rovers. The first is based on fuzzy description of the terrain, and genetic algorithm to find a traversable path in a rugged terrain. The second planner uses a global optimization method with a cost function that is the path distance divided by the velocity limit obtained from the consideration of the rover static and dynamic stability. A description of both methods is provided, and the results of paths produced are given which show the effectiveness of the path planners in finding near optimal paths. The features of the methods and their suitability and application for rover path planning are compared
Author
Roving Vehicles; Terrain; Genetic Algorithms

20000054884 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
Autonomous Rock Tracking and Acquisition from a Mars Rover
Maimone, Mark W.; Nesnas, Issa A.; Das, Hari; [1999]; In English; No Copyright; Avail: CASI; A02, Hardcopy

Future Mars exploration missions will perform two types of experiments: science instrument placement for close-up measurement, and sample acquisition for return to Earth. In this paper we describe algorithms we developed for these tasks, and demonstrate them in field experiments using a self-contained Mars Rover prototype, the Rocky 7 rover. Our algorithms perform visual servoing on an elevation map instead of image features, because the latter are subject to abrupt scale changes during the approach. ‘This allows us to compensate for the poor odometry that results from motion on loose terrain. We demonstrate the successful grasp of a 5 cm long rock over 1m away using 103-degree field-of-view stereo cameras, and

placement of a flexible mast on a rock outcropping over 5m away using 43 degree FOV stereo cameras.
Author
Autonomy; Mars Surface; Rocks; Roving Vehicles; Command and Control; Guidance (Motion); Robotics; Trajectory Planning; Position Sensing; Task Planning (Robotics); Mars (Planet)

20000053102 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
Automated Planning and Scheduling for Planetary Rover Distributed Operations
Backes, Paul G.; Rabideau, Gregg; Tso, Kam S.; Chien, Steve; [1999]; In English; No Copyright; Avail: CASI; A02, Hardcopy

Automated planning and Scheduling, including automated path planning, has been integrated with an Internet-based distributed operations system for planetary rover operations. The resulting prototype system enables faster generation of valid rover command sequences by a distributed planetary rover operations team. The Web Interface for Telescience (WITS) provides Internet-based distributed collaboration, the Automated Scheduling and Planning Environment (ASPEN) provides automated planning and scheduling, and an automated path planner provided path planning. The system was demonstrated on the Rocky 7 research rover at JPL.
Author
Scheduling; Trajectory Planning; Planetary Surfaces; Communication Networks; Data Acquisition

20000052595 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
Performance Characteristics of Lithium-Ion Cells for Mars Sample Return Athena Rover
Ratnakumar, B. V.; Smart, M. C.; Ewell, R.; Surampudi, S.; Marsh, R.; 1999; In English
Report No.(s): 1999-01-2639; Copyright; Avail: Other Sources

In contrast to the primary batteries (lithium thionyl chloride) on the Sojourner Mars Rover and the upcoming 2001 Mars Rover, the Mars Sample Return (MSR) Athena Rover will utilize rechargeable lithium ion batteries, following the footsteps of MSP 2001 Lander. The MSR Athena Rover will contain a rechargeable lithium ion battery of 16 V and a total energy of 150 Wh. The mass and volume of the projected power system will be a maximum of 3 kg and 2 liters, respectively. Each battery consists of twelve cells (6-7 Ah), combined in three parallel strings of four cells (16 V) each, such that the capability of the Rover shall be maintained even in the event of one string failure. In addition to the usual requirements of high specific energy and energy density and long cycle life (100 cycles), the battery is required to operate at wide range of temperatures, especially at sub-zero temperatures down to -20 C. In this paper, we report various performance characterization tests carried out on lithium ion cells, fabricated by different manufacturers under a NASA/DoD lithium ion battery consortium.
Author
Performance Tests; Primary Batteries; Storage Batteries; Lithium Batteries; Charge Efficiency

20000012725 NASA Ames Research Center, Moffett Field, CA USA
Thermal Infrared Spectroscopy from Mars Landers and Rovers: A New Angle on Remote Sensing
Moersch, J.; Horton, K.; Lucey, P.; Roush, T.; Ruff, S.; Smith, M.; Workshop on Mars 2001: Integrated Science in Preparation for Sample Return and Human Exploration; 1999; In English; No Copyright; Avail: CASI; A01, Hardcopy

The MINUTES instrument of the Athena Precursor Experiment (APEX) on the Mars Surveyor 2001 lander mission will perform the first thermal infrared remote sensing observations from the surface of another planet. Experience gained from this experiment will be used to guide observations from identical instruments mounted on the Athena rovers, to be launched in 2003 and 2005. The utility of infrared spectrometers in determining the mineralogic composition of geologic surfaces from airborne and spaceborne platforms has been amply demonstrated. However, relatively little experience exists in using functionally similar instruments on the ground in the context of planetary science. What work has been done on this problem has mostly utilized field spectrometers that are designed to look down on nearby target rocks. While many Mini-TES observations will be made with this type of geometry, it is likely that other observations will be made looking horizontally at the more vertically-oriented facets of rock targets, to avoid spectral contamination from dust mantles. On rover missions, the Mini-TES may also be pointed horizontally at rocks several meters away, to determine if they are worthy of approaching for in situ observations and possible sample cacheing. While these observations will undoubtedly prove useful, there are important, and perhaps unappreciated, differences between horizontal-viewing, surface-based spectroscopy and the more traditional nadir-viewing, orbit or aircraft-based observations. Plans also exist to step the Mini-TES in a rastering motion to build hyperspectral scenes. Horizontal viewing hyperspectral cubes also possess unique qualities that call for innovative analysis techniques. The effect of viewing geometry: In thermal emission spectroscopy, regardless of whether an instrument

is looking down on or horizontally at a target, the same basic equation governs the radiance reaching the sensor .
Author
Infrared Spectroscopy; Mars Surveyor 2001 Mission; Remote Sensing; Mars Surface; Mars (Planet)

20000012701 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
Geologic Measurements using Rover Images: Lessons from Pathfinder with Application to Mars 2001
Bridges, N. T.; Haldemann, A. F. C.; Herkenhoff, K. E.; Workshop on Mars 2001: Integrated Science in Preparation for Sample Return and Human Exploration; 1999; In English; No Copyright; Avail: CASI; A01, Hardcopy

The Pathfinder Sojourner rover successfully acquired images that provided important and exciting information on the geology of Mars. This included the documentation of rock textures, barchan dunes, soil crusts, wind tails, and ventifacts. It is expected that the Marie Curie rover cameras will also successfully return important information on landing site geology. Critical to a proper analysis of these images will be a rigorous determination of rover location and orientation. Here, the methods that were used to compute rover position for Sojourner image analysis are reviewed. Based on this experience, specific recommendations are made that should improve this process on the '01 mission.
Author
Mars Pathfinder; Mars Surface; Mars Landing; Roving Vehicles; Mars (Planet); Positioning; Position (Location)

19990053861 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
Mobility Sub-System for the Exploration Technology Rover
Lindemann, Randel; Reid, Lisa; Voorhees, Chris; 33rd Aerospace Mechanisms Symposium; May 1999; In English; No Copyright; Avail: CASI; A03, Hardcopy

A new six-wheeled robotic roving vehicle was developed for NASA's Exploration Technology (ET) program. The rover which is called the Field, Integrated, Design, and Operations (FIDO) rover is being used for advanced technology development. In addition, copies of FIDO's Mobility Sub-System (MSS) are being used for software development in several NASA projects, including the prototype for the flight Athena Rover of the Mars Sample Return (MSR) 2003 mission. The focus of this paper is the work done on the MSS, specifically the development and test of the wheel drive actuators, which are fundamental to vehicle mobility.
Author
Actuators; Mechanical Drives; Robotics; Roving Vehicles; Structural Design

19990036056 NASA Ames Research Center, Moffett Field, CA USA
Rovers for Mars Polar Exploration
Stoker, C.; The First International Conference on Mars Polar Science and Exploration; 1998; In English; No Copyright; Avail: Other Sources; Abstract Only;

Mobility is a generic capability needed for Mars exploration. Requirements for mobility range from those needed to get observations of individual rocks all the way to those for getting high-resolution observations of regional areas. The Pathfinder mission and field experiments simulating rover missions provide guidance as to rover capabilities that can reasonably be expected in the next decade. Success of rover missions in achieving science goals depends on having adequate support imaging to enable traverses to targets of high science interest. Rover field experiments to date have used aerial photographs to provide support imaging. Pathfinder Sojourner operated in the field of view of the IMP camera. Plans for the future involve the use of descent imagers. However, the descent imager planned for the 2001 mission achieves resolution adequate to plan rover traverses only in the near vicinity of the lander (within a few hundred meters). Aircraft could provide aerial support imaging with a resolution of 10 cm over the entire area accessible to a rover. Aircraft could also provide the mobility needed to explore regional scale areas
Author
Aerial Photography; Imaging Techniques; Mars Exploration; Roving Vehicles; Ground Truth; Photointerpretation; Mars Surveyor 98 Program

19990014049 NASA Lewis Research Center, Cleveland, OH USA
Electrostatic Charging of the Pathfinder Rover
Siebert, Mark W.; Kolecki, Joseph C.; 1996; In English; 34th Aerospace Sciences, 15-18 Jan. 1996, Reno, NV, USA
Report No.(s): AIAA Paper 96-0486; No Copyright; Avail: CASI; A03, Hardcopy

The Mars Pathfinder mission will send a lander and a rover to the martian surface. Because of the extremely dry

conditions on Mars, electrostatic charging of the rover is expected to occur as it moves about. Charge accumulation may result in high electrical potentials and discharge through the martian atmosphere. Such discharge could interfere with the operation of electrical elements on the rover. A strategy was sought to mitigate this charge accumulation as a precautionary measure. Ground tests were performed to demonstrate charging in laboratory conditions simulating the surface conditions expected at Mars. Tests showed that a rover wheel, driven at typical rover speeds, will accumulate electrical charge and develop significant electrical potentials (average observed, 110 volts). Measurements were made of wheel electrical potential, and wheel capacitance. From these quantities, the amount of absolute charge was estimated. An engineering solution was developed and recommended to mitigate charge accumulation. That solution has been implemented on the actual rover.
Author
Mars Pathfinder; Mars Surface; Wheels; Capacitance; Electric Charge; Electrostatics; Mars Environment; Roving Vehicles

19980201211 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
Rover and Telerobotics Technology Program
Weisbin, Charles R.; 1998; In English
Report No.(s): NASA/CR-1998-208257; NAS 1.26:208257; PB98-129844; No Copyright; Avail: CASI; A03, Hardcopy

The Jet Propulsion Laboratory's (JPL's) Rover and Telerobotics Technology Program, sponsored by the National Aeronautics and Space Administration (NASA), responds to opportunities presented by NASA space missions and systems, and seeds commerical applications of the emerging robotics technology. The scope of the JPL Rover and Telerobotics Technology Program comprises three major segments of activity: NASA robotic systems for planetary exploration, robotic technology and terrestrial spin-offs, and technology for non-NASA sponsors. Significant technical achievements have been reached in each of these areas, including complete telerobotic system prototypes that have built and tested in realistic scenarios relevant to prospective users. In addition, the program has conducted complementary basic research and created innovative technology and terrestrial applications, as well as enabled a variety of commercial spin-offs.
Author
Robotics; Space Exploration; Technology Utilization; Telerobotics; Roving Vehicles; Autonomous Navigation

19970025198 NASA Lewis Research Center, Cleveland, OH USA
Mars Pathfinder Rover-Lewis Research Center Technology Experiments Program
Stevenson, Steven M.; Jul. 1997; In English; 32nd Intersociety Energy Conversion Engineering, 27 Jul. - 1 Aug. 1997, Honolulu, HI, USA
Contract(s)/Grant(s): RTOP 632-40-44
Report No.(s): NASA-TM-107449; NAS 1.15:107449; E-10726; No Copyright; Avail: CASI; A02, Hardcopy

An overview of NASA's Mars Pathfinder Program is given and the development and role of three technology experiments from NASA's Lewis Research Center and carried on the Mars Pathfinder rover is described. Two recent missions to Mars were developed and managed by the Jet Propulsion Laboratory, and launched late last year: Mars Global Surveyor in November 1996 and Mars Pathfinder in December 1996. Mars Global Surveyor is an orbiter which will survey the planet with a number of different instruments, and will arrive in September 1997, and Mars Pathfinder which consists of a lander and a small rover, landing on Mars July 4, 1997. These are the first two missions of the Mars Exploration Program consisting of a ten year series of small robotic martian probes to be launched every 26 months. The Pathfinder rover will perform a number of technology and operational experiments which will provide the engineering information necessary to design and operate more complex, scientifically oriented surface missions involving roving vehicles and other machinery operating in the martian environment. Because of its expertise in space power systems and technologies, space mechanisms and tribology, Lewis Research Center was asked by the Jet Propulsion Laboratory, which is heading the Mars Pathfinder Program, to contribute three experiments concerning the effects of the martian environment on surface solar power systems and the abrasive qualities of the Mars surface material. In addition, rover static charging was investigated and a static discharge system of several fine Tungsten points was developed and fixed to the rover. These experiments and current findings are described herein.
Author
Mars Pathfinder; Mars Environment; Mars Exploration; Environmental Tests; Roving Vehicles; Spacecraft Power Supplies; Mars Landing; Mars Probes; Mars Surface; Aerospace Engineering

19970019968 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
Mars Pathfinder Spacecraft, Lander, and Rover Testing in Simulated Deep Space and Mars Surface Environments
Johnson, Kenneth R.; Nineteenth Space Simulation Conference Cost Effective Testing for the 21st Century; Jan. 1997; In English; No Copyright; Avail: CASI; A03, Hardcopy

The Mars Pathfinder (MPF) Spacecraft was built and tested at the Jet Propulsion Laboratory during 1995/96. MPF is scheduled to launch in December 1996 and to land on Mars on July 4, 1997. The testing program for MPF required subjecting the mission hardware to both deep space and Mars surface conditions. A series of tests were devised and conducted from 1/95 to 7/96 to study the thermal response of the MPF spacecraft to the environmental conditions in which it will be exposed during the cruise phase (on the way to Mars) and the lander phase (landed on Mars) of the mission. Also, several tests were conducted to study the thermal characteristics of the Mars rover, Sojourner, under Mars surface environmental conditions. For these tests, several special test fixtures and methods were devised to simulate the required environmental conditions. Creating simulated Mars surface conditions was a challenging undertaking since Mars' surface is subjected to diurnal cycling between -20 C and -85 C, with windspeeds to 20 m/sec, occurring in an 8 torr CO2 atmosphere. This paper describes the MPF test program which was conducted at JPL to verify the MPF thermal design.
Author
Mars Pathfinder; Roving Vehicles; Mars Landing; Orbital Space Tests; Vacuum Tests; Thermal Cycling Tests; Thermal Vacuum Tests; Space Vehicle Checkout Program

19960025612 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
Mars pathfinder Rover egress deployable ramp assembly
Spence, Brian R.; Sword, Lee F.; 30th Aerospace Mechanisms Symposium; May 1996; In English; No Copyright; Avail: CASI; A03, Hardcopy

The Mars Pathfinder Program is a NASA Discovery Mission, led by the Jet Propulsion Laboratory, to launch and place a small planetary Rover for exploration on the Martian surface. To enable safe and successful egress of the Rover vehicle from the spacecraft, a pair of flight-qualified, deployable ramp assemblies have been developed. This paper focuses on the unique, lightweight deployable ramp assemblies. A brief mission overview and key design requirements are discussed. Design and development activities leading to qualification and flight systems are presented.
Author
Mars Pathfinder; Mars Surface; Roving Vehicles; Ramps (Structures); Egress

19950070425 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
'Beach-Ball' Robotic Rovers
Smyth, David E.; NASA Tech Briefs; Nov 1, 1995; ISSN 0145-319X; 19, 11; In English
Report No.(s): NPO-19272; No Copyright; Additional information available through: National Technology Transfer Center (NTTC), Wheeling, WV 26003, (Tel: 1-800-678-6882).

Robotic vehicles resembling large beach balls proposed for carrying scientific instruments. Conceived for use in exploring planet Mars, also useful on Earth to carry meteorological or pollution-monitoring equipment to remote locations across rough terrain and even across water. Each vehicle features approximately spherical balloonlike outer shell inflated to suitable pressure. Three diametral tethers approximately perpendicular to each other attached to shell. Control box moves itself along tethers to shift center of gravity, causing vehicle to roll. Alternatively, instead of shell, structure of approximately spherical outline made of twisted rods; of course, not suitable for traversing water or thick vegetation.
Instrument Packages; Measuring Instruments; Remote Sensing; Robotics; Roving Vehicles; Terrain Analysis

19950056270 NASA, Washington, DC, USA
Advancing our ambitions: The 1994 Mars rover tests
Anderson, Charlene M.; Planetary Report; September/October 1994; ISSN 0736-3680; 14, 5; In English; Copyright; Avail: Other Sources

Successes on the space policy front have been matched by advances in technical projects. Last spring the most ambitious Mars Rover test program yet was tackled. Using rover images, four objectives were established: (1) locate the landing site by identifying features seen in descent images, (2) analyze the soil at the site, (3) search for and identify rocks and, (4) find and examine a rock outcrop in cross section. All the tests were completed but the last. The program for 1995 is already being planned.
Herner
Mars Probes; Mars Sample Return Missions; Mission Planning; Performance Tests; Roving Vehicles; Spacecraft Design

19950023543 Interface Video Systems, Inc., Washington, DC, USA

Rover story

Jul 9, 1990; In English

Report No.(s): NASA-CR-198757; JB-0-06-0272; NONP-NASA-VT-95-56825; No Copyright; Avail: CASI; B01, Videotape-Beta; V01, Videotape-VHS

Future Mars exploration missions and operations are discussed using computer animation along with proposed vehicles and equipment, for example, a Mars surface land rover. There is a Presidential Address by President George Bush where he discusses future goals for space exploration. This video also outlines the Outreach Program, which offers the public the chance to suggest new ideas for space research and exploration.

Author

Mars Exploration; Mars Sample Return Missions; Mars Surface; Technological Forecasting

19950017345 Alcatel Espace, Toulouse, France

Terrain modelling and motion planning for an autonomous exploration rover

Richard, F.; Benoliel, S.; Faugeras, O.; Grandjean, P.; Hayard, M.; Simeon, T.; JPL, Third International Symposium on Artificial Intelligence, Robotics, and Automation for Space 1994; Oct 1, 1994; In English; No Copyright; Avail: CASI; A01, Hardcopy

To assess the feasibility of planetary exploration missions using rovers, the French national agency CNES, with a consortium of European laboratories and industrial concerns, has initiated the Eureka project, ‘Illustration of an Autonomous Robot for the Exploration of Space’ (IARES). IARES is a demonstrator composed of a rover and a ground station, linked by telemetry and telecommand. It is aimed at verifying, on earth, robotic concepts developed by the RISP group of French laboratories (LAAS, INRIA, CERT, LETI) to perform scientific missions such as autonomous terrain sample collecting over large areas. To cope with the actual needs of planet exploration, IARES suitability is assessed through constraints on limited bandwidth, time delay and on-board resources. This autonomy relies heavily on robust onboard trajectory generation capabilities. This paper presents the main functions of the IARES navigation sub-system and shows how they are combined to allow movement in Mars-like environments. Section 2 gives an overall description of the IARES system. Section 3 details the functions of the Navigation sub-system, and finally, section 4 illustrates with a simple example the use of these functions.

Author (revised)

Autonomous Navigation; Computer Vision; Inertial Reference Systems; Robot Control; Robot Sensors; Robotics; Robots; Roving Vehicles; Surface Navigation; Teleoperators; Terrain Analysis; Terrain Following; Trajectory Control; Trajectory Planning

19950017292 National Space Development Agency, Tsukuba, Japan

Small image laser range finder for planetary rover

Wakabayashi, Yasufumi; Honda, Masahisa; Adachi, Tadashi; Iijima, Takahiko; JPL, Third International Symposium on Artificial Intelligence, Robotics, and Automation for Space 1994; Oct 1, 1994; In English; No Copyright; Avail: CASI; A01, Hardcopy

A variety of technical subjects need to be solved before planetary rover navigation could be a part of future missions. The sensors which will perceive terrain environment around the rover will require critical development efforts. The image laser range finder (ILRF) discussed here is one of the candidate sensors because of its advantage in providing range data required for its navigation. The authors developed a new compact-sized ILRF which is a quarter of the size of conventional ones. Instead of the current two directional scanning system which is comprised of nodding and polygon mirrors, the new ILRF is equipped with the new concept of a direct polygon mirror driving system, which successfully made its size compact to accommodate the design requirements. The paper reports on the design concept and preliminary technical specifications established in the current development phase.

Author

Laser Range Finders; Navigation; Planetary Surfaces; Roving Vehicles

19950017272 Tokyo Univ., Sagamihara, Japan

Control technique for planetary rover

Nakatani, Ichiro; Kubota, Takashi; Adachi, Tadashi; Saitou, Hiroaki; Okamoto, Sinya; JPL, Third International Symposium on Artificial Intelligence, Robotics, and Automation for Space 1994; Oct 1, 1994; In English; No Copyright; Avail: CASI; A01, Hardcopy

Beginning next century, several schemes for sending a planetary rover to the moon or Mars are being planned. As part of the development program, autonomous navigation technology is being studied to allow the rover the ability to move autonomously over a long range of unknown planetary surface. In the previous study, we ran the autonomous navigation experiment on an outdoor test terrain by using a rover test-bed that was controlled by a conventional sense-plan-act method. In some cases during the experiment, a problem occurred with the rover moving into untraversable areas. To improve this situation, a new control technique has been developed that gives the rover the ability of reacting to the outputs of the proximity sensors, a reaction behavior if you will. We have developed a new rover test-bed system on which an autonomous navigation experiment was performed using the newly developed control technique. In this outdoor experiment, the new control technique effectively produced the control command for the rover to avoid obstacles and be guided to the goal point safely.
Author (revised)
Architecture (Computers); Automatic Control; Autonomous Navigation; Planetary Surfaces; Robot Control; Robot Dynamics; Robot Sensors; Robotics; Roving Vehicles; Terrain Analysis; Terrain Following; Trajectory Planning

19950017270
Subsumption-based architecture for autonomous movement planning for planetary rovers
Nakasuka, Shinichi; Shirasaka, Seikoh; JPL, Third International Symposium on Artificial Intelligence, Robotics, and Automation for Space 1994; Oct 1, 1994; In English; No Copyright; Avail: CASI; A01, Hardcopy

The paper proposes a new architecture for autonomously generating and managing movement plans of planetary rovers. The system utilizes the uniform representation of the instantaneous subgoals in the form of virtual sensor states and the autonomous generation of the subsumption type plan network, which are expected to lead to the capability to pursue the overall goal while efficiently managing various unpredicted anomalies in a partially unknown, ill-structured environment such as a planetary surface.
Author
Architecture (Computers); Artificial Intelligence; Automatic Control; Autonomous Navigation; Computer Systems Design; Machine Learning; Planetary Surfaces; Real Time Operation; Robot Dynamics; Robotics; Roving Vehicles; Teleoperators; Trajectory Planning

19950017269 Tokyo Univ., Sagamihara, Japan
Path planning for planetary rover using extended elevation map
Nakatani, Ichiro; Kubota, Takashi; Yoshimitsu, Tetsuo; JPL, Third International Symposium on Artificial Intelligence, Robotics, and Automation for Space 1994; Oct 1, 1994; In English; No Copyright; Avail: CASI; A01, Hardcopy

This paper describes a path planning method for planetary rovers to search for paths on planetary surfaces. The planetary rover is required to travel safely over a long distance for many days over unfamiliar terrain. Hence it is very important how planetary rovers process sensory information in order to understand the planetary environment and to make decisions based on that information. As a new data structure for informational mapping, an extended elevation map (EEM) has been introduced, which includes the effect of the size of the rover. The proposed path planning can be conducted in such a way as if the rover were a point while the size of the rover is automatically taken into account. The validity of the proposed methods is verified by computer simulations.
Author (revised)
Algorithms; Architecture (Computers); Automatic Control; Data Structures; Mathematical Models; Planetary Surfaces; Relief Maps; Robot Dynamics; Robotics; Roving Vehicles; Terrain Analysis; Terrain Following; Trajectory Planning

19950005124 Sandia National Labs., Albuquerque, NM, USA
A multitasking behavioral control system for the Robotic All Terrain Lunar Exploration Rover (RATLER)
Klarer, P.; NASA. Johnson Space Center, Conference on Intelligent Robotics in Field, Factory, Service and Space (CIRFFSS 1994), Volume 2; Mar 1, 1994; In English
Report No.(s): AIAA PAPER 94-1281-CP; Copyright; Avail: CASI; A02, Hardcopy

An alternative methodology for designing an autonomous navigation and control system is discussed. This generalized hybrid system is based on a less sequential and less anthropomorphic approach than that used in the more traditional artificial intelligence (AI) technique. The architecture is designed to allow both synchronous and asynchronous operations between various behavior modules. This is accomplished by intertask communications channels which implement each behavior module and each interconnection node as a stand-alone task. The proposed design architecture allows for construction of hybrid systems which employ both subsumption and traditional AI techniques as well as providing for a teleoperator's

interface. Implementation of the architecture is planned for the prototype Robotic All Terrain Lunar Explorer Rover (RATLER) which is described briefly.
CASI
Artificial Intelligence; Control Systems Design; Lunar Exploration; Lunar Roving Vehicles; Real Time Operation; Robot Control; Robotics

19950005122 Massachusetts Inst. of Tech., Cambridge, MA, USA
The MITy micro-rover: Sensing, control, and operation
Malafeew, Eric; Kaliardos, William; NASA. Johnson Space Center, Conference on Intelligent Robotics in Field, Factory, Service and Space (CIRFFSS 1994), Volume 2; Mar 1, 1994; In English
Report No.(s): AIAA PAPER 94-1278-CP; Copyright; Avail: CASI; A02, Hardcopy

The sensory, control, and operation systems of the 'MITy' Mars micro-rover are discussed. It is shown that the customized sun tracker and laser rangefinder provide internal, autonomous dead reckoning and hazard detection in unstructured environments. The micro-rover consists of three articulated platforms with sensing, processing and payload subsystems connected by a dual spring suspension system. A reactive obstacle avoidance routine makes intelligent use of robot-centered laser information to maneuver through cluttered environments. The hazard sensors include a rangefinder, inclinometers, proximity sensors and collision sensors. A 486/66 laptop computer runs the graphical user interface and programming environment. A graphical window displays robot telemetry in real time and a small TV/VCR is used for real time supervisory control. Guidance, navigation, and control routines work in conjunction with the mapping and obstacle avoidance functions to provide heading and speed commands that maneuver the robot around obstacles and towards the target.
CASI
Control Systems Design; Dead Reckoning; Detection; Laser Range Finders; Monte Carlo Method; Obstacle Avoidance; Robot Control; Robots; Roving Vehicles; Telemetry

19950005121 Massachusetts Inst. of Tech., Cambridge, MA, USA
Low computation vision-based navigation for a Martian rover
Gavin, Andrew S.; Brooks, Rodney A.; NASA. Johnson Space Center, Conference on Intelligent Robotics in Field, Factory, Service and Space (CIRFFSS 1994), Volume 2; Mar 1, 1994; In English
Report No.(s): AIAA PAPER 94-1277-CP; Copyright; Avail: CASI; A03, Hardcopy

Construction and design details of the Mobot Vision System, a small, self-contained, mobile vision system, are presented. This system uses the view from the top of a small, roving, robotic vehicle to supply data that is processed in real-time to safely navigate the surface of Mars. A simple, low-computation algorithm for constructing a 3-D navigational map of the Martian environment to be used by the rover is discussed.
CASI
Algorithms; Computer Vision; Digital Techniques; Mars (Planet); Mars Surface; Navigation; Navigation Aids; Real Time Operation; Robotics; Roving Vehicles

19940033426 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Finding the path to a better Mars rover
Pivirotto, Donna S.; Aerospace America; Sept. 1993; ISSN 0740-722X; 31, 9; In English; Copyright; Avail: Other Sources

A Microrover Flight Experiment (MFEX) based on a basic Rocky 4 design and conducted in the framework of the NASA Mars Environmental Survey (MESUR) Pathfinder program is described. The MFEX rover design features six powered wheels attached by a set of 'bogie levers' to a single body. The rover is designed to perform technology, science, and mission experiments. Instruments on the rover mechanisms will determine wheel-soil interactions, detect hazards, and determine navigational errors. Science data will be gathered using an alpha-proton-X-ray spectrometer against one or more rocks, and possible soil. The pathfinder will also serve as an engineering test of a transport and landing system for the MESUR network mission and the rover will image the lander to assess its condition.
AIAA
Mars Environment; Mars Sample Return Missions; Mars Surface; Roving Vehicles

19940031005 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Planetary Rover Program
Jul 1, 1990; In English
Report No.(s): JPL-AVC-138-90; NASA-CR-196108; NONP-NASA-VT-94-15919; No Copyright; Avail: CASI; B01, Videotape-Beta; V01, Videotape-VHS

This video presentation explains the Planetary Rover Program and shows testing in the Arroyo near JPL.
CASI
NASA Space Programs; Roving Vehicles

19940029517 Sandia National Labs., Albuquerque, NM, USA
Lunar exploration rover program developments
Klarer, P. R.; NASA. Johnson Space Center, The Seventh Annual Workshop on Space Operations Applications and Research (SOAR 1993), Volume 1; Jan 1, 1994; In English; No Copyright; Avail: CASI; A02, Hardcopy

The Robotic All Terrain Lunar Exploration Rover (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.
Author
Autonomy; Lunar Exploration; Lunar Roving Vehicles; Man Machine Systems; Telerobotics

19940025276 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Smart focal-plane technology for micro-instruments and micro-rovers
Fossum, Eric R.; Proceedings of the Workshop on Microtechnologies and Applications to Space Systems; Jun 15, 1993; In English; No Copyright; Avail: CASI; A01, Hardcopy

It is inevitable that micro-instruments and micro-rovers for space exploration will contain one or more focal-plane arrays for imaging, spectroscopy, or navigation. In this paper, we explore the state-of-the-art in focal-plane technology for visible sensors. Also discussed is present research activity in advanced focal-plane technology with particular emphasis on the development of smart sensors. The paper concludes with a discussion of possible future directions for the advancement of the technology.
Author
Focal Plane Devices; Focusing; Imaging Techniques; Microinstrumentation; Roving Vehicles; Space Exploration

19940025127 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Mars rover mechanisms designed for Rocky 4
Rivellini, Tommaso P.; NASA. Ames Research Center, The 27th Aerospace Mechanisms Symposium; May 1, 1993; In English; No Copyright; Avail: CASI; A03, Hardcopy

A Mars rover prototype vehicle named Rocky 4 was designed and built at JPL during the fall of 1991 and spring 1992. This vehicle is the fourth in a series of rovers designed to test vehicle mobility and navigation software. Rocky 4 was the first attempt to design a vehicle with 'flight like' mass and functionality. It was consequently necessary to develop highly efficient mechanisms and structures to meet the vehicles very tight mass limit of 3 Kg for the entire mobility system (7 Kg for the full system). This paper will discuss the key mechanisms developed for the rover's innovative drive and suspension system. These are the wheel drive and strut assembly, the rocker-bogie suspension mechanism and the differential pivot. The end-to-end design, analysis, fabrication and testing of these components will also be discussed as will their performance during field testing. The lessons learned from Rocky 4 are already proving invaluable for the design of Rocky 6. Rocky 6 is currently being designed to fly on NASA's MESUR mission to Mars scheduled to launch in 1996.
Author (revised)
Mars Surface; Mechanical Drives; Pivots; Prototypes; Roving Vehicles; Struts; Test Vehicles

19940024883 Florida State Univ., Tallahassee, FL, USA
Lunar surface operations. Volume 4: Lunar rover trailer
Shields, William; Feteih, Salah; Hollis, Patrick; Jul 1, 1993; In English
Contract(s)/Grant(s): NASW-4435
Report No.(s): NASA-CR-195554; NAS 1.26:195554; No Copyright; Avail: CASI; A05, Hardcopy

The purpose of the project was to design a lunar rover trailer for exploration missions. The trailer was designed to carry

cargo such as lunar geological samples, mining equipment and personnel. It is designed to operate in both day and night lunar environments. It is also designed to operate with a maximum load of 7000 kilograms. The trailer has a ground clearance of 1.0 meters and can travel over obstacles 0.75 meters high at an incline of 45 degrees. It can be transported to the moon fully assembled using any heavy lift vehicle with a storage compartment diameter of 5.0 meters. The trailer has been designed to meet or exceed the performance of any perceivable lunar vehicle.
Author
Lunar Mining; Lunar Roving Vehicles; Lunar Surface; Trailers

19940021789 Sandia National Labs., Albuquerque, NM, USA
A multitasking behavioral control system for the Robotic All-Terrain Lunar Exploration Rover (RATLER)
Klarer, Paul; NASA. Langley Research Center, Selected Topics in Robotics for Space Exploration; Dec 1, 1993; In English; No Copyright; Avail: CASI; A02, Hardcopy

An approach for a robotic control system which implements so called ‘behavioral’ control within a realtime multitasking architecture is proposed. The proposed system would attempt to ameliorate some of the problems noted by some researchers when implementing subsumptive or behavioral control systems, particularly with regard to multiple processor systems and realtime operations. The architecture is designed to allow synchronous operations between various behavior modules by taking advantage of a realtime multitasking system’s intertask communications channels, and by implementing each behavior module and each interconnection node as a stand-alone task. The potential advantages of this approach over those previously described in the field are discussed. An implementation of the architecture is planned for a prototype Robotic All Terrain Lunar Exploration Rover (RATLER) currently under development and is briefly described.
Author (revised)
Control Systems Design; Lunar Roving Vehicles; Real Time Operation; Robotics; Task Planning (Robotics)

19940021788 Sandia National Labs., Albuquerque, NM, USA
The Robotic All-Terrain Lunar Exploration Rover (RATLER): Increased mobility through simplicity
Pletta, J. Bryan; NASA. Langley Research Center, Selected Topics in Robotics for Space Exploration; Dec 1, 1993; In English; No Copyright; Avail: CASI; A03, Hardcopy

A new concept mobility chassis for a robotic rover is described which is inherently simple with few moving parts or complex linkages. The RATLER design utilizes a four-wheel drive, skid steered propulsion system in conjunction with passive articulation of the dual body vehicle. This uniquely simple method of chassis articulation allows all four wheels to remain in contact with the ground even while climbing obstacles as large as 1.3 wheel diameters. A prototype mobility platform was built which is approximately 1 m(sup 2) with 0.5 m diameter wheels and all-wheel electric drive. The theoretical mobility limitations are discussed and compared with the results of field trials of the prototype platform. The theoretical model contrasted with measured performance is then used to predict the expected mobility of the RATLER design on the Lunar surface.
Author (revised)
Chassis; Lunar Exploration; Lunar Roving Vehicles; Mobility; Robotics

19940021787 NASA Langley Research Center, Hampton, VA, USA
Early lunar rover mission studies
Gillespie, V. P.; Selected Topics in Robotics for Space Exploration; Dec 1, 1993; In English; No Copyright; Avail: CASI; A03, Hardcopy

Viewgraphs on Early Lunar Rover Mission studies are included. The chronology of events and study project description are addressed. Issues identified for analysis and basic questions to be addressed are listed. LaRC Early Lunar Mission study results are included.
CASI
Lunar Roving Vehicles; Robotics; Space Exploration; Teleoperators

19940021211 Virginia Polytechnic Inst. and State Univ., Blacksburg, VA, USA
Pressurized Lunar Rover (PLR)
Creel, Kenneth; Frampton, Jeffrey; Honaker, David; Mcclure, Kerry; Zeinali, Mazyar; Bhardwaj, Manoj; Bulsara, Vatsal; Kokan, David; Shariff, Shaun; Svarverud, Eric, et al.; USRA, Proceedings of the 8th Annual Summer Conference: NASA(USRA Advanced Design Program; JAN 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

The objective of this project was to design a manned pressurized lunar rover (PLR) for long-range transportation and for exploration of the lunar surface. The vehicle must be capable of operating on a 14-day mission, traveling within a radius of 500 km during a lunar day or within a 50-km radius during a lunar night. The vehicle must accommodate a nominal crew of four, support two 28-hour EVA's, and in case of emergency, support a crew of six when near the lunar base. A nominal speed of ten km/hr and capability of towing a trailer with a mass of two mt are required. Two preliminary designs have been developed by two independent student teams. The PLR 1 design proposes a seven meter long cylindrical main vehicle and a trailer which houses the power and heat rejection systems. The main vehicle carries the astronauts, life support systems, navigation and communication systems, lighting, robotic arms, tools, and equipment for exploratory experiments. The rover uses a simple mobility system with six wheels on the main vehicle and two on the trailer. The nonpressurized trailer contains a modular radioisotope thermoelectric generator (RTG) supplying 6.5 kW continuous power. A secondary energy storage for short-term peak power needs is provided by a bank of lithium-sulfur dioxide batteries. The life support system is partly a regenerative system with air and hygiene water being recycled. A layer of water inside the composite shell surrounds the command center allowing the center to be used as a safe haven during solar flares. The PLR 1 has a total mass of 6197 kg. It has a top speed of 18 km/hr and is capable of towing three metric tons, in addition to the RTG trailer. The PLR 2 configuration consists of two four-meter diameter, cylindrical hulls which are passively connected by a flexible passageway, resulting in the overall vehicle length of 11 m. The vehicle is driven by eight independently suspended wheels. The dual-cylinder concept allows articulated as well as double Ackermann steering. The primary power of 8 kW is supplied by a dynamic isotope system using a closed Brayton cycle with a xenon-hydrogen mixture as the working fluid. A sodium-sulfur battery serves as the secondary power source. Excess heat produced by the primary power system and other rover systems is rejected by radiators located on the top of the rear cylinder. The total mass of the PLR 2 is 7015 kg. Simplicity and low total weight have been the driving principles behind the design of PLR 1. The overall configuration consists of a 7-m-long, 3-m-diameter cylindrical main vehicle and a two-wheeled trailer. The cylinder of the main body is capped by eight-section, faceted, semi-hemispherical ends. The trailer contains the RTG power source and is not pressurized. The shell of the main body is constructed of a layered carbon fiber/foam/Kevlar sandwich structure. Included in the shell is a layer of water for radiation protection. The layer of water extends from the front of the rover over the crew compartment and creates a safe haven for the crew during a solar flare-up. The carbon fiber provides the majority of the strength and stiffness and the Kevlar provides protection from micrometeoroids. The Kevlar is covered with a gold foil and multi-layer insulation (MLI) to reduce radiation degradation and heat transfer through the wall. A thin thermoplastic layer seals the fiber and provides additional strength.
Author (revised)

Design Analysis; Life Support Systems; Lunar Mobile Laboratories; Manned Lunar Surface Vehicles; Pressurized Cabins; Trailers

19940021190 Idaho Univ., Moscow, ID, USA

Planetary surface exploration MESUR/autonomous lunar rover

Stauffer, Larry; Dilorenzo, Matt; Austin, Dave; Ayers, Raymond; Burton, David; Gaylord, Joe; Kennedy, Jim; Laux, Richard; Lentz, Dale; Nance, Preston, et al.; USRA, Proceedings of the 8th Annual Summer Conference: NASA(USRA Advanced Design Program; JAN 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

Planetary surface exploration micro-rovers for collecting data about the Moon and Mars have been designed by the Department of Mechanical Engineering at the University of Idaho. The goal of both projects was to design a rover concept that best satisfied the project objectives for NASA/Ames. A second goal was to facilitate student learning about the process of design. The first micro-rover is a deployment mechanism for the Mars Environmental Survey (MESUR) Alpha Particle/Proton/X-ray (APX) Instrument. The system is to be launched with the 16 MESUR landers around the turn of the century. A Tubular Deployment System and a spiked-legged walker have been developed to deploy the APX from the lander to the Martian Surface. While on Mars, the walker is designed to take the APX to rocks to obtain elemental composition data of the surface. The second micro-rover is an autonomous, roving vehicle to transport a sensor package over the surface of the moon. The vehicle must negotiate the lunar terrain for a minimum of one year by surviving impacts and withstanding the environmental extremes. The rover is a reliable track-driven unit that operates regardless of orientation that NASA can use for future lunar exploratory missions. This report includes a detailed description of the designs and the methods and procedures which the University of Idaho design teams followed to arrive at the final designs.
Author

Environmental Surveys; Lunar Roving Vehicles; Lunar Surface; Mars Surface; Planetary Surfaces; Space Exploration

19940021181 Florida Agricultural and Mechanical Univ., Tallahassee, FL, USA, Florida State Univ., Tallahassee, FL, USA
The Extended Mission Rover (EMR)
Shields, W.; Halecki, Anthony; Chung, Manh; Clarke, Ken; Frankle, Kevin; Kassemkhani, Fariba; Kuhlhoff, John; Lenzini, Josh; Lobdell, David; Morgan, Sam, et al.; USRA, Proceedings of the 8th Annual Summer Conference: NASA(USRA Advanced Design Program; JAN 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

A key component in ensuring America's status as a leader in the global community is its active pursuit of space exploration. On the twentieth anniversary of Apollo 11, President George Bush challenged the nation to place a man on the moon permanently and to conduct human exploration of Mars in the 21st century. The students of the FAMU/FSU College of Engineering hope to make a significant contribution to this challenge, America's Space Exploration Initiative (SEI), with their participation in the NASA/USRA Advanced Design Program. The project selected by the 1991/1992 Aerospace Design group is the design of an Extended Mission Rover (EMR) for use on the lunar surface. This vehicle will serve as a mobile base to provide future astronauts with a 'shirt-sleeve' living and working environment. Some of the proposed missions are planetary surface exploration, construction and maintenance, hardware setup, and in situ resource experimentation. This vehicle will be put into use in the 2010-2030 time frame.
Author
Lunar Exploration; Lunar Surface; Manned Lunar Surface Vehicles; Mission Planning; Moon

19940021176 California Univ., Los Angeles, CA, USA
Hardware design of a spherical mini-rover
Tarlton, John; USRA, Proceedings of the 8th Annual Summer Conference: NASA(USRA Advanced Design Program; JAN 1, 1992; In English; No Copyright; Avail: CASI; A01, Hardcopy

In this hardware project the students designed the prototype of a novel mini-rover for the exploration of a planetary surface. In an actual application, a large number of such miniature roving devices would be released from a landing craft. Each rover would be equipped with a Cd 109 radio-isotope source (a gamma ray emitter) irradiating the planetary surface below the rover, and an x-ray fluorescence detector for a quantitative assay of high atomic weight elements in the planet's surface. (Similar, miniaturized, hand-held devices have recently been developed for use in gold mines). The device developed by the students was limited to demonstrating the mechanical and electrical drive. The geometric external shape is a sphere; hence there is no danger of the rover being turned on its back and stopped. Propulsion is by means of an interior mass, eccentric to the sphere and driven by an electric motor. In an inter-disciplinary effort in mechanical and electrical engineering, the students designed the mechanical parts, built the transistorized circuit board, and tested the device.
Author
Electric Motors; Gamma Rays; Planetary Surfaces; Roving Vehicles; Spheres; X Ray Detectors

19940020333 Idaho Univ., Moscow, ID, USA
Design of a wheeled articulating land rover
Stauffer, Larry; Dilorenzo, Mathew; Yandle, Barbara; JAN 1, 1994; In English
Contract(s)/Grant(s): NASW-4435
Report No.(s): NASA-CR-195520; NAS 1.26:195520; No Copyright; Avail: CASI; A06, Hardcopy

The WALRUS is a wheeled articulating land rover that will provide Ames Research Center with a reliable, autonomous vehicle for demonstrating and evaluating advanced technologies. The vehicle is one component of the Ames Research Center's on-going Human Exploration Demonstration Project. Ames Research Center requested a system capable of traversing a broad spectrum of surface types and obstacles. In addition, this vehicle must have an autonomous navigation and control system on board and its own source of power. The resulting design is a rover that articulates in two planes of motion to allow for increased mobility and stability. The rover is driven by six conical shaped aluminum wheels, each with an independent, internally coupled motor. Mounted on the rover are two housings and a removable remote control system. In the housings, the motor controller board, tilt sensor, navigation circuitry, and QED board are mounted. Finally, the rover's motors and electronics are powered by thirty C-cell rechargeable batteries, which are located in the rover wheels and recharged by a specially designed battery charger.
Author
Autonomous Navigation; Control Systems Design; Research Vehicles; Robotics; Robots; Roving Vehicles; Surface Navigation

19940018954 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Experiments with a small behaviour controlled planetary rover
Miller, David P.; Desai, Rajiv S.; Gat, Erann; Ivlev, Robert; Loch, John; CNES, Missions, Technologies, and Design of Planetary Mobile Vehicles; Jan 1, 1993; In English; Copyright; Avail: Other Sources

A series of experiments that were performed on the Rocky 3 robot is described. Rocky 3 is a small autonomous rover capable of navigating through rough outdoor terrain to a predesignated area, searching that area for soft soil, acquiring a soil sample, and depositing the sample in a container at its home base. The robot is programmed according to a reactive behavior control paradigm using the ALFA programming language. This style of programming produces robust autonomous performance while requiring significantly less computational resources than more traditional mobile robot control systems. The code for Rocky 3 runs on an eight bit processor and uses about ten k of memory.
ESA
Autonomy; Computer Programs; Hardware; Robot Control; Robots; Roving Vehicles; Surface Navigation

19940018952 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Mobility analysis, simulation, and scale model testing for the design of wheeled planetary rovers
Lindemann, Randel A.; Eisen, Howard J.; CNES, Missions, Technologies, and Design of Planetary Mobile Vehicles; Jan 1, 1993; In English; Copyright; Avail: Other Sources

The use of computer based techniques to model and simulate wheeled rovers on rough natural terrains is considered. Physical models of a prototype vehicle can be used to test the correlation of the simulations in scaled testing. The computer approaches include a quasi-static planar or two dimensional analysis and design tool based on the traction necessary for the vehicle to have imminent mobility. The computer program modeled a six by six wheel drive vehicle of original kinematic configuration, called the Rocker Bogie. The Rocker Bogie was optimized using the quasi-static software with respect to its articulation parameters prior to fabrication of a prototype. In another approach used, the dynamics of the Rocker Bogie vehicle in 3-D space was modeled on an engineering workstation using commercial software. The model included the complex and nonlinear interaction of the tire and terrain. The results of the investigation yielded numerical and graphical results of the rover traversing rough terrain on the earth, moon, and Mars. In addition, animations of the rover excursions were also generated. A prototype vehicle was then used in a series of testbed and field experiments. Correspondence was then established between the computer models and the physical model. The results indicated the utility of the quasi-static tool for configurational design, as well as the predictive ability of the 3-D simulation to model the dynamic behavior of the vehicle over short traverses.
ESA
Computerized Simulation; Mobility; Planetary Surfaces; Robotics; Roving Vehicles; Terrain; Three Dimensional Models

19940018941 NASA, Washington, DC, USA
Evolving directions in NASA's planetary rover requirements and technology
Weisbin, C. R.; Montemerlo, Mel; Whittaker, W.; CNES, Missions, Technologies, and Design of Planetary Mobile Vehicles; Jan 1, 1993; In English; Copyright; Avail: Other Sources

The evolution of NASA's planning for planetary rovers (that is robotic vehicles which may be deployed on planetary bodies for exploration, science analysis, and construction) and some of the technology that was developed to achieve the desired capabilities is reviewed. The program is comprised of a variety of vehicle sizes and types in order to accommodate a range of potential user needs. This includes vehicles whose weight spans a few kilograms to several thousand kilograms; whose locomotion is implemented using wheels, tracks, and legs; and whose payloads vary from microinstruments to large scale assemblies for construction. Robotic vehicles and their associated control systems, developed in the late 1980's as part of a proposed Mars Rover Sample Return (MRSR) mission, are described. Goals suggested at the time for such a MRSR mission included navigating for one to two years across hundreds of kilometers of Martian surface; traversing a diversity of rugged, unknown terrain; collecting and analyzing a variety of samples; and bringing back selected samples to the lander for return to Earth. Current plans (considerably more modest) which have evolved both from technological 'lessons learned' in the previous period, and modified aspirations of NASA missions are presented. Some of the demonstrated capabilities of the developed machines and the technologies which made these capabilities possible are described.
ESA
Mission Planning; Planetary Surfaces; Robotics; Roving Vehicles

19940018937 Massachusetts Inst. of Tech., Cambridge, MA, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
The mass of massive rover software
Miller, David P.; CNES, Missions, Technologies, and Design of Planetary Mobile Vehicles; Jan 1, 1993; In English; Copyright; Avail: Other Sources

A planetary rover, like a spacecraft, must be fully self contained. Once launched, a rover can only receive information

from its designers, and if solar powered, power from the Sun. As the distance from Earth increases, and the demands for power on the rover increase, there is a serious tradeoff between communication and computation. Both of these subsystems are very power hungry, and both can be the major driver of the rover's power subsystem, and therefore the minimum mass and size of the rover. This situation and software techniques that can be used to reduce the requirements on both communication and computation, allowing the overall robot mass to be greatly reduced, are discussed.
ESA
Roving Vehicles; Space Exploration; Spacecraft Power Supplies; Weight Reduction

19940018928 NASA Lewis Research Center, Cleveland, OH, USA
Electrical power technology for robotic planetary rovers
Bankston, C. P.; Shirbacheh, M.; Bents, D. J.; Bozek, J. M.; CNES, Missions, Technologies, and Design of Planetary Mobile Vehicles; Jan 1, 1993; In English; Copyright; Avail: Other Sources

Power technologies which will enable a range of robotic rover vehicle missions by the end of the 1990s and beyond are discussed. The electrical power system is the most critical system for reliability and life, since all other on board functions (mobility, navigation, command and data, communications, and the scientific payload instruments) require electrical power. The following are discussed: power generation, energy storage, power management and distribution, and thermal management.
ESA
Electric Power; Energy Technology; Robotics; Roving Vehicles; Space Exploration

19940018915 NASA Langley Research Center, Hampton, VA, USA
Early lunar rover mission studies
Gillespie, Vernon P.; CNES, Missions, Technologies, and Design of Planetary Mobile Vehicles; Jan 1, 1993; In English; Copyright; Avail: Other Sources

Results of lunar mission studies aimed at developing mission goals and high level requirements are reported. A mission concept to meet the mission requirements was developed and the design of mission hardware was to follow. Mission concepts not only included operations analysis and plans but also fabrication and test planning, quality control measures, and project organization. The design of mission concepts and hardware identified issues that are not easily resolved. Although none of the issues identified appear to be unresolvable, many will be difficult to resolve within Space Exploration Initiative constraints. These issues discussed which appear to have the potential for negative project impact are rover mobility, power, imaging, telemanagment, and remote control.
ESA
Lunar Exploration; Lunar Roving Vehicles; Mission Planning

19940018914 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Unmanned lunar rovers: Utilization for exploration
Plescia, J. B.; Lane, A. L.; Miller, D. P.; CNES, Missions, Technologies, and Design of Planetary Mobile Vehicles; Jan 1, 1993; In English; Copyright; Avail: Other Sources

A small lunar rover and its use for lunar exploration are described. Constraints on a rover mission in the fields of communications, power, speed, navigation/hazard avoidance, and operational time are discussed. The rover design concept consistent with the constraints is described. The instruments to be used, again constrained by mass and power requirements, are listed. Three mission objectives are examined: geological exploration; resource assessment; and a geotechnical survey. It was determined that a small rover, with a mass of less than 60 kg and which would be compatible with being carried on the first Artemis lunar lander, could be built and could accomplish significant scientific exploration or the collection of engineering information.
ESA
Geotechnical Engineering; Lunar Exploration; Lunar Roving Vehicles; Measuring Instruments; Utilization

19940018913 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Lunar rover navigation concepts
Burke, James D.; CNES, Missions, Technologies, and Design of Planetary Mobile Vehicles; Jan 1, 1993; In English; Copyright; Avail: Other Sources

With regard to the navigation of mobile lunar vehicles on the surface, candidate techniques are reviewed and progress of

simulations and experiments made up to now are described. Progress that can be made through precursor investigations on Earth is considered. In the early seventies the problem was examined in a series of relevant tests made in the California desert. Meanwhile, Apollo rovers made short exploratory sorties and robotic Lunokhods traveled over modest distances on the Moon. In these early missions some of the required methods were demonstrated. The navigation problem for a lunar traverse can be viewed in three parts: to determine the starting point with enough accuracy to enable the desired mission; to determine the event sequence required to reach the site of each traverse objective; and to redetermine actual positions enroute. The navigator's first tool is a map made from overhead imagery. The Moon was almost completely photographed at moderate resolution by spacecraft launched in the sixties, but that data set provides imprecise topographic and selenodetic information. Therefore, more advanced orbital missions are now proposed as part of a resumed lunar exploration program. With the mapping coverage expected from such orbiters, it will be possible to use a combination of visual landmark navigation and external radio and optical references (Earth and Sun) to achieve accurate surface navigation almost everywhere on the near side of the Moon. On the far side and in permanently dark polar areas, there are interesting exploration targets where additional techniques will have to be used.
ESA
Lunar Roving Vehicles; Navigation Aids; Surface Navigation

19940018910 Jet Propulsion Lab., California Inst. of Tech., Wrightwood, CA, USA
Science objectives for short-range rovers on Mars
Golombek, M. P.; CNES, Missions, Technologies, and Design of Planetary Mobile Vehicles; Jan 1, 1993; In English; Copyright; Avail: Other Sources

The baseline small lander network mission MESUR (Mars Environmental Survey) is reviewed and the tasks that a microrover could do to improve the science return on such a mission are described. An early precursor small lander mission under study, called MESUR Pathfinder, and the science, technology, and mission engineering tasks that are being considered for the microrover are also described. A description of a microrover (instrumented with microsensors), which is applicable to a small Mars lander mission, is given.
ESA
Mars (Planet); Roving Vehicles

19940018904 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Rover requirements for the planet surface segment of the space exploration initiative
Roberts, Barney B.; Connolly, John F.; CNES, Missions, Technologies, and Design of Planetary Mobile Vehicles; Jan 1, 1993; In English; Copyright; Avail: Other Sources

Annotated requirements for rovers to be used for the First Lunar Outpost (FLO) of the Space Exploration Initiative (SEI) and for Mars missions are presented. The requirements are presented in the form of functions as opposed to performance. SEI surface systems will be required to execute many roving vehicle functions ranging from transporting humans to recovery and transporting raw materials to a processing plant. Some of the roving vehicles will be highly automated. These automation functions may include the following: teleoperated site survey and certification; teleoperation for repair; autonomous operations for resource location and mining; autonomous navigation and terrain traverse; and telerobotic scientific investigations. These requirements are complex, contradictory, and will be costly if they are not carefully analyzed and properly allocated to conceptual elements. Of greatest importance will be the iterative analysis of requirements and synergistic utilization of vehicle elements.
ESA
Lunar Roving Vehicles; Lunar Surface; Mars Surface; Requirements; Roving Vehicles; Space Exploration

19940018902 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Past US studies and developments for planetary rovers
Burke, James D.; CNES, Missions, Technologies, and Design of Planetary Mobile Vehicles; Jan 1, 1993; In English; Copyright; Avail: Other Sources

The history of planetary rovers in the U.S. space program is outlined in the context of the goals, mission and spacecraft designs, and operations designs. The American lunar rover work has had three main stages. In the early sixties, the capacity of Surveyor lunar landers to deliver rovers with a mass of about 50 kg to the Moon was exploited. Several such machines were built and tested beginning in 1964 but none went to the Moon. A manned 400 kg short range rover was then developed. Three of these operated on the Moon in 1971 and 1972 as part of the Apollo 15, 16 and 17 missions. Following these Apollo

successes, attempts were made to provide two kinds of follow on models: automated or dual mode (human carrying or not) rovers in the few hundred kg size class, and multi-ton mobile habitats that could carry humans on extended traverses. With the closing of both Soviet and American lunar exploration in the seventies, neither of these proposals succeeded. In parallel with these lunar developments, a lengthy technology program on Martian roving has gone on in the U.S., sometimes coming close to preproject status and sometimes fading away, but never quite being abandoned. As a result it is possible today to contemplate a wide range of lunar and Martian roving missions that could be made practical within a few years. However, with today's funding constraints none of the well studied, larger mission concepts appear to fit. Therefore new efforts are being made toward developing much smaller rovers taking advantage of new miniature techniques, not only in mobility systems but also in the scientific instruments that a small rover can carry. Illustrations are included.
ESA
Histories; Lunar Roving Vehicles; NASA Space Programs; Planetary Landing; Spacecraft Design

19940016114 NASA Langley Research Center, Hampton, VA, USA
Method for remotely powering a device such as a lunar rover
Deyoung, Russell J., inventor; Williams, Michael D., inventor; Walker, Gilbert H., inventor; Schuster, Gregory L., inventor; Lee, Ja H., inventor; Nov 9, 1993; In English; See also N92-30388
Patent Info.: Filed 6 Jan. 1992; US-PATENT-5,260,639; US-PATENT-APPL-SN-822457; NASA-CASE-LAR-14789-1; No Copyright; Avail: US Patent and Trademark Office

A method of supplying power to a device such as a lunar rover located on a planetary surface is provided. At least one, and preferably three, laser satellites are set in orbit around the planet. Each satellite contains a nuclear reactor for generating electrical power. This electrical power is converted into a laser beam which is passed through an amplifying array and directed toward the device such as a lunar rover. The received laser beam is then converted into electrical power for use by the device.
Official Gazette of the U.S. Patent and Trademark Office
Laser Power Beaming; Lunar Roving Vehicles; Nuclear Reactors; Power Amplifiers; Satellite Power Transmission

19940011839 Academy of Sciences (USSR), Saint Petersburg, Ussr
International testing of a Mars rover prototype
Kemurjian, Alexsandr Leonovich; Linkin, V.; Friedman, L.; Lunar and Planetary Inst., Twenty-Fourth Lunar and Planetary Science Conference. Part 2: G-M; JAN 1, 1993; In English; No Copyright; Avail: Other Sources

Tests on a prototype engineering model of the Russian Mars 96 Rover were conducted by an international team in and near Death Valley in the USA in late May, 1992. These tests were part of a comprehensive design and testing program initiated by the three Russian groups responsible for the rover development. The specific objectives of the May tests were: (1) evaluate rover performance over different Mars-like terrains; (2) evaluate state-of-the-art teleoperation and autonomy development for Mars rover command, control and navigation; and (3) organize an international team to contribute expertise and capability on the rover development for the flight project. The range and performance that can be planned for the Mars mission is dependent on the degree of autonomy that will be possible to implement on the mission. Current plans are for limited autonomy, with Earth-based teleoperation for the nominal navigation system. Several types of television systems are being investigated for inclusion in the navigation system including panoramic camera, stereo, and framing cameras. The tests used each of these in teleoperation experiments. Experiments were included to consider use of such TV data in autonomy algorithms. Image processing and some aspects of closed-loop control software were also tested. A micro-rover was tested to help consider the value of such a device as a payload supplement to the main rover. The concept is for the micro-rover to serve like a mobile hand, with its own sensors including a television camera.
Author (revised)
Command and Control; Design Analysis; Mars Environment; Roving Vehicles; Spacecraft Performance; Television Systems

19940011724 Brown Univ., Providence, RI, USA
Rover mounted ground penetrating radar as a tool for investigating the near-surface of Mars and beyong
Grant, J. A.; Schultz, P. H.; Lunar and Planetary Inst., Twenty-Fourth Lunar and Planetary Science Conference. Part 2: G-M; JAN 1, 1993; In English; No Copyright; Avail: Other Sources

In spite of the highly successful nature of recent planetary missions to the terrestrial planets and outer satellites a number of questions concerning the evolution of their surfaces remain unresolved. For example, knowledge of many characteristics of the stratigraphy and soils comprising the near-surface on Mars remains largely unknown, but is crucial in order to accurately define the history of surface processes and near-surface sedimentary record. Similar statements can be made regarding our

understanding of near-surface stratigraphy and processes on other extraterrestrial planetary bodies. Ground penetrating radar (GPR) is a proven and standard instrument capable of imaging the subsurface at high resolution to 10's of meters depth in a variety of terrestrial environments. Moreover, GPR is portable and easily modified for rover deployment. Data collected with a rover mounted GPR could resolve a number of issues related to planetary surface evolution by defining shallow stratigraphic records and would provide context for interpreting results of other surface analyses (e.g. elemental or mineralogical). A discussion of existing GPR capabilities is followed first by examples of how GPR might be used to better define surface evolution on Mars and then by a brief description of possible GPR applications to the Moon and other planetary surfaces.
Author
Ground Penetrating Radar; Lunar Roving Vehicles; Mars Surface; Mineralogy; Natural Satellites; Planetary Surfaces; Radar Imagery; Roving Vehicles; Space Exploration; Stratigraphy; Terrestrial Planets

19930074561 Wisconsin Univ., Madison, WI, USA
Mars rover vehicle
USRA, NASA(USRA University Advanced Design Program Fourth Annual Summer Conference; JAN 1, 1988; In English; 1 functional color page; No Copyright; Avail: CASI; A01, Hardcopy; 1 functional color page

This year the University of Wisconsin-Madison design team studied surface operations for a Mars base. Specifically, research was conducted concerning the possibilities for a Mars Rover Sample Return mission. This year's focus was on the development of a system that would accomplish the primary tasks of the rover, to gather and return samples. All the aspects of this complex and challenging task were investigated. In order to achieve a complete system devices were designed for every stage from sample acquisition to processing and final storage.
Author
Mars Sample Return Missions; Mars Surface; Mars Surface Samples; Roving Vehicles

19930071349 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA, NASA, Washington, DC, USA
Evolving directions in NASA's planetary rover requirements and technology
Weisbin, C. R.; Montemerlo, Mel; Whittaker, W.; Robotics and Autonomous Systems; 1993; ISSN 0921-8890; In English; Copyright; Avail: Other Sources

This paper reviews the evolution of NASA's planning for planetary rovers (i.e. robotic vehicles which may be deployed on planetary bodies for exploration, science analysis, and construction) and some of the technology that has been developed to achieve the desired capabilities. The program is comprised of a variety of vehicle sizes and types in order to accommodate a range of potential user needs. This includes vehicles whose weight spans a few kilograms to several thousand kilograms; whose locomotion is implemented using wheels, tracks, and legs; and whose payloads vary from microinstruments to large scale assemblies for construction. We first describe robotic vehicles, and their associated control systems, developed by NASA in the late 1980's as part of a proposed Mars Rover Sample Return (MRSR) mission. Suggested goals at that time for such an MRSR mission included navigating for one to two years across hundreds of kilometers of Martian surface; traversing a diversity of rugged, unknown terrain; collecting and analyzing a variety of samples; and bringing back selected samples to the lander for return to Earth. Subsequently, we present the current plans (considerably more modest) which have evolved both from technological 'lessons learned' in the previous period, and modified aspirations of NASA missions. This paper describes some of the demonstrated capabilities of the developed machines and the technologies which made these capabilities possible.
Mars Sample Return Missions; NASA Space Programs; Roving Vehicles; Space Exploration; Technology Assessment

19930069176 NASA, Washington, DC, USA
Thermal and range fusion for a planetary rover
Caillas, Claude; In: Mobile robots VI; Proceedings of the Meeting, Boston, MA, Nov. 14, 15, 1991 (A93-53170 23-63); 1992; In English
Contract(s)/Grant(s): NAGW-1175; Copyright; Avail: Other Sources

This paper describes how fusion between thermal and range imaging allows us to discriminate different types of materials in outdoor scenes. First, we analyze how pure vision segmentation algorithms applied to thermal images allow discriminating materials such as rock and sand. Second, we show how combining thermal and range information allows us to better discriminate rocks from sand. Third, as an application, we examine how an autonomous legged robot can use these techniques to explore other planets.
Computer Vision; Infrared Imagery; Pattern Recognition; Rangefinding; Robot Dynamics; Roving Vehicles

19930066047 NASA, Washington, DC, USA

Mars rover sample return mission utilizing in situ production of the return propellants

Bruckner, A. P.; Nill, L.; Schubert, H.; Thill, B.; Warwick, R.; Jun 1, 1993; In English; 29th AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference and Exhibit, June 28-30, 1993, Monterey, CA, USA

Report No.(s): AIAA PAPER 93-2242; Copyright; Avail: Other Sources

This paper presents an unmanned Mars sample return mission that utilizes propellants manufactured in situ from the Martian atmosphere for the return trip. A key goal of the mission is to demonstrate the considerable benefits that can be realized through the use of indigenous resources and to test the viability of this approach as a precursor to manned missions to Mars. Two in situ propellant combinations, methane/oxygen and carbon monoxide/oxygen, are compared to imported terrestrial hydrogen/oxygen within a single mission architecture, using a single Earth launch vehicle. The mission is assumed to be launched from Earth in 2003. Upon reaching Mars, the landing vehicle aerobrakes, deploys a small satellite, and lands on the Martian surface. Once on the ground, the propellant production unit is activated, and the product gases are liquefied and stored in the empty tanks of the Earth Return Vehicle (ERV). Power for these activities is provided by a dynamic isotope power system. A semiautonomous rover, powered by the indigenous propellants, gathers between 25 and 30 kg of soil and rock samples which are loaded aboard the ERV for return to Earth. After a surface stay time of approximately 1.5 years, the ERV leaves Mars for the return voyage to Earth. When the vehicle reaches the vicinity of Earth, the sample return capsule detaches, and is captured and circularized in LEO via aerobraking maneuvers.

AIAA

Fuel Production; Mars Landing; Mars Sample Return Missions; Return to Earth Space Flight; Roving Vehicles

19930059857 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA

Stereo vision for planetary rovers - Stochastic modeling to near real-time implementation

Matthies, Larry; In: Geometric methods in computer vision; Proceedings of the Meeting, San Diego, CA, July 25, 26, 1991 (A93-43851 17-67); 1991; In English; Copyright; Avail: Other Sources

JPL has achieved the first autonomous cross-country robotic traverses to use stereo vision, with all computing onboard the vehicle. This paper describes the stereo vision system, including the underlying statistical model and the details of the implementation. It is argued that the overall approach provides a unifying paradigm for practical domain-independent stereo ranging.

AIAA

Computer Vision; Planetary Surfaces; Real Time Operation; Roving Vehicles; Stereoscopic Vision; Stochastic Processes

19930051514 NASA, Washington, DC, USA

Performance of a six-legged planetary rover - Power, positioning, and autonomous walking

Krotkov, Eric; Simmons, Reid; In: 1992 IEEE International Conference on Robotics and Automation, 8th, Nice, France, May 12-14, 1992, Proceedings. Vol. 1 (A93-35501 13-63); 1992; In English

Contract(s)/Grant(s): NAGW-1175; Copyright; Avail: Other Sources

The authors quantify several performance metrics for the Ambler, a six-legged robot configured for autonomous traversal of Mars-like terrain. They present power consumption measures for walking on sandy terrain and for vertical lifts at different velocities. They document the accuracy of a novel dead reckoning approach, and analyze the accuracy. They describe the results of autonomous walking experiments in terms of terrain traversed, walking speed, number of instructions executed and endurance.

AIAA

Mars Surface; Performance Tests; Planetary Environments; Robot Control; Roving Vehicles; Walking Machines

19930046915 NASA Lyndon B. Johnson Space Center, Houston, TX, USA

Rover concepts for lunar exploration

Connolly, John F.; Feb 1, 1993; In English; AIAA, AHS, and ASEE, Aerospace Design Conference, Feb. 16-19, 1993, Irvine, CA, USA

Report No.(s): AIAA PAPER 93-0996; Copyright; Avail: Other Sources

The paper describes the requirements and design concepts developed for the First Lunar Outpost (FLO) and the follow-on lunar missions by the Human Planet Surface Project Office at the Johnson Space Center, which include inputs from scientists, technologists, operators, personnel, astronauts, mission designers, and program managers. Particular attention is given to the

requirements common to all rover concepts, the precursor robotic missions, the FLO scenario and capabilities, and the FLO evolution.
AIAA
Lunar Exploration; Lunar Resources; Lunar Roving Vehicles; Lunar Surface; Teleoperators

19930046885 NASA, Washington, DC, USA
Design issues for Mars planetary rovers
Lee, Gordon K. F.; Dejarnette, Fred R.; Walberg, Gerald D.; Feb 1, 1993; In English; AIAA, AHS, and ASEE, Aerospace Design Conference, Feb. 16-19, 1993, Irvine, CA, USA
Contract(s)/Grant(s): NAGW-1331
Report No.(s): AIAA PAPER 93-0957; Copyright; Avail: Other Sources

The paper presents some of the design issues and vehicle requirements that need to be addressed for the Mars planetary rovers. Some of the designs currently being investigated, including the JPL rover, the Martin Marietta vehicle, and the French Space Agency's VAP project, are examined. The rover must satisfy such mission requirements as surveying the terrain, preparing the landing sites, loading and unloading components for base operations, and aiding in the recovery of in situ materials.
AIAA
Mars (Planet); Planetary Surfaces; Robotics; Roving Vehicles; Space Exploration

19930045148 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Manipulator control for rover planetary exploration
Cameron, Jonathan M.; Tunstel, Edward; Nguyen, Tam; Cooper, Brian K.; In: Cooperative intelligent robotics in space III; Proceedings of the Meeting, Boston, MA, Nov. 16-18, 1992 (A93-29101 10-54); 1992; In English; Copyright; Avail: Other Sources

An anticipated goal of Mars surface exploration missions will be to survey and sample surface rock formations which appear scientifically interesting. In such a mission, a planetary rover would navigate close to a selected sampling site and the remote operator would use a manipulator mounted on the rover to perform a sampling operation. Techniques for accomplishing the necessary manipulation for the sampling components of such a mission have been developed and are presented. We discuss the implementation of a system for controlling a seven (7) degree of freedom Puma manipulator, equipped with a special rock gripper mounted on a planetary rover prototype, intended for the purpose of performing the sampling operation. Control is achieved by remote teleoperation. This paper discusses the real-time force control and supervisory control aspects of the rover manipulation system. Integration of the Puma manipulator with the existing distributed computer architecture is also discussed. The work described is a contribution toward achieving the coordinated manipulation and mobility necessary for a Mars sample acquisition and return scenario.
AIAA
Mars Surface; Robot Control; Roving Vehicles; Space Exploration; Telerobotics

19930045145 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Reducing software mass through behavior control
Miller, David P.; In: Cooperative intelligent robotics in space III; Proceedings of the Meeting, Boston, MA, Nov. 16-18, 1992 (A93-29101 10-54); 1992; In English; Copyright; Avail: Other Sources

Attention is given to the tradeoff between communication and computation as regards a planetary rover (both these subsystems are very power-intensive, and both can be the major driver of the rover's power subsystem, and therefore the minimum mass and size of the rover). Software techniques that can be used to reduce the requirements on both communciation and computation, allowing the overall robot mass to be greatly reduced, are discussed. Novel approaches to autonomous control, called behavior control, employ an entirely different approach, and for many tasks will yield a similar or superior level of autonomy to traditional control techniques, while greatly reducing the computational demand. Traditional systems have several expensive processes that operate serially, while behavior techniques employ robot capabilities that run in parallel. Traditional systems make extensive world models, while behavior control systems use minimal world models or none at all.
AIAA
Planetary Surfaces; Robot Control; Roving Vehicles; Software Reliability; Weight Reduction

19930041978 NASA Langley Research Center, Hampton, VA, USA

Power transmission by laser beam from lunar-synchronous satellites to a lunar rover

Williams, M. D.; Deyoung, R. J.; Schuster, G. L.; Choi, S. H.; Dagle, J. E.; Coomes, E. P.; Antoniak, Z. I.; Bamberger, J. A.; Bates, J. M.; Chiu, M. A., et al.; In: IECEC '92; Proceedings of the 27th Intersociety Energy Conversion Engineering Conference, San Diego, CA, Aug. 3-7, 1992. Vol. 2 (A93-25851 09-44); 1992; In English; Copyright; Avail: Other Sources

This study addresses the possibility of beaming laser power from synchronous lunar orbits (L1 and L2 LaGrange points) to a manned long-range lunar rover. The rover and two versions of a satellite system (one powered by a nuclear reactor; the other by photovoltaics) are described in terms of their masses, geometry, power needs, mission and technological capabilities. Laser beam power is generated by a laser diode array in the satellite and converted to 30 kW of electrical power at the rover. Present technological capabilities, with some extrapolation to near future capabilities, are used in the descriptions. The advantages of the two satellite/rover systems over other such systems and over rovers with on-board power are discussed along with the possibility of enabling other missions.

AIAA

Laser Power Beaming; Lunar Surface; Satellite Power Transmission; Synchronous Satellites

19930036773 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA

Design and structural analysis of Mars Rover RTG

Schock, Alfred; Hamrick, Thomas; Sankarankandath, Kumar; Shirbacheh, Michael; In: Space nuclear power systems 1989; Proceedings of the 6th Symposium, Albuquerque, NM, Jan. 8-12, 1989. Vol. 1 (A93-20752 06-20); 1992; In English; Copyright; Avail: Other Sources

The Mars Rover and Sample Return mission's radioisotope thermoelectric generator (RTG) is presently subjected to a structural and mass analysis in view of a reference mission scenario, an illustrative Rover design and Martian activities agenda, and RTG power system requirements and environmental constraints. The modular heat-source stack in the Rover RTG can be held together by axial load springs. The RTGs should be mounted on the Rover with a vertical orientation, in order to avoid the buildup of windborne Martian sand on its heat-rejection surfaces.

AIAA

Mars Sample Return Missions; Radioisotope Batteries; Roving Vehicles; Thermoelectric Generators

19930029796 NASA Lewis Research Center, Cleveland, OH, USA

Shielding analysis for a manned Mars rover powered by an SP-100 type reactor

Morley, Nicholas J.; El-Genk, Mohamed S.; In: Space nuclear power systems; Proceedings of the 8th Symposium, Albuquerque, NM, Jan. 6-10, 1991. Pt. 1 (A93-13751 03-20); 1991; In English

Contract(s)/Grant(s): NAG3-992; Copyright; Avail: Other Sources

Shield design is one of the most crucial tasks in the integration of a nuclear reactor power system to a manned Mars rover. A multilayered W and LiH shield is found to minimize the shield mass and satisfy the dose rate limit of 30 rem/y to the rover crew. The effect on dose rate of tungsten layers thicknesses and position within the lithium hydride shields is investigated. Due to the large cross section for the W (n,gamma) reaction, secondary gammas become a significant radiation source. The man-rated shield mass for the Mars rover vehicle is correlated to the reactor thermal power. The correlation fits to within 9 percent of the calculated shield mass and results in an uncertainty of below 4 percent in the overall rover mass. The shield mass varied from 8600 kg to 20580 kg for a reactor thermal power of 100 to 1000 kW(t), respectively.

AIAA

Lithium Hydrides; Manned Mars Missions; Radiation Shielding; Roving Vehicles; Space Power Reactors; Tungsten

19930029786 NASA Lewis Research Center, Cleveland, OH, USA

Estimates of power requirements for a Manned Mars Rover powered by a nuclear reactor

Morley, Nicholas J.; El-Genk, Mohamed S.; Cataldo, Robert; Bloomfield, Harvey; In: Space nuclear power systems; Proceedings of the 8th Symposium, Albuquerque, NM, Jan. 6-10, 1991. Pt. 1 (A93-13751 03-20); 1991; In English

Contract(s)/Grant(s): NAG3-992; Copyright; Avail: Other Sources

This paper assesses the power requirement for a Manned Mars Rover vehicle. Auxiliary power needs are fulfilled using a hybrid solar photovoltaic/regenerative fuel cell system, while the primary power needs are meet using an SP-100 type reactor. The primary electric power needs, which include 30-kW(e) net user power, depend on the reactor thermal power and the efficiency of the power conversion system. Results show that an SP-100 type reactor coupled to a Free Piston Stirling Engine yields the lowest total vehicle mass and lowest specific mass for the power system. The second lowest mass was for

a SP-100 reactor coupled to a Closed Brayton Cycle using He/Xe as the working fluid. The specific mass of the nuclear reactor power system, including a man-rated radiation shield, ranged from 150-kg/kW(e) to 190-kg/KW(e) and the total mass of the Rover vehicle varied depend upon the cruising speed.
AIAA
Manned Mars Missions; Nuclear Electric Power Generation; Regenerative Fuel Cells; Roving Vehicles; Solar Cells; Space Power Reactors

19930029700 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Dynamic modeling and simulation of planetary rovers
Lindemann, Randel A.; Feb 1, 1992; In English; AIAA, Aerospace Design Conference, Feb. 3-6, 1992, Irvine, CA, USA
Report No.(s): AIAA PAPER 92-1269; Copyright; Avail: Other Sources

This paper documents a preliminary study into the dynamic modeling and computer simulation of wheeled surface vehicles. The research centered on the feasibility of using commercially available multibody dynamics codes running on engineering workstations to perform the analysis. The results indicated that physically representative vehicle mechanics can be modeled and simulated in state-of-the-art Computer Aided Engineering environments, but at excessive cost in modeling and computation time. The results lead to the recommendation for the development of an efficient rover mobility-specific software system. This system would be used for vehicle design and simulation in planetary environments; controls prototyping, design, and testing; as well as local navigation simulation and expectation planning.
AIAA
Computer Aided Design; Computerized Simulation; Dynamic Models; Planetary Surfaces; Roving Vehicles

19930029667 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Adaptive multisensor fusion for planetary exploration rovers
Collin, Marie-France; Kumar, Krishen; Pampagnin, Luc-Henri; In: Artificial intelligence, robotics, and automatic control, applied to space (Intelligence artificielle, robotique et automatique, appliquees a l'espace); 1992; In English; Copyright; Avail: Other Sources

The purpose of the adaptive multisensor fusion system currently being designed at NASA/Johnson Space Center is to provide a robotic rover with assured vision and safe navigation capabilities during robotic missions on planetary surfaces. Our approach consists of using multispectral sensing devices ranging from visible to microwave wavelengths to fulfill the needs of perception for space robotics. Based on the illumination conditions and the sensors capabilities knowledge, the designed perception system should automatically select the best subset of sensors and their sensing modalities that will allow the perception and interpretation of the environment. Then, based on reflectance and emittance theoretical models, the sensor data are fused to extract the physical and geometrical surface properties of the environment surface slope, dielectric constant, temperature and roughness. The theoretical concepts, the design and first results of the multisensor perception system are presented.
AIAA
Adaptive Control; Computer Vision; Multisensor Applications; Multisensor Fusion; Robot Control; Roving Vehicles

19930022928 Sandia National Labs., Albuquerque, NM, USA
RATLER: Robotic All-Terrain Lunar Exploration Rover
Purvis, J. W.; Klarer, P. R.; NASA. Lyndon B. Johnson Space Center, The Sixth Annual Workshop on Space Operations Applications and Research (SOAR 1992); Feb 1, 1993; In English; No Copyright; Avail: CASI; A02, Hardcopy

A robotic rover vehicle designed for use in the exploration of the Lunar surface is described. 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. Skid steering and modular construction are used to produce a simple, rugged, highly agile mobility chassis with a reduction in the number of parts required when compared to current designs being considered for planetary exploration missions. The design configuration, mobility parameters, and performance of several existing RATLER prototypes are discussed.
Author (revised)
Design Analysis; Lunar Exploration; Lunar Roving Vehicles; Lunar Surface; Prototypes; Robotics; Terrain

19930022926 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA

Planetary rover developments at JPL

Wilcox, Brian; NASA. Lyndon B. Johnson Space Center, The Sixth Annual Workshop on Space Operations Applications and Research (SOAR 1992); Feb 1, 1993; In English; No Copyright; Avail: Other Sources

Planetary rover research has recently focused on small rovers, which are competent to explore and assist in in-situ analysis of limited areas around a landing site (as opposed to the larger, long range rovers, which have been assumed to accompany sample return missions). Navigation and mobility concepts of these small rovers are, in some cases, somewhat different than what was assumed in the past. The sensing, computing, communication, and power resources of these missions dictate a rethinking of the 'large mission' approach. Recent results and demonstrations along this new direction are described.

Author (revised)

Mobility; Planetary Surfaces; Roving Vehicles; Surface Navigation

19930019930 Colorado Univ., Boulder, CO, USA

Lunar rovers and local positioning system

Avery, James; Su, Renjeng; Space Construction Activities; Nov 1, 1991; In English; No Copyright; Avail: CASI; A01, Hardcopy

Telerobotic rovers equipped with adequate actuators and sensors are clearly necessary for extraterrestrial construction. They will be employed as substitutes for humans, to perform jobs like surveying, sensing, signaling, manipulating, and the handling of small materials. Important design criteria for these rovers include versatility and robustness. They must be easily programmed and reprogrammed to perform a wide variety of different functions, and they must be robust so that construction work will not be jeopardized by parts failures. The key qualities and functions necessary for these rovers to achieve the required versatility and robustness are modularity, redundancy, and coordination. Three robotic rovers are being built by CSC as a test bed to implement the concepts of modularity and coordination. The specific goal of the design and construction of these robots is to demonstrate the software modularity and multirobot control algorithms required for the physical manipulation of constructible elements. Each rover consists of a transporter platform, bus manager, simple manipulator, and positioning receivers. These robots will be controlled from a central control console via a radio-frequency local area network (LAN). To date, one prototype transporter platform frame was built with batteries, motors, a prototype single-motor controller, and two prototype internal LAN boards. Software modules were developed in C language for monitor functions, i/o, and parallel port usage in each computer board. Also completed are the fabrication of half of the required number of computer boards, the procurement of 19.2 Kbaud RF modems for inter-robot communications, and the simulation of processing requirements for positioning receivers. In addition to the robotic platform, the fabrication of a local positioning system based on infrared signals is nearly completed. This positioning system will make the rovers into a moving reference system capable of performing site surveys. In addition, a four degree mechanical manipulator especially suited for coordinated teleoperation was conceptually designed and is currently being analyzed. This manipulator will be integrated into the rovers as their end effector. Twenty internal LAN cards fabricated by a commercial firm are being used, a prototype manipulator and a range finder for a positioning system were built, a prototype two-motor controller was designed, and one of the robots is performing its first telerobotic motion. In addition, the robots' internal LAN's were coordinated and tested, hardware design upgrades based on fabrication and fit experience were completed, and the positioning system is running. The rover system is able to perform simple tasks such as sensing and signaling; coordination systems which allow construction tasks to begin were established, and soon coordinated teams of robots in the laboratory will be able to manipulate common objects.

Author (revised)

Construction; Design Analysis; Lunar Roving Vehicles; Positioning; Robot Dynamics; Telerobotics

19930019615 NASA Lyndon B. Johnson Space Center, Houston, TX, USA

Sources sought for innovative scientific instrumentation for scientific lunar rovers

Meyer, C.; Lunar and Planetary Inst., Workshop on Advanced Technologies for Planetary Instruments, Part 1; JAN 1, 1993; In English; No Copyright; Avail: Other Sources

Lunar rovers should be designed as integrated scientific measurement systems that address scientific goals as their main objective. Scientific goals for lunar rovers are presented. Teleoperated robotic field geologists will allow the science team to make discoveries using a wide range of sensory data collected by electronic 'eyes' and sophisticated scientific instrumentation. rovers need to operate in geologically interesting terrain (rock outcrops) and to identify and closely examine interesting rock samples. Enough flight-ready instruments are available to fly on the first mission, but additional instrument development based

on emerging technology is desirable. Various instruments that need to be developed for later missions are described.
Author (revised)
Control Equipment; Instruments; Lunar Roving Vehicles; Lunar Surface; Robot Control; Teleoperators; Telerobotics

19930017227 Colorado Univ., Boulder, CO, USA
Telerobotic rovers for extraterrestrial construction
Grasso, Chris; Pavlich, Jane; Jermstad, Wayne; Matthews, Mike; Snyder, Gary; Steffen, Chris; Avery, Jim; Su, Renjeng; Lund, Walter; Center for Space Construction Third Annual Symposium; JAN 1, 1991; In English; No Copyright; Avail: CASI; A03, Hardcopy

The topics are presented in viewgraph form and include the following: fundamental concepts; advantages of modularity; modular robot; robot design; motor control system; simple manipulator; 4 degree of freedom manipulator; intermodule communication; network layout; positioning system--IR-TROP; IR TROP system design; testbed layout; modularized control; and centralized control. The objectives are the following: to design small modular robots; to test robotic cooperation and teleoperation; to develop modular control software; to develop intermodule communication network; to develop high accuracy positioning system; and to explore distributed algorithms for coordination.
Derived from text
Communication Networks; Lunar Construction Equipment; Lunar Roving Vehicles; Manipulators; Positioning Devices (Machinery); Robots; Teleoperators; Telerobotics

19930013028 Houston Univ., TX, USA
Fuzzy logic path planning system for collision avoidance by an autonomous rover vehicle
Murphy, Michael G.; NASA. Johnson Space Center, Proceedings of the Third International Workshop on Neural Networks and Fuzzy Logic, Volume 2; Jan 1, 1993; In English; No Copyright; Avail: Other Sources

The Space Exploration Initiative of the USA will make great demands upon NASA and its limited resources. One aspect of great importance will be providing for autonomous (unmanned) operation of vehicles and/or subsystems in space flight and surface exploration. An additional, complicating factor is that much of the need for autonomy of operation will take place under conditions of great uncertainty or ambiguity. Issues in developing an autonomous collision avoidance subsystem within a path planning system for application in a remote, hostile environment that does not lend itself well to remote manipulation by Earth-based telecommunications is addressed. A good focus is unmanned surface exploration of Mars. The uncertainties involved indicate that robust approaches such as fuzzy logic control are particularly appropriate. Four major issues addressed are (1) avoidance of a fuzzy moving obstacle; (2) backoff from a deadend in a static obstacle environment; (3) fusion of sensor data to detect obstacles; and (4) options for adaptive learning in a path planning system. Examples of the need for collision avoidance by an autonomous rover vehicle on the surface of Mars with a moving obstacle would be wind-blown debris, surface flow or anomalies due to subsurface disturbances, another vehicle, etc. The other issues of backoff, sensor fusion, and adaptive learning are important in the overall path planning system.
Author (revised)
Adaptive Control; Collision Avoidance; Fuzzy Systems; Roving Vehicles; Trajectory Planning; Unmanned Spacecraft

19930008973 Florida Agricultural and Mechanical Univ., Tallahassee, FL, USA
Extended mission/lunar rover, executive summary
JAN 1, 1992; In English
Contract(s)/Grant(s): NASW-4435
Report No.(s): NASA-CR-192017; NAS 1.26:192017; No Copyright; Avail: CASI; A03, Hardcopy

The design project selected to be undertaken by the 1991/92 Aerospace Design Group was that of conceptually designing an Extended Mission Rover for use on the Lunar Surface. This vehicle would serve the function as a mobile base of sorts, and be able to provide future astronauts with a mobile 'shirt-sleeve' self-sufficient living and working environment. Some of the proposed missions would be planetary surface exploration, construction and maintenance, hardware set-up and in-situ resource experimentation. The need for this type of vehicle has already been declared in the Stafford Group's report on the future of America's Space Program, entitled 'America at the Threshold: America's Space Exploration Initiative'. In the four architectures described within the report, the concept of a pressurized vehicle occurred multiple times. The approximate time frame that this vehicle would be put into use is 2010-2030.
Author
Lunar Exploration; Lunar Roving Vehicles; Lunar Surface; Rover Project

19930008925 Texas Univ., Austin, TX, USA

Design of a compliant wheel for a miniature rover to be used on Mars

Carroll, Mark; Johnson, Jess; Yong, Jimmy; JAN 1, 1991; In English; 4 functional color pages

Contract(s)/Grant(s): NASW-4435

Report No.(s): NASA-CR-192012; NAS 1.26:192012; No Copyright; Avail: CASI; A08, Hardcopy; 4 functional color pages

The Jet Propulsion Laboratory has identified the need for a compliant wheel for a miniature martian rover vehicle. This wheel must meet requirements of minimum mass, linear radial deflection, and reliability in cryogenic conditions over a five year lifespan. Additionally, axial and tangential deflections must be no more than 10 percent of the radial value. The team designed a wheel by use of finite element and dimensionless parameter analysis. Due to the complex geometry of the wheel, a finite element model describing its behavior was constructed to investigate different wheel configurations. Axial and tangential deflections were greatly reduced but did not meet design criteria. A composite material was selected for its high strength, toughness, fatigue resistance, and damping characteristics. The team chose a Kevlar fiber filled thermoplastic composite. This report is divided into four primary sections. First, the introduction section gives background information, defines the task, and discusses the scope and limitations of the project. Second, the alternative designs section introduces alternative design solutions, addresses advantages and disadvantages of each, and identifies the parameters used to determine the best design. Third, the design solution section introduces the methods used to evaluate the alternates, and gives a description of the design process used. Finally, the conclusion and recommendations section evaluates the wheel design, and offers recommendations pertaining to improvement of the design solution.

Author

Composite Structures; Design Analysis; Elastic Properties; Fiber Composites; Finite Element Method; Mars (Planet); Mars Surface; Roving Vehicles; Surface Vehicles; University Program; Wheels

19930008913 Idaho Univ., Moscow, ID, USA

Planetary surface exploration: MESUR/autonomous lunar rover

Stauffer, Larry; Dilorenzo, Matt; Austin, Dave; Ayers, Raymond; Burton, David; Gaylord, Joe; Kennedy, Jim; Lentz, Dale; Laux, Richard; Nance, Preston, et al.; Jun 1, 1992; In English

Contract(s)/Grant(s): NASW-4435

Report No.(s): NASA-CR-192073; NAS 1.26:192073; No Copyright; Avail: CASI; A04, Hardcopy

Planetary surface exploration micro-rovers for collecting data about the Moon and Mars was designed by the Department of Mechanical Engineering at the University of Idaho. The goal of both projects was to design a rover concept that best satisfied the project objectives for NASA-Ames. A second goal was to facilitate student learning about the process of design. The first micro-rover is a deployment mechanism for the Mars Environmental SURvey (MESUR) Alpha Particle/Proton/X-ray instruments (APX). The system is to be launched with the sixteen MESUR landers around the turn of the century. A Tubular Deployment System and a spiked-legged walker was developed to deploy the APX from the lander to the Martian surface. While on Mars the walker is designed to take the APX to rocks to obtain elemental composition data of the surface. The second micro-rover is an autonomous, roving vehicle to transport a sensor package over the surface of the moon. The vehicle must negotiate the lunar-terrain for a minimum of one year by surviving impacts and withstanding the environmental extremes. The rover is a reliable track-driven unit that operates regardless of orientation which NASA can use for future lunar exploratory missions. A detailed description of the designs, methods, and procedures which the University of Idaho design teams followed to arrive at the final designs are included.

Author

Lunar Surface; Mars Surface; Roving Vehicles; Space Exploration; Spacecraft Design; University Program

19930008827 Virginia Polytechnic Inst. and State Univ., Blacksburg, VA, USA

Design of a pressurized lunar rover

Bhardwaj, Manoj; Bulsara, Vatsal; Kokan, David; Shariff, Shaun; Svarverud, Eric; Wirz, Richard; Apr 24, 1992; In English; 3 functional color pages

Contract(s)/Grant(s): NASW-4435

Report No.(s): NASA-CR-192033; NAS 1.26:192033; No Copyright; Avail: CASI; A06, Hardcopy; 3 functional color pages

A pressurized lunar rover is necessary for future long-term habitation of the moon. The rover must be able to safely perform many tasks, ranging from transportation and reconnaissance to exploration and rescue missions. Numerous designs were considered in an effort to maintain a low overall mass and good mobility characteristics. The configuration adopted consists of two cylindrical pressure hulls passively connected by a pressurized flexible passageway. The vehicle has an overall length of 11 meters and a total mass of seven metric tons. The rover is driven by eight independently powered two meter

diameter wheels. The dual-cylinder concept allows a combination of articulated frame and double Ackermann steering for executing turns. In an emergency, the individual drive motors allow the option of skid steering as well. Two wheels are connected to either side of each cylinder through a pinned bar which allows constant ground contact. Together, these systems allow the rover to easily meet its mobility requirements. A dynamic isotope power system (DIPS), in conjunction with a closed Brayton cycle, supplied the rover with a continuous supply of 8.5 kW. The occupants are all protected from the DIPS system's radiation by a shield of tantalum. The large amount of heat produced by the DIPS and other rover systems is rejected by thermal radiators. The thermal radiators and solar collectors are located on the top of the rear cylinder. The solar collectors are used to recharge batteries for peak power periods. The rover's shell is made of graphite-epoxy coated with multi-layer insulation (MLI). The graphite-epoxy provides strength while the thermally resistant MLI gives protection from the lunar environment. An elastomer separates the two materials to compensate for the thermal mismatch. The communications system allows for communication with the lunar base with an option for direct communication with earth via a lunar satellite link. The various links are combined into one signal broadcast in the S-band at 2.3 GHz. The rover is fitted with a parabolic reflector disk for S-band transmission, and an omnidirectional antenna for local extravehicular activity (EVA) communication. The rover's guidance, navigation, and control subsystem consists of an inertial guidance system, an orbiting lunar satellite, and an obstacle avoidance system. In addition, the rover is equipped with a number of external fixtures including two telerobotic arms, lights, cameras, EVA storage, manlocks, a docking fixture, solar panels, thermal radiators, and a scientific airlock. In conclusion, this rover meets all of the design requirements and clearly surpasses them in the areas of mobility and maneuverability.
Author
Brayton Cycle; Graphite-Epoxy Composites; Lunar Roving Vehicles; Pressurized Cabins; Radiation Shielding; Radioisotope Batteries

19930008826 Virginia Polytechnic Inst. and State Univ., Blacksburg, VA, USA
Pressurized lunar rover
Creel, Kenneth; Frampton, Jeffrey; Honaker, David; Mcclure, Kerry; Zeinali, Mazyar; May 1, 1992; In English; 2 functional color pages
Contract(s)/Grant(s): NASW-4435
Report No.(s): NASA-CR-192034; NAS 1.26:192034; No Copyright; Avail: CASI; A06, Hardcopy; 2 functional color pages

The pressurized lunar rover (PLR) consists of a 7 m long, 3 m diameter cylindrical main vehicle and a trailer which houses the power and heat rejection systems. The main vehicle carries the astronauts, life support systems, navigation and communication systems, directional lighting, cameras, and equipment for exploratory experiments. The PLR shell is constructed of a layered carbon-fiber/foam composite. The rover has six 1.5 m diameter wheels on the main body and two 1.5 m diameter wheels on the trailer. The wheels are constructed of composites and flex to increase traction and shock absorption. The wheels are each attached to a double A-arm aluminum suspension, which allows each wheel 1 m of vertical motion. In conjunction with a 0.75 m ground clearance, the suspension aids the rover in negotiating the uneven lunar terrain. The 15 N-m torque brushless electric motors are mounted with harmonic drive units inside each of the wheels. The rover is steered by electrically varying the speeds of the wheels on either side of the rover. The PLR trailer contains a radiosotope thermoelectric generator providing 6.7 kW. A secondary back-up energy storage system for short-term high-power needs is provided by a bank of batteries. The trailer can be detached to facilitate docking of the main body with the lunar base via an airlock located in the rear of the PLR. The airlock is also used for EVA operation during missions. Life support is a partly regenerative system with air and hygiene water being recycled. A layer of water inside the composite shell surrounds the command center. The water absorbs any damaging radiation, allowing the command center to be used as a safe haven during solar flares. Guidance, navigation, and control are supplied by a strapdown inertial measurement unit that works with the on-board computer. Star mappers provide periodic error correction. The PLR is capable of voice, video, and data transmission. It is equipped with two 5 W X-band transponder, allowing simultaneous transmission and reception. An S-band transponder is used to communicate with the crew during EVA. The PLR has a total mass of 6197 kg. It has a nominal speed of 10 km/hr and a top speed of 18 km/hr. The rover is capable of towing 3 metric tons (in addition to the RTG trailer).
Author
Air Locks; Life Support Systems; Lunar Roving Vehicles; Pressurized Cabins; Radiation Shielding; Radioisotope Batteries; Thermoelectric Generators; University Program

19930008073 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Lunar surface rovers
Plescia, J. B.; Lane, A. L.; Miller, D.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

Many questions of lunar science remain unanswered because of a lack of specific data. With the potential for returning humans to the Moon and establishing a long-term presence there, a new realm of exploration is possible. Numerous plans have been outlined for orbital and surface missions. The capabilities and objectives of a small class of rovers to be deployed on the lunar surface are described. The objective of these small rovers is to collect detailed in situ information about the composition and distribution of materials on the lunar surface. Those data, in turn, would be applied to a variety of lunar geoscience questions and form a basis for planning human activities on the lunar surface.
Author
Lunar Roving Vehicles; Lunar Surface; Payloads; Research Vehicles; Spacecraft Equipment

19930008066 Los Alamos National Lab., NM, USA
Robotic lunar rover technologies and SEI supporting technologies at Sandia National Laboratories
Klarer, Paul R.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

Existing robotic rover technologies at Sandia National Laboratories (SNL) can be applied toward the realization of a robotic lunar rover mission in the near term. Recent activities at the SNL-RVR have demonstrated the utility of existing rover technologies for performing remote field geology tasks similar to those envisioned on a robotic lunar rover mission. Specific technologies demonstrated include low-data-rate teleoperation, multivehicle control, remote site and sample inspection, standard bandwidth stereo vision, and autonomous path following based on both internal dead reckoning and an external position location update system. These activities serve to support the use of robotic rovers for an early return to the lunar surface by demonstrating capabilities that are attainable with off-the-shelf technology and existing control techniques. The breadth of technical activities at SNL provides many supporting technology areas for robotic rover development. These range from core competency areas and microsensor fabrication facilities, to actual space qualification of flight components that are designed and fabricated in-house.
Author
Lunar Roving Vehicles; Lunar Surface; Robotics; Technology Utilization

19930008047 Los Alamos National Lab., NM, USA
TOPLEX: Teleoperated Lunar Explorer. Instruments and operational concepts for an unmanned lunar rover
Blacic, James D.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

A Teleoperated Lunar Explorer, or TOPLEX, consisting of a lunar lander payload in which a small, instrument-carrying lunar surface rover is robotically landed and teleoperated from Earth to perform extended lunar geoscience and resource evaluation traverses is proposed. The rover vehicle would mass about 100 kg and carry approximately 100 kg of analytic instruments. Four instruments are envisioned: (1) a Laser-Induced Breakdown Spectrometer (LIBS) for geochemical analysis at ranges up to 100 m, capable of operating in three different modes; (2) a combined x-ray fluorescence and x-ray diffraction (XRF/XRD) instrument for elemental and mineralogic analysis of acquired samples; (3) a mass spectrometer system for stepwise heating analysis of gases released from acquired samples; and (4) a geophysical instrument package for subsurface mapping of structures such as lava tubes.
Author
Instrument Packages; Laser Spectrometers; Lunar Resources; Lunar Roving Vehicles; Mass Spectrometers; Teleoperators; Unmanned Spacecraft; X Ray Diffraction; X Ray Fluorescence

19930004820 NASA Marshall Space Flight Center, Huntsville, AL, USA
The Lunar Roving Vehicle: Historical perspective
Morea, Saverio F.; NASA. Johnson Space Center, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 2; Sep 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

As NASA proceeds with its studies, planning, and technology efforts in preparing for the early twenty-first century, it seems appropriate to reexamine past programs for potential applicability in meeting future national space science and exploration goals and objectives. Both the National Commission on Space (NCOS) study and NASA's 'Sally Ride study' suggest future programs involving returning to the Moon and establishing man's permanent presence there, and/or visiting the planet Mars in both the unmanned and manned mode. Regardless of when and which of these new bold initiatives is selected as our next national space goal, implementing these potentially new national thrusts in space will undoubtedly require the use of both manned and remotely controlled roving vehicles. Therefore, the purpose of this paper is to raise the consciousness level

of the current space exploration planners to what, in the early 1970s, was a highly successful roving vehicle. During the Apollo program the vehicle known as the Lunar Roving Vehicle (LRV) was designed for carrying two astronauts, their tools, and the equipment needed for rudimentary exploration of the Moon. This paper contains a discussion of the vehicle, its characteristics, and its use on the Moon. Conceivably, the LRV has the potential to meet some future requirements, either with relatively low cost modifications or via an evolutionary route. This aspect, however, is left to those who would choose to further study these options.
Author
Histories; Lunar Roving Vehicles

19920075925 Carnegie-Mellon Univ., Pittsburgh, PA, USA
Autonomous planetary rover at Carnegie Mellon
Whittaker, William; Kanade, Takeo; Mitchell, Tom; Feb 1, 1990; In English
Contract(s)/Grant(s): NAGW-1175
Report No.(s): NASA-CR-187763; NAS 1.26:187763; CMU-RI-TR-90-04; AD-A243521; Copyright; Avail: CASI; A03, Hardcopy

This report describes progress in research on an autonomous robot for planetary exploration. In 1989, the year covered by this report, a six-legged walking robot, the Ambler, was configured, designed, and constructed. This configuration was used to overcome shortcomings exhibited by existing wheeled and walking robot mechanisms. The fundamental advantage of the Ambler is that the actuators for body support are independent of those for propulsion; a subset of the planar joints propel the body, and the vertical actuators support and level the body over terrain. Models of the Ambler's dynamics were developed and the leveling control was studied. An integrated system capable of walking with a single leg over rugged terrain was implemented and tested. A prototype of an Ambler leg is suspended below a carriage that slides along rails. To walk, the system uses a laser scanner to find a clear, flat foothold, positions the leg above the foothold, contacts the terrain with the foot, and applies force enough to advance the carriage along the rails. Walking both forward and backward, the system has traversed hundreds of meters of rugged terrain including obstacles too tall to step over, trenches too deep to step in, closely spaced rocks, and sand hills. In addition, preliminary experiments were conducted with concurrent planning and execution, and a leg recovery planner that generates time and power efficient 3D trajectories using 2D search was developed. A Hero robot was used to demonstrate mobile manipulation. Indoor tasks include collecting cups from the lab floor, retrieving printer output, and recharging when its battery gets low. The robot monitors its environment, and handles exceptional conditions in a robust fashion, using vision to track the appearance and disappearance of cups, onboard sonars to detect imminent collisions, and monitors to detect the battery level.
J.P.S.
Planetary Surfaces; Robot Dynamics; Robotics; Roving Vehicles; Self Adaptive Control Systems; Walking

19920074535 NASA, Washington, DC, USA
Ambler - Performance of a six-legged planetary rover
Krotkov, E. P.; Simmons, R. G.; Whittaker, W. L.; Aug 1, 1992; In English
Contract(s)/Grant(s): NAGW-1175
Report No.(s): IAF PAPER 92-0735; Copyright; Avail: Other Sources

In this paper, several performance metrics are quantified for the Ambler, a six-legged robot configured for autonomous traversal of Mars-like terrain. Power consumption measures are presented for walking on sandy terrain and for vertical lifts at different velocities. The performance of a novel dead reckoning approach is documented, and its accuracy is analyzed. The results of autonomous walking experiments are described in terms of terrain traversed, walking speed, and endurance.
AIAA
Mars Surface; Robotics; Roving Vehicles; Walking Machines

19920068930 NASA Marshall Space Flight Center, Huntsville, AL, USA
Lubricant and seal technologies for the next generation of lunar roving vehicles
Ramsey, Paul S.; JAN 1, 1991; In English; 23rd International SAMPE Technical Conference, Oct. 21-24, 1991, Kiamesha Lake, NY, USA
Contract(s)/Grant(s): NAS8-37857; Copyright; Avail: Other Sources

In a recent study commissioned by NASA it was determined that tribological failures can be life-limiting in many applications for the next generation of lunar rover vehicles and therefore warrant special consideration. This paper describes

the technological issues and key findings of the study. Recommended technology development needs are also presented. Because the suitability of lubricant and seal concepts must be evaluated in the context of a specific application, these technology programs are tied to advanced development of key system components. The mobility subsystem mechanisms on rover vehicles plus selected components of attached tools were determined to be essential elements which warrant advanced development in order to enhance reliability and decrease maintenance requirements. Accurate assessments of EVA, logistic support, and spare parts requirements cannot be accomplished until the advanced development programs near completion.
AIAA
Lubricants; Lunar Roving Vehicles; Seals (Stoppers); Tribology

19920067950 NASA Lewis Research Center, Cleveland, OH, USA
SEI rover solar-electrochemical power system options
Withrow, Colleen A.; Kohout, Lisa L.; Bents, David J.; Colozza, Anthony J.; JAN 1, 1991; In English; 26th IECEC '91: Intersociety Energy Conversion Engineering Conference, Aug. 4-9, 1991, Boston, MA, USA; Copyright; Avail: Other Sources

A trade study of power system technology for proposed lunar vehicles and services is presented. A variety of solar-based power systems were selected and analyzed for each. The analysis determined the power system mass, volume, and deployed area. A comparison was made between periodic refueling/recharging systems and onboard power systems to determine the most practical system. The trade study concluded that the power system significantly impacts the physical characteristics of the vehicle. The refueling/recharging systems were lighter and more compact, but dependent on availability of established lunar base infrastructure. Onboard power systems pay a mass penalty for being fully developed systems.
AIAA
Energy Storage; Hydrogen Oxygen Fuel Cells; Lunar Roving Vehicles; Regenerative Fuel Cells; Sodium Sulfur Batteries; Solar Cells

19920059622 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Vision-based planetary rover navigation
Wilcox, Brian H.; JAN 1, 1990; In English; Visual Communications and Image Processing '90, Oct. 1-4, 1990, Lausanne, Switzerland; Copyright; Avail: Other Sources

NASA and JPL have developed a testbed 'planetary rover' vehicle with sufficient power supplies, sensors, and computational resources for the demonstration of semiautonomous navigation. Attention is presently given to this vehicle's vision-based navigation techniques. The proposed design and its variants allow advantage to be taken of enormous quantities of both spatial and temporal information that are normally wasted, by sampling very fine detail over the full focal plane area to precisely determine those parts of the image that are accurately at the focus range of the pinhole array used. This should generate accurate and reliable real-time range information in a wide variety of natural scenes, with little or no computation.
AIAA
Autonomous Navigation; Computer Vision; Planetary Surfaces; Roving Vehicles; Telerobotics

19920055878 NASA Ames Research Center, Moffett Field, CA, USA
A visual display aid for planning rover traversals
Bernard, Herbert F.; Ellis, Stephen R.; Mar 1, 1992; In English
Report No.(s): AIAA PAPER 92-1313; Copyright; Avail: Other Sources

An interactive graphical planning system has been developed, which allows a human operator to design and check traversals (cross-country paths) for a planetary rover vehicle. The display provides the operator with necessary information about the terrain and indicates violations of operational or dynamic constraints on the rover. The operator can select different kinds of two-dimensional maps as well as a perspective view of the rover environment to plan the traversals. An experiment has been carried out to determine the ability of the operator to estimate the rover attitude in a large variety of situations. It turned out that the estimation error is highly dependent on the rover attitude itself. This result can be used to determine a vertical scale for the perspective representation of the terrain which avoids an underestimation of dangerous rover attitudes.
AIAA
Geological Surveys; NASA Space Programs; Planetary Surfaces; Roving Vehicles; Terrain Analysis

19920054699 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
The impact of Mars surface characteristics on rover design
Pivirotto, Donna L. S.; JAN 1, 1991; In English; 2nd COSPAR Colloquium on the Environmental Model of Mars, Jan. 22-26, 1990, Sopron, Hungary; Copyright; Avail: Other Sources

The characteristics of the surface of Mars will have a profound effect on the design and operation of roving vehicles. The design impacts of surface conditions, and the implications of knowing these conditions well or poorly, are described. It is a clear benefit to have orbital imaging, and radar subsurface sounding data at a scale of about one meter before designing the rover. In addition, knowledge of the terrain to one meter scale is important for efficient traverse and operations planning.
AIAA
Design Analysis; Mars Surface; Mission Planning; Roving Vehicles

19920054698 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA, NASA, Washington, DC, USA
Surface knowledge and risks to landing and roving - The scale problem
Bourke, Roger D.; JAN 1, 1991; In English; 2nd COSPAR Colloquium on the Environmental Model of Mars, Jan. 22-26, 1990, Sopron, Hungary; Copyright; Avail: Other Sources

The role of surface information in the performance of surface exploration missions is discussed. Accurate surface models based on direct measurements or inference are considered to be an important component in mission risk management. These models can be obtained using high resolution orbital photography or a combination of laser profiling, thermal inertia measurements, and/or radar. It is concluded that strategies for Martian exploration should use high confidence models to achieve maximum performance and low risk.
AIAA
Mars Environment; Mars Landing; Mars Surface; Risk; Viking Lander Spacecraft

19920035037 Carnegie-Mellon Univ., Pittsburgh, PA, USA
A six-legged rover for planetary exploration
Simmons, Reid; Krotkov, Eric; Bares, John; JAN 1, 1991; In English; 8th AIAA Computing in Aerospace Conference, Oct. 21-24, 1991, Baltimore, MD, USA
Contract(s)/Grant(s): NAGW-1175
Report No.(s): AIAA PAPER 91-3812; Copyright; Avail: Other Sources

To survive the rigors and isolation of planetary exploration, an autonomous rover must be competent, reliable, and efficient. This paper presents the Ambler, a six-legged robot featuring orthogonal legs and a novel circulating gait, which has been designed for traversal of rugged, unknown environments. An autonomous software system that integrates perception, planning, and real-time control has been developed to walk the Ambler through obstacle strewn terrain. The paper describes the information and control flow of the walking system, and how the design of the mechanism and software combine to achieve competent walking, reliable behavior in the face of unexpected failures, and efficient utilization of time and power.
AIAA
Planetary Landing; Research Vehicles; Roving Vehicles; Space Exploration; Walking Machines

19920029832 NASA, Washington, DC, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
1991 NASA Planetary Rover Program
Lavery, David; Bedard, Roger J., Jr.; Oct 1, 1991; In English
Report No.(s): IAF PAPER 91-037; Copyright; Avail: Other Sources

The principal accomplishments of the 1991 Nasa Planetary Rover Program are described. The work to date has focused on development of unmanned science rover technology within the context of high mobility wheeled vehicles at the JPL and an innovative legged locomotion concept at Carnegie Mellon University. Attention is given to mission operations research including simulation environment, mission scenario simulation experiments, and the rover system executive software that will reside onboard a rover in future planetary surface missions.
AIAA
NASA Space Programs; Planetary Surfaces; Roving Vehicles

19920024070 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Artemis program: Rover/Mobility Systems Workshop results
Weaver, Dave; Third SEI Technical Interchange: Proceedings; JAN 1, 1992; In English; No Copyright; Avail: CASI; A01, Hardcopy

Information is given in viewgraph form on the Artemis Program Rover/Mobility Systems Workshop results. Topics covered include an outpost site survey and resource assessment for Mare Tranquillitatis (15 n, 22 E). Viable mobility systems

appear to be capable of supporting a 1997 launch. Achieving the defined mission objectives within a 65 kg payload appears to be possible, although with limited capability.
CASI
Landing Sites; Lunar Bases; Lunar Exploration; Lunar Maria; Lunar Roving Vehicles; Mission Planning; Moon; Payloads; Space Exploration; Topography

19920020197 Draper (Charles Stark) Lab., Inc., Cambridge, MA, USA
A systems analysis of the impact of navigation instrumentation on-board a Mars rover, based on a covariance analysis of navigation performance
Leber, Douglas Eric; May 1, 1992; In English
Contract(s)/Grant(s): NAS9-18426
Report No.(s): NASA-CR-189868; NAS 1.26:189868; CSDL-T-1126; Copyright; Avail: CASI; A05, Hardcopy

As part of the Space Exploration Initiative, the exploration of Mars will undoubtedly require the use of rovers, both manned and unmanned. Many mission scenarios have been developed, incorporating rovers which range in size from a few centimeters to ones large enough to carry a manned crew. Whatever the mission, accurate navigation of the rover on the Martian surface will be necessary. This thesis considers the initial rover missions, where minimal in-situ navigation aids will be available on Mars. A covariance analysis of the rover's navigation performance is conducted, assuming minimal on-board instrumentation (gyro compass and speedometer), a single orbiting satellite, and a surface beacon at the landing site. Models of the on-board instruments are varied to correspond to the accuracy of various levels of these instruments currently available. A comparison is made with performance of an on-board IMU. Landing location and satellite orbits are also varied.
CASI
Autonomous Navigation; Covariance; Mars Surface; Navigation Aids; Roving Vehicles; Simulation; Systems Analysis

19920018623 Carnegie-Mellon Univ., Pittsburgh, PA, USA
Autonomous planetary rover
Krotkov, Eric; Simmons, Reid; Whittaker, William; Feb 1, 1992; In English
Contract(s)/Grant(s): NAGW-1175
Report No.(s): NASA-CR-190465; NAS 1.26:190465; AD-A248161; CMU-RI-TR-92-02; No Copyright; Avail: CASI; A04, Hardcopy

This report describes progress in research on an autonomous robot for planetary exploration performed during 1991 at the Robotics Institute, Carnegie Mellon University. The report summarizes the achievements during calendar year 1991, and lists personnel and publications. In addition, it includes several papers resulting from the research. Research in 1991 focused on understanding the unique capabilities of the Ambler mechanism and on autonomous walking in rough, natural terrain. We also designed a sample acquisition system, and began to configure a successor to the Ambler.
DTIC
Autonomous Navigation; Planetary Surfaces; Robotics; Robots; Roving Vehicles

19920015079 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Position determination of a lander and rover at Mars with Earth-based differential tracking
Kahn, R. D.; Folkner, W. M.; Edwards, C. D.; Vijayaraghavan, A.; The Telecommunications and Data Acquisition Report; Feb 15, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

The presence of two or more landed or orbiting spacecraft at a planet provides the opportunity to perform extremely accurate Earth-based navigation by simultaneously acquiring Doppler data and either Same-Beam Interferometry (SBI) or ranging data. Covariance analyses were performed to investigate the accuracy with which lander and rover positions on the surface of Mars can be determined. Simultaneous acquisition of Doppler and ranging data from a lander and rover over two or more days enables determination of all components of their relative position to under 20 m. Acquiring one hour of Doppler and SBI enables three dimensional lander-rover relative position determination to better than 5 m. Twelve hours of Doppler and either SBI or ranging from a lander and a low circular or half synchronous circular Mars orbiter makes possible lander absolute position determination to tens of meters.
CASI
Doppler Effect; Interferometry; Navigation; Planetary Landing; Rangefinding; Roving Vehicles; Tracking (Position)

19920012058 Houston Univ., TX, USA

Fuzzy logic path planning system for collision avoidance by an autonomous rover vehicle

Murphy, Michael G.; Texas A and M Univ., NASA(ASEE Summer Faculty Fellowship Program, 1991, Volume 2; Dec 1, 1991; In English; No Copyright; Avail: CASI; A02, Hardcopy

Systems already developed at JSC have shown the benefits of applying fuzzy logic control theory to space related operations. Four major issues are addressed that are associated with developing an autonomous collision avoidance subsystem within a path planning system designed for application in a remote, hostile environment that does not lend itself well to remote manipulation of the vehicle involved through Earth-based telecommunication. A good focus for this is unmanned exploration of the surface of Mars. The uncertainties involved indicate that robust approaches such as fuzzy logic control are particularly appropriate. The four major issues addressed are: (1) avoidance of a single fuzzy moving obstacle; (2) back off from a dead end in a static obstacle environment; (3) fusion of sensor data to detect obstacles; and (4) options for adaptive learning in a path planning system.

CASI

Automatic Control; Collision Avoidance; Control Systems Design; Fuzzy Systems; Logic Design; Roving Vehicles; Space Communication; Trajectory Planning

19920003988 NASA Lewis Research Center, Cleveland, OH, USA

SEI power source alternatives for rovers and other multi-kWe distributed surface applications

Bents, D. J.; Kohout, Lisa L.; Mckissock, B. I.; Rodriguez, C. D.; Withrow, C. A.; Colozza, A.; Hanlon, J. C.; Schmitz, P. C.; ESA, European Space Power Conference. Volume 1: Power Systems, Power Electronics, Batteries and Fuel Cells; Aug 1, 1991; In English; Copyright; Avail: CASI; A02, Hardcopy

Results of the study performed to support the Space Exploration Initiative (SEI) which investigated power system alternatives for the rover vehicles and servicers that would be used for construction and operation of a lunar base is described. Using the mission requirements and power profiles that were subsequently generated for each of these rovers and servicers, candidate power sources incorporating various power generation and energy storage technologies were identified. The technologies were those believed most appropriate to the SEI missions, and included solar, electrochemical, and isotope systems. The candidates were characterized with respect to system mass, deployed area and volume. For each of the missions a preliminary selection was made. Results of this study depict the available power sources in light of the mission requirements as they are currently defined.

ESA

Electric Generators; Electrochemical Cells; Energy Storage; Roving Vehicles; Spacecraft Power Supplies

19910068662 NASA Langley Research Center, Hampton, VA, USA

A lunar rover powered by an orbiting laser diode array

De Young, R. J.; Williams, M. D.; Walker, G. H.; Schuster, G. L.; Lee, J. H.; Space Power - Resources, Manufacturing and Development; JAN 1, 1991; ISSN 0883-6272; 10, 1, 19; In English; Copyright; Avail: Other Sources

A conceptual design of a high-power, long-duration lunar rover powered by a laser beam is proposed. The laser transmitter in lunar orbit consists of an SP-100 nuclear reactor prime power source providing 100 kW of electricity to a laser array that emits 50 kW of laser radiation. The laser radiation is beamed to the lunar surface where it is received by a GaAlAs solid-state, laser-to-electric converter. This converter provides 22 kW of electrical power to the rover vehicle for science, locomotion, and crew needs. The mass of the laser transmitter is approximately 5000 kg, whereas the mass of the rover power supply is 520 kg. The rover power unit is significantly less massive than alternative rover power units.

AIAA

Gallium Arsenide Lasers; Laser Arrays; Laser Beams; Lunar Roving Vehicles; Nuclear Reactors

19910053309 New Mexico Univ., Albuquerque, NM, USA, NASA Lewis Research Center, Cleveland, OH, USA

A comparison of energy conversion systems for meeting the power requirements of manned rover for Mars missions

El-Genk, Mohamed S.; Morley, Nicholas; Cataldo, Robert; Bloomfield, Harvey; JAN 1, 1990; In English; 25th Intersociety Energy Conversion Engineering Conference, Aug. 12-17, 1990, Reno, NV, USA

Contract(s)/Grant(s): NAG3-992; Copyright; Avail: Other Sources

Several types of conversion systems of interest for a nuclear Mars manned application are examined, including: free-piston Stirling engines (FPSE), He/Xe closed Brayton cycle (CBC), CO2 open Brayton, and SiGe/GaP thermoelectric systems. Optimization studies were conducted to determine the impact of the conversion system on the overall mass of the

nuclear power system and the mobility power requirement of the rover vehicle. The results of an analysis of a manned Mars rover equipped with a nuclear reactor power system show that the free-piston Stirling engine and the He/Xe closed Brayton cycle are the best available options for minimizing the overall mass and electric power requirements of the rover vehicle. While the current development of Brayton technology is further advanced than that of FPSE, the FPSE could provide approximately 13.5 percent lower mass than the He/Xe closed Brayton system. Results show that a specific mass of 160 is achievable with FPSE, for which the mass of the radiation shield (2.8 tons) is about half that for He/Xe CBC (5 tons).
AIAA
Energy Conversion; Manned Mars Missions; Power Conditioning; Roving Vehicles; Spacecraft Power Supplies

19910050505 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Path planning and execution monitoring for a planetary rover
Gat, Erann; Slack, Marc G.; Miller, David P.; Firby, R. James; JAN 1, 1990; In English; Copyright; Avail: Other Sources

A path planner and an execution monitoring planner that will enable the rover to navigate to its various destinations safely and correctly while detecting and avoiding hazards are described. An overview of the complete architecture is given. Implementation and testbeds are described. The robot can detect unforseen obstacles and take appropriate action. This includes having the rover back away from the hazard and mark the area as untraversable in the in the rover's internal map. The experiments have consisted of paths roughly 20 m in length. The architecture works with a large variety of rover configurations with different kinematic constraints.
AIAA
Applications Programs (Computers); Autonomous Navigation; Planetary Surfaces; Roving Vehicles; Trajectory Planning

19910043079 New Mexico Univ., Albuquerque, NM, USA, NASA Lewis Research Center, Cleveland, OH, USA
Preliminary assessment of the power requirements of a manned rover for Mars missions
El-Genk, Mohamed S.; Morley, Nicholas J.; Cataldo, Robert; Bloomfield, Harvey; JAN 1, 1990; In English; Space 90: The Second International Conference, Apr. 22-26, 1990, Albuquerque, NM, USA
Contract(s)/Grant(s): NAG3-992; Copyright; Avail: Other Sources

A preliminary study to determine the total mass and power requirements of a manned Mars rover is presented. Estimates of the power requirements for the nuclear reactor power system are determined as functions of the number of crew members, the emergency return trip scenario in case of a total malfunction of the reactor system, the cruising speed and range of the vehicle, and the specific mass of the power system. It is shown that the cruising speed of the vehicle and the soil traction factor significantly affect the traversing power requirement and therefore the mass of the nuclear power system. The cruising speed of the vehicle must be limited to 14.5 and 24 km/hr for power system specific masses of 150 kg/kWe and 50 kg/kWe, respectively, for the nuclear power system mass not to exceed 50 percent of the total mass of the rover.
AIAA
Manned Mars Missions; Nuclear Reactors; Power Reactors; Roving Vehicles

19910041996 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Autonomous navigation and control of a Mars rover
Miller, D. P.; Atkinson, D. J.; Wilcox, B. H.; Mishkin, A. H.; JAN 1, 1990; In English; IFAC Symposium, July 17-21, 1989, Tsukuba, Japan; Copyright; Avail: Other Sources

A Mars rover will need to be able to navigate autonomously kilometers at a time. This paper outlines the sensing, perception, planning, and execution monitoring systems that are currently being designed for the rover. The sensing is based around stereo vision. The interpretation of the images use a registration of the depth map with a global height map provided by an orbiting spacecraft. Safe, low energy paths are then planned through the map, and expectations of what the rover's articulation sensors should sense are generated. These expectations are then used to ensure that the planned path is correctly being executed.
AIAA
Autonomous Navigation; Image Processing; Mars Surface; Roving Vehicles; Stereoscopic Vision; Trajectory Planning

19910029407 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Lunar rover developments at JPL
Burke, James D.; Bickler, Donald B.; Pivirotto, Donna L.; Oct 1, 1990; In English
Report No.(s): IAF PAPER 90-433; Copyright; Avail: Other Sources

Results of previous JPL developments are summarized and the current work related to lunar roving missions is discussed. Objectives of a long lunar transverse are reviewed and include lunar resource prospecting and base site surveys. Rover design criteria are presented, noting that payload instrumentation would include both television cameras for driving and cameras producing panoramic facsimile for high-fidelity scientific imaging and landmark navigation, as well as a multipurpose imaging system with multispectral, close-up, and microscopic capabilities. Instrumentation providing for chemical and mineral analysis, a gravimeter, and a magnetometer are also important. Rover performance requirements include a capability to support a 50 kg payload mass with a rover mass of 500 to 600 kg, powering and supporting the payload, managing the on-board resources available to each instrument, and handling all of the mission data. Desert tests of lunar roving navigation and field geology are discussed.
AIAA
Design Analysis; Lunar Exploration; Lunar Surface; Roving Vehicles

19910029133 NASA, Washington, DC, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
NASA Planetary Rover Program
Lavery, David; Bedard, Roger J., Jr.; Oct 1, 1990; In English
Report No.(s): IAF PAPER 90-038; Copyright; Avail: Other Sources
The NASA Planetary Rover Project was initiated in 1989. The emphasis of the work to date has been on development of autonomous navigation technology within the context of a high mobility wheeled vehicle at the JPL and an innovative legged locomotion concept at Carnegie Mellon University. The status and accomplishments of these two efforts are discussed. First, however, background information is given on the three rover types required for the Space Exploration Initiative.
AIAA
Planetary Surfaces; Robotics; Roving Vehicles; Space Exploration

19910027669 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA, Science Applications International Corp., Schaumburg, IL, USA
Design of a Mars rover and sample return mission
Bourke, Roger D.; Kwok, Johnny H.; Friedlander, Alan; JAN 1, 1990; In English; Copyright; Avail: Other Sources
The design of a Mars Rover Sample Return (MRSR) mission that satisfies scientific and human exploration precursor needs is described. Elements included in the design include an imaging rover that finds and certifies safe landing sites and maps rover traverse routes, a rover that operates the surface with an associated lander for delivery, and a Mars communications orbiter that allows full-time contact with surface elements. A graph of MRSR candidate launch vehice performances is presented.
AIAA
Mars Sample Return Missions; Roving Vehicles; Spacecraft Trajectories

19910025524 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Site characterization rover missions
Pivirotto, Donna Shirley; Sep 1, 1990; In English
Report No.(s): AIAA PAPER 90-3785; Copyright; Avail: Other Sources
Concepts for site characterization rovers capable of efficient operation on Mars with human supervision from earth are discussed. In particular, attention is given to strategies for developing and evaluating the necessary technology for implementing the roving vehicles and process technologies required for a systematic and integrated implementation of technologically advanced rovers. A vehicle testbed program is also described.
AIAA
Landing Sites; Mars Sample Return Missions; Remote Control; Robotics; Roving Vehicles

19910018963 NASA Lewis Research Center, Cleveland, OH, USA
SEI power source alternatives for rovers and other multi-kWe distributed surface applications
Bents, David J.; Kohout, L. L.; Mckissock, Barbara I.; Rodriguez, C. D.; Withrow, C. A.; Colozza, A.; Hanlon, James C.; Schmitz, Paul C.; JAN 1, 1991; In English; European Space Power Conference, 2-5 Sep. 1991, Florence, Italy
Contract(s)/Grant(s): NAS3-25266; RTOP 591-14-11
Report No.(s): NASA-TM-104360; E-6155; NAS 1.15:104360; No Copyright; Avail: CASI; A03, Hardcopy
To support the Space Exploration Initiative (SEI), a study was performed to investigate power system alternatives for the

rover vehicles and servicers that were subsequently generated for each of these rovers and servicers, candidate power sources incorporating various power generation and energy storage technologies were identified. The technologies were those believed most appropriate to the SEI missions, and included solar, electrochemical, and isotope systems. The candidates were characterized with respect to system mass, deployed area, and volume. For each of the missions a preliminary selection was made. Results of this study depict the available power sources in light of mission requirements as they are currently defined.
CASI
Auxiliary Power Sources; Lunar Bases; Lunar Roving Vehicles; Power Supplies

19910018625 New Mexico Univ., Albuquerque, NM, USA
Conceptual studies on the integration of a nuclear reactor system to a manned rover for Mars missions
El-Genk, Mohamed S.; Morley, Nicholas J.; Jul 1, 1991; In English
Contract(s)/Grant(s): NAG3-992
Report No.(s): NASA-CR-185841; NAS 1.26:185841; No Copyright; Avail: CASI; A05, Hardcopy

Multiyear civilian manned missions to explore the surface of Mars are thought by NASA to be possible early in the next century. Expeditions to Mars, as well as permanent bases, are envisioned to require enhanced piloted vehicles to conduct science and exploration activities. Piloted rovers, with 30 kWe user net power (for drilling, sampling and sample analysis, onboard computer and computer instrumentation, vehicle thermal management, and astronaut life support systems) in addition to mobility are being considered. The rover design, for this study, included a four car train type vehicle complete with a hybrid solar photovoltaic/regenerative fuel cell auxiliary power system (APS). This system was designed to power the primary control vehicle. The APS supplies life support power for four astronauts and a limited degree of mobility allowing the primary control vehicle to limp back to either a permanent base or an accent vehicle. The results showed that the APS described above, with a mass of 667 kg, was sufficient to provide live support power and a top speed of five km/h for 6 hours per day. It was also seen that the factors that had the largest effect on the APS mass were the life support power, the number of astronauts, and the PV cell efficiency. The topics covered include: (1) power system options; (2) rover layout and design; (3) parametric analysis of total mass and power requirements for a manned Mars rover; (4) radiation shield design; and (5) energy conversion systems.
CASI
Manned Mars Missions; Mars Surface; Nuclear Power Reactors; Roving Vehicles; Systems Integration

19910017792 Houston Univ., TX, USA
Fuzzy logic control system to provide autonomous collision avoidance for Mars rover vehicle
Murphy, Michael G.; NASA(ASEE Summer Faculty Fellowship Program, 1990, Volume 2; Dec 1, 1990; In English
Contract(s)/Grant(s): NGT-44-005-803; No Copyright; Avail: CASI; A03, Hardcopy

NASA is currently involved with planning unmanned missions to Mars to investigate the terrain and process soil samples in advance of a manned mission. A key issue involved in unmanned surface exploration on Mars is that of supporting autonomous maneuvering since radio communication involves lengthy delays. It is anticipated that specific target locations will be designated for sample gathering. In maneuvering autonomously from a starting position to a target position, the rover will need to avoid a variety of obstacles such as boulders or troughs that may block the shortest path to the target. The physical integrity of the rover needs to be maintained while minimizing the time and distance required to attain the target position. Fuzzy logic lends itself well to building reliable control systems that function in the presence of uncertainty or ambiguity. The following major issues are discussed: (1) the nature of fuzzy logic control systems and software tools to implement them; (2) collision avoidance in the presence of fuzzy parameters; and (3) techniques for adaptation in fuzzy logic control systems.
CASI
Collision Avoidance; Control Systems Design; Expert Systems; Fuzzy Systems; Logic Design; Mars Sample Return Missions; Roving Vehicles

19910014307 NASA Lewis Research Center, Cleveland, OH, USA
SEI rover solar-electrochemical power system options
Withrow, Colleen A.; Kohout, Lisa L.; Bents, David J.; Colozza, Anthony J.; May 1, 1991; In English; 26th Intersociety Energy Conversion Engineering Conference, 4-9 Aug. 1991, Boston, MA, USA
Contract(s)/Grant(s): NAS3-25266; RTOP 326-81-10
Report No.(s): NASA-TM-104402; E-6224; NAS 1.15:104402; No Copyright; Avail: CASI; A03, Hardcopy

A trade study of power system technology for proposed lunar vehicles and servicers is presented. A variety of solar-based

power systems were selected and analyzed for each. The analysis determined the power system mass, volume, and deployed area. A comparison was made between periodic refueling/recharging systems and onboard power systems to determine the most practical system. The trade study concluded that the power system significantly impacts the physical characteristics of the vehicle. The refueling/recharging systems were lighter and more compact, but dependent on availability of established lunar base infrastructure. Onboard power systems pay a mass penalty for being fully developed systems.
CASI
Energy Storage; Hydrogen Oxygen Fuel Cells; Lunar Roving Vehicles; Regenerative Fuel Cells; Sodium Sulfur Batteries; Solar Cells

19910013887 Boeing Aerospace Co., Huntsville, AL, USA
Piloted rover technology study
Thrasher, D. L.; Aug 10, 1990; In English
Contract(s)/Grant(s): NAS8-37857
Report No.(s): NASA-CR-186989; NAS 1.26:186989; D615-10014; No Copyright; Avail: CASI; A09, Hardcopy

This is the May 25, 1990 summary report for Space Transfer Concepts and Analyses (STCA) Study, special study task 9.1, Piloted Rovers Technology Study. Piloted rover concepts, mission scenarios, and the requirements necessary for completion of these missions resulting in the establishment of a lunar base. These tasks were intended to lead to a logical conclusion concerning which piloted rovers technologies are needed to accomplish the various missions, along with a recommended schedule for the development of these technologies.
CASI
Lunar Bases; Lunar Exploration; Lunar Roving Vehicles; Manned Lunar Surface Vehicles; Mission Planning

19910012854 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Mini-rovers for Mars explorations
Miller, David P.; NASA. Lewis Research Center, Vision-21: Space Travel for the Next Millennium; Apr 1, 1990; In English; No Copyright; Avail: CASI; A02, Hardcopy

Rovers are desirable for surface exploration because they allow sampling, and sample returns from several diverse locations on a planet's surface. Unfortunately, the rovers currently being examined for Mars exploration have several undesirable features. These rovers are quite massive (500 kg to one ton), have very complicated operations, and are very expensive. A possible alternative is described to using large rovers for exploring the surface of Mars. The idea of mini-rovers is proposed. Mini-rovers weigh less than 5 kg, are trivial to control from the ground, and can do a more thorough survey of the terrain (per kilogram of mass) than can be obtained by large rovers. By redesigning the Mars sample return mission to accommodate the idea of mini-rovers and small spacecraft, considerable mass and cost savings can be achieved.
CASI
Mars (Planet); Mars Sample Return Missions; Mars Surface; Mars Surface Samples; Mission Planning; Roving Vehicles

19910011373 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
The real-time control of planetary rovers through behavior modification
Miller, David P.; NASA, Lyndon B. Johnson Space Center, Fourth Annual Workshop on Space Operations Applications and Research (SOAR 90); Jan 1, 1991; In English; No Copyright; Avail: CASI; A02, Hardcopy

It is not yet clear of what type, and how much, intelligence is needed for a planetary rover to function semi-autonomously on a planetary surface. Current designs assume an advanced AI system that maintains a detailed map of its journeys and the surroundings, and that carefully calculates and tests every move in advance. To achieve these abilities, and because of the limitations of space-qualified electronics, the supporting rover is quite sizable, massing a large fraction of a ton, and requiring technology advances in everything from power to ground operations. An alternative approach is to use a behavior driven control scheme. Recent research has shown that many complex tasks may be achieved by programming a robot with a set of behaviors and activation or deactivating a subset of those behaviors as required by the specific situation in which the robot finds itself. Behavior control requires much less computation than is required by tradition AI planning techniques. The reduced computation requirements allows the entire rover to be scaled down as appropriate (only down-link communications and payload do not scale under these circumstances). The missions that can be handled by the real-time control and operation of a set of small, semi-autonomous, interacting, behavior-controlled planetary rovers are discussed.
CASI
Automatic Control; Control Systems Design; Real Time Operation; Robot Control; Roving Vehicles

19910011338 NASA, Washington, DC, USA
NASA Planetary Rover Program
Lavery, David; Bedard, Roger J., Jr.; NASA, Lyndon B. Johnson Space Center, Fourth Annual Workshop on Space Operations Applications and Research (SOAR 90); Jan 1, 1991; In English
Contract(s)/Grant(s): NAS7-918; NAGW-1175; No Copyright; Avail: CASI; A02, Hardcopy

The NASA Planetary Rover Project was initiated in 1989. The emphasis of the work to date has been on development of autonomous navigation technology within the context of a high mobility wheeled vehicle at the JPL and an innovative legged locomotion concept at Carnegie Mellon University. The status and accomplishments of these two efforts are discussed. First, however, background information is given on the three rover types required for the Space Exploration Initiative (SEI) whose objective is a manned mission to Mars.
CASI
Autonomous Navigation; Manned Mars Missions; Planetary Surfaces; Robotics; Roving Vehicles; Space Exploration

19910005287 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Mars Rover/Sample Return (MRSR) Mission: Mars Rover Technology Workshop
JAN 1, 1987; In English, 28-30 Apr. 1987, Pasadena, CA, USA
Report No.(s): NASA-TM-101129; JPL-D-4788; NAS 1.15:101129; No Copyright; Avail: CASI; A99, Hardcopy

A return to the surface of Mars has long been an objective of NASA mission planners. The ongoing Mars Rover and Sample Return (MRSR) mission study represents the latest stage in that interest. As part of NASA's preparation for a possible MRSR mission, a technology planning workshop was held to attempt to define technology requirements, options, and preliminary plans for the principal areas of Mars rover technology. The proceedings of that workshop are presented.
CASI
Mars Sample Return Missions; Mars Surface; Mission Planning; Roving Vehicles

19900067291 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA, NASA Ames Research Center, Moffett Field, CA, USA, NASA, Washington, DC, USA
Project Pathfinder: Planetary Rover Project plan
Bedard, Roger J., Jr.; Friedland, Peter E.; Montemerlo, Mel; Sep 1, 1988; In English
Contract(s)/Grant(s): PROJ. PATHFINDER
Report No.(s): NASA-TM-101122; NAS 1.15:101122; No Copyright; Avail: CASI; A05, Hardcopy
Extravehicular Activity; Mars Surface Samples; NASA Programs; Planetary Landing; Roving Vehicles; Space Exploration

19900066934 Carnegie-Mellon Univ., Pittsburgh, PA, USA
The 1988 year end report on autonomous planetary rover at Carnegie Mellon
Kanade, Takeo; Mitchell, Tom; Whittaker, William; Jan 1, 1989; In English
Contract(s)/Grant(s): NAGW-1175
Report No.(s): NASA-CR-186827; NAS 1.26:186827; CMU-RI-TR-89-3; No Copyright; Avail: CASI; A05, Hardcopy
Laser Range Finders; Mars (Planet); Planetary Surfaces; Robotics; Robots; Roving Vehicles; Terrain; Walking Machines

19900060057 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Orbit/deorbit analysis for a Mars rover and sample return mission
Penzo, Paul A.; Journal of Spacecraft and Rockets; Aug 1, 1990; ISSN 0022-4650; 27; In English; Copyright; Avail: Other Sources
Astrodynamics; Mars Sample Return Missions; Mars Satellites; Mars Surface Samples; Orbit Calculation; Roving Vehicles

19900056472 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA, Science Applications International Corp., Schaumburg, IL, USA
Mars Rover and Sample Return Mission design
Kwok, Johnny H.; Friedlander, Alan L.; JAN 1, 1989; In English; AAS/NASA Intl. Symposium on Orbital Mechanics and Mission Design, Apr. 24-27, 1989, Greenbelt, MD, USA
Report No.(s): AAS PAPER 89-198; Copyright; Avail: Other Sources

The current reference Mars Rover and Sample Return mission is described. Technical issues are outlined, including high-resolution image acquisition and reconstruction, approach navigation, ground and flight systems operational complexity,

rover autonomy, autonomous rendezvous and docking in Mars orbit, aerocapture and aeromaneuver, estimating the probability of mission success, and end-to-end information system design. Focus is placed on lander hazard identification and avoidance, pinpoint landing guidance and control, Mars ascent vehicle guidance and control, planetary protection and quarantine, sample acquisition and preservation, project management and control, systems requirements and interface control, and costing. In addition, program issues such as international participation, fiscal constraints, and launch-vehicle availability are considered.
AIAA
Mars Sample Return Missions; Mission Planning; Roving Vehicles

19900048963 Science Applications International Corp., Schaumburg, IL, USA, Science Applications International Corp., Washington, DC, USA
Mars Rover/Sample Return - Phase A cost estimation
Stancati, Michael L.; Spadoni, Daniel J.; May 1, 1990; In English
Contract(s)/Grant(s): NASW-4214; Copyright; Avail: Other Sources

This paper presents a preliminary cost estimate for the design and development of the Mars Rover/Sample Return (MRSR) mission. The estimate was generated using a modeling tool specifically built to provide useful cost estimates from design parameters of the type and fidelity usually available during early phases of mission design. The model approach and its application to MRSR are described.
AIAA
Cost Estimates; Mars Sample Return Missions; Mars Surface Samples; Roving Vehicles

19900029609 NASA, Washington, DC, USA
Planetary protection and back contamination control for a Mars rover sample return mission
Rummel, John D.; JAN 1, 1989; In English
Report No.(s): AAS PAPER 87-197; Copyright; Avail: Other Sources

A commitment to avoid the harmful contamination of outer space and avoid adverse changes in the environment of the earth has been long reflected in NASA's Planetary Protection policy. Working under guidelines developed by the Committee on Space Research (COSPAR), NASA has implemented the policy in an interactive process that has included the recommendations of the U.S. National Academy of Sciences. Measures taken to prevent the contamination of earth during the Apollo missions were perhaps the most visible manifestations of this policy, and provided numerous lessons for future sample return opportunities. This paper presents the current status of planetary protection policy within NASA, and a prospectus on how planetary protection issues might be addressed in relation to a Mars Rover Sample Return mission.
AIAA
Earth Environment; Environment Protection; Mars Surface Samples; Pollution Control; Return to Earth Space Flight

19900029607 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Mars Rover Sample Return mission study
Bourke, Roger D.; JAN 1, 1989; In English
Report No.(s): AAS PAPER 87-195; Copyright; Avail: Other Sources

The Mars Rover/Sample Return mission is examined as a precursor to a manned mission to Mars. The value of precursor missions is noted, using the Apollo lunar program as an example. The scientific objectives of the Mars Rover/Sample Return mission are listed and the basic mission plans are described. Consideration is given to the options for mission design, launch configurations, rover construction, and entry and lander design. Also, the potential for international cooperation on the Mars Rover/Sample Return mission is discussed.
AIAA
Mars Surface Samples; Mission Planning; Return to Earth Space Flight; Roving Vehicles

19900029488 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Mars Rover options
Pivirotto, Donna Shirley; Bickler, Donald; JAN 1, 1989; In English
Report No.(s): AAS PAPER 87-244; Copyright; Avail: Other Sources

The paper will describe a nested set of Mars Rover options which are being considered. The option ranges include: low-to-high levels of technology, especially in autonomous activities; low (400 kg) to high (1500 kg) allowable mass; and coarse (100-meter) to fine (1-meter) knowledge of the terrain to be traversed. The options which will be selected for further

study at the end of FY 1988 will be heavily dependent on such factors as the availability of precursor mission data (especially imaging) and the bounds on mass and volume imposed by the launch, Martian entry, and landing systems.
AIAA
Mars Sample Return Missions; Mission Planning; Roving Vehicles

19900029487 Science Applications International Corp., Schaumburg, IL, USA
Mars Rover/Sample Return mission definition
Friedlander, Alan L.; JAN 1, 1989; In English
Contract(s)/Grant(s): NASW-4214
Report No.(s): AAS PAPER 87-243; Copyright; Avail: Other Sources

Mission trade studies for a preliminary definition of a flight-separable Mars Rover/Sample Return (MRSR) mission are presented. The MRSR initiative consists of two separate mission elements: a Mars Rover and a Mars Sample Return. Various strategies are discussed for completing the interplanetary portion of the MRSR mission. Five mission options which are characterized by different launch configurations are discussed, and the resulting spacecraft mass needed to accomplish the mission is presented relative to the capabilities of launch vehicles assumed to be available during the timeframe under consideration.
AIAA
Mars Sample Return Missions; Mission Planning; Roving Vehicles

19900026361 Fairchild Space and Electronics Co., Germantown, MD, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Mars rover RTG study
Schock, A.; Hamrick, T.; Or, T.; Sankarankandath, V.; Skrabek, E.; Shirbacheh, M.; Oct 1, 1989; In English
Report No.(s): IAF PAPER 89-270; Copyright; Avail: Other Sources

The paper describes the design and analysis of radioisotope thermoelectric generators (RTGs) for powering the Mars rover vehicle, which is a critical element of the unmanned Mars Rover and Sample Return mission (MRSR). A brief description is given of a reference mission scenario, an illustrative rover design and activity pattern on Mars, power system requirements, and environmental constraints, including the RTG cooling requirements during transit to Mars. The key RTG design problem, i.e. venting the helium generated by the fuel's alpha decay without intrusion of the Martian atmosphere into the RTG, is identified and a design approach to solve that problem is proposed. The study's primary objective is to quantify the performance improvements achievable in new successfully developed technologies, to estimate the required time, effort, success probability, and programmatic risk in developing these new technologies, and thus to help identify the best strategy for meeting the MRSR system goals. Finally, the paper compares the RTGs' specific powers for different power levels (250W vs 125W), different thermoelectric element designs (standard vs short unicouples vs multicouples), and different thermoelectric figures of merit (0.00058K to the -1 to 0.00140K to the -1).
AIAA
Mars Sample Return Missions; Radioisotope Batteries; Roving Vehicles; Thermoelectric Generators

19900026220 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Planetary Rover local navigation and hazard avoidance
Miller, David P.; Wilcox, Brian H.; Varsi, Giulio; Oct 1, 1989; In English
Report No.(s): IAF PAPER 89-047; Copyright; Avail: Other Sources

A Planetary Rover will have to be able to navigate through its local environment autonomously, due to communication delays. This implies that the vehicle must be able to sense its environment, plan a course through that environment, and react appropriately to unexpected situations as they appear. All this must be done while guiding the vehicle toward the goals that have been given to it from its operators on the earth. This paper describes research at the Jet Propulsion Laboratory which concentrates on the sensing, perception, planning and execution monitoring that must be carried out by the rover to ensure that a safe and efficient path is found by the rover, and that that path is performed correctly.
AIAA
Autonomous Navigation; Obstacle Avoidance; Operational Hazards; Roving Vehicles

19900024678 FMC Corp., Santa Clara, CA, USA, Robot Intelligence International, San Diego, CA, USA
Mars rover concept development
Mctamaney, Louis S.; Douglas, Barry D.; Harmon, Scott Y.; JAN 1, 1989; In English; Mobile Robots III, Nov. 10-11, 1988, Cambridge, MA, USA
Contract(s)/Grant(s): JPL-958074; Copyright; Avail: Other Sources

A structured study effort to develop an extensive, innovative set of mobility and navigation concepts for a planetary exploration vehicle along with the concomitant value system and evaluation tools is presented. A further objective is to submit these concepts to a rigorous, structured evaluation process to derive the most promising candidate systems. To support the evaluation process, a three-layer computer model of the Martian surface was developed, based on the 1/64 deg Digital Elevation Model (DEM) of Mars. Local surface roughness based on measured Martian slope distribution and power spectral density was superimposed on the DEM, and rocks based on Moore's distribution model were added. To assess performance, selected concepts were modeled using DADS, and simulations were run with the vehicle traversing the Martian surface model, including one-meter-high vertical steps and one-meter-wide crevasses. The design details of three promising candidate systems are presented, along with the discussion of their evolution with some recommendations.
AIAA
Functional Design Specifications; Mars Landing; Robotics; Roving Vehicles

19900024677 Martin Marietta Space Systems, Inc., Denver, CO, USA
Hazard avoidance for a Mars rover
Spiessbach, Andrew J.; JAN 1, 1989; In English; Mobile Robots III, Nov. 10-11, 1988, Cambridge, MA, USA
Contract(s)/Grant(s): JPL-958073; Copyright; Avail: Other Sources

The challenging geology of the surface of Mars, when coupled with the impossibility of continuous remote driving from earth, dictate the need for autonomous hazard detection, recognition and possibly hazard avoidance capabilities onboard any robotic Mars roving vehicle. The main technical issues represented by terrain hazards are accidental damage and vehicle entrapment. Several approaches to vehicle design geared to prevent such immobilization threats are identified. The gamut of alternatives for rover autonomy are also presented, and the applicability of the various options for the Mars Rover/Sample Return mission are assessed in the context of the technology state of the art for hazard sensors and processing algorithms.
AIAA
Autonomous Navigation; Mars Landing; Obstacle Avoidance; Roving Vehicles

19900024676 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Mars rover local navigation and hazard avoidance
Wilcox, B. H.; Gennery, D. B.; Mishkin, A. H.; JAN 1, 1989; In English; Mobile Robots III, Nov. 10-11, 1988, Cambridge, MA, USA; Copyright; Avail: Other Sources

A Mars rover sample return mission has been proposed for the late 1990's. Due to the long speed-of-light delays between earth and Mars, some autonomy on the rover is highly desirable. JPL has been conducting research in two possible modes of rover operation, Computer-Aided Remote Driving and Semiautonomous Navigation. A recently-completed research program used a half-scale testbed vehicle to explore several of the concepts in semiautonomous navigation. A new, full-scale vehicle with all computational and power resources on-board will be used in the coming year to demonstrate relatively fast semiautonomous navigation. The computational and power requirements for Mars rover local navigation and hazard avoidance are discussed.
AIAA
Autonomous Navigation; Mars Sample Return Missions; Obstacle Avoidance; Roving Vehicles

19900024571 NASA Goddard Space Flight Center, Greenbelt, MD, USA, National Inst. of Standards and Technology, Gaithersburg, MD, USA, Geological Survey, Reston, VA, USA
Possible use of pattern recognition for the analysis of Mars rover X-ray fluorescence spectra
Yin, Lo I; Trombka, Jacob I.; Seltzer, Stephen M.; Johnson, Robert G.; Philpotts, John A.; Journal of Geophysical Research; Oct 10, 1989; ISSN 0148-0227; 94; In English; Copyright; Avail: Other Sources

On the Mars rover sample-return mission, the rover vehicle will collect and select samples from different locations on the Martian surface to be brought back to earth for laboratory studies. It is anticipated that an in situ energy-dispersive X-ray fluorescence (XRF) spectrometer will be on board the rover. On such a mission, sample selection is of higher priority than in situ quantitative chemical anlaysis. With this in mind, a pattern recognition technique is proposed as a simple, direct, and speedy alternative to detailed chemical analysis of the XRF spectra. The validity and efficacy of the pattern recognition technique are demonstrated by the analyses of laboratory XRF spectra obtained from a series of geological samples, in the form both of standardized pressed pellets and as unprepared rocks. It is found that pattern recognition techniques applied to the raw XRF spectra can provide for the same discrimination among samples as a knowledge of their actual chemical composition.

AIAA

Mars Sample Return Missions; Pattern Recognition; X Ray Fluorescence; X Ray Spectra

19900023567 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA

A computational system for a Mars rover

Lambert, Kenneth E.; Oct 1, 1989; In English

Report No.(s): AIAA PAPER 89-3026; Copyright; Avail: Other Sources

This paper presents an overview of an onboard computing system that can be used for meeting the computational needs of a Mars rover. The paper begins by presenting an overview of some of the requirements which are key factors affecting the architecture. The rest of the paper describes the architecture. Particular emphasis is placed on the criteria used in defining the system and how the system qualitatively meets the criteria.

AIAA

Architecture (Computers); Expert Systems; Mars Sample Return Missions; Onboard Data Processing; Roving Vehicles

19900019753 Texas Univ., Austin, TX, USA

Satellite-map position estimation for the Mars rover

Hayashi, Akira; Dean, Thomas; JPL, California Inst. of Tech., Proceedings of the NASA Conference on Space Telerobotics, Volume 2; Jan 31, 1989; In English

Contract(s)/Grant(s): F49620-88-C-0132; NSF IRI-86-12644; No Copyright; Avail: CASI; A02, Hardcopy

A method for locating the Mars rover using an elevation map generated from satellite data is described. In exploring its environment, the rover is assumed to generate a local rover-centered elevation map that can be used to extract information about the relative position and orientation of landmarks corresponding to local maxima. These landmarks are integrated into a stochastic map which is then matched with the satellite map to obtain an estimate of the robot's current location. The landmarks are not explicitly represented in the satellite map. The results of the matching algorithm correspond to a probabilistic assessment of whether or not the robot is located within a given region of the satellite map. By assigning a probabilistic interpretation to the information stored in the satellite map, researchers are able to provide a precise characterization of the results computed by the matching algorithm.

CASI

Mars Surface; Position (Location); Relief Maps; Robots; Roving Vehicles

19900019751 NASA, Washington, DC, USA

Planetary rover technology development requirements

Bedard, Roger J., Jr.; Muirhead, Brian K.; Montemerlo, Melvin D.; Hirschbein, Murray S.; JPL, California Inst. of Tech., Proceedings of the NASA Conference on Space Telerobotics, Volume 2; Jan 31, 1989; In English; No Copyright; Avail: CASI; A02, Hardcopy

Planetary surface (including lunar) mobility and sampling capability is required to support proposed future National Aeronautics and Space Administration (NASA) solar system exploration missions. The NASA Office of Aeronautics and Space Technology (OAST) is addressing some of these technology needs in its base research and development program, the Civil Space Technology Initiative (CSTI) and a new technology initiative entitled Pathfinder. The Pathfinder Planetary Rover (PPR) and Sample Acquisition, Analysis and Preservation (SAAP) programs will develop and validate the technologies needed to enable both robotic and piloted rovers on various planetary surfaces. The technology requirements for a planetary roving vehicle and the development plans of the PPR and SAAP programs are discussed.

CASI

Mobility; Planetary Surfaces; Project Management; Robotics; Roving Vehicles

19900019699 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA

A system architecture for a planetary rover

Smith, D. B.; Matijevic, J. R.; Proceedings of the NASA Conference on Space Telerobotics, Volume 1; Jan 31, 1989; In English; No Copyright; Avail: CASI; A03, Hardcopy

Each planetary mission requires a complex space vehicle which integrates several functions to accomplish the mission and science objectives. A Mars Rover is one of these vehicles, and extends the normal spacecraft functionality with two additional functions: surface mobility and sample acquisition. All functions are assembled into a hierarchical and structured format to understand the complexities of interactions between functions during different mission times. It can graphically show data flow between functions, and most importantly, the necessary control flow to avoid unambiguous results. Diagrams are presented organizing the functions into a structured, block format where each block represents a major function at the system level. As such, there are six blocks representing telecomm, power, thermal, science, mobility and sampling under a supervisory block called Data Management/Executive. Each block is a simple collection of state machines arranged into a hierarchical order very close to the NASREM model for Telerobotics. Each layer within a block represents a level of control for a set of state machines that do the three primary interface functions: command, telemetry, and fault protection. This latter function is expanded to include automatic reactions to the environment as well as internal faults. Lastly, diagrams are presented that trace the system operations involved in moving from site to site after site selection. The diagrams clearly illustrate both the data and control flows. They also illustrate inter-block data transfers and a hierarchical approach to fault protection. This systems architecture can be used to determine functional requirements, interface specifications and be used as a mechanism for grouping subsystems (i.e., collecting groups of machines, or blocks consistent with good and testable implementations).
CASI

Architecture (Computers); Functional Design Specifications; Numerical Control; Planetary Surfaces; Robotics; Roving Vehicles; Sampling; Telemetry

19900016232 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA

Planning for execution monitoring on a planetary rover

Gat, Erann; Firby, R. James; Miller, David P.; NASA, Lyndon B. Johnson Space Center, Third Annual Workshop on Space Operations Automation and Robotics (SOAR 1989); Mar 1, 1990; In English; No Copyright; Avail: CASI; A01, Hardcopy

A planetary rover will be traversing largely unknown and often unknowable terrain. In addition to geometric obstacles such as cliffs, rocks, and holes, it may also have to deal with non-geometric hazards such as soft soil and surface breakthroughs which often cannot be detected until rover is in imminent danger. Therefore, the rover must monitor its progress throughout a traverse, making sure to stay on course and to detect and act on any previously unseen hazards. Its onboard planning system must decide what sensors to monitor, what landmarks to take position readings from, and what actions to take if something should go wrong. The planning systems being developed for the Pathfinder Planetary Rover to perform these execution monitoring tasks are discussed. This system includes a network of planners to perform path planning, expectation generation, path analysis, sensor and reaction selection, and resource allocation.
CASI

Monitors; Planetary Surfaces; Roving Vehicles; Surface Navigation; Terrain; Trajectory Control

19900016037 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA

USA planetary rover status: 1989

Pivirotto, Donna L. S.; Dias, William C.; May 15, 1990; In English

Contract(s)/Grant(s): NAS7-918

Report No.(s): NASA-CR-186843; NAS 1.26:186843; JPL-PUBL-90-6; No Copyright; Avail: CASI; A06, Hardcopy

A spectrum of concepts for planetary rovers and rover missions, is covered. Rovers studied range from tiny micro rovers to large and highly automated vehicles capable of traveling hundreds of kilometers and performing complex tasks. Rover concepts are addressed both for the Moon and Mars, including a Lunar/Mars common rover capable of supporting either program with relatively small modifications. Mission requirements considered include both Science and Human Exploration. Studies include a range of autonomy in rovers, from interactive teleoperated systems to those requiring and onboard System Executive making very high level decisions. Both high and low technology rover options are addressed. Subsystems are described for a representative selection of these rovers, including: Mobility, Sample Acquisition, Science, Vehicle Control, Thermal Control, Local Navigation, Computation and Communications. System descriptions of rover concepts include diagrams, technology levels, system characteristics, and performance measurement in terms of distance covered, samples collected, and area surveyed for specific representative missions. Rover development schedules and costs are addressed for Lunar and Mars exploration initiatives.
CASI

Lunar Exploration; Mission Planning; Navigation; Planetary Surfaces; Roving Vehicles; Spacecraft Design

19900015755 Duke Univ., Durham, NC, USA

Mars Rover imaging systems and directional filtering

Wang, Paul P.; Old Dominion Univ., NASA/American Society for Engineering Ed; Sep 1, 1989; In English; No Copyright; Avail: CASI; A01, Hardcopy

Computer literature searches were carried out at Duke University and NASA Langley Research Center. The purpose is to enhance personal knowledge based on the technical problems of pattern recognition and image understanding which must be solved for the Mars Rover and Sample Return Mission. Intensive study effort of a large collection of relevant literature resulted in a compilation of all important documents in one place. Furthermore, the documents are being classified into: Mars Rover; computer vision (theory); imaging systems; pattern recognition methodologies; and other smart techniques (AI, neural networks, fuzzy logic, etc).

CASI

Artificial Intelligence; Computer Vision; Expert Systems; Image Filters; Imaging Techniques; Mars Sample Return Missions; Neural Nets; Pattern Recognition

19900000843 NASA Lewis Research Center, Cleveland, OH, USA

Applicability of the beamed power concept to lunar rovers, construction, mining, explorers and other mobile equipment

Christian, Jose L., Jr.; NASA. Langley Research Center, Second Beamed Space-Power Workshop; Jul 1, 1989; In English; No Copyright; Avail: CASI; A03, Hardcopy

Some of the technical issues dealing with the feasibility of high power (10 Kw to 100 Kw) mobile manned equipment for settlement, exploration and exploitation of Lunar resources are addressed. Short range mining/construction equipment, a moderate range (50 Km) exploration vehicle, and an unlimited range explorer are discussed.

CASI

Beams (Radiation); Lunar Exploration; Lunar Roving Vehicles; Power Beaming; Solar Arrays; Solar Power Satellites

19900000841 NASA Langley Research Center, Hampton, VA, USA

Laser-powered Martian rover

Harries, W. L.; Meador, W. E.; Miner, G. A.; Schuster, Gregory L.; Walker, G. H.; Williams, M. D.; Second Beamed Space-Power Workshop; Jul 1, 1989; In English; No Copyright; Avail: CASI; A03, Hardcopy

Two rover concepts were considered: an unpressurized skeleton vehicle having available 4.5 kW of electrical power and limited to a range of about 10 km from a temporary Martian base and a much larger surface exploration vehicle (SEV) operating on a maximum 75-kW power level and essentially unrestricted in range or mission. The only baseline reference system was a battery-operated skeleton vehicle with very limited mission capability and range and which would repeatedly return to its temporary base for battery recharging. It was quickly concluded that laser powering would be an uneconomical overkill for this concept. The SEV, on the other hand, is a new rover concept that is especially suited for powering by orbiting solar or electrically pumped lasers. Such vehicles are visualized as mobile habitats with full life-support systems onboard, having unlimited range over the Martian surface, and having extensive mission capability (e.g., core drilling and sampling, construction of shelters for protection from solar flares and dust storms, etc.). Laser power beaming to SEV's was shown to have the following advantages: (1) continuous energy supply by three orbiting lasers at 2000 km (no storage requirements as during Martian night with direct solar powering); (2) long-term supply without replacement; (3) very high power available (MW level possible); and (4) greatly enhanced mission enabling capability beyond anything currently conceived.

CASI

Beams (Radiation); Laser Applications; Laser Power Beaming; Mars (Planet); Roving Vehicles; Solar Energy Conversion; Solar Power Satellites

19900000241 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA

Stabilizing Wheels For Rover Vehicle

Collins, Earl R., Jr.; NASA Tech Briefs; May 1, 1990; ISSN 0145-319X; 14, 5; In English

Report No.(s): NPO-17495; No Copyright; Additional information available through: National Technology Transfer Center (NTTC), Wheeling, WV 26003, (Tel: 1-800-678-6882).

Proposed articulated, normally-four-wheeled vehicle holds extra pair of wheels in reserve. Deployed to lengthen wheelbase on slopes, thereby making vehicle more stable, and to aid vehicle in negotiating ledge or to right vehicle if turned upside down. Extra wheels are drive wheels mounted on arms so they pivot on axis of forward drive wheels. Both extra wheels

and arms driven by chains, hydraulic motors, or electric motors. Concept promises to make remotely controlled vehicles more stable and maneuverable in such applications as firefighting, handling hazardous materials, and carrying out operations in dangerous locations.
Roving Vehicles; Stability Augmentation; Vehicle Wheels

19890066063 Carnegie-Mellon Univ., Pittsburgh, PA, USA
Terrain mapping for a roving planetary explorer
Hebert, M.; Caillas, C.; Krotkov, E.; Kweon, I. S.; Kanade, T.; JAN 1, 1989; In English; 1989 IEEE International Conference on Robotics and Automation, May 14-19, 1989, Scottsdale, AZ, USA
Contract(s)/Grant(s): NAGW-1175; Copyright; Avail: Other Sources

A prototype legged vehicle is being developed for an exploratory mission on another planet, conceivably Mars, where it is to traverse uncharted areas and collect material samples. The rover can construct from range imagery a geometric terrain representation; i.e., elevation map that includes uncertainty, unknown areas, and local features. An algorithm for constructing an elevation map from a single range image is presented: by virtue of working in spherical-polar space, the algorithm is independent of the desired map resolution and the orientation of the sensor, unlike algorithms that work in Cartesian space. Also presented is a two-stage matching technique (feature matching followed by iconic matching) that identifies the transformation T corresponding to the vehicle displacement between two viewing positions. To support legged locomotion over rough terrain, methods for evaluating regions of the constructed elevation maps as footholds are developed.
AIAA
Interplanetary Flight; Planetary Mapping; Roving Vehicles; Terrain Analysis

19890063032 Carnegie-Mellon Univ., Pittsburgh, PA, USA
Ambler - An autonomous rover for planetary exploration
Bares, John; Hebert, Martial; Kanade, Takeo; Krotkov, Eric; Mitchell, Tom, et al.; Computer; Jun 1, 1989; ISSN 0018-9162; 22; In English
Contract(s)/Grant(s): NAGW-1175; Copyright; Avail: Other Sources

The authors are building a prototype legged rover, called the Ambler (loosely an acronym for autonomous mobile exploration robot) and testing it on full-scale, rugged terrain of the sort that might be encountered on the Martian surface. They present an overview of their research program, focusing on locomotion, perception, planning, and control. They summarize some of the most important goals and requirements of a rover design and describe how locomotion, perception, and planning systems can satisfy these requirements. Since the program is relatively young (one year old at the time of writing) they identify issues and approaches and describe work in progress rather than report results. It is expected that many of the technologies developed will be applicable to other planetary bodies and to terrestrial concerns such as hazardous waste assessment and remediation, ocean floor exploration, and mining.
AIAA
Locomotion; Mars Surface; Robots; Roving Vehicles; Space Exploration; Viking Lander 2

19890059159 NASA Lewis Research Center, Cleveland, OH, USA
Preliminary assessment of rover power systems for the Mars Rover Sample Return Mission
Bents, D. J.; Space Power; JAN 1, 1989; ISSN 0951-5089; 8, 3, 19; In English
Report No.(s): IAF PAPER ICOSP89-9-6; Copyright; Avail: Other Sources

Four isotope power system concepts were presented and compared on a common basis for application to on-board electrical prime power for an autonomous planetary rover vehicle. A representative design point corresponding to the Mars Rover Sample Return (MRSR) preliminary mission requirements (500 W) was selected for comparison purposes. All systems concepts utilize the General Purpose Heat Source (GPHS) isotope heat source developed by DOE. Two of the concepts employ thermoelectric (TE) conversion: one using the GPHS Radioisotope Thermoelectric Generator (RTG) used as a reference case, the other using an advanced RTG with improved thermoelectric materials. The other two concepts employed are dynamic isotope power systems (DIPS): one using a closed Brayton cycle (CBC) turboalternator, and the other using a free piston Stirling cycle engine/linear alternator (FPSE) with integrated heat source/heater head. Near-term technology levels have been assumed for concept characterization using component technology figure-of-merit values taken from the published literature. For example, the CBC characterization draws from the historical test database accumulated from space Brayton cycle subsystems and components from the NASA B engine through the mini-Brayton rotating unit. TE system performance is estimated from Voyager/multihundred Watt (MHW)-RTG flight experience through Mod-RTG performance estimates

considering recent advances in TE materials under the DOD/DOE/NASA SP-100 and NASA Committee on Scientific and Technological Information programs. The Stirling DIPS system is characterized from scaled-down Space Power Demonstrator Engine (SPDE) data using the GPHS directly incorporated into the heater head. The characterization/comparison results presented here differ from previous comparison of isotope power (made for LEO applications) because of the elevated background temperature on the Martian surface compared to LEO, and the higher sensitivity of dynamic systems.
AIAA
Mars Sample Return Missions; Radioisotope Batteries; Roving Vehicles; Spacecraft Power Supplies; Thermoelectric Generators

19890039001 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Mars rover 1988 concepts
Pivirotto, Donna Shirley; Penn, Thomas J.; Dias, William C.; Jan 1, 1989; In English
Report No.(s): AIAA PAPER 89-0419; Copyright; Avail: Other Sources

Results of FY88 studies of a sample-collecting Mars rover are presented. A variety of rover concepts are discussed which include different technical approaches to rover functions. The performance of rovers with different levels of automation is described and compared to the science requirement for 20 to 40 km to be traversed on the Martian surface and for 100 rock and soil samples to be collected. The analysis shows that a considerable amount of automation in roving and sampling is required to meet this requirement. Additional performance evaluation shows that advanced RTG's producing 500 W and 350 WHr of battery storage are needed to supply the rover.
AIAA
Mars Probes; Planetary Landing; Roving Vehicles

19890038253 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Autonomous navigation and mobility for a planetary rover
Miller, David P.; Mishkin, Andrew H.; Lambert, Kenneth E.; Bickler, Donald; Bernard, Douglas E.; Jan 1, 1989; In English
Report No.(s): AIAA PAPER 89-0859; Copyright; Avail: Other Sources

This paper presents an overview of the onboard subsystems that will be used in guiding a planetary rover. Particular emphasis is placed on the planning and sensing systems and their associated costs, particularly in computation. Issues that will be used in evaluating trades between the navigation system and mobility system are also presented.
AIAA
Autonomous Navigation; Mars Surface; Mobility; Onboard Data Processing; Roving Vehicles

19890038128 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Mars Rover Sample Return aerocapture configuration design and packaging constraints
Lawson, Shelby J.; Jan 1, 1989; In English
Report No.(s): AIAA PAPER 89-0631; Copyright; Avail: Other Sources

This paper discusses the aerodynamics requirements, volume and mass constraints that lead to a biconic aeroshell vehicle design that protects the Mars Rover Sample Return (MRSR) mission elements from launch to Mars landing. The aerodynamic requirements for Mars aerocapture and entry and packaging constraints for the MRSR elements result in a symmetric biconic aeroshell that develops a L/D of 1.0 at 27.0 deg angle of attack. A significant problem in the study is obtaining a cg that provides adequate aerodynamic stability and performance within the mission imposed constraints. Packaging methods that relieve the cg problems include forward placement of aeroshell propellant tanks and incorporating aeroshell structure as lander structure. The MRSR missions developed during the pre-phase A study are discussed with dimensional and mass data included. Further study is needed for some missions to minimize MRSR element volume so that launch mass constraints can be met.
AIAA
Aerocapture; Mars Probes; Mars Sample Return Missions; Roving Vehicles; Spacecraft Configurations; Spacecraft Design

19890038127 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Aerodynamic requirements for a Mars rover/sample return aerocapture vehicle
Ess, Robert H., Jr.; Munday, Stephen R.; Jan 1, 1989; In English
Report No.(s): AIAA PAPER 89-0630; Copyright; Avail: Other Sources

The sensitivity of Martian aerocapture performance to L/D and flight path angle is studied. By adding the minimum

energy constraint to the classical corridor width definition, an L/D of at least 0.8 was found to be necessary to ensure a 3.0-deg actual corridor width. The plane change desired during the aeropass was also found to affect L/D requirements.
AIAA
Aerocapture; Aerodynamic Characteristics; Mars Probes; Mars Sample Return Missions; Roving Vehicles; Spacecraft Design

19890037984 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Mars Rover Sample Return ascent, rendezvous, and return to earth
Lance, Nick; Jan 1, 1989; In English
Report No.(s): AIAA PAPER 89-0424; Copyright; Avail: Other Sources

Ascent, rendezvous and earth return are three operational mission sequences in the sample return phase of the Mars Rover Sample Return (MRSR) mission. In the conduct of the current study, several vehicles have been identified to enable the sample return phase of the mission. These elements are the Mars Ascent Vehicle (MAV), the Earth Return Vehicle (ERV), the rendezvous and docking module (RDM), and the sample return capsule (SRC). The sample return elements, when combined with other elements performing the launch and delivery functions, form the basis of the MRSR system. This paper summarizes the significant mission aspects of the sample return phase, describes the Mars ascent and earth return scenario, illustrates the conceptual designs developed for the MAV, ERV, RDM, and SRC, and discusses the results of significant trade studies conducted.
AIAA
Mars Probes; Mars Sample Return Missions; Mars Surface Samples; Mission Planning; Roving Vehicles

19890037983 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
The 'sample experiment' on the Mars Rover/Sample Return mission
Gooding, James L.; Jan 1, 1989; In English
Report No.(s): AIAA PAPER 89-0423; Copyright; Avail: Other Sources

Sample Experiment denotes the set of all operations that include collection, analysis, packaging, and environmental control of atmospheric and geologic samples of Mars. Various functions may be distributed among surface roving vehicles, stationary landers, and spacecraft but the Sample Experiment remains an integrated mission activity that extends from Mars landing through delivery of the sample payload to the recieving facility on Earth. Technological challenges not faced in previous planetary missions include development of robotic systems to manipulate and characterize samples and to reliably seal them in containers with minimal contamination or degradation.
AIAA
Mars Sample Return Missions; Mars Surface Samples; Planetary Landing; Rover Project

19890037981 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Mars Rover Sample Return Orbiter design concepts
Randolph, J. E.; Jan 1, 1989; In English
Report No.(s): AIAA PAPER 89-0421; Copyright; Avail: Other Sources

The observational orbiter of the Mars Rover Sample Return mission will observe the (10x10 km) landing sites and provide data that will be used in the decision to commit the landing vehicles to a landing at a chosen site. To provide observational data from orbit at a surface resolution consistent with the hazard tolerance of the landing vehicles, the orbiter imaging subsystem must be capable of 0.25 meters resolution per picture element (pixel). The design of the imaging, pointing, and data subsystems capable of providing this capability has been completed in this study. The rationale for these requirements and the more detailed derived requirements affecting the spacecraft design are discussed.
AIAA
Mars Probes; Mars Sample Return Missions; Mission Planning; Roving Vehicles; Spacecraft Design; Spacecraft Modules

19890037980 Martin Marietta Corp., Denver, CO, USA, Ohio State Univ., Columbus, OH, USA
Semi-autonomous design concepts for a Mars rover
Spiessbach, Andrew J.; Larimer, Stanley J.; Lisec, Thomas R.; Waldron, Kenneth J.; Jan 1, 1989; In English
Contract(s)/Grant(s): JPL-958073
Report No.(s): AIAA PAPER 89-0420; Copyright; Avail: Other Sources

Studies of rover mobility and surface rendezvous for a Mars Rover/Sample Return (MRSR) mission have been performed. The objective of these efforts has been to identify and address the most challenging issues and develop the most promising

design options for the rover mobility and navigation subsystems. A series of trade studies culminated in three candidate design concepts: a large, but otherwise conventional four-wheel drive vehicle; a sophisticated and agile six-legged walking vehicle; and a greatly simplified legged vehicle. This paper summarizes the key design features for these three concepts. For each design, the approaches to vehicle locomotion, sensing and navigation are discussed first. Timelines are developed for the adopted concepts of operation which constrain the range of the remaining parameters. Estimates of rover mass, volume, and power are provided, and performance is projected for vehicle range, terrain traversibility and navigation accuracy.
AIAA
Autonomous Navigation; Mars Surface Samples; Roving Vehicles; Walking Machines

19890037979 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Conceptual design of the Mars Rover Sample Return system
Rose, James R.; Jan 1, 1989; In English
Report No.(s): AIAA PAPER 89-0418; Copyright; Avail: Other Sources

The results of the prephase A study of the Mars Rover Sample Return system are presented. Four mission scenarios are studied, two in the B-configuration, and two D-configuration missions. They incorporated variations in delivery-to-Mars mode, earth-return mode (propulsive or aerocapture), landing site latitude, and rover size and capability in order to identify system drivers.
AIAA
Interplanetary Flight; Mars Sample Return Missions; Mars Surface Samples; Mission Planning; Roving Vehicles

19890037978 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA, Science Applications International Corp., Schaumburg, IL, USA
Mars Rover Sample Return mission
Bourke, Roger D.; Kwok, Johnny H.; Friedlander, Alan; Jan 1, 1989; In English
Report No.(s): AIAA PAPER 89-0417; Copyright; Avail: Other Sources

To gain a detailed understanding of the character of the planet Mars, it is necessary to send vehicle to the surface and return selected samples for intensive study in earth laboratories. Toward that end, studies have been underway for several years to determine the technically feasible means for exploring the surface and returning selected samples. This paper describes several MRSR mission concepts that have emerged from the most recent studies.
AIAA
Mars Landing; Mars Probes; Mars Sample Return Missions; Roving Vehicles

19890037921 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Orbit design and perturbation analysis for Mars rover and sample return mission concepts
Kwok, Johnny H.; Jan 1, 1989; In English
Report No.(s): AIAA PAPER 89-0347; Copyright; Avail: Other Sources

Mission options using out-of-orbit entry and Mars orbit rendezvous before earth return are discussed. The following major flight elements are required to conduct a Mars rover and sample return mission: the rover, the sample return orbiter, and the Mars ascent vehicle. The effects of perturbations on orbital motion are studied using Cowell's method and an averaging technique.
AIAA
Mars Probes; Mars Sample Return Missions; Mars Surface Samples; Mission Planning; Orbit Calculation; Orbit Perturbation; Spacecraft Orbits

19890033289 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Space telerobots and planetary rovers
Ruoff, Carl F.; Nov 1, 1988; In English
Report No.(s): AIAA PAPER 88-5011; Copyright; Avail: Other Sources

Space telerobots and planetary rovers are advanced forms of space automation that are being studied for missions beginning in the 1990s. This paper describes telerobots and planetary rovers, points out that pure autonomy is far beyond the state of the art, and goes on to discuss how useful, realizable telerobots and rovers can be developed in the context of human-machine systems. Telerobot and rover computational and architectural requirements are also briefly examined, and examples of current work, including the development of dedicated analog processing chips based upon neural networks are

described. The paper closes with some speculations on the terrestrial implications of space robotics and some general conclusions.
AIAA
Mission Planning; Robotics; Roving Vehicles; Teleoperators; Telerobotics

19890033287 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Mars Rover Sample Return - Rover challenges
Allen, Lew; Nov 1, 1988; In English
Report No.(s): AIAA PAPER 88-5009; Copyright; Avail: Other Sources

Mission requirements, design considerations, and scenarios are presented for the Mars Rover Sample Return mission to send rovers to Mars to collect samples for return to earth. Rover automation is examined in detail. Issues of rover design related to mobility, local navigation, and sample acquisition are discussed. Scenarios for rover operation are given, including a comparison between the level of automation of the computer-aided remote driving system and the level of the semiautonomous navigation system. It is suggested that the rover must be more automated than previous aircraft.
AIAA
Mars Sample Return Missions; Mars Surface Samples; Roving Vehicles

19890033286 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Mars Rover Sample Return mission delivery and return challenges
Cohen, Aaron; Nov 1, 1988; In English
Report No.(s): AIAA PAPER 88-5007; Copyright; Avail: Other Sources

The Mars Rover Sample Return mission is a robotic exploration mission culminating in the return of atmospheric and surface samples from Mars to Earth. To accomplish this complex mission requires sophisticated autonomous systems for many time-critical operations associated with the delivery and return phases, since the round trip light times preclude Earth-based control of these operations. In addition, there are significant engineering and technology challenges to be addressed to meet the mission science and exploration objectives.
AIAA
Mars Probes; Mars Sample Return Missions; Mars Surface Samples; Mission Planning; Roving Vehicles

19890025283 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
A Mars rover mission concept
Randolph, J. E.; Turner, P. R.; JAN 1, 1988; In English; AAS/AIAA Astrodynamics Conference, Dec. 6-9, 1987, Kalispell, MT, USA
Report No.(s): AAS PAPER 87-440; Copyright; Avail: Other Sources

This paper discusses the design concept of the Mars Rover/Sample Return (MRSR) mission. Special consideration is given to the issues of the power source, the scale and performance of the mobility subsystem, the requirements of the sampling subsystem, and the degree of automation, as well as to the features and the orbit design of a Mars orbiting vehicle (MOV) supporting the landed operations. The details of the integrated aeroshell configuration, that includes the rover, the lander, and the MOV during the Mars orbit insertion phase are described, and the diagrams of the MRSR mission and its elements are presented.
AIAA
Aerodynamic Brakes; Mars Landing; Mars Surface Samples; Reentry Vehicles; Roving Vehicles; Spacecraft Design

19890025282 Science Applications International Corp., Schaumburg, IL, USA
Mars Rover/Sample Return landing strategy
Friedlander, Alan L.; German, Darla J.; JAN 1, 1988; In English; AAS/AIAA Astrodynamics Conference, Dec. 6-9, 1987, Kalispell, MT, USA
Contract(s)/Grant(s): NASW-4214
Report No.(s): AAS PAPER 87-439; Copyright; Avail: Other Sources

This paper describes the analysis and results of an investigation of the Mars Rover/Sample Return mission's landing strategy, together with the trade-offs of different landing strategies. The percentile points and the descriptive statistics of the probability distribution of traverse distances are calculated using a simple model formulated on the basis of landing error

characteristics. The results show that variations in the landing stratgegy can significantly affect the traverse distance requirements, which range from 20 to 200 km.
AIAA
Lift Drag Ratio; Mars Landing; Mars Sample Return Missions; Mars Surface Samples; Monte Carlo Method; Probability Distribution Functions; Reentry Vehicles; Roving Vehicles

19890025281 Science Applications International Corp., Schaumburg, IL, USA
Mars Rover/Sample Return mission trade studies
Soldner, John K.; Hoffman, Stephen J.; JAN 1, 1988; In English; AAS/AIAA Astrodynamics Conference, Dec. 6-9, 1987, Kalispell, MT, USA
Contract(s)/Grant(s): NASW-4214
Report No.(s): AAS PAPER 87-437; Copyright; Avail: Other Sources

Mission trade studies for a preliminary definition of a flight-separable Mars Rover/Sample Return (MRSR) mission are presented. The MRSR initiative consists of two separate mission elements: a Mars Rover and a Mars Sample Return. Various strategies are discussed for completing the interplanetary portion of the MRSR mission. Five mission options which are characterized by different launch configurations are discussed, and the resulting spacecraft mass needed to accomplish the mission is presented relative to the capabilities of launch vehicles assumed to be available during the timeframe under consideration.
AIAA
Mars Sample Return Missions; Mars Surface Samples; Mission Planning; Roving Vehicles; Space Exploration; Space Missions

19890024460 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
A vision system for a Mars rover
Wilcox, Brian H.; Gennery, Donald B.; Mishkin, Andrew H.; Cooper, Brian K.; Lawton, Teri B.; Lay, N. Keith; Katzmann, Steven P.; JAN 1, 1988; In English; Mobile Robots II, Nov. 5-6, 1987, Cambridge, MA, USA; Copyright; Avail: Other Sources

A Mars rover must be able to sense its local environment with sufficient resolution and accuracy to avoid local obstacles and hazards while moving a significant distance each day. Power efficiency and reliability are extremely important considerations, making stereo correlation an attractive method of range sensing compared to laser scanning, if the computational load and correspondence errors can be handled. Techniques for treatment of these problems, including the use of more than two cameras to reduce correspondence errors and possibly to limit the computational burden of stereo processing, have been tested at JPL. Once a reliable range map is obtained, it must be transformed to a plan view and compared to a stored terrain database, in order to refine the estimated position of the rover and to improve the database. The slope and roughness of each terrain region are computed, which form the basis for a traversability map allowing local path planning. Ongoing research and field testing of such a system is described.
AIAA
Computer Vision; Mars Probes; Roving Vehicles

19890024420 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Reasoning with inaccurate spatial knowledge
Doshi, Rajkumar S.; White, James E.; Lam, Raymond; Atkinson, David J.; JAN 1, 1988; In English; Intelligent Robots and Computer Vision, Nov. 2-6, 1987, Cambridge, MA, USA; Copyright; Avail: Other Sources

This paper describes work in progress on spatial planning for a semiautonomous mobile robot vehicle. The overall objective is to design a semiautonomous rover to plan routes in unknown, natural terrains. The approach to spatial planning involves deduction of common-sense spatial knowledge using geographical information, natural terrain representations, and assimilation of new and possibly conflicting terrain information. This report describes the ongoing research and implementation.
AIAA
Artificial Intelligence; Autonomy; Remotely Piloted Vehicles; Robots; Roving Vehicles

19890016996 NASA Ames Research Center, Moffett Field, CA, USA
Mars Rover Sample Return: A sample collection and analysis strategy for exobiology
Sims, M. H.; Fischler, M.; Schwartz, D. E.; Rosenthal, Donald A.; Mancinelli, Rocco L.; Nedell, Susan S.; Gamble, E.; Mckay, Christopher P.; Exobiology and Future Mars Missions; Mar 1, 1989; In English; No Copyright; Avail: CASI; A01, Hardcopy

For reasons defined elsewhere it is reasonable to search for biological signatures, both chemical and morphological, of extinct life on Mars. Life on Earth requries the presence of liquid water, therefore, it is important to explore sites on Mars where standing bodies of water may have once existed. Outcrops of layered deposits within the Valles Marineris appear to be ancient lake beds. Because the outcrops are well exposed, relatively shallow core samples would be very informative. The most important biological signature to detect would be organics, microfossils, or larger stromato-like structures, although the presence of cherts, carbonates, clays, and shales would be significant. In spite of the limitations of current robotics and pattern recognition, and the limitations of rover power, computation, Earth communication bandwidth, and time delays, a partial scenario was developed to implement such a scientific investigation. The rover instrumentation and the procedures and decisions and IR spectrometer are described in detail. Preliminary results from a collaborative effort are described, which indicate the rover will be able to autonomously detect stratification, and hence will ease the interpretation burden and lead to greater scientific productivity during the rover's lifetime.
A.D.
Biological Evolution; Exobiology; Extraterrestrial Life; Mars Sample Return Missions; Mars Surface Samples; Roving Vehicles

19890016973 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Methods and decision making on a Mars rover for identification of fossils
Eberlein, Susan; Yates, Gigi; NASA, Ames Research Center, Exobiology and Future Mars Missions; Mar 1, 1989; In English; No Copyright; Avail: CASI; A01, Hardcopy

A system for automated fusion and interpretation of image data from multiple sensors, including multispectral data from an imaging spectrometer is being developed. Classical artificial intelligence techniques and artificial neural networks are employed to make real time decision based on current input and known scientific goals. Emphasis is placed on identifying minerals which could indicate past life activity or an environment supportive of life. Multispectral data can be used for geological analysis because different minerals have characteristic spectral reflectance in the visible and near infrared range. Classification of each spectrum into a broad class, based on overall spectral shape and locations of absorption bands is possible in real time using artificial neural networks. The goal of the system is twofold: multisensor and multispectral data must be interpreted in real time so that potentially interesting sites can be flagged and investigated in more detail while the rover is near those sites; and the sensed data must be reduced to the most compact form possible without loss of crucial information. Autonomous decision making will allow a rover to achieve maximum scientific benefit from a mission. Both a classical rule based approach and a decision neural network for making real time choices are being considered. Neural nets may work well for adaptive decision making. A neural net can be trained to work in two steps. First, the actual input state is mapped to the closest of a number of memorized states. After weighing the importance of various input parameters, the net produces an output decision based on the matched memory state. Real time, autonomous image data analysis and decision making capabilities are required for achieving maximum scientific benefit from a rover mission. The system under development will enhance the chances of identifying fossils or environments capable of supporting life on Mars
CASI
Artificial Intelligence; Computer Vision; Decision Making; Extraterrestrial Life; Fossils; Image Processing; Mars Surface Samples; Neural Nets; Robotics; Roving Vehicles

19890014147 NASA Lewis Research Center, Cleveland, OH, USA
Preliminary assessment of rover power systems for the Mars Rover Sample Return Mission
Bents, David J.; JAN 1, 1989; In English; International Conference on Space Power, 5-7 Jun. 1989, Cleveland, OH, USA
Contract(s)/Grant(s): RTOP 586-01-11
Report No.(s): NASA-TM-102003; E-4707; NAS 1.15:102003; No Copyright; Avail: CASI; A03, Hardcopy

Four isotope power system concepts were presented and compared on a common basis for application to on-board electrical prime power for an autonomous planetary rover vehicle. A representative design point corresponding to the Mars Rover Sample Return (MRSR) preliminary mission requirements (500 W) was selected for comparison purposes. All systems concepts utilize the General Purpose Heat Source (GPHS) isotope heat source developed by DOE. Two of the concepts employ thermoelectric (TE) conversion: one using the GPHS Radioisotope Thermoelectric Generator (RTG) used as a reference case, the other using an advanced RTG with improved thermoelectric materials. The other two concepts employed are dynamic isotope power systems (DIPS): one using a closed Brayton cycle (CBC) turboalternator, and the other using a free piston Stirling cycle engine/linear alternator (FPSE) with integrated heat source/heater head. Near term technology levels have been assumed for concept characterization using component technology figure-of-merit values taken from the published literature. For example, the CBC characterization draws from the historical test database accumulated from space Brayton cycle

subsystems and components from the NASA B engine through the mini-Brayton rotating unit. TE system performance is estimated from Voyager/multihundred Watt (MHW)-RTG flight experience through Mod-RTG performance estimates considering recent advances in TE materials under the DOD/DOE/NASA SP-100 and NASA Committee on Scientific and Technological Information programs. The Stirling DIPS system is characterized from scaled-down Space Power Demonstrator Engine (SPDE) data using the GPHS directly incorporated into the heater head. The characterization/comparison results presented here differ from previous comparison of isotope power (made for Low Earth Orbit (LEO) applications) because of the elevated background temperature on the Martian surface compared to LEO, and the higher sensitivity of dynamic systems to elevated sink temperature. The mass advantage of dynamic systems is significantly reduced for this application due to Mars' elevated background temperature.
CASI

Mars Sample Return Missions; Radioisotope Batteries; Roving Vehicles; Spacecraft Power Supplies; Thermoelectric Generators

19890010508 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA

Machine vision for space telerobotics and planetary rovers

Wilcox, Brian H.; NASA. Lyndon B. Johnson Space Center, 2nd Annual Workshop on Space Operations Automation and Robotics (SOAR 1988); Nov 1, 1988; In English; No Copyright; Avail: CASI; A01, Hardcopy

Machine vision allows a non-contact means of determining the three-dimensional shape of objects in the environment, enabling the control of contact forces when manipulation by a telerobot or traversal by a vehicle is desired. Telerobotic manipulation in Earth orbit requires a system that can recognize known objects in spite of harsh lighting conditions and highly specular or absorptive surfaces. Planetary surface traversal requires a system that can recognize the surface shape and properties of an unknown and arbitrary terrain. Research on these two rather disparate types of vision systems is described.
CASI

Applications Programs (Computers); Computer Vision; Kinematics; Knowledge Bases (Artificial Intelligence); Manipulators; Robotics; Roving Vehicles; Target Recognition; Teleoperators; Telerobotics; Terrain Analysis

19890008984 Arizona Univ., Tucson, AZ, USA

Sampling strategies on Mars: Remote and not-so-remote observations from a surface rover

Singer, R. B.; Lunar and Planetary Inst., Workshop on Mars Sample Return Science; JAN 1, 1988; In English; No Copyright; Avail: CASI; A01, Hardcopy

The mobility and speed of a semi-autonomous Mars rover are of necessity limited by the need to think and stay out of trouble. This consideration makes it essential that the rover's travels be carefully directed to likely targets of interest for sampling and in situ study. Short range remote sensing conducted from the rover, based on existing technology, can provide significant information about the chemistry and mineralogy of surrounding rocks and soils in support of sampling efforts. These observations are of course of direct scientific importance as well. Because of the small number of samples actually to be returned to Earth, it is also important that candidate samples be analyzed aboard the rover so that diversity can be maximized. It is essential to perform certain types of analyses, such as those involving volatiles, prior to the thermal and physical shocks of the return trip to Earth. In addition, whatever measurements can be made of nonreturned samples will be important to enlarge the context of the detailed analyses to be performed later on the few returned samples. Some considerations related to these objectives are discussed.
CASI

Chemical Analysis; Core Sampling; Mars Sample Return Missions; Mars Surface Samples; Remote Sensing; Roving Vehicles

19890008946 NASA Goddard Space Flight Center, Greenbelt, MD, USA

A Mars orbital laser altimeter for rover trafficability: Instrument concept and science potential

Garvin, J. B.; Zuber, M. T.; Lunar and Planetary Inst., Workshop on Mars Sample Return Science; JAN 1, 1988; In English; No Copyright; Avail: CASI; A01, Hardcopy

Limited information on the types of geologic hazards (boulders, troughs, craters etc.) that will affect rover trafficability on Mars are available for the two Viking Lander sites, and there are no prospects for increasing this knowledge base in the near future. None of the instrument payloads on the upcoming Mars Observer or Soviet PHOBOS missions can directly measure surface obstacles on the scales of concern for rover safety (a few meters). Candidate instruments for the Soviet Mars 92 orbiter/balloon/rover mission such as balloon-borne stereo imaging, rover panoramic imaging, and orbital synthetic aperature imaging (SAR) are under discussion, but data from this mission may not be available for target areas of interest for

the U.S. Mars Rover Sample Return (MRSR) mission. In an effort to determine how to directly measure the topography of surface obstacles that could affect rover trafficability on Mars, we are studying how to design a laser altimeter with extremely high spatial and vertical resolution that would be suitable for a future Mars Orbiter spacecraft (MRSR precursor or MRSR orbiter). This report discusses some of the design issues associated with such an instrument, gives examples of laser altimeter data collected for Mars analog terrains on Earth, and outlines the scientific potential of data that could be obtained with the system.
CASI
Collision Avoidance; Laser Altimeters; Mars Surface; Orbital Workshops; Roving Vehicles

19890005770 NASA, Washington, DC, USA
A preliminary study of Mars rover/sample return missions
Jan 1, 1987; In English
Report No.(s): NASA-TM-101218; NAS 1.15:101218; No Copyright; Avail: CASI; A05, Hardcopy

The Solar System Exploration Committee (SSEC) of the NASA Advisory Council recommends that a Mars Sample Return mission be undertaken before the year 2000. Comprehensive studies of a Mars Sample Return mission have been ongoing since 1984. The initial focus of these studies was an integrated mission concept with the surface rover and sample return vehicle elements delivered to Mars on a single launch and landed together. This approach, to be carried out as a unilateral U.S. initiative, is still a high priority goal in an Augmented Program of exploration, as the SSEC recommendation clearly states. With this background of a well-understood mission concept, NASA decided to focus its 1986 study effort on a potential opportunity not previously examined; namely, a Mars Rover/Sample Return (MRSR) mission which would involve a significant aspect of international cooperation. As envisioned, responsibility for the various mission operations and hardware elements would be divided in a logical manner with clearly defined and acceptable interfaces. The U.S. and its international partner would carry out separately launched but coordinated missions with the overall goal of accomplishing in situ science and returning several kilograms of surface samples from Mars. Important considerations for implementation of such a plan are minimum technology transfer, maximum sharing of scientific results, and independent credibility of each mission role. Under the guidance and oversight of a Mars Exploration Strategy Advisory Group organized by NASA, a study team was formed in the fall of 1986 to develop a preliminary definition of a flight-separable, cooperative mission. The selected concept assumes that the U.S. would undertake the rover mission with its sample collection operations and our international partner would return the samples to Earth. Although the inverse of these roles is also possible, this study report focuses on the rover functions of MRSR because rover operations have not been studied in as much detail as the sample return functions of the mission.
CASI
Mars Sample Return Missions; Mars Surface Samples; Roving Vehicles; Sampling; Solar System; Space Exploration

19880068088 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Mars rover technology development requirements
Bedard, Roger; Cunningham, Glenn; Gershman, Robert; Pivirotto, Donna; Wilcox, Brian; Oct 1, 1988; In English
Report No.(s): IAF PAPER 88-003; Copyright; Avail: Other Sources

The technology development requirements for various Mars rover range capabilities are discussed, focusing on local navigation of the rover. The capabilities of two methods are compared. In one method, operators on the earth view stereo pictures sent by the rover and determine short traverse paths which the rover follows. The other method achieves more autonomous capability by using computer vision from orbital imagery with approximate long routes commanded from earth. The locomotion, navigation, ground operations, computation, power, thermal control, communications, sample acquisition, and analysis and preservation requirements are examined.
AIAA
Mars Landing; Mars Surface; Mission Planning; Roving Vehicles

19880059262 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Advanced propulsion for the Mars Rover Sample Return Mission
Palaszewski, Bryan; Frisbee, Robert; Jul 1, 1988; In English
Report No.(s): AIAA PAPER 88-2900; Copyright; Avail: Other Sources

The present evaluation of highly detailed advanced propulsion system design concepts for the Mars Rover Sample Return Mission proceeded by comparing a baseline chemical propulsion option with both storable and cryogenic advanced chemical

propulsion alternatives and solar- and nuclear-based electric propulsion OTVs. Substantial launch mass reductions and commensurate payload mass increases were obtainable with both advanced chemical and electric propulsion cycles.
AIAA
Chemical Propulsion; Electric Propulsion; Mars Sample Return Missions; Mars Surface Samples; Spacecraft Propulsion

19880037013 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
A Mars rover for the 1990's
Wilcox, Brian H.; Gennery, Donald B.; Oct 1, 1987; ISSN 0007-084X; 40; In English; Copyright; Avail: Other Sources

Some technical issues concerning a Mars rover launched in the 1990s are discussed. Two particular modes of controlling the traveling of the vehicle are described. In one mode, most of the control is from earth, by human operators viewing stereo pictures sent from the rover and designating short routes to follow. In the other mode, computer vision is used in order to make the rover more autonomous, but reliability is aided by the use of orbital imagery and approximate long routes sent from earth. In the latter case, it is concluded that average travel rates of around 10 km/day are feasible.
AIAA
Mars Landing; Roving Vehicles; Technological Forecasting

19880034991 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Aeroassist vehicle requirements for a Mars Rover/Sample Return Mission
Meyerson, Robert E.; Cerimele, Christopher J.; Jan 1, 1988; In English
Report No.(s): AIAA PAPER 88-0303; Copyright; Avail: Other Sources

A three degree-of-freedom computer simulation has been developed to perform Martian aeroassist trajectories using the HYPAS guidance algorithm. This simulator was used to perform a parametric study at the Johnson Space Center of various low L/D vehicles and their performance with the inclusion of vehicle and atmospheric dispersions. The ultimate goal is to define an extreme (minimum L/D) aeroassist configuration for the Mars Rover/Sample Return Mission to compare with the previously defined biconic aeroshell. The study shows that a raked cone vehicle with L/D betweeen 0.3 and 0.6 will perform adequately in the Martian environment in the presence of dispersions. Average apoapsis error for the 0.6 L/D vehicle was 11.9 km (6.4 nm) above the 2000 km target which compares fairly well with an error of 3.5 km (1.9 nm) for the 1.5 L/D biconic vehicle. The study concluded that the low L/D raked configuration warrants further study which could include stability analysis as well as the inclusion of density shears and dynamic atmospheric variations.
AIAA
Aeroassist; Mars Sample Return Missions; Mars Surface Samples; Roving Vehicles

19880010842 Utah State Univ., Logan, UT, USA
Mars Lander/Rover vehicle development: An advanced space design project for USRA and NASA/OAST
JAN 1, 1987; In English
Contract(s)/Grant(s): NGT-21-002-080
Report No.(s): NASA-CR-182562; NAS 1.26:182562; No Copyright; Avail: CASI; A06, Hardcopy

The accomplishments of the Utah State University (USU) Mars Lander/Rover (MLR) design class during the Winter Quarter are delineated and explained. Environment and trajectory, ground systems, balloon system, and payload system are described. Results from this effort will provide a valid and useful basis for further studies of Mars exploratory vehicles.
B.G.
Computerized Simulation; Landing Modules; Mars Environment; Mars Landing; Mars Observer; Mission Planning; Payloads; Roving Vehicles; Spacecraft Design

19870061367 Utah State Univ., Logan, UT, USA
Design considerations for a Martian Balloon Rover
Redd, F.; Levesque, R. J.; Williams, G. E.; JAN 1, 1987; In English
Report No.(s): AIAA PAPER 87-2306; Copyright; Avail: Other Sources

The present NASA-sponsored design feasibility study for a balloon-borne sensor platform that is to be used over environmentally dissimilar sites on Mars gives attention to specific environmental and configurational parameters of a baseline balloon design, with a view to day/night altitude variations in response to temperature extremes. It is concluded that a Martian Balloon Rover can be developed using current technology; projected reductions in high-strength fabric density and

radiation-resistant coatings will further enhance mission effectiveness, permitting either balloon size reductions or payload capacity increases.
AIAA
Balloons; Mars Surface; Roving Vehicles

19870040026 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA, Ohio State Univ., Columbus, OH, USA
Current status of mission/system design for a Mars rover
Klein, Gail; Cooper, Brian; Waldron, Kenneth; Unmanned Systems; JAN 1, 1986; 5; In English; Copyright; Avail: Other Sources

The system integration issues associated with the design of Rovers for Mars ground surface operations are addressed in this article. Requirements are established for both long distance traverse between geology sites and for geologic survey operations. To satisfy these mission requirements, a semi-autonomous vehicle design has been proposed and its performance capabilities are assessed. Furthermore, the mobility, power consumption, coordination and control (maneuverability), and reliability issues associated with the design of mobility systems to permit vehicle traverse over rugged terrain are examined and the direction of future work required to address these issues is outlined.
AIAA
Mars Landing; Mars Probes; Mars Surface; Mission Planning; Roving Vehicles

19870039343 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Mars to earth optical communication link for the proposed Mars Sample Return mission roving vehicle
Sipes, Donald L., Jr.; JAN 1, 1986; In English; Copyright; Avail: Other Sources

The Mars Sample Return (MSR) mission planed for 1989 will deploy a rover from its landing craft to survey the Martian surface. During traversals of the rover from one site to the next in search of samples, three-dimensional images from a pair of video cameras will be transmitted to earth; the terrestrial operators will then send back high level direction commands to the rover. Attention is presently given to the effects of wind and dust on communications, the architecture of the optical communications package, and the identification of technological areas requiring further development for MSR incorporation.
AIAA
Mars Landing; Mars Sample Return Missions; Optical Communication; Roving Vehicles; Space Communication

19870008324 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Rover technology for manned Mars missions
Klein, Gail; NASA. Marshall Space Flight Center Manned Mars Missions. Working Group Papers, Volume 1, Section 1-4; May 1, 1986; In English; No Copyright; Avail: CASI; A03, Hardcopy

A set of roving vehicle design requirements were postulated, corresponding to an idealized Mars transport vehicle operational scenario which could serve as a reference for a manned Mars mission. The ability of conventional vehicles to satisfy these requirements were examined. The study indicated that no conventional vehicle could satisfy all of the requirements, as the vehicles are presently configured. Consequently, the requirements have to either be relaxed and/or an alternative, less conventional vehicle design will have to be developed. A possible unconventional vehicle design which has received considerable attention for DARPA and the Army is the walker vehicle. The design issues associated with this vehicle are presented, along with a comparison of the performance capabilities of this technology vs. conventional vehicle technology.
CASI
Manned Mars Missions; Mars Landing; Mars Surface; Roving Vehicles; Walking Machines

19860055876 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA, Ohio State Univ., Columbus, OH, USA
Mars Rover
Klein, G.; Cooper, B.; Waldron, K.; Jun 1, 1986; In English
Report No.(s): AIAA PAPER 86-1198; Copyright; Avail: Other Sources

The system integration issues associated with the design of Rovers for Mars ground surface operations are addressed in this paper. Requirements are established for both long distance traverse between geology sites and for geologic survey operations. To satisfy these mission requirements, a semi-autonomous vehicle design has been proposed and its performance capabilities are assessed. Furthermore, the mobility, power consumption, coordination and control (maneuverability), and reliability issues associated with the design of mobility systems to permit vehicle traverse over rugged terrain are examined

and the direction of future work required to address these issues is outlined.
AIAA
Computer Aided Design; Design Analysis; Geological Surveys; Mars Surface; Roving Vehicles

19860044047 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
A Mars sample return mission using a rover for sample acquisition
De Vries, J. P.; Norton, H. N.; JAN 1, 1985; In English
Report No.(s): AAS 84-159; Copyright; Avail: Other Sources

Mission and vehicle concepts are discussed for obtaining surface and subsurface samples of Mars, acquired by a roving vehicle, and returning those samples to earth for detailed analyses in scientific laboratories. Mission options that were traded off in order to arrive at a baseline mission considered most worthy of further study comprised the following: (1) direct entry vs entry out of Mars orbit; (2) direct return from the Mars surface vs rendezvous in Mars orbit and return to earth from there; and (3) propulsive orbit injection and aeroballistic entry (similar to Viking) vs aerocapture into Mars orbit and aeromaneuvering entry. After a comparison of relative merits - based primarily on mass and cost estimates and secondarily on configurational constraints - a baseline mission was selected: out-of-orbit entry, return after Mars orbit rendezvous, and aerocapture/aeromaneuvering. Trajectory design is based on the 1996 launch opportunity. Launch mass requirements for eight mission options, a mission and vehicle description for the baseline mission, and the outline of a mission sequence of events are presented.
AIAA
Interplanetary Flight; Mars Sample Return Missions; Mars Surface Samples; Mission Planning; Roving Vehicles; Space Missions

19860029510 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Designing a Mars surface rover
Ruoff, C.; Wilcox, B.; Klein, G.; Aerospace America; Nov 1, 1985; ISSN 0740-722X; 23; In English; Copyright; Avail: Other Sources

Only three categories of vehicular configuration are under consideration for the Mars rover geological exploration mission: a six-wheeled 'lunar roving vehicle' (LRV), an elastic loopwheeled mobility system (ELMS), and a 'walking' vehicle. The LRV uses three compliantly coupled modules, each of which is equipped with two powered wheels. The ELMS uses three loopwheels that are reminiscent of tracks mounted on an articulated suspension. Walkers, which use leg-like mechanisms, are the least developed of the three categories. A comparative assessment of the capabilities and economies of the three vehicle types is presented.
AIAA
Mars Surface Samples; Robots; Roving Vehicles; Walking Machines

19830077481 Bendix Corp., Ann Arbor, MI, USA
Dual-mode manned/automated lunar roving vehicle design definition study. Volume 2: Vehicle design and systems integration. Book 4: Systems safety analysis
Jan 1, 1970; In English; 8volumes
Contract(s)/Grant(s): NAS8-24528
Report No.(s): NASA-CR-119309; NAS 1.26:119309; BSR-2816-VOL-2-BK-4; No Copyright; Avail: CASI; A08, Hardcopy
Lunar Roving Vehicles; Safety; Structural Design Criteria; Systems Integration

19830077480 Grumman Aerospace Corp., Bethpage, NY, USA
Dual mode lunar roving vehicle preliminary design study. Volume 2: Vehicle design and system integration. Book 1: DLRV system design and analysis. Book 2: DLRV tie-down, off-loading, and checkout. Book 3: Ground support equipment. Book 4: System safety analysis
Feb 1, 1970; In English; 7volumes
Contract(s)/Grant(s): NAS8-24529
Report No.(s): NASA-CR-119668; NAS 1.26:119668; No Copyright; Avail: CASI; A22, Hardcopy
Design Analysis; Lunar Roving Vehicles; Structural Design Criteria; Systems Integration

19810002387 Rensselaer Polytechnic Inst., Troy, NY, USA
Electronic and software subsystems for an autonomous roving vehicle
Doig, G. A.; Oct 1, 1980; In English
Contract(s)/Grant(s): JPL-954880; NSG-7369
Report No.(s): NASA-CR-163668; RPI-TR-MP-76; No Copyright; Avail: CASI; A04, Hardcopy

The complete electronics packaging which controls the Mars roving vehicle is described in order to provide a broad overview of the systems that are part of that package. Some software debugging tools are also discussed. Particular emphasis is given to those systems that are controlled by the microprocessor. These include the laser mast, the telemetry system, the command link prime interface board, and the prime software.

A.R.H.

Automatic Control; Computer Programs; Electronic Packaging; Mars Surface; Onboard Equipment; Roving Vehicles

19800053296 Rensselaer Polytechnic Inst., Troy, NY, USA
A laser rangefinder path selection system for Martian rover using logarithmic scanning scheme
Shen, C. N.; Kim, C. S.; JAN 1, 1980; In English; 8th Automatic control in space, July 2-6, 1979, Oxford
Contract(s)/Grant(s): NSG-7184; Copyright; Avail: Other Sources

This paper deals with a laser rangefinder path selection scheme for an autonomous Martian roving vehicle. The overall scheme consists of the following interrelated sub-systems; logarithmic scanning sub-system, obstacle detection scheme (Sonalkar and Shen (1975); Kim and Shen (1978)), terrain modeling and estimation (Shen and Stare (1977); Pawlowski (1978)), and path selection algorithm (Netch and Shen (1977)). Independent and separate studies for the last three sub-systems were performed previously. With the introduction of the logarithmic scanning, an integrated study is completed in this paper. This study serves as a possible alternate choice other than TV cameras for navigating the Martian surface. Moreover, if hybrid TV and laser systems are used, a laser-only standby system can be put to work in case the TV part of the hybrid system fails to operate.

AIAA

Automatic Control; Laser Range Finders; Mariner Spacecraft; Roving Vehicles; Surface Navigation

19800036742 Rensselaer Polytechnic Inst., Troy, NY, USA
Guidance of an autonomous planetary rover based on a short-range hazard detection system
Yerazunis, S. W.; Frederick, D. K.; Hunter, E.; Troiani, N.; JAN 1, 1979; In English; Modeling and simulation., April 25-27, 1979, Pittsburgh, PA
Contract(s)/Grant(s): JPL-954880; NSG-7369; Copyright; Avail: Other Sources

The guidance of an autonomous planetary roving vehicle using a scanning laser/multidetector terrain sensor for short-range hazard detection has been simulated. The sensor data are used to model the terrain, thereby providing the information required by a path selection algorithm to control the motion of the rover. These simulation studies are providing the basis for developing both the real-time computer control software and the hardware systems for laboratory and field testing of rover.

AIAA

Guidance (Motion); Hazards; Planetary Landing; Remote Sensors; Roving Vehicles; Terrain Analysis

19800025239 Rensselaer Polytechnic Inst., Troy, NY, USA
A linear photodiode array employed in a short range laser triangulation obstacle avoidance sensor
Odenthal, J. P.; Dec 1, 1980; In English
Contract(s)/Grant(s): JPL-954880; NSG-7369
Report No.(s): NASA-CR-163613; RPI-TR-MP-74; No Copyright; Avail: CASI; A07, Hardcopy

An opto-electronic receiver incorporating a multi-element linear photodiode array as a component of a laser-triangulation rangefinder was developed as an obstacle avoidance sensor for a Martian roving vehicle. The detector can resolve the angle of laser return in 1.5 deg increments within a field of view of 30 deg and a range of five meters. A second receiver with a 1024 elements over 60 deg and a 3 meter range is also documented. Design criteria, circuit operation, schematics, experimental results and calibration procedures are discussed.

A.R.H.

Laser Range Finders; Linear Arrays; Mars Surface; Photodiodes; Robots; Roving Vehicles; Triangulation

19800022688 Rensselaer Polytechnic Inst., Troy, NY, USA
Laser optical appraisal and design of a PRIME/Rover interface
Donaldson, J. A.; Jul 1, 1980; In English
Contract(s)/Grant(s): JPL-954880; NSG-7369
Report No.(s): NASA-CR-163508; RPI-TR-MP-68; No Copyright; Avail: CASI; A05, Hardcopy

An appraisal of whether to improve the existing multi-laser/multi detector system was undertaken. Two features of the elevation scanning mast which prevent the system from meeting desired specifications were studied. Then elevation scanning mast has 20 detectors, as opposed to the desired 40. This influences the system's overall resolution. The mirror shaft encoder's finite resolution prevents the laser from being aimed exactly as desired. This influences the system's overall accuracy. It was concluded that the existing system needs no modification at present. The design and construction of a data emulator which allowed testing data transactions with a PRIME computer is described, and theory of operation briefly discussed. A full blown PRIME/Rover Interface was designed and built. The capabilities of this Interface and its operating principles are discussed.
R.K.G.
Barriers; Computer Systems Design; Data Processing Equipment; Lasers; Mars (Planet); Optical Tracking; Roving Vehicles; Target Recognition

19800022247 Rensselaer Polytechnic Inst., Troy, NY, USA
A propulsion and steering control system for the Mars rover
Turner, J. M.; Aug 1, 1980; In English
Contract(s)/Grant(s): JPL-954880; NSG-7369
Report No.(s): NASA-CR-163501; RPI-TR-MP-77; No Copyright; Avail: CASI; A05, Hardcopy

The design of a propulsion and steering control system for the Rensselaer Polytechnic Institute prototype autonomous Mars roving vehicle is presented. The vehicle is propelled and steered by four independent electric motors. The control system must regulate the speeds of the motors so they work in unison during turns and on irregular terrain. An analysis of the motor coordination problem on irregular terrain, where each motor must supply a different torque at a different speed is presented. A procedure was developed to match the output of each motor to the varying load. A design for the control system is given. The controller uses a microprocessor which interprets speed and steering commands from an off-board computer, and produces the appropriate drive voltages for the motors.
T.M.
Computer Programs; Controllers; Microprocessors; Roving Vehicles; Servomechanisms; Steering; Torque Motors

19800022246 Rensselaer Polytechnic Inst., Troy, NY, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
A propulsion system for the Mars rover vehicle
Bogdan, D. C.; Aug 1, 1980; In English
Contract(s)/Grant(s): JPL-954880; NSG-7369
Report No.(s): NASA-CR-163494; RPI-TR-MP-70; No Copyright; Avail: CASI; A04, Hardcopy

The vehicle control electronics for the Mars rover vehicle is described. A functional description of the electronics and its place in the entire system is given. The hardware involved is described from a user's point of view. Changes and additions to the software are included.
T.M.
Control Equipment; Electronic Control; Propulsion System Configurations; Roving Vehicles; Wiring

19800022245 Rensselaer Polytechnic Inst., Troy, NY, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
An advanced terrain modeler for an autonomous planetary rover
Hunter, E. L.; Jul 1, 1980; In English
Contract(s)/Grant(s): JPL-954880; NSG-7369
Report No.(s): NASA-CR-163485; RPI-TR-MP-67; No Copyright; Avail: CASI; A05, Hardcopy

A roving vehicle capable of autonomously exploring the surface of an alien world is under development and an advanced terrain modeler to characterize the possible paths of the rover as hazardous or safe is presented. This advanced terrain modeler has several improvements over the Troiani modeler that include: a crosspath analysis, better determination of hazards on slopes, and methods for dealing with missing returns at the extremities of the sensor field. The results from a package of

programs to simulate the roving vehicle are then examined and compared to results from the Troiani modeler.
L.F.M.
Lunar Roving Vehicles; Product Development; Roving Vehicles; Simulators; Space Exploration

19800021872 Rensselaer Polytechnic Inst., Troy, NY, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
A high speed telemetry data link for an autonomous roving vehicle
Cipolle, D. J.; Aug 1, 1980; In English
Contract(s)/Grant(s): JPL-954880; NSG-7369
Report No.(s): NASA-CR-163495; RPI-TR-MP-72; No Copyright; Avail: CASI; A06, Hardcopy

A data link system used on a prototype autonomous roving vehicle is described. This system provides a means of acquiring, formatting, and transmitting information on board the vehicle to a controlling computer. Included is a statement of requirements and the design philosophy. Additionally, interfacing with the rover systems is discussed, along with the overall performance of the telemetry link.
CASI
Data Links; Planetary Surfaces; Roving Vehicles; Telemetry

19800016718 Defense Research Corp., Santa Barbara, CA, USA
Design and manufacture of wheels for a dual-mode (manned - automatic) lunar surface roving vehicle. Volume 2: Proposed test plan
May 1, 1970; In English
Contract(s)/Grant(s): NAS8-25194
Report No.(s): NASA-CR-163200; TR70-30-VOL-2; No Copyright; Avail: CASI; A03, Hardcopy

A developmental test plan for the wheel and wheel drive assembly of the dual-mode (manned/automated) lunar surface roving vehicle is presented. The tests cover performance, as well as critical environmental characteristics. Insofar as practical, the environmental conditions imposed will be in the sequence expected during the hardware's life from storage through the lunar mission. Test procedures are described for static load deflection and endurance tests. Soft soil tests to determine mobility characteristics including drawbar-pull and thrust vs slip, and motion resistance for various wheel loads are also discussed. Test designs for both ambient and thermal vacuum conditions are described. Facility, transducer, and instrumentation requirements are outlined.
M.G.
Lunar Roving Vehicles; Performance Tests; Vehicle Wheels

19800016717 Defense Research Corp., Santa Barbara, CA, USA
Design and manufacture of wheels for a dual-mode (manned - automatic) lunar surface roving vehicle. Volume 1: Detailed technical report
May 1, 1970; In English
Contract(s)/Grant(s): NAS8-25194
Report No.(s): NASA-CR-163199; TR70-30-VOL-1; No Copyright; Avail: CASI; A08, Hardcopy

The concept development, testing, evaluation, and the selection of a final wheel design concept for a dual-mode lunar surface vehicle (DLRV) is detailed. Four wheel configurations were fabricated (one open wheel and three closed wheel) (and subjected to a series of soft soil, mechanical, and endurance tests. Results show that the open wheel has lower draw-bar pull (slope climbing) capability in loose soil due to its higher ground pressure and tendency to dig in at high wheel slip. Endurance tests indicate that a double mesh, fully enclosed wheel can be developed to meet DLRV life requirements. There is, however, a 1.0 to 1.8 lb/wheel weight penalty associated with the wheel enclosure. Also the button cleats used as grousers for the closed-type wheels result in local stress concentration and early fatigue failure of the wire mesh. Load deflection tests indicate that the stiffness of the covered wheel increased by up to 50% after soil bin testing, due to increased friction between the fabric and the wire mesh caused by the sand. No change in stiffness was found for the open wheel. The single woven mesh open wheel design with a chevron tread is recommended for continued development
M.G.
Design Analysis; Lunar Roving Vehicles; Vehicle Wheels

19790080008 Rensselaer Polytechnic Inst., Troy, NY, USA
Data acquisition and path selection decision making for an autonomous roving vehicle
Shen, C. N.; Yerazunis, S. W.; Sep 1, 1979; In English
Contract(s)/Grant(s): NASW-3279
Report No.(s): NASA-CR-162222; RPI-TR-MP-64; No Copyright; Avail: CASI; A03, Hardcopy
Data Acquisition; Ground Tracks; Roving Vehicles

19790073820 Bellcomm, Inc., Washington, DC, USA
Modular timeline elements for lunar roving vehicle traverse station stops
Slaybaugh, J. C.; Mar 24, 1970; In English
Contract(s)/Grant(s): NASW-417
Report No.(s): NASA-CR-112691; B70-03072; No Copyright; Avail: CASI; A03, Hardcopy
Lunar Communication; Lunar Roving Vehicles; Surface Navigation

19790073438 Bellcomm, Inc., Washington, DC, USA
Use of a battery from the extended lm to power a lunar roving vehicle
Gillespie, J.; Jan 25, 1968; In English
Contract(s)/Grant(s): NASW-417
Report No.(s): NASA-CR-93384; No Copyright; Avail: CASI; A02, Hardcopy
Electric Batteries; Landing Modules; Lunar Roving Vehicles; Lunar Spacecraft; Power Supplies

19790073289 Bellcomm, Inc., Washington, DC, USA
Apollo 13 LM battery anomaly and lunar roving vehicle battery inference
Campbell, W. O.; Jul 16, 1970; In English
Contract(s)/Grant(s): NASW-417
Report No.(s): NASA-CR-113360; B70-07059; No Copyright; Avail: CASI; A01, Hardcopy
Electric Batteries; Electrical Properties; Lunar Roving Vehicles

19790073208 Bellcomm, Inc., Washington, DC, USA
On the problem of continuous television during Rover traverses, case 320
Oconnor, J. J.; Aug 26, 1971; In English
Contract(s)/Grant(s): NASW-417
Report No.(s): NASA-CR-121544; B71-08036; No Copyright; Avail: CASI; A03, Hardcopy
Apollo Project; Lunar Roving Vehicles; Television Cameras; Television Reception

19790072560 Bellcomm, Inc., Washington, DC, USA
Equations of motion of the lunar roving vehicle
Kaufman, S.; Mar 31, 1970; In English
Contract(s)/Grant(s): NASW-417
Report No.(s): NASA-CR-113382; TM-70-2031-1; No Copyright; Avail: CASI; A05, Hardcopy

Equations of motion for lunar roving vehicles

CASI
Equations of Motion; Lunar Exploration; Lunar Roving Vehicles

19790072530 Bellcomm, Inc., Washington, DC, USA
Lunar rover wheel performance tests
Richey, J. D.; Jan 27, 1970; In English
Contract(s)/Grant(s): NASW-417
Report No.(s): NASA-CR-126063; CASE-320; B70-01047; No Copyright; Avail: CASI; A02, Hardcopy
Lunar Roving Vehicles; Performance Tests; Vehicle Wheels

19790072523 Bellcomm, Inc., Washington, DC, USA
A description of the rover navigation system simulation program
Bar-Itzhack, I. Y.; Jul 27, 1971; In English
Contract(s)/Grant(s): NASW-417
Report No.(s): NASA-CR-121317; B71-07045; No Copyright; Avail: CASI; A03, Hardcopy
Computerized Simulation; Lunar Roving Vehicles; Surface Navigation

19790072520 Bellcomm, Inc., Washington, DC, USA
The navigation system of the lunar roving vehicle
Heffron, W. G.; La Piana, F.; Dec 11, 1970; In English
Contract(s)/Grant(s): NASW-417
Report No.(s): NASA-CR-116268; TM-70-2014-8; No Copyright; Avail: CASI; A03, Hardcopy
Lunar Roving Vehicles; Navigation Aids

19790072506 Bellcomm, Inc., Washington, DC, USA
Review of Dual-mode Lunar Roving Vehicle /DLRV/ - Design definition study
Slaybaugh, J. C.; Oct 29, 1969; In English
Contract(s)/Grant(s): NASW-417
Report No.(s): NASA-CR-107362; B69-10096; No Copyright; Avail: CASI; A03, Hardcopy
Configuration Management; Lunar Roving Vehicles; Systems Engineering

19790039787 Rensselaer Polytechnic Inst., Troy, NY, USA
Path selection process utilizing rapid estimation scheme
Ring, H.; Shen, C. N.; JAN 1, 1978; In English; 9th Modeling and simulation. Volume 9 - Ninth Annual Pittsburgh Conference, April 27-28, 1978, Pittsburgh, PA
Contract(s)/Grant(s): NSG-7184; Copyright; Avail: Other Sources

The paper describes the use of a rapid estimation scheme for path selection by a roving vehicle. Essentially, the evaluation procedure simulates movement of the rover over each of several corridors lying radially outward from the scanning position. Two levels of corridors are used, and the path selection scheme selects the optimal primary corridor according to a dynamic programming algorithm. In the present version, the length of the corridors is variable. The rapid estimation scheme provides information to define corridor dimensions. This corridor structure, which varies as a function of the terrain, eliminates the need for backtracking, except in certain extreme cases. Computer results are promising in that obstacles were avoided while corridor lengths were kept to a maximum where safety permitted.
AIAA
Mars Probes; Paths; Roving Vehicles; Terrain Analysis

19790039786 Rensselaer Polytechnic Inst., Troy, NY, USA
A stochastic analysis of terrain evaluation variables for path selection
Donohue, J. G.; Shen, C. N.; JAN 1, 1978; In English; 9th Modeling and simulation. Volume 9 - Ninth Annual Pittsburgh Conference, April 27-28, 1978, Pittsburgh, PA
Contract(s)/Grant(s): NSG-7184; Copyright; Avail: Other Sources

A stochastic analysis was performed on the variables associated with the characteristics of the terrain encountered by a roving system with an autonomous navigation system. A laser rangefinder is employed to detect terrain features at ranges up to 75 m. Analytic expressions and a numerical scheme were developed to calculate the variance of data on these four variables: (1) body clearance, (2) in-path slope, (3) tilt slope, and (4) wheel deviation. The variance is due to noise in the range data. It was found that the standard deviation of these terrain variables is large enough to warrant the use of a safety margin to aid the roving vehicle in avoiding high risk areas.
AIAA
Paths; Roving Vehicles; Stochastic Processes; Terrain Analysis

19790030975 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
A discrete adaptive guidance system for a roving vehicle
Miller, J. A.; JAN 1, 1977; In English; 16th Conference on Decision and Control, and Symposium on Adaptive Processes, 16th, and Special Symposium on Fuzzy Set Theory and Applications, December 7-9, 1977, New Orleans, LA
Contract(s)/Grant(s): NAS7-100; Copyright; Avail: Other Sources

An adaptive guidance technique which provides a self-correcting path following capability in an environment sensitive semi-autonomous roving robot is described. A real-time maneuver planning function performs tradeoffs between speed, magnitude of expected deviations and accelerations to best satisfy the design goals of vehicle safety and reliability, subsystem autonomy, performance accuracy and operational efficiency. The appropriate combination of maneuver parameters is selected through an iterative process using knowledge of vehicle performance characteristics, environmental model updates and vehicle state
AIAA
Adaptive Control; Command Guidance; Maneuverability; Numerical Control; Planetary Surfaces; Robots; Roving Vehicles

19790012782 Lockheed Missiles and Space Co., Huntsville, AL, USA
Operational loopwheel suspension system for Mars rover demonstration model
Trautwein, W.; Robinson, G. D.; Dec 1, 1978; In English
Contract(s)/Grant(s): JPL-955050
Report No.(s): NASA-CR-158364; LMSC-HREC-TR-D568800; No Copyright; Avail: CASI; A03, Hardcopy

The loopwheel (or elastic loop) mobility concept, appears to be uniquely qualified to provide a high degree of mobility at low weight and stowage requirements for the next Mars mission now in the early planning stage. Traction elements compatible with sterilization and Mars surface environmental constraints were designed and are compatible with the rover mass, range and stowage requirements of JPL's point design Mars rover. In order to save cost, the loopwheel suspensions for the demonstration model were made of S-glass/epoxy instead of titanium, alloy specified for flight units. The load carrying fiberglass loop core is covered by a rubber tread on the outside. Reinforced rubber gear belts bonded along the inside edges provide positive engagement and transmission drive torques. A 12 Vdc drive motor with a 167:1 gear head is installed in the payload section of the hull. A chain drive transmits the motor power to the rear sprocket in the demonstration model, whereas future flight units would be directly driven by brushless hub motors within each sprocket and independent four-leg height control.
A.R.H.
Exploration; Loops; Roving Vehicles; Suspension Systems (Vehicles); Vehicle Wheels; Vehicular Tracks

19790008719 Rensselaer Polytechnic Inst., Troy, NY, USA
Data acquisition and path selection decision making for an autonomous roving vehicle
Shen, C. N.; YERAZUNIS; Jan 1, 1979; In English
Contract(s)/Grant(s): NSG-7184
Report No.(s): NASA-CR-158103; RPI-TR-MP-62; No Copyright; Avail: CASI; A03, Hardcopy

The feasibility of using range/pointing angle data such as might be obtained by a laser rangefinder for the purpose of terrain evaluation in the 10-40 meter range on which to base the guidance of an autonomous rover was investigated. The decision procedure of the rapid estimation scheme for the detection of discrete obstacles has been modified to reinforce the detection ability. With the introduction of the logarithmic scanning scheme and obstacle identification scheme, previously developed algorithms are combined to demonstrate the overall performance of the intergrated route designation system using laser rangefinder. In an attempt to cover a greater range, 30 m to 100 mm, the problem estimating gradients in the presence of positioning angle noise at middle range is investigated.
CASI
Data Acquisition; Guidance Sensors; Laser Range Finders; Roving Vehicles

19790000174 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Guidance system for a roving vehicle
Miller, J. A.; NASA Tech Briefs; Dec 1, 1979; ISSN 0145-319X; 4, 2; In English
Report No.(s): NPO-14376; No Copyright; See also B78-10026

Computer controlled guidance system for semiautonomous robot guides robot in incompletely defined environment. System operates in real time avoiding obstacles detected by 'stereo television and laser range finder eyes.'
Guidance (Motion); Robots; Roving Vehicles

19780066292 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA, Bionetics Corp., Pasadena, CA, USA
Vision-based guidance for an automated roving vehicle
Griffin, M. D.; Cunningham, R. T.; Eskenazi, R.; JAN 1, 1978; In English; Guidance and Control Conference, August 7-9, 1978, Palo Alto, CA
Contract(s)/Grant(s): NAS7-100
Report No.(s): AIAA PAPER 78-1294; Copyright; Avail: Other Sources
A controller designed to guide an automated vehicle to a specified target without external intervention is described. The intended application is to the requirements of planetary exploration, where substantial autonomy is required because of the prohibitive time lags associated with closed-loop ground control. The guidance algorithm consists of a set of piecewise-linear control laws for velocity and steering commands, and is executable in real time with fixed-point arithmetic. The use of a previously-reported object tracking algorithm for the vision system to provide position feedback data is described. Test results of the control system on a breadboard rover at the Jet Propulsion Laboratory are included.
AIAA
Algorithms; Automatic Control; Guidance (Motion); Roving Vehicles; Visual Control

19780059143 Rensselaer Polytechnic Inst., Troy, NY, USA
Obstacle detection for the Mars Rover by a two dimensional rapid estimation scheme
Alland, S.; Shen, C. N.; JAN 1, 1977; In English; Annual Pittsburgh Conference, April 21-22, 1977, Pittsburgh, PA
Contract(s)/Grant(s): NGL-7184; Copyright; Avail: Other Sources
This paper discusses an obstacle detection system applicable to a Mars Rover mission forseen possible in the early 1980's. The sensing device on the rover will be a laser rangefinder which scans the surface ahead of the vehicle. Terrain range data information is stored in matrix form. The range varies from point to point along the surface with sharp changes due to the presence of obstacles. The noise contaminated laser rangefinder readings are processed by an algorithm involving a modified version of the Kalman Filter, along with a decision scheme, to obtain complete outlines of discrete obstacles.
AIAA
Kalman Filters; Laser Range Finders; Mars Surface; Maximum Likelihood Estimates; Roving Vehicles

19780059126 Rensselaer Polytechnic Inst., Troy, NY, USA
Terrain evaluation and route designation based on noisy rangefinder data
Netch, A.; Shen, C. N.; JAN 1, 1977; In English; Annual Pittsburgh Conference, April 21-22, 1977, Pittsburgh, PA
Contract(s)/Grant(s): NGL-7184; Copyright; Avail: Other Sources
This paper discusses an approach to terrain evaluation and route designation for an autonomous Mars rover. The evaluation procedure simulates movement of the rover over a terrain model estimated from noisy range readings. During the simulated movement a potential path is analyzed for adverse gradients and minimum vehicle body clearance which could inhibit the rover's progress. The route designation scheme employs dynamic programming to select the optimal path based on the evaluation results.
AIAA
Computerized Simulation; Mars Surface; Motion Simulators; Rangefinding; Roving Vehicles; Terrain Analysis

19780048004 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
A Mars orbiter/rover/penetrator mission for the 1984 opportunity
Hastrup, R.; Driver, J.; Nagorski, R.; Sep 1, 1977; In English; Astrodynamics Specialist Conference, Sept. 7-9, 1977, Jackson Hole, WY, US
Contract(s)/Grant(s): NAS7-100
Report No.(s): AAS PAPER 77-6; Copyright; Avail: Other Sources
A point design mission is described that utilizes the 1984 opportunity to extend the exploration of Mars after the successful Viking operations and provide the additional scientific information needed before conducting a sample return mission. Two identical multi-element spacecraft are employed, each consisting of (1) an orbiter, (2) a Viking-derived landing system that delivers a heavily instrumented, semi-autonomous rover, and (3) three penetrators deployed from the approach

trajectory. Selection of the orbit profiles requires consideration of several important factors in order to satisfy all of the mission goals.
AIAA
Earth-Mars Trajectories; Roving Vehicles; Space Missions; Viking Lander Spacecraft; Viking Orbiter Spacecraft

19780039993 Rensselaer Polytechnic Inst., Troy, NY, USA
Estimation of terrain iso-gradients from a stochastic range data measurement matrix
Shen, C. N.; Stare, J. G.; JAN 1, 1977; In English; Joint Automatic Control Conference, June 22-24, 1977, San Francisco, CA
Contract(s)/Grant(s): NSG-7184; Copyright; Avail: Other Sources

The problem of estimating terrain iso-gradients for an autonomous roving vehicle is complicated by the measurement error inherent in the range data matrix. In this paper, the in-path and cross-path slopes at each data point in the multivariable range matrix are expressed in terms of parameters at that data point and those at its surrounding points. The sensitivity in the change of these slopes - due to the errors in measurements in range, elevation angle and azimuth angle are formulated. These sensitivities are used to determine the appropriate statistics of the gradient, which are then used to describe the terrain with a known probability of accuracy.
AIAA
Computer Techniques; Mars Surface; Matrices (Mathematics); Roving Vehicles; Stochastic Processes; Terrain Analysis

19780039948 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
The automation of remote vehicle control
Paine, G.; JAN 1, 1977; In English; Joint Automatic Control Conference, June 22-24, 1977, San Francisco, CA
Contract(s)/Grant(s): NAS7-100; Copyright; Avail: Other Sources

The automation of remote vehicles is becoming necessary to overcome the requirement of having man present as a controller. By removing man, remote vehicles can be operated in areas where the environment is too hostile for man, his reaction times are too slow, time delays are too long, and where his presence is too costly, or where system performance can be improved. This paper addresses the development of automated remote vehicle control for nonspace and space tasks from warehouse vehicles to proposed Mars rovers. The state-of-the-art and the availability of new technology for implementing automated control are reviewed and the major problem areas are outlined. The control strategies are divided into those where the path is planned in advance or constrained, or where the system is a teleoperator, or where automation or robotics have been introduced.
AIAA
Automatic Control; Mars Surface; Remote Control; Remote Handling; Roving Vehicles

19780039947 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
An application of microprocessors to a Mars Roving Vehicle
Dobrotin, B. M.; Rennels, D. A.; JAN 1, 1977; In English; Joint Automatic Control Conference, June 22-24, 1977, San Francisco, CA
Contract(s)/Grant(s): NAS7-100; Copyright; Avail: Other Sources

This paper presents an approach to a microprocessor based computing system for a Mars Roving Vehicle. This represents a practical example in that it combines a breadboard robot (the Rover) with a distributed microprocessor computing system, both of which are under development at JPL and are being considered for a 1984 Mars Rover Mission. A summary of the Rover functions is presented, along with an approach of applying distributed computers. The Rover is then partitioned into its main subsystems (executive, locomotion, manipulation, and vision) and subsystem and system interfaces established. Computing requirements are discussed and a system diagram developed.
AIAA
Computer Techniques; Mars Surface; Microprocessors; Numerical Control; Roving Vehicles

19780038657 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
A design for a 1984 Mars rover
Dobrotin, B. M.; French, J. R.; Paine, G.; Purdy, W. I.; Jan 1, 1978; In English; 16th Aerospace Sciences Meeting, Jan. 16-18, 1978, Huntsville, AL
Contract(s)/Grant(s): NAS7-100
Report No.(s): AIAA PAPER 78-81; Copyright; Avail: Other Sources

A Mars rover is planned for the mid-1980's as a follow-up to the Viking program, and as a prelude to a return-to-earth mission of Martian samples in the late eighties or early nineties. An overall view of the rover's configuration is presented with a summary of basic design parameters. Six subsystems are outlined: computing, with a 10 to the 8th bit bubble memory; mobility, designed for a journey of 100 km in 2 earth years; science sample acquisition, including a soil auger and hard rock drill; power, supplied by an RTG and stored in batteries; telecommunication, with 50 K bit UHF transmission relayed through an orbiter; and visual imaging, employing two television cameras, each with an 800 x 800 pixel charge coupled device. Scientific research goals include information about Martian seismic characteristics, magnetic field, surface heat flow, chemical composition, geology along a transverse, and meteorology. Attention is given to the necessity of rover autonomy from earth commands.
AIAA
Mars Excursion Module; Roving Vehicles; Systems Engineering; Viking Mars Program

19780021189 Rensselaer Polytechnic Inst., Troy, NY, USA
Elevation scanning laser/multi-sensor hazard detection system controller and mirror/mast speed control components
Craig, J.; Yerazunis, S. W.; Aug 1, 1978; In English
Contract(s)/Grant(s): NSG-7369
Report No.(s): NASA-CR-157466; RPI-TR-MP-59; No Copyright; Avail: CASI; A07, Hardcopy

The electro-mechanical and electronic systems involved with pointing a laser beam from a roving vehicle along a desired vector are described. A rotating 8 sided mirror, driven by a phase-locked dc motor servo system, and monitored by a precision optical shaft encoder is used. This upper assembly is then rotated about an orthogonal axis to allow scanning into all 360 deg around the vehicle. This axis is also driven by a phase locked dc motor servo-system, and monitored with an optical shaft encoder. The electronics are realized in standard TTL integrated circuits with UV-erasable proms used to store desired coordinates of laser fire. Related topics such as the interface to the existing test vehicle are discussed.
A.R.H.
Controllers; Electromechanical Devices; Lasers; Rotating Mirrors; Roving Vehicles; Scanners; Shafts (Machine Elements)

19780021188 Rensselaer Polytechnic Inst., Troy, NY, USA
Evaluation of the propulsion control system of a planetary rover and design of a mast for an elevation scanning laser/multi-detector system
Knaub, D.; Yerazunis, S. W.; Jul 1, 1978; In English
Contract(s)/Grant(s): JPL-954880; NSG-7369
Report No.(s): NASA-CR-157465; RPI-TR-MP-58; No Copyright; Avail: CASI; A07, Hardcopy

Vertical wheel loads, wheel speeds, and torque relationships are considered in the design of a propulsion system capable of responding to steering, slope climbing, and irregular local terrains. The system developed is applied to the RPI Mars roving vehicle. The mechanical system required to implement the elevation laser scanning/multidetector principle was the design and construction of a mechanical system for implementing the elevation scanning/multidetector principle is also discussed.
A.R.H.
Control; Lasers; Mechanical Drives; Optical Scanners; Roving Vehicles; Supports; System Effectiveness

19780020199 Rensselaer Polytechnic Inst., Troy, NY, USA
Procedures for the interpretation and use of elevation scanning laser/multi-sensor data for short range hazard detection and avoidance for an autonomous planetary rover
Troiani, N.; Yerazunis, S. W.; Jul 1, 1978; In English
Contract(s)/Grant(s): NSG-7369
Report No.(s): NASA-CR-157337; RPI-TR-MP-57; No Copyright; Avail: CASI; A06, Hardcopy

An autonomous roving science vehicle that relies on terrain data acquired by a hierarchy of sensors for navigation was one method of carrying out such a mission. The hierarchy of sensors included a short range sensor with sufficient resolution to detect every possible obstacle and with the ability to make fast and reliable terrain characterizations. A multilaser, multidetector triangulation system was proposed as a short range sensor. The general system was studied to determine its perception capabilities and limitations. A specific rover and low resolution sensor system was then considered. After studying the data obtained, a hazard detection algorithm was developed that accounts for all possible terrains given the sensor

resolution. Computer simulation of the rover on various terrains was used to test the entire hazard detection system.
J.A.M.
Lasers; Roving Vehicles; Scanners

19780020198 Rensselaer Polytechnic Inst., Troy, NY, USA
Autonomous control of roving vehicles for unmanned exploration of the planets
Yerazunis, S. W.; Jul 1, 1978; In English
Contract(s)/Grant(s): NSG-7369
Report No.(s): NASA-CR-157338; RPI-TR-MP-56; No Copyright; Avail: CASI; A04, Hardcopy

The guidance of an autonomous rover for unmanned planetary exploration using a short range (0.5 - 3.0 meter) hazard detection system was studied. Experimental data derived from a one laser/one detector system were used in the development of improved algorithms for the guidance of the rover. The new algorithms which account for the dynamic characteristics of the Rensselaer rover can be applied to other rover concepts provided that the rover dynamic parameters are modified appropriately. The new algorithms will also be applicable to the advanced scanning system. The design of an elevation scanning laser/multisensor hazard detection system was completed. All mechanical and electronic hardware components with the exception of the sensor optics and electronic components were constructed and tested.
J.A.M.
Roving Vehicles; Space Exploration

19780016310 Lockheed Missiles and Space Co., Huntsville, AL, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Mars Rover system loopwheel definition support
Trautwein, W.; Oct 1, 1977; In English
Contract(s)/Grant(s): JPL-954795
Report No.(s): NASA-CR-157085; LMSC-HREC-TR-D497484; No Copyright; Avail: CASI; A05, Hardcopy

The feasibility of the loopwheel suspension system for use on a Mars roving vehicle was analyzed. Various steering concepts were evaluated and an optimum concept was identified on the basis of maximum probability of mission success. In the structural analysis of the loopwheel core and tread as the major fatigue critical components, important technology areas were identified.
CASI
Feasibility Analysis; Mars Probes; Roving Vehicles; Wheels

19780002528 Rensselaer Polytechnic Inst., Troy, NY, USA
Design and evaluation of a toroidal wheel for planetary rovers
Koskol, J.; Yerazunis, S. W.; Oct 1, 1977; In English
Contract(s)/Grant(s): NGL-33-018-081
Report No.(s): NASA-CR-155202; RPI-TR-MP-53; No Copyright; Avail: CASI; A05, Hardcopy

The inverted toroidal wheel concept was perceived, mathematically quantified, and experimentally verified. The wheel design has a number of important characteristics, namely; (1) the low footprint pressures required for Mars exploration (0.5 to 1.0 psi); (2) high vehicle weight to wheel weight ratios capable of exceeding 10:1; (3) extremely long cyclic endurances tending towards infinite life; and (4) simplicity of design. The concept, in combination with appropriate materials such as titanium or composites, provides a planetary roving vehicle with a very high degree of exploratory mobility, a substantial savings in weight and a high assurity of mission success. Design equations and computation procedures necessary to formulate an inverted wheel are described in detail.
CASI
Design Analysis; Mars Landing; Roving Vehicles; Vehicle Wheels

19770084248 Rensselaer Polytechnic Inst., Troy, NY, USA
Data acquisition and path selection decision making for an autonomous roving vehicle
Frederick, D. K.; Shen, C. N.; Yerazunis, S. W.; Aug 1, 1977; In English
Contract(s)/Grant(s): NSG-7184
Report No.(s): NASA-CR-154957; RPI-TR-MP-52; No Copyright; Avail: CASI; A04, Hardcopy
Data Acquisition; Decision Making; Dynamic Programming; Roving Vehicles

19770077710 Southwest Research Inst., San Antonio, TX, USA
Application of features of the NASA lunar rover to vehicle control for paralyzed drivers
Mcfarland, S. R.; Aug 1, 1975; In English
Contract(s)/Grant(s): NAS9-14473; SWRI PROJ. 13-4188-101
Report No.(s): NASA-CR-151358; No Copyright; Avail: CASI; A05, Hardcopy
Command and Control; Human Factors Engineering; Lunar Roving Vehicles

19770075202 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Petrography of rock specimens by remote TV: Its potential for use on remotely controlled lunar and planetary roving vehicles
Choate, R.; Jun 1, 1971; In English
Report No.(s): NASA-CR-152718; JPL-760-71; No Copyright; Avail: CASI; A07, Hardcopy
Lunar Rocks; Lunar Roving Vehicles; Remotely Piloted Vehicles

19770055351 Rensselaer Polytechnic Inst., Troy, NY, USA
Accuracy estimate of the laser rangefinder for Mars rover
Ostroski, T.; Shen, C. N.; JAN 1, 1976; In English; 7th Annual Pittsburgh Conference on Modeling and simulation, April 26-27, 1976, Pittsburgh, PA
Contract(s)/Grant(s): NSG-7184; Copyright; Avail: Other Sources

A method was developed to determine the accuracy of a rangefinder when errors exist due to the test setup. An analytic procedure was developed to evaluate actual data from a test performed on the laser rangefinder for the Mars rover project. AIAA

Instrument Errors; Laser Range Finders; Mars Surface; Range Errors; Rover Project; Roving Vehicles

19770022842 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Lunar rover vehicle - an implication for rehabilitation
Mcfarland, S. R.; Primeauk, G. R.; JPL The 2nd Conf. on Remotely Manned Systems (RMS); Jun 1, 1975; In English; No Copyright; Avail: CASI; A01, Hardcopy

The feasibility of adapting the lunar roving vehicle control concept to automobiles and vans for quadriplegics was investigated. Topics discussed include the current state of automobile handicapped controls, a description of the affected population, and a design for interfacing the control system into a passenger vehice.

Automobiles; Human Factors Engineering; Lunar Roving Vehicles; Paralysis; Technology Utilization

19770015213 Cornell Univ., Ithaca, NY, USA
Control elements for an unmanned Martian roving vehicle
Wehe, R. L.; Osborn, R. E.; Dec 31, 1976; In English
Contract(s)/Grant(s): NASW-2750
Report No.(s): NASA-CR-152836; MRV-75-1; No Copyright; Avail: CASI; A03, Hardcopy

The roving vehicle simulator was operated autonomously under control of the simulated on-board computer. With the microwave radar obstacle sensor mounted and operating, it was able to avoid a student placed in its path and to return to the originally assigned direction when that path was clear. The tactile obstacle sensor was able to detect impassable obstacles while allowing the vehicle to negotiate passable obstacles.
CASI

Mars Surface; NASA Programs; Roving Vehicles; Unmanned Spacecraft

19760040185 Rensselaer Polytechnic Inst., Troy, NY, USA
Path selection system simulation and evaluation for a Martian roving vehicle
Frederick, D. K.; JAN 1, 1975; In English; 6th Modeling and simulation. Volume 6, April 24, 25, 1975, Pittsburgh, PA
Contract(s)/Grant(s): NGL-33-018-091; Copyright; Avail: Other Sources

A comprehensive digital computer simulation program has been developed for evaluating the path-selection system performance of an autonomous roving vehicle being designed for the exploration of Mars. Vehicle performance over realistic three-dimensional terrains in the presence of random motion disturbances and sensor measurement noise is simulated and

plotted on a terrain contour map. In addition, a numerical figure-of-merit is computed automatically for each run.
AIAA
Digital Simulation; Mars Surface; Rangefinding; Roving Vehicles; Terrain Analysis; Vehicular Tracks

19760040183 Rensselaer Polytechnic Inst., Troy, NY, USA
Measurement scanning schemes for terrain modeling
Friedman, M.; Shen, C. N.; JAN 1, 1975; In English; 6th Modeling and simulation. Volume 6, April 24, 25, 1975, Pittsburgh, PA
Contract(s)/Grant(s): NGL-33-018-091; Copyright; Avail: Other Sources

A scanning scheme for the laser rangefinder aboard an autonomous Mars Rover is developed. The rover is expected to be able to traverse an incline of slope up to 25% deg positive or negative. The total azimuth angle of the rangefinder is calculated so that the rangefinder can scan a width of 3 m at a distance of 3 m. A combination of two approaches is considered: scanning the field with a data point spacing appropriate for the terrain modeling technique, followed by zoom scanning with reduced spacing aimed at an obstacle location indicated in a previous terrain scan. It is found that the scan time and total number of data points can be reduced by dividing the field into corridors. The scan is divided into two subscans: the initial scan covering the entire field, and a corridor scan. The corridor scan method reduces the core required in the on-board computer. Hardware changes are expected to be small since the parameters of the corridor are fixed and a continuously variable point spacing is not necessary.
AIAA
Laser Range Finders; Mars Excursion Module; Optical Scanners; Roving Vehicles; Terrain Analysis

19760021169 Rensselaer Polytechnic Inst., Troy, NY, USA
Analysis and design of a capsule landing system and surface vehicle control system for Mars exploration
Gisser, D. G.; Frederick, D. K.; Sandor, G. N.; Shen, C. N.; Yerazunis, S. W.; Jun 30, 1976; In English
Contract(s)/Grant(s): NGL-33-018-981
Report No.(s): NASA-CR-148539; RPI-TR-MP-49; No Copyright; Avail: CASI; A05, Hardcopy

Problems related to the design and control of an autonomous rover for the purpose of unmanned exploration of the planets were considered. Building on the basis of prior studies, a four wheeled rover of unusual mobility and maneuverability was further refined and tested under both laboratory and field conditions. A second major effort was made to develop autonomous guidance. Path selection systems capable of dealing with relatively formidable hazard and terrains involving various short range (1.0-3.0 meters), hazard detection systems using a triangulation detection concept were simulated and evaluated. The mechanical/electronic systems required to implement such a scheme were constructed and tested. These systems include: laser transmitter, photodetectors, the necessary data handling/controlling systems and a scanning mast. In addition, a telemetry system to interface the vehicle, the off-board computer and a remote control module for operator intervention were developed. Software for the autonomous control concept was written. All of the systems required for complete autonomous control were shown to be satisfactory except for that portion of the software relating to the handling of interrupt commands.
CASI
Control Equipment; Design Analysis; Mars Exploration; Mars Landing; Mars Surface; Performance Tests; Remote Control; Roving Vehicles

19760020060 Rensselaer Polytechnic Inst., Troy, NY, USA
Data acquisition and path selection decision making for an autonomous roving vehicle
Frederick, D. K.; Shen, C. N.; Yerazunis, S. W.; Jul 1, 1976; In English
Contract(s)/Grant(s): NSG-7184
Report No.(s): NASA-CR-148296; No Copyright; Avail: CASI; A03, Hardcopy

Problems related to the guidance of an autonomous rover for unmanned planetary exploration were investigated. Topics included in these studies were: simulation on an interactive graphics computer system of the Rapid Estimation Technique for detection of discrete obstacles; incorporation of a simultaneous Bayesian estimate of states and inputs in the Rapid Estimation Scheme; development of methods for estimating actual laser rangefinder errors and their application to date provided by Jet Propulsion Laboratory; and modification of a path selection system simulation computer code for evaluation of a hazard detection system based on laser rangefinder data.
CASI
Automatic Control; Guidance (Motion); Laser Range Finders; Roving Vehicles

19760016044 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Planetary mission summary. Volume 4: Mars rover
Aug 1, 1974; In English; 13volumes
Report No.(s): NASA-CR-147096; JPL-SP-43-10-VOL-4; No Copyright; Avail: CASI; A03, Hardcopy
For abstract, see N76-23129.
Interplanetary Spacecraft; Mars Surface; Mission Planning; Roving Vehicles; Space Exploration

19750066566 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Scene analysis in support of a Mars Rover
Ohandley, D. A.; JAN 1, 1973; In English
Contract(s)/Grant(s): NAS7-100
Report No.(s): NASA-CR-142530; Copyright; Avail: CASI; A03, Hardcopy
Mars (Planet); Roving Vehicles

19750050470
Human vs autonomous control of planetary roving vehicles
Whitney, W. M.; JAN 1, 1974; In English; International Conference on Systems, Man, and Cybernetics, October 2-4, 1974, Dallas, TX
Contract(s)/Grant(s): NAS7-100; Copyright; Avail: Other Sources

Supervisory or semiautonomous control has some compelling advantages over step-by-step human command and verification for the operation of roving vehicles on remote planetary surfaces. There are also disadvantages in relation to the complex system that must be mobilized and the chain of events that must be enacted to conduct a mission. Which of the two control methods is better on technical grounds may not be the deciding factor in its acceptance or rejection. Some of the issues that affect changes in spacecraft design and operation are summarized. To accelerate the movement toward more autonomous machines, it will be necessary to understand and to address the problems that such autonomy will create for other elements of the control system and for the control process.
AIAA
Automatic Control; Manual Control; Planetary Surfaces; Roving Vehicles; System Effectiveness; Technology Assessment

19750039846
The impact of robots on planetary mission operations
Hooke, A. A.; Larman, B. T.; Whitney, W. M.; JAN 1, 1974; In English; International Telemetering Conference, October 15-17, 1974, Los Angeles, CA
Contract(s)/Grant(s): NAS7-100; Copyright; Avail: Other Sources

Unmanned roving vehicles sent to explore remote planetary surfaces must carry out some of their tasks without step-by-step human control. To realize the benefits that accrue from such semiautonomous machines, current planning (and carrying out) of mission profiles will be subject to some changes. Specifically, it is shown that mission profiles will have to be based on tasks or functions rather than sequences of timed events, while scientists will have to center their attention on instrument control. Present ideas concerning spacecraft safety, testing (and simulation) of vehicle performance, telemetry design, and ground station equipment must be reexamined.
AIAA
Automata Theory; Command and Control; Mission Planning; Planetary Surfaces; Robots; Roving Vehicles

19750026717
Seven dangers of designer overspecialization
Sandor, G. N.; Mechanical Engineering; Oct 1, 1974; 96; In English
Contract(s)/Grant(s): NGL-33-018-091; Copyright; Avail: Other Sources

Seven dangers of overspecialization as they apply to the design process are analyzed. They are: missing the real need, formulation of the wrong problem, wrong design concept, wrong hardware, wrong model, over- or underanalysis and poor presentation. As an example, the design of an unmanned Rover for a mission to Mars is studied with the conclusion reached that, specialization, although necessary, should not shut out all other aspects of design or other disciplines.
AIAA
Design; Education; Engineering Management; Industrial Management; Management Planning; Personnel Management

19750021903 Army Engineer Waterways Experiment Station, Vicksburg, MS, USA
Effect of yaw angle on steering forces for the lunar roving vehicle wheel
Green, A. J.; Oct 1, 1974; In English
Report No.(s): NASA-CR-143290; AD-A006518; AEWES-TR-M-71-7; No Copyright; Avail: CASI; A04, Hardcopy

A series of tests was conducted with a Lunar Roving Vehicle (LRV) wheel operating at yaw angles ranging from -5 to +90 deg. The load was varied from 42 to 82 lb (187 to 365 N), and the speed was varied from 3.5 to 10.0 ft/sec (1.07 to 3.05 m/sec). It was noted that speed had an effect on side thrust and rut depth. Side thrust, rut depth, and skid generally increased as the yaw angle increased. For the range of loads used, the effect of load on performance was not significant.
DTIC
Lunar Roving Vehicles; Steering; Vehicle Wheels; Yaw

19750003186 Bendix Field Engineering Corp., Greenbelt, MD, USA
Tracking the Lunar Rover vehicle with very long baseline interferometry techniques
Shnidman, D.; NASA. Goddard Space Flight Center Proc. of the 4th Precise Time and Time Interval Planning Meeting; Nov 16, 1972; In English; No Copyright; Avail: CASI; A02, Hardcopy

The principles of operation of Very Long Baseline Interferometry (VLBI) are discussed. The application of VLBI techniques for tracking lunar rover vehicles during the Apollo 16 and 17 missions is reported. A map of the Apollo 16 lunar rover track is provided. Charts are developed to show the incremental motion of the lunar vehicle during the mission.
CASI
Apollo 16 Flight; Interferometry; Lunar Exploration; Lunar Roving Vehicles

19740077559 Bendix Corp., Ann Arbor, MI, USA
Dual-mode manned/automated lunar roving vehicledesign definition study
Jan 1, 1970; In English
Contract(s)/Grant(s): NAS8-24528
Report No.(s): NASA-CR-120325; BSR-2815; No Copyright; Avail: CASI; A20, Hardcopy
Lunar Roving Vehicles; Structural Design

19740073764 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Scientific instruments for lunar exploration. Part B: Surveyors, roving vehicles, and rough-landed probes
Brereton, R. G., et al.; May 1, 1967; In English
Contract(s)/Grant(s): NAS7-100
Report No.(s): NASA-CR-137093; JPL-ASD-760-3; No Copyright; Avail: CASI; A04, Hardcopy
Instruments; Roving Vehicles; Surveyor Lunar Probes

19740056756
Control strategies for planetary rover motion and manipulator control
Trautwein, W.; Jun 1, 1973; In English; 5th Symposium on Automatic Control in Space, June 4-8, 1973, Genoa, Italy
Contract(s)/Grant(s): NAS8-28437; Copyright; Avail: Other Sources

An unusual insect-like vehicle designed for planetary surface exploration is made the occasion for a discussion of control concepts in path selection, hazard detection, obstacle negotiation, and soil sampling. A control scheme which actively articulates the pitching motion between a single-loop front module and a dual loop rear module leads to near optimal behavior in soft soil; at the same time the vehicle's front module acts as a reliable tactile forward probe with a detection range much longer than the stopping distance. Some optimal control strategies are discussed, and the photos of a working scale model are displayed.
AIAA
Automatic Control; Dynamic Control; Manipulators; Planetary Surfaces; Roving Vehicles

19740053367
A practical obstacle detection system for the Mars Rover
Reed, M.; Sanyal, P.; Shen, C. N.; JAN 1, 1974; In English; Milwaukee Symposium on Automatic Control, March 28-30, 1974, Milwaukee, WI
Contract(s)/Grant(s): NGL-33-018-091; Copyright; Avail: Other Sources

Discussion of an obstacle detection system which uses a laser range finder as the principal sensing device. The laser scans the scene ahead and stores the range data for the terrain in a matrix form. This matrix can be thought of as a ‘range image’. This range varies from point to point, but sharp changes are caused by the presence of obstacles. Some existing algorithms and one developed by the authors were used to obtain the outlines of obstacles from the ‘range image’. All these algorithms end with a thresholding operation. A theoretical analysis shows how a proper value of the threshold may be chosen, given the type of irregularity of the terrain to be detected. The analysis also shows how large the statistics of measurement noise can be allowed without leading to false alarms.
AIAA
Barriers (Landforms); Guidance Sensors; Laser Range Finders; Mars Surface; Roving Vehicles; Terrain Analysis

19740042095
Stochastic estimates of gradient from laser measurements for an autonomous Martian Roving Vehicle
Shen, C. N.; Burger, P.; JAN 1, 1973; In English; 3rd Symposium of the Identification and system parameter estimation, June 12-15, 1973, Delft, Netherlands
Contract(s)/Grant(s): NGL-33-018-091; Copyright; Avail: Other Sources
The general problem presented in this paper is one of estimating the state vector x from the state equation h = Ax, where h, A, and x are all stochastic. Specifically, the problem is for an autonomous Martian Roving Vehicle to utilize laser measurements in estimating the gradient of the terrain. Error exists due to two factors - surface roughness and instrumental measurements. The errors in slope depend on the standard deviations of these noise factors. Numerically, the error in gradient is expressed as a function of instrumental inaccuracies. Certain guidelines for the accuracy of permissable gradient must be set. It is found that present technology can meet these guidelines.-
AIAA
Gradients; Mars Landing; Maximum Likelihood Estimates; Roving Vehicles; State Vectors; Stochastic Processes

19740025179 Rensselaer Polytechnic Inst., Troy, NY, USA
Parameter estimation for terrain modeling from gradient data
Dangelo, K. R.; May 1, 1974; In English
Contract(s)/Grant(s): NGL-33-018-091
Report No.(s): NASA-CR-140057; RPI-TR-MP-46; No Copyright; Avail: CASI; A05, Hardcopy
A method is developed for modeling terrain surfaces for use on an unmanned Martian roving vehicle. The modeling procedure employs a two-step process which uses gradient as well as height data in order to improve the accuracy of the model’s gradient. Least square approximation is used in order to stochastically determine the parameters which describe the modeled surface. A complete error analysis of the modeling procedure is included which determines the effect of instrumental measurement errors on the model’s accuracy. Computer simulation is used as a means of testing the entire modeling process which includes the acquisition of data points, the two-step modeling process and the error analysis. Finally, to illustrate the procedure, a numerical example is included.
CASI
Mars Surface; Roving Vehicles; Surface Navigation; Terrain Analysis

19740023634 Rensselaer Polytechnic Inst., Troy, NY, USA
Recognition of three dimensional obstacles by an edge detection scheme
Reed, M. A.; May 1, 1974; In English
Contract(s)/Grant(s): NGL-33-018-091
Report No.(s): NASA-CR-139661; RPI-TR-MP-45; No Copyright; Avail: CASI; A04, Hardcopy
The need for an obstacle detection system on the Mars roving vehicle was assumed, and a practical scheme was investigated and simulated. The principal sensing device on this vehicle was taken to be a laser range finder. Both existing and original algorithms, ending with thresholding operations, were used to obtain the outlines of obstacles from the raw data of this laser scan. A theoretical analysis was carried out to show how proper value of threshold may be chosen. Computer simulations considered various mid-range boulders, for which the scheme was quite successful. The extension to other types of obstacles, such as craters, was considered. The special problems of bottom edge detection and scanning procedure are discussed.
CASI
Laser Range Finders; Mars Surface; Roving Vehicles

19740019610 Rensselaer Polytechnic Inst., Troy, NY, USA
System design optimization for a Mars-roving vehicle and perturbed-optimal solutions in nonlinear programming
Pavarini, C.; Jun 1, 1974; In English
Report No.(s): NASA-CR-138817; RPI-TR-MP-43; No Copyright; Avail: CASI; A09, Hardcopy

Work in two somewhat distinct areas is presented. First, the optimal system design problem for a Mars-roving vehicle is attacked by creating static system models and a system evaluation function and optimizing via nonlinear programming techniques. The second area concerns the problem of perturbed-optimal solutions. Given an initial perturbation in an element of the solution to a nonlinear programming problem, a linear method is determined to approximate the optimal readjustments of the other elements of the solution. Then, the sensitivity of the Mars rover designs is described by application of this method.
CASI
Mars Surface; Nonlinear Programming; Roving Vehicles

19740014692 Rensselaer Polytechnic Inst., Troy, NY, USA
Composition dependent effects in gas chromatography
Lavoie, R. C.; May 1, 1974; In English
Contract(s)/Grant(s): NGL-33-018-091
Report No.(s): NASA-CR-138452; MP-41; No Copyright; Avail: CASI; A05, Hardcopy

Fundamantal concepts are developed which are required to optimize a gas chromatograph-mass spectrometer chemical analysis system suitable for use on an unmanned roving vehicle for Mars exploration. Prior efforts have developed simulation models for the chromatograph which were compared with data obtained from a test facility. Representation of binary systems by superposition was shown to be a first-order approximation and in certain cases large discrepencies were noted. This subtask has as its objective generation of additional binary data and analysis of the observed nonlinear effects.
CASI
Gas Chromatography; Mass Spectrometers

19740011776 Martin Marietta Aerospace, Denver, CO, USA
Viking '79 Rover study. Volume 2: Detailed technical report
Mar 1, 1974; In English; 2volumes
Contract(s)/Grant(s): NAS1-12425
Report No.(s): NASA-CR-132418; No Copyright; Avail: CASI; A18, Hardcopy

For abstract, see N74-19888.
Mars (Planet); Roving Vehicles; Surface Vehicles

19740011775 Martin Marietta Aerospace, Denver, CO, USA
Viking '79 Rover study. Volume 1: Summary report
Mar 1, 1974; In English; 2volumes
Contract(s)/Grant(s): NAS1-12425
Report No.(s): NASA-CR-132417; No Copyright; Avail: CASI; A06, Hardcopy

The results of a study to define a roving vehicle suitable for inclusion in a 1979 Viking mission to Mars are presented. The study focused exclusively on the 1979 mission incorporating a rover that would be stowed on and deployed from a modified Viking lander. The overall objective of the study was to define a baseline rover, the lander/rover interfaces, a mission operations concept, and a rover development program compatible with the 1979 launch opportunity. During the study, numerous options at the rover system and subsystem levels were examined and a baseline configuration was selected. Launch vehicle, orbiter, and lander performance capabilities were examined to ensure that the baseline rover could be transported to Mars using minimum-modified Viking '75 hardware and designs.
CASI
Mars (Planet); Roving Vehicles; Surface Vehicles

19740009844 Rensselaer Polytechnic Inst., Troy, NY, USA
Dynamic evaluation of RPI's 0.4 scale unmanned Martian roving vehicle model
Ryder, A. G.; Dec 1, 1973; In English
Contract(s)/Grant(s): NGL-33-018-091
Report No.(s): NASA-CR-137077; RPI-TR-MP-38; No Copyright; Avail: CASI; A04, Hardcopy

A design for a Mars Roving Vehicle is presented in a three dimensional model considering three degrees of freedom. In addition, the physical characteristics of the 0.4 scale RPI-MRV are presented along with the basic dynamic responses.
CASI
Dynamic Models; Roving Vehicles

19740009428 NASA Langley Research Center, Hampton, VA, USA
A conceptual design and operational characteristics for a Mars rover for a 1979 or 1981 Viking science mission
Darnell, W. L.; Wessel, V. W.; Feb 1, 1974; In English
Contract(s)/Grant(s): RTOP 684-33-60-01
Report No.(s): NASA-TN-D-7462; L-9254; No Copyright; Avail: CASI; A05, Hardcopy

The feasibility of a small Mars rover for use on a 1979 or 1981 Viking mission was studied and a preliminary design concept was developed. Three variations of the concept were developed to provide comparisons in mobility and science capability of the rover. Final masses of the three rover designs were approximately 35 kg, 40 kg, and 69 kg. The smallest rover is umbilically connected to the lander for power and communications purposes whereas the larger two rovers have secondary battery power and a 2-way very high frequency communication link to the lander. The capability for carrying Viking rovers (including development system) to the surface of Mars was considered first. It was found to be feasible to carry rovers of over 100 kg. Virtually all rover systems were then studied briefly to determine a feasible system concept and a practical interface with the comparable system of a 1979 or 1981 lander vehicle.
CASI
Mars Surface; Roving Vehicles; Viking Mars Program

19740008070 Rensselaer Polytechnic Inst., Troy, NY, USA
Laser scanning methods and a phase comparison, modulated laser range finder for terrain sensing on a Mars roving vehicle
Herb, G. T.; May 1, 1973; In English
Contract(s)/Grant(s): NGL-33-018-091
Report No.(s): NASA-CR-136774; RPI-TR-MP-34; No Copyright; Avail: CASI; A04, Hardcopy

Two areas of a laser range finder for a Mars roving vehicle are investigated: (1) laser scanning systems, and (2) range finder methods and implementation. Several ways of rapidly scanning a laser are studied. Two digital deflectors and a matrix of laser diodes, are found to be acceptable. A complete range finder scanning system of high accuracy is proposed. The problem of incident laser spot distortion on the terrain is discussed. The instrumentation for a phase comparison, modulated laser range finder is developed and sections of it are tested.
CASI
Laser Range Finders; Mars Surface; Roving Vehicles

19740003321 NASA Marshall Space Flight Center, Huntsville, AL, USA
Lunar roving vehicle navigation system performance review
Smith, E. C.; Mastin, W. C.; Nov 1, 1973; In English
Report No.(s): NASA-TN-D-7469; M-219; No Copyright; Avail: CASI; A04, Hardcopy

The design and operation of the lunar roving vehicle (LRV) navigation system are briefly described. The basis for the premission LRV navigation error analysis is explained and an example included. The real time mission support operations philosophy is presented. The LRV navigation system operation and accuracy during the lunar missions are evaluated.
CASI
Lunar Roving Vehicles; Navigation; Performance; Systems Engineering

19730058554
Tracking the Apollo Lunar Rover with interferometry techniques.
Salzberg, I. M.; IEEE; Sep 1, 1973; In English; Copyright; Avail: Other Sources

Apollo 16 and 17 Lunar Rover position history while transporting astronauts over the lunar surface has been determined to a resolution of better than 1 m and uncertainties of less than 25 m utilizing a specialized very-long baseline interferometry (VLBI) tracking technique. This paper describes the technique, discusses the National Aeronautics and Space Administration

worldwide tracking system used to obtain data, discusses the data, and presents results.
AIAA
High Resolution; Interferometry; Lunar Roving Vehicles; Radio Tracking

19730052510

Lunar and planetary rover concepts.

Moore, J. W.; JAN 1, 1973; In English; 1st National Conference on Remotely manned systems: Exploration and operation in space, September 13-15, 1972, Pasadena, CA

Contract(s)/Grant(s): NAS7-100; Copyright; Avail: Other Sources

Roving vehicle systems and concepts which evolved from lunar mission and mission studies, as well as from Martian mission studies, are discussed. Additional planetary mission applications for rovers and other remotely manned systems are briefly described. These mission include such targets as Venus, the natural satellites of some planets, and selected asteroids.
AIAA
Lunar Roving Vehicles; Mars Surface; Remote Control; Roving Vehicles

19730052509

Science aspects of a remotely controlled Mars surface roving vehicle.

Choate, R.; Jaffe, L. D.; JAN 1, 1973; In English; 1st National Conference on Remotely manned systems: Exploration and operation in space, September 13-15, 1972, Pasadena, CA

Contract(s)/Grant(s): NAS7-100; Copyright; Avail: Other Sources

Particular attention is given to aspects pertinent to teleoperation, remote control, onboard control, and man-machine relationships in carrying out scientific operations with such a vehicle. It is assumed that landed operations would comprise one Martian year and that the traverse would extend across an area approximately 500 km wide. The mission is assumed to be planned for the early 1980s. Its objective is to obtain data which will aid in answering a number of questions regarding the history of the solar system, the formation of Mars, and the evolution of life on Mars. A series of candidate rover payloads is proposed to meet the requirements. The smallest payload includes a TV camera, a general-purpose manipulator arm, a crusher and siever, an X-ray diffractometer-spectrometer, a gravimeter, a magnetometer, meteorological instruments, and a radio transponder.
AIAA
Mars Surface; Remote Control; Roving Vehicles; Surface Vehicles

19730039203

A simplified satellite navigation system for an autonomous Mars roving vehicle.

Janosko, R. E.; Shen, C. N.; JAN 1, 1972; In English; 5th World Congress of the International Federation of Automatic Control, June 12-17, 1972, Paris, France

Contract(s)/Grant(s): NGL-33-018-091; Copyright; Avail: Other Sources

The use of a retroflecting satellite and a laser rangefinder to navigate a Martian roving vehicle is considered in this paper. It is shown that a simple system can be employed to perform this task. An error analysis is performed on the navigation equations and it is shown that the error inherent in the scheme proposed can be minimized by the proper choice of measurement geometry. A nonlinear programming approach is used to minimize the navigation error subject to constraints that are due to geometric and laser requirements. The problem is solved for a particular set of laser parameters and the optimal solution is presented.
AIAA
Error Analysis; Laser Range Finders; Mars Surface; Roving Vehicles; Satellite Navigation Systems; Surface Navigation

19730035791

System modeling and optimal design of a Mars-roving vehicle.

Smith, E. J.; Pavarini, C.; Vandenburg, N.; JAN 1, 1972; In English; 11th Conference on Decision and Control and Symposium on Adaptive Processes, December 13-15, 1972, New Orleans, LA

Contract(s)/Grant(s): NGL-33-018-091; Copyright; Avail: Other Sources

The problem of systematically determining the optimal design for an unmanned Mars-roving vehicle is considered. A system model, identifying all feasible designs, is generated by consideration of the physical constraints on the design parameters, and the requirement that the system be deliverable to the Mars surface. An expression which evaluates system

performance relative to mission goals is developed. The model and objective function together allow simulation of the effects of design trade-offs upon system performance for all feasible designs. Nonlinear programming techniques are utilized to identify the optimal design.
AIAA
Computerized Simulation; Mars Surface; Nonlinear Programming; Optimization; Roving Vehicles; Systems Engineering

19730034688
Equations of motion of the lunar roving vehicle.
Kaufman, S.; Journal of Spacecraft and Rockets; Jan 1, 1973; 10; In English
Contract(s)/Grant(s): NASW-417; Copyright; Avail: Other Sources

Equations of motion have been formulated for a four-wheel vehicle as it traverses a terrain characterized by slopes, craters, bumps, washboards, or a power spectrum. Independent suspension and electric motor propulsion are considered. These equations were programmed on the UNIVAC 1108 digital computer. Results are given for the steerability of the Lunar Roving Vehicle (LRV) which was found to be satisfactory for normal operating speeds and turning radii. The vehicle was also found to be satisfactory against overturning in both the pitch and roll mode, and results are presented for various speeds as the LRV engages a bump on meter in diameter and of varying heights. Speed, power consumption, and load characteristics are presented for the LRV traversing a simulated lunar soil at full throttle. Comparisons are given against data compiled from the Apollo 15 mission.
AIAA
Digital Simulation; Equations of Motion; Lunar Roving Vehicles

19730019824 Rensselaer Polytechnic Inst., Troy, NY, USA
Stochastic estimates of gradient from laser measurements for an autonomous Martian roving vehicle
Burger, P. A.; May 1, 1973; In English
Contract(s)/Grant(s): NGL-33-018-091
Report No.(s): NASA-CR-133498; RPI-TR-MP-33; No Copyright; Avail: CASI; A03, Hardcopy

The general problem of estimating the state vector x from the state equation h = Ax where h, A, and x are all stochastic, is presented. Specifically, the problem is for an autonomous Martian roving vehicle to utilize laser measurements in estimating the gradient of the terrain. Error exists due to two factors - surface roughness and instrumental measurements. The errors in slope depend on the standard deviations of these noise factors. Numerically, the error in gradient is expressed as a function of instrumental inaccuracies. Certain guidelines for the accuracy of permissable gradient must be set. It is found that present technology can meet these guidelines.
CASI
Lasers; Mars Surface; Roving Vehicles; Slopes; Terrain

19730017155 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Apollo 17 mission. Lunar roving vehicle/traverse gravimeter experiment motion sensitivity
Apr 1, 1973; In English
Contract(s)/Grant(s): PROJ. APOLLO
Report No.(s): NASA-TM-X-69268; JSC-07948; No Copyright; Avail: CASI; A03, Hardcopy

The results of the lunar roving vehicle/traverse gravimeter experiment motion sensitivity test shows that the gravity measurements in both the normal and bypass modes should not be adversely affected by motion induced in the lunar roving vehicle by operation of the television camera position drive device or the operation of the surface electrical properties receiver/recorder. Motion of the traverse gravimeter experiment occurred when a 1.4-hertz resonant mode in pitch of the pallet was excited. Both of these modes were excited by camera elevation changes with the camera axis positioned fore and aft.
CASI
Apollo 17 Flight; Gravimeters; Lunar Roving Vehicles

19730011545 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Apollo 16 mission anomaly report no. 9: Lunar roving vehicle electrical system meter anomalies
Jan 1, 1973; In English
Report No.(s): NASA-TM-X-69123; MSC-07684; No Copyright; Avail: CASI; A02, Hardcopy

The off-scale low indications of the voltmeters for batteries one and two at initial powerup of the Apollo 16 lunar roving

vehicle were analyzed. No single condition was found that would explain the anomalous meter indications. It is concluded that the intermittent conditions must have existed in the multiple wire splices to the meters.
CASI
Apollo 16 Flight; Electric Batteries; Lunar Roving Vehicles

19730010149 Boeing Co., Huntsville, AL, USA
Lunar roving vehicle deployment mechanism
Hunter, A. B.; Spacey, B. W.; NASA. Lyndon B. Johnson Space Center The 7th Aerospace Mech. Symp.; Nov 1, 1972; In English; No Copyright; Avail: CASI; A02, Hardcopy

The space support equipment that supports the lunar roving vehicle during the flight to the moon and permits the vehicle to be deployed from the lunar module onto the lunar surface with a minimum amount of astronaut participation is discussed. The design and evolution of the equipment are reviewed. The success of the overall lunar roving vehicle design, including the space support equipment, was demonstrated on the Apollo 15 and 16 missions.
CASI
Lunar Roving Vehicles; Systems Analysis

19730008090 NASA Marshall Space Flight Center, Huntsville, AL, USA
Mobility performance of the lunar roving vehicle: Terrestrial studies: Apollo 15 results
Costes, N. C.; Farmer, J. E.; George, E. B.; Dec 1, 1972; In English; 4th Intern. Conf. of the Intern. Soc. for Terrain-Vehicle Systems, 24-28 Apr. 1972, Stockholm and Kiruna, Sweden
Contract(s)/Grant(s): RTOP 914-40-00-00-00
Report No.(s): NASA-TR-R-401; M451; No Copyright; Avail: CASI; A05, Hardcopy

The constriants of the Apollo 15 mission dictated that the average and limiting performance capabilities of the first manned lunar roving vehicle be known or estimated within narrow margins. Extensive studies were conducted and are compared with the actual performance of the lunar roving vehicle during the Apollo 15 mission. From this comparison, conclusions are drawn relating to the capabilities and limitation of current terrestrial methodology in predicting the mobility performance of lunar roving vehicles under in-situ environmental conditions, and recommendations are offered concerning the performance of surface vehicles on future missions related to lunar or planetary exploration.
CASI
Lunar Roving Vehicles; Manned Lunar Surface Vehicles; Performance

19730007492 NASA Marshall Space Flight Center, Huntsville, AL, USA
Recommendations relative to the scientific missions of a Mars Automated Roving Vehicle (MARV)
Spencer, R. L., editor; Jan 1, 1973; In English
Report No.(s): NASA-TM-X-64719; No Copyright; Avail: CASI; A04, Hardcopy

Scientific objectives of the MARV mission are outlined and specific science systems requirements and experimental payloads defined. All aspects of the Martian surface relative to biotic and geologic elements and those relating to geophysical and geochemical properties are explored.
CASI
Experiment Design; Mars Surface; Roving Vehicles; Space Exploration

19730002507 Army Engineer Waterways Experiment Station, Vicksburg, MS, USA
Operations and maintenance manual for a scale-model lunar roving vehicle
Lessem, A. S.; Apr 1, 1972; In English
Contract(s)/Grant(s): NASA ORDER H-72026-A
Report No.(s): NASA-CR-129176; AEWES-MISC-PAPER-M-72-3; No Copyright; Avail: CASI; A04, Hardcopy

A one-sixth scale model of the lunar roving vehicle used in the Apollo 15 mission was built and instrumented to conduct model studies of vehicle mobility. The model was free running under radio control and was equipped with a lightweight telemetry transmitter that allowed 16 channels of data to be gathered simultaneously. String payout and fifth-wheel devices were developed to measure vehicle velocity. Other real-time measurements included wheel torque, wheel speed, center-of-gravity accelerations, and steering forces. Calibration, operations, and maintenance procedures were worked out. Details of the development of the instrumentation, its maintenance, and some of the problems encountered, are recorded serve as a preliminary operations and maintenance manual for this specific model. In addition, information regarding soil processing and

testing that may be useful to NASA personnel planning mobility research with the model in soil is furnished.
CASI
Apollo 15 Flight; Lunar Roving Vehicles; Performance Tests; Scale Models; Telemetry

19730000326 NASA Marshall Space Flight Center, Huntsville, AL, USA
Articulated elastic-loop roving vehicles
Chang, C. J.; Trautwein, W.; Oct 1, 1973; In English
Report No.(s): MFS-22691; No Copyright

Prototype vehicle features exceptional obstacle-negotiating and slope-climbing capabilities plus high propulsive efficiency. Concept should interest designers of polar or ocean-bottom research vehicles. Also, its large footprint and low ground pressure will minimize ecological damage on terrain with low bearing strength, as in off-the-road application.
Composite Materials; Exploration; Maneuverability; Roving Vehicles

19720055484
Lunar roving vehicle thermal control system.
Elliott, R. G.; Paoletti, C. J.; Britt, M. A.; Aug 1, 1972; In English; American Society of Mechanical Engineers, Environmental Control and Life Support Systems Conference, Aug. 14-16, 1972, San Francisco, CA
Contract(s)/Grant(s): NAS8-25145
Report No.(s): ASME PAPER 72-ENAV-27; Copyright; Avail: Other Sources

A thermal control system was incorporated into the Lunar Roving Vehicle (LRV) to maintain temperature sensitive components within appropriate temperature limits during the translunar transportation phase, lunar surface operation, and quiescent periods between lunar traverses. This paper describes the thermal control system and discusses its thermal characteristics during all phases of operation. The basic concept is a passive system which stores internally generated energy during operation with subsequent radiation to space. The external environments are regulated by selected radiative surface finishes. Multi-layer insulation blankets, space radiators, flexible thermal straps, and fusible mass heat sinks were designed to control the temperatures of the electronic components.
AIAA
Lunar Roving Vehicles; Spacecraft Electronic Equipment; Temperature Control; Thermal Protection

19720048650
Toward remotely controlled planetary rovers.
Moore, J. W.; Astronautics and Aeronautics; Jun 1, 1972; 10; In English; Copyright; Avail: Other Sources

Studies of unmanned planetary rovers have emphasized a Mars mission. Relatively simple rovers, weighing about 50 kg and tethered to the lander, may precede semiautonomous roving vehicles. It is conceivable that the USSR will deploy a rover on Mars before Viking lands. The feasibility of the roving vehicle as an explorational tool hinges on its ability to operate for extended periods of time relatively independent of earth, to withstand the harshness of the Martian environment, and to travel hundreds of kilometers independent of the spacecraft that delivers it.
AIAA
Mars Surface; Remote Control; Roving Vehicles

19720032762
The Apollo Lunar Roving Vehicle.
Haeussermann, W.; JAN 1, 1971; In English; 4th Symposium on Automatic Control in Space, September 6-10, 1971, Dubrovnik, Yugoslavia; Copyright; Avail: Other Sources

After listing the basic requirements such as operational demands and lunar environmental conditions, characteristic design data of the roving vehicle are given with special attention to the four wheel drive and its control system, the steering system, and the navigational instrumentation. The overall system is optimized in view of total mass, range, mobility, load carrying capability, safety, highest reliability through redundancy, and last but not least, cost and development time. Optimization of the drive and power system has first been evaluated by mathematical models and computational simulation of the vehicle hardware, the wheel/soil interaction, and the lunar terrain profile. The next step to refine optimization and evaluation of the drive, steering, and power system including man/machine interaction has been carried out by the use of a six-degree-of-

freedom simulator subjecting the astronauts in their space suits to simulated vehicle motions while driving over a simulated terrain, observable on a cathode ray tube display.
AIAA
Lunar Roving Vehicles; Navigation Instruments; Optimal Control; Steering

19720019624 NASA Goddard Space Flight Center, Greenbelt, MD, USA
Lunar roving vehicle magnetic tests
Boyle, J. C.; Oct 1, 1971; In English
Report No.(s): NASA-TM-X-65927; X-325-72-179; No Copyright; Avail: CASI; A03, Hardcopy

The qualification model of the lunar roving vehicle (LRV) was tested in the Spacecraft Magnetic Test Facility (SMTF) at the GSFC Magnetic Test Site. Magnetic field measurements were made, both with the vehicle in its as received state and also subsequent to final deperm treatment. These measurements, together with information supplied to GSFC regarding the magnetic moment of the astronaut's extravehicular mobility units (EMU's) were used to calculate 0.5 nanotesla (gamma) contours around the LRV. The results are tabulated. Magnetic field measurements were also made with various items of LRV equipment operational. No significant changes were noted, except during operation of the vehicle wheels.
CASI
Apollo 16 Flight; Lunar Roving Vehicles; Magnetic Measurement

19720010605 Rensselaer Polytechnic Inst., Troy, NY, USA
An optimal system design process for a Mars roving vehicle
Pavarini, C.; Baker, J.; Goldberg, A.; Nov 1, 1971; In English
Contract(s)/Grant(s): NGL-33-018-091
Report No.(s): NASA-CR-125615; RPI-TR-MP-24; No Copyright; Avail: CASI; A05, Hardcopy

The problem of determining the optimal design for a Mars roving vehicle is considered. A system model is generated by consideration of the physical constraints on the design parameters and the requirement that the system be deliverable to the Mars surface. An expression which evaluates system performance relative to mission goals as a function of the design parameters only is developed. The use of nonlinear programming techniques to optimize the design is proposed and an example considering only two of the vehicle subsystems is formulated and solved.
CASI
Computer Aided Design; Mars Landing; Roving Vehicles

19720007590 Alabama Univ., University, AL, USA
A study and analysis of the MSFC lunar roving vehicle dust profile test program
Mullis, C. H.; Nov 1, 1971; In English
Contract(s)/Grant(s): NAS8-26715
Report No.(s): NASA-CR-121075; BER-139-92; No Copyright; Avail: CASI; A03, Hardcopy

The dust problem and fender design for the LRV were studied under reduced gravity with a lunar soil simulant. The test equipment, soil characteristics of the lunar soil simulant, and the test procedures are described. It is concluded: (1) The fender plus flap design is adequate. (2) Vacuum conditions tend to eliminate or reduce suspended dust clouds. (3) Reduced gravity conditions tend to increase the dust problems. (4) Slow starting speeds are necessary to minimize slip and reduce initial dust generation.
CASI
Lunar Dust; Lunar Roving Vehicles; Space Environment Simulation

19720007017 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
A method for lunar roving vehicle position determination from three landmark observations with a sun compass
Blucker, T. J.; Stimmel, G. L.; Jun 25, 1971; In English
Report No.(s): NASA-TM-X-67447; MSC-04440; MSC-IN-71-FM-238; No Copyright; Avail: CASI; A02, Hardcopy

A simplified method is described for determining the position of the lunar roving vehicle on the lunar surface during Apollo 15. The method is based upon sun compass azimuth measurements of three lunar landmarks. The difference between

the landmark azimuth and the sun azimuth is measured and the resulting data are voice relayed to the Mission Control Center for processing.
CASI
Apollo 15 Flight; Lunar Roving Vehicles; Lunar Topography; Position (Location); Solar Compasses

19720004516 NASA Marshall Space Flight Center, Huntsville, AL, USA
Mobility systems activity for lunar rovers at MSFC
Jones, C. S., Jr.; Nola, F. J.; Sep 9, 1971; In English
Report No.(s): NASA-TM-X-64623; No Copyright; Avail: CASI; A03, Hardcopy

The Apollo Lunar Roving Vehicle (LRV) mobility system is described. Special emphasis is given to the redundancy aspects and to the selection of the drive motors. A summary chart of the performance on the lunar surface during the Apollo 15 flight is included. An appendix gives details on some development work on high efficiency drive systems and compares these systems to the selected system.
CASI
Apollo 15 Flight; Equipment Specifications; Lunar Roving Vehicles; Mechanical Drives

19710064493
Objectives and requirements of unmanned rover exploration of the moon
Conel, J. E.; Fanale, F. P.; Nash, D. B.; Aug 1, 1971; In English; Copyright; Avail: Other Sources

Unmanned lunar rover exploration objectives and requirements, considering heterogeneous surface
AIAA
Lunar Exploration; Lunar Roving Vehicles

19710054010
America's Lunar Roving Vehicle
Adams, W. R.; Arnett, C. D.; Morea, S. F.; Jul 1, 1971; In English; SPACE SYSTEMS MEETING, JUL. 19-20, 1971, DENVER, CO
Report No.(s): AIAA PAPER 71-847; Copyright; Avail: Other Sources

Lunar roving vehicle for Apollo 15 mission, discussing power, control, navigation and deployment systems in relation to lunar exploration requirements
AIAA
Apollo 15 Flight; Lunar Exploration; Lunar Roving Vehicles

19710051799
Lunar terrain roughness with respect to roving vehicles
Vaughan, O. H.; GEOLOGICAL PROBLEMS IN LUNAR and PLANETARY RESEARCH.; JAN 1, 1971; In English; Copyright; Avail: Other Sources

Mobility capability of lunar roving vehicles relative to terrain roughness, computing power requirements
AIAA
Electric Power; Energy Requirements; Lunar Roving Vehicles; Surface Roughness

19710040653
Surface navigation system and error analysis for Martian rover
Chen, H. M.; Shen, C. N.; JAN 1, 1971; In English; 4TH HAWAII INTERNATIONAL CONFERENCE ON SYSTEM SCIENCES, JAN. 12-14, 1971, HONOLULU, HI
Contract(s)/Grant(s): NGR-33-018-191; Copyright; Avail: Other Sources

Surface navigation system and error analysis for Martian roving vehicle, using continuous tracking of pole star and local vertical
AIAA
Error Analysis; Mars Surface; Roving Vehicles; Surface Navigation; Tracking (Position)

19710040628

Unmanned lunar roving vehicle remote guidance study

Filetti, K. A.; Hornbrook, G. K.; JAN 1, 1971; In English; 4TH HAWAII INTERNATIONAL CONFERENCE ON SYSTEM SCIENCES, JAN. 12-14, 1971, HONOLULU, HI; Copyright; Avail: Other Sources

Unmanned lunar roving vehicle remote guidance, discussing onboard vs on-earth steering and velocity control, imaging system, obstacle detection and avoidance

AIAA

Guidance (Motion); Lunar Roving Vehicles; Remote Control

19710040627

Unmanned lunar roving vehicle elevation determination analysis

Martin, R. V.; Nowak, L. A.; JAN 1, 1971; In English; 4TH HAWAII INTERNATIONAL CONFERENCE ON SYSTEM SCIENCES, JAN. 12-14, 1971, HONOLULU, HI; Copyright; Avail: Other Sources

Elevation determination methods for unmanned lunar roving vehicle, considering instruments, orbiter tracking, etc

AIAA

Elevation; Lunar Roving Vehicles; Lunar Topography

19700051827

Apollo lunar vehicles - Introduction- NASA studies formulated rover philosophy and requirements

Milwitzky, B.; May 1, 1970; In English; Copyright; Avail: Other Sources

Apollo lunar roving vehicles for manned exploration, discussing design proposals

AIAA

Apollo Project; Lunar Exploration; Lunar Roving Vehicles

19700049259

Traction drive system design considerations for a lunar roving vehicle

Doran, B. J.; Jones, C. S., Jr.; Nola, F. J.; Jan 1, 1970; In English; SOCIETY of AUTOMOTIVE ENGINEERS, AUTOMOTIVE ENGINEERING CONGRESS, JAN. 12-16, 1970, DETROIT, MI

Report No.(s): SAE PAPER 700023; Copyright; Avail: Other Sources

Optimal traction drive system design for lunar roving vehicle, considering weight, energy consumption, operational flexibility, power supply, motor and power train

AIAA

Electric Motors; Lunar Roving Vehicles; Mechanical Drives; Structural Weight; Traction

19700033703 Hughes Aircraft Co., El Segundo, CA, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA

Preliminary analysis for lunar roving vehicle study, ground data systems and operations. Volume 3 - Roving vehicle navigation Elevation determination analyses/

Jun 30, 1970; In English

Contract(s)/Grant(s): NAS7-100; JPL-952668

Report No.(s): NASA-CR-110874; C0077-VOL-3; No Copyright; Avail: CASI; A04, Hardcopy

Elevation determination analyses for lunar roving vehicles

CASI

Elevation; Lunar Roving Vehicles

19700033702 Hughes Aircraft Co., El Segundo, CA, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA

Preliminary analysis for lunar roving vehicle study, ground data systems and operations. Volume 2 - Roving vehicle payload /Science mode time line analyses/

Jun 30, 1970; In English

Contract(s)/Grant(s): NAS7-100; JPL-952668

Report No.(s): NASA-CR-110873; C0077-VOL-2; No Copyright; Avail: CASI; A04, Hardcopy

Stationary science time line analyses for roving vehicle payload
CASI
Lunar Roving Vehicles; Payloads

19700033701 Hughes Aircraft Co., El Segundo, CA, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Preliminary analysis for lunar roving vehicle study, ground data systems and operations. Volume 1 - Roving vehicle guidance /Remote driving study/
Jun 30, 1970; In English
Contract(s)/Grant(s): NAS7-100; JPL-952668
Report No.(s): NASA-CR-110872; C0077-VOL-1; No Copyright; Avail: CASI; A08, Hardcopy
Remote driving of lunar roving vehicle by superimposing driving aids on TV panorama
CASI
Lunar Roving Vehicles; Remote Control; Spacecraft Television

19700028123 State Univ. of New York, Buffalo, NY, USA
Maneuvering the dual mode manned/automated lunar roving vehicle, June 1969 - March 1970
Lewandowski, G. M.; Wood, W. F.; Mar 23, 1970; In English
Contract(s)/Grant(s): NAS8-25110
Report No.(s): NASA-CR-102823; CAL-VS-2860-D; No Copyright; Avail: CASI; A05, Hardcopy
Digital maps of hazards to movement for dual mode Lunar Roving Vehicle
CASI
Digital Data; Lunar Maps; Lunar Roving Vehicles; Operational Hazards

19700026210 Tennessee Univ., Knoxville, TN, USA
Dual-mode lunar roving vehicle navigation systems Final report
Hung, J. C.; Jan 20, 1970; In English
Contract(s)/Grant(s): NAS8-24858
Report No.(s): NASA-CR-102795; SR-20; No Copyright; Avail: CASI; A10, Hardcopy
Dead reckoning and position fix navigation systems for lunar roving vehicles
CASI
Dead Reckoning; Doppler Navigation; Lunar Roving Vehicles; Navigation Instruments

19700024682 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Operation profiles for lunar roving missions
Mc Cormick, C. W.; May 1, 1970; In English
Contract(s)/Grant(s): NAS7-100
Report No.(s): NASA-CR-109800; JPL-760-46; No Copyright; Avail: CASI; A09, Hardcopy
Operational and functional requirements for lunar roving vehicle mission
CASI
Functional Analysis; Lunar Roving Vehicles; Mission Planning; Operational Problems

19700022957 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Future projects - Geophysical experiments for the manned portion of a lunar roving vehicle mission
Brereton, R. G.; SPACE PROGRAMS SUM. NO. 37-61, N70-32267 17-30(; Feb 28, 1970; In English; Copyright; Avail: Other Sources
Geophysical experiments for manned portion of future lunar roving vehicle missions
CASI
Apollo Project; Lunar Exploration; Lunar Roving Vehicles

19700018231 Grumman Aircraft Engineering Corp., Bethpage, NY, USA
Hazard detection methods for a lunar roving vehicle Final report
Elefant, J.; Lavan, E.; Veshlage, E.; Jan 1, 1970; In English
Contract(s)/Grant(s): NAS8-25098
Report No.(s): NASA-CR-102510; DCN-1-X-40-94302-/IF/; No Copyright; Avail: CASI; A05, Hardcopy

Radar and seismic techniques for hazard detection system for lunar roving vehicles

CASI
Lunar Roving Vehicles; Operational Hazards; Warning Systems

19700011350 NASA Marshall Space Flight Center, Huntsville, AL, USA
A simplified dead reckoning navigation system for the manned lunar roving vehicle
Green, W. L.; Sep 30, 1969; In English
Report No.(s): NASA-TM-X-53953; No Copyright; Avail: CASI; A04, Hardcopy

Dead reckoning navigation system for manned lunar roving vehicle

CASI
Dead Reckoning; Lunar Roving Vehicles; Surface Navigation

19700009492 NASA Marshall Space Flight Center, Huntsville, AL, USA
Traction drive system design considerations for a lunar roving vehicle
Doran, B. J.; Jones, C. S., Jr.; Nola, F. J.; Nov 25, 1969; In English
Report No.(s): NASA-TM-X-53972; No Copyright; Avail: CASI; A03, Hardcopy

Optimum design considerations of traction drive for lunar roving vehicle

CASI
Lunar Roving Vehicles; Mechanical Drives; Optimization; Systems Engineering

19680006389 NASA Marshall Space Flight Center, Huntsville, AL, USA
Visual simulation facility for evaluation of lunar surface roving vehicles
Howell, J. T.; Knighton, M. H.; Lahser, H. F.; Spear, J. S.; Thomas, L. G.; Vinz, F. L., et al.; Feb 1, 1968; In English
Report No.(s): NASA-TN-D-4276; No Copyright; Avail: CASI; A03, Hardcopy

Visual simulation facility for evaluation of lunar surface roving vehicles

CASI
Lunar Roving Vehicles; Test Facilities; Training Simulators

19680005777 Defense Research Corp., Santa Barbara, CA, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Roving vehicle motion control Final report
Corry, T. M.; Johnson, D. E.; Johnston, R. J.; Lingerfelt, J. E.; Miller, B. P.; Dec 1, 1967; In English
Contract(s)/Grant(s): NAS7-100; JPL-951829
Report No.(s): NASA-CR-92643; TR-67-60; No Copyright; Avail: CASI; A09, Hardcopy

Roving vehicle motion control for unmanned planetary and lunar exploration

CASI
Lunar Roving Vehicles; Planetary Surfaces; Space Exploration

19670042356
Scientific exploration of the moon using a roving vehicle.
Downey, J. A., III; Tiffany, O. L.; Zaitzeff, E. M.; Jan 1, 1966; In English
Contract(s)/Grant(s): NASW-1064; Copyright; Avail: Other Sources

Measurements that could be carried out during traverse of moon in Kepler-Encke region to determine subsurface structure, surface density and chemical composition, etc

AIAA
Chemical Composition; Composition (Property); Conferences; Lunar Exploration; Lunar Geology; Moon; Roving Vehicles; Surface Layers

19670030340 General Motors Corp., Santa Barbara, CA, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA

Roving vehicle motion control Quarterly report, 1 Jun. - 31 Aug. 1967

Corry, T. M.; Johnson, D. E.; Johnston, R. J.; Lingerfelt, J. E.; ; Sep 1, 1967; In English

Contract(s)/Grant(s): NAS7-100; JPL-951829

Report No.(s): NASA-CR-89583; TR67-45; No Copyright; Avail: CASI; A05, Hardcopy

System functional requirements and configurations for roving vehicle missions on Moon and Mars - motion control

Author (CASI)

Command and Control; Functional Design Specifications; Lunar Roving Vehicles; Mars (Planet); Moon; Roving Vehicles; Space Missions; Transportation

19670026750 General Motors Corp., Santa Barbara, CA, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA

Roving vehicle motion control Quarterly report, 1 Mar. - 31 May 1967

Corry, T. M.; Johnson, D. E.; Johnston, R. J.; Lingerfelt, J. E.; ; Jun 1, 1967; In English

Contract(s)/Grant(s): NAS7-100; JPL-951829

Report No.(s): NASA-CR-88285; TR67-34; QR-1; No Copyright; Avail: CASI; A04, Hardcopy

System and subsystem requirements for remote control of roving space vehicle motion

Author (CASI)

Astrodynamics; Constraints; Deep Space Network; Remote Control; Roving Vehicles; Spacecraft

19670026464 General Electric Co., Philadelphia, PA, USA

Auxiliary power systems for a lunar roving vehicle

Erlanson, E. P.; Aug 1, 1967; In English

Contract(s)/Grant(s): NAS3-7627

Report No.(s): NASA-CR-784; REPT.-66SD4395; No Copyright; Avail: CASI; A13, Hardcopy

Auxiliary power systems and life support and cabin environmental control systems for lunar roving vehicle

Author (CASI)

Auxiliary Power Sources; Brayton Cycle; Environmental Control; Life Support Systems; Lunar Roving Vehicles; Rankine Cycle

19670025505 Massachusetts Inst. of Tech., Cambridge, MA, USA

Development of visual, contact and decision subsystems for a Mars rover, July 1966 - January 1967

Bever, J. G.; Kilmer, W. L.; Mc Culloch, W. S.; Moreno-Diaz, R.; ; Jul 1, 1967; In English

Contract(s)/Grant(s): NSR-22-009-138; NGR-22-009-140

Report No.(s): NASA-CR-87503; R-565; No Copyright; Avail: CASI; A06, Hardcopy

Visual, contact, and decision subsystems for Mars rover

Author (CASI)

Animals; Decision Making; Mars (Planet); Mars Surface; Roving Vehicles; Surface Vehicles; Tactile Discrimination

19670010054 Bendix Corp., Ann Arbor, MI, USA

Lunar surface mobility systems comparison and evolution /Mobev/, volume II. Book 3 - Systems engineering /lunar roving vehicles/ Final report

Nov 1, 1966; In English

Contract(s)/Grant(s): NAS8-20334

Report No.(s): NASA-CR-82750; BSR-1428, VOL. II, BK. 3; No Copyright; Avail: CASI; A12, Hardcopy

Lunar Roving Vehicles systems and sybsystems engineering designs an Design Point Vehicle selection - lunar surface mobility systems comparison and evolution /Mobev/

Author (CASI)

Lunar Roving Vehicles; Lunar Surface; Mobility; Roving Vehicles; Systems Engineering

19660061814

Power systems for an unmanned lunar roving vehicle.

Hsi, K.; Pellmann, R. R.; /AIAA UNMANNED SPACECRAFT MEETING; Sep 1, 1966; In English

Contract(s)/Grant(s): JPL-950656; Copyright; Avail: Other Sources

Unmanned lunar roving vehicle power requirements, comparing radioisotope thermoelectric generator and solar cell/battery systems

AIAA

Conferences; Lunar Roving Vehicles; Radioactive Isotopes; Radioactivity; Solar Cells; Spacecraft Power Supplies; Thermoelectric Generators; Thermoelectric Power Generation; Thermoelectricity

19660052880

Manned system design for lunar surface roving vehicles.

Burns, N. M.; Grubbs, H. Y.; Nicholson, R. M.; Jan 1, 1966; In English; Copyright; Avail: Other Sources

Human and man/system requirements to provide criteria for choosing alternative mission and lunar surface roving vehicles design concepts

AIAA

Conferences; Lunar Surface Vehicles; Man Machine Systems; Manned Spacecraft; Mission Planning; Roving Vehicles; Systems Engineering

19660040100

Scientific exploration of the moon using a roving vehicle.

Tiffany, O. L.; Zaitzeff, E. M.; Jan 1, 1966; In English

Contract(s)/Grant(s): NAS8-20199

Report No.(s): SAE PAPER 660145; Copyright; Avail: Other Sources

Apollo extension system /AES/ for lunar surface exploration

AIAA

Apollo Extension System; Apollo Project; Conferences; Lunar Roving Vehicles; Lunar Surface; Moon; Roving Vehicles

19660028019 Honeywell, Inc., Minneapolis, MN, USA

Man system criteria for extraterrestrial roving vehicles. Phase IB - The Lunex II SIMULATION Interim technical report

Haaland, J. E.; Jun 15, 1966; In English

Contract(s)/Grant(s): NAS8-20006

Report No.(s): NASA-CR-78245; No Copyright; Avail: CASI; A12, Hardcopy

Using human performance and physiological measures during lunar surface mission simulation to evaluate minimum volume cabin design for lunar roving vehicle

Author (CASI)

Human Performance; Lunar Roving Vehicles; Lunar Surface; Physiological Responses; Physiology; Roving Vehicles; Simulation; Spacecraft Cabin Simulators

19660022562

Feasibility study for lunar worm planetary roving vehicle concept Final technical report

Dobson, F. A.; Fulton, D. G.; Jul 27, 1966; In English

Contract(s)/Grant(s): NAS1-5709

Report No.(s): NASA-CR-66098; RSC-6720; No Copyright; Avail: CASI; A10, Hardcopy

Mobility and structural analyses of bellows concept for lunar roving vehicle

Author (CASI)

Bellows; Feasibility; Lunar Roving Vehicles; Mobility; Structural Analysis; Structural Design

19660015678 Bendix Corp., Ann Arbor, MI, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA

Surveyor Lunar Roving Vehicle, phase I. Volume I - Program summary Final technical report

Apr 1, 1964; In English

Contract(s)/Grant(s): NAS7-100; JPL-950656

Report No.(s): NASA-CR-71257; BSR-903, VOL. I; No Copyright; Avail: CASI; A03, Hardcopy

Roving vehicle payload for Surveyor lunar soft landing spacecraft
Author (CASI)
Lunar Landing; Lunar Roving Vehicles; Lunar Surface Vehicles; Payloads; Roving Vehicles; Soft Landing; Soft Landing Spacecraft; Surveyor Project

19660015676 Honeywell, Inc., Minneapolis, MN, USA
Man system criteria for extraterrestrial surface roving vehicles Interim technical report
Haaland, J. E.; Nicholson, R. M.; Feb 7, 1966; In English
Contract(s)/Grant(s): NAS8-20006
Report No.(s): NASA-CR-74743; No Copyright; Avail: CASI; A15, Hardcopy
Man-machine system for extraterrestrial surface roving vehicles
Author (CASI)
Criteria; Lunar Roving Vehicles; Man Machine Systems; Roving Vehicles; Space Exploration; Surface Vehicles

19660014483 Bendix Corp., Ann Arbor, MI, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Surveyor Lunar Roving Vehicle, phase I. Volume II - Mission and system studies Final technical report
Apr 1, 1964; In English
Contract(s)/Grant(s): NAS7-100; JPL-950656
Report No.(s): NASA-CR-71258; BSR-903, VOL. II; No Copyright; Avail: CASI; A11, Hardcopy
Summary of missions and systems studies for Surveyor Lunar Roving Vehicle /SLRV/
Author (CASI)
Lunar Exploration; Lunar Roving Vehicles; Mission Planning; Surveyor Project; Systems Analysis

19660010424 General Motors Corp., Santa Barbara, CA, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Surveyor lunar roving vehicle, phase I. Volume II - Appendixes, section III - Mechanical subsystems Final report
Apr 23, 1964; In English
Contract(s)/Grant(s): NAS7-100; JPL-950657
Report No.(s): NASA-CR-71260; TR-64-26, VOL. II, SECT. III; No Copyright; Avail: CASI; A20, Hardcopy
Surveyor LRV mechanical subsystems evaluation
Author (CASI)
Lunar Roving Vehicles; Surveyor Project

19660010423 General Motors Corp., Santa Barbara, CA, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Surveyor lunar roving vehicle, phase I. Volume II - Appendixes, section I - Concept evaluation and analysis Final report
Apr 23, 1964; In English
Contract(s)/Grant(s): NAS7-100; JPL-950657
Report No.(s): NASA-CR-71261; TR-64-26, VOL. II, SECT. I; No Copyright; Avail: CASI; A17, Hardcopy
Surveyor LRV concept evaluation and analysis
Author (CASI)
Lunar Roving Vehicles; Surveyor Project; Systems Analysis; Tradeoffs

19660008345 Bendix Corp., Ann Arbor, MI, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Surveyor Lunar Roving Vehicle, interim study Final technical report
Feb 1, 1965; In English
Contract(s)/Grant(s): NAS7-100; JPL-951057
Report No.(s): BSR-1096; No Copyright; Avail: CASI; A10, Hardcopy
Remote control study of Surveyor Lunar Roving Vehicle /SLRV/ test model
Author (CASI)
Lunar Roving Vehicles; Remote Control; Scale Models; Surveyor Project

19660006194 Bendix Corp., Ann Arbor, MI, USA
Surveyor lunar roving vehicle, phase I. Volume III - Preliminary design and system description. Book 2 - Validation of preliminary design Final report
Apr 1, 1964; In English
Contract(s)/Grant(s): NAS7-100; JPL-950656
Report No.(s): NASA-CR-69397, VOL. III; BSR-903, VOL. III, BK. 2; No Copyright; Avail: CASI; A16, Hardcopy
Validation of preliminary design for Surveyor lunar roving vehicle - mobility, structure, deployment, folding and erection mechanism, and Apollo support scientific experiments
Author (CASI)
Apollo Project; Construction; Deployment; Folding; Folding Structures; Lunar Roving Vehicles; Mobility; Surveyor Project; Validity

19660006193 General Motors Corp., Santa Barbara, CA, USA
Surveyor lunar roving vehicle, phase I. Volume II - Appendixes. Section V - Additional information on RTE Final report
Apr 23, 1964; In English
Contract(s)/Grant(s): NAS7-100; JPL-950657
Report No.(s): NASA-CR-69398; TR-64-26, VOL. II, SEC. V; No Copyright; Avail: CASI; A03, Hardcopy
Surveyor lunar roving vehicle - electronics, power supply, and components
Author (CASI)
Electronics; Lunar Roving Vehicles; Power Supplies; Surveyor Project

19660006192 General Motors Corp., Santa Barbara, CA, USA
Surveyor lunar roving vehicle, phase I. Volume II - Appendixes. Section IV - Reliability Final report
Apr 23, 1964; In English
Contract(s)/Grant(s): NAS7-100; JPL-950657
Report No.(s): NASA-CR-69399; TR-64-26, VOL. II, SEC. IV; No Copyright; Avail: CASI; A08, Hardcopy
Surveyor lunar roving vehicle reliability - failure modes, reliability tradeoffs, mission capability, and hardware
Author (CASI)
Dynamic Response; Dynamic Structural Analysis; Failure Modes; Hardware; Lunar Roving Vehicles; Reliability; Spherical Shells; Surveyor Project; Thin Walled Shells; Tradeoffs

19660006188 Bendix Corp., Ann Arbor, MI, USA
Surveyor lunar roving vehicle, phase I. Volume IV - Reliability Final report
Apr 1, 1964; In English
Contract(s)/Grant(s): NAS7-100; JPL-950656
Report No.(s): NASA-CR-69397, VOL. IV; BSR-903, VOL. IV; No Copyright; Avail: CASI; A18, Hardcopy
Reliability of Surveyor lunar roving vehicle design - mathematical models, failure modes, and predictions
Author (CASI)
Failure Modes; Lunar Roving Vehicles; Mathematical Models; Reliability; Surveyor Project

19660006187 General Motors Corp., Santa Barbara, CA, USA
Surveyor lunar roving vehicle, phase I. Volume II - Appendixes. Section II - Electronic subsystems Final report
Apr 23, 1964; In English
Contract(s)/Grant(s): NAS7-100; JPL-950657
Report No.(s): NASA-CR-69396; TR-64-26, VOL. II; No Copyright; Avail: CASI; A19, Hardcopy
Surveyor lunar roving vehicle - operation ground equipment, communications, power supply, command and control, television subsystems and systems engineering
Author (CASI)
Command and Control; Control Systems Design; Controllers; Ground Support Equipment; Lunar Roving Vehicles; Power Supplies; Surveyor Project; Systems Engineering; Telecommunication; Television Systems

19660005264

Surveyor lunar roving vehicle, phase I. Volume III - Preliminary design and system description. Book 2 - Validation of preliminary design, sections 7-13 Final technical report

Apr 1, 1964; In English

Contract(s)/Grant(s): NAS7-100; JPL-950656

Report No.(s): NASA-CR-69102; BSR-903, VOL.III,BK.2,SEC.7-13; No Copyright; Avail: CASI; A21, Hardcopy

Systems design validation of Surveyor lunar roving vehicle - navigation, control and display, television, telecommunications, power supply, and thermal control

Author (CASI)

Display Devices; Lunar Roving Vehicles; Navigation Aids; Surveyor Project; Systems Engineering; Telecommunication; Television Systems; Temperature Control; Validity

19660004186 Bendix Corp., Ann Arbor, MI, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA

Surveyor Lunar Roving Vehicle, phase I. Volume III - Preliminary design and system description. Book I - System description and performance characteristics Final technical report

Apr 1, 1964; In English

Contract(s)/Grant(s): JPL-950656

Report No.(s): NASA-CR-68625; BSR-903, VOL. III, BK. 1; No Copyright; Avail: Other Sources

Surveyor Lunar Roving Vehicle /SLRV/ system description and performance characteristics

Author (CASI)

Descriptions; Lunar Roving Vehicles; Performance; Surveyor Project; Systems Analysis

19660004162 Bendix Corp., Ann Arbor, MI, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA

Surveyor Lunar Roving Vehicle, phase I. Volume V - System evaluation Final technical report

Apr 1, 1964; In English

Contract(s)/Grant(s): JPL-950656

Report No.(s): NASA-CR-68648; BSR-903, VOL. V; No Copyright; Avail: Other Sources

Surveyor Lunar Roving Vehicle /SLRV/ mission in support of Apollo LEM program

Author (CASI)

Apollo Project; Lunar Module; Lunar Roving Vehicles; Mission Planning; Surveyor Project; Systems Analysis

19650014414 Hayes International Corp., Birmingham, AL, USA

Apollo logistics support systems molab studies. lunar shelter/rover conceptual design and evaluation

San Juan, E. C.; Nov 1, 1964; In English

Contract(s)/Grant(s): NAS8-5307

Report No.(s): NASA-CR-61049; No Copyright; Avail: CASI; A06, Hardcopy

Lunar shelter/rover conceptual design for lunar mobile laboratory /Molab/ Apollo project Logistics Support System

Author (CASI)

Apollo Project; Logistics; Lunar Mobile Laboratories; Lunar Roving Vehicles; Lunar Shelters; Support Systems

Subject Term Index

Personal Author Index

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Roving Vehicles for Lunar and Planetary Exploration		5. Report Date January 2004
		6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address NASA Scientific and Technical Information Program Office		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Langley Research Center Hampton, VA 23681		13. Type of Report and Period Covered
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This special bibliography includes the design, development, and application of lunar and Mars rovers; vehicle instrumentation and power supplies; navigation and control technologies; and site selection.

17. Key Words (Suggested by Author(s)) Lunar Roving Vehicles Mars Roving Vehicles Bibliographies Mars Landing Sites Navigation Site Selection	18. Distribution Statement Unclassified – Unlimited Subject Category – 14

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	151	

For sale by the NASA Center for AeroSpace Information, 7121 Standard Drive, Hanover, MD 21076-1320