MICRO PLANETARY ROVER "MICRO5"

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Abstract

This paper describes a newly developed rover with small size, light-weight, low power consumption. In recent years, many researchers have extensively studied and developed unmanned mobile robots for surface exploration of the moon or planets. A lunar or planetary rover is required to travel safely over a long distance for many days in unfamiliar terrain. This paper presents scientific signification, requirements, and technology of a lunar or planetary rover. This paper proposes a new mobility system, which has four wheels and one supported wheel. This novel suspension system is a simple and light mechanism like a four-wheeled rover and provides a high degree of mobility like a six-wheeled rover. The performance of the developed rover is shown by some experiments.

1. Introduction

Toward the turn of the century, several schemes sending an unmanned mobile explorer to the moon or Mars are being planned for scientific exploration. In recent years, many researchers have studied and developed lunar or planetary rovers for unmanned surface exploration of planets[1][2][3]. Especially micro-rover missions have received a lot of attention, because small, low-cost missions are typically constrained by mass, budget and schedule. In July 1997, NASA/JPL succeeded in Mars Pathfinder mission and the Sojourner rover could move on the Martian surface and gather and transmit voluminous data back to the Earth[4]. NASA plans to send some rovers to Mars in 2001, 2003, 2005 Missions[5]. NASA/JPL has developed a small rover prototype, called Rocky 7. This microrover is capable of long traverses, autonomous navigation and science instrument control. This rover carries three science instruments and can be commanded from any computer platform from any location using the World Wide Web.

As a part of a development program, teleoperation or autonomous navigation technologies are earnestly studied for realizing a rover to be able to move on an unknown lunar or planetary surface[6]. In recent years, many researchers have earnestly studied and developed planetary rovers for unmanned surface exploration of planets[7][8]. However, there are few navigation systems that can travel safely over a long distance for many days in unknown terrain. There have also been proposed only few practical path planning methods based on sensory data[9][10][11][12].

Recently rover field tests have been performed for evaluating the planetary rover performance. In December 1996, NASA/JPL demonstrated the field tests by the Rocky 7 in the Mojave Desert[13]. The Rocky 7 navigation is based on operator way point designation and on autonomous behavior navigation for movement to the specified targets. In June 1997, CMU rover Nomad navigated 200[km] of the planetary-like Atacama Desert in South America while under the control of operators in North America[14]. The authors also have done a long range test for the perfect autonomous rover at a slag heap in Izu-Ohshima in Japan[15].

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The authors have studied a lunar or planetary rover which can travel safely over a long distance on rough terrain. The authors have developed a small, light-weight microrover with a new mobility system, which is called "Micro5". This paper describes the design and implementation of a small rover for future Lunar or Planetary missions requiring long traverses and rover-based science experiments. This paper provides a system overview of a newly developed microrover Micro5.

This paper is structured as follows. In Section 2, the rover mission is discussed. In Section 3, the prototype Micro5 developed for lunar or planetary exploration is explained. Then a new mobility system is proposed in Section 4. Section 5 discusses some experiments and demonstrations for Micro5. Cooperative exploration mission based on buddy system is proposed in Section 6. Finally, Section 7 is for conclusion.

2. Rover Mission

With a new type of launch vehicle, M-V rocket, our Institute(ISAS) has a capability of lunar or planetary exploration. ISAS launched "Nozomi" spacecraft which will be a Mars orbiter. ISAS plans to send Lunar-A spacecraft with penetraters to the moon. ISAS is also promoting SELENE mission with NASDA, which includes a lunar orbiter and lander. The authors have been conducting a wide variety of researches on the rover for the future missions[16][17]. Figure 1 shows an example of the concept of rover missions, where some rovers explore the moon or planets cooperatively.

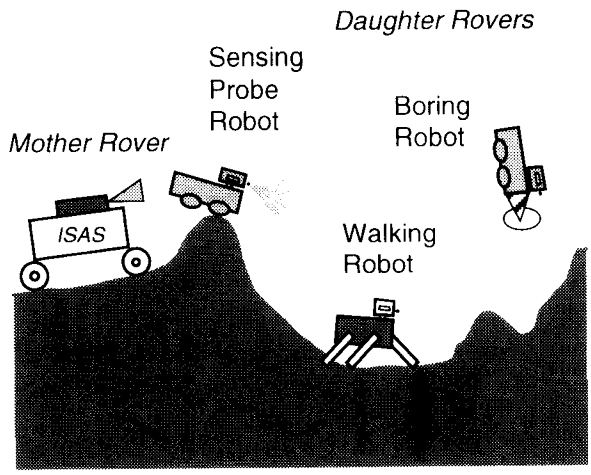


Fig.1 Concept of Rover Mission

2.1 Science missions

Candidates for our missions here, not all of which, though, will be accommodated by our rovers, are as follows :

1. Geology by photo images : topographical survey, identifying size, and shape of rocks, composition of rocks, craters etc.
2. Element Analysis : analysis of age using mass-spectrometer, element analysis using X-ray spectrometer, or γ-ray spectrometer , study of mineral composition using visible or infrared reflection spectrometer etc.
3. Wide Area Investigation : studies on magnetic anomalies using magnetometer, gravity anomalies, electro-magnetic structure of the crust using VLF, seismo-logical observation using seismo-meter network etc.
4. Investigation by Manipulator : analysis of regolith, measurement of heat flux, element analysis etc.

2.2 Rover requirements

Lunar or planetary rovers are expected to travel in wide areas and explore the surface in detail. Exploration requirements for lunar or planetary rovers are as follows :

1. Large area exploration
2. Underground exploration
3. Long term exploration
4. Sample collection and analysis
5. Placement of scientific instruments
6. Exposed surface exploration such as craters

2.3 Engineering missions

The engineering objective of our rover here is to establish various engineering techniques for the future deep space missions such as :

1. Autonomous soft landing technique
2. Adaptation for planetary environment
3. Reliable mobility development
4. Navigation and guidance
5. Tele-science technology
6. Small, light, Low-power instruments
7. Mission operation technology

3. MICRO5

The authors have developed a small rover Micro5 for future Lunar or Planetary exploration missions requiring long traverses and rover-based science experiments. The overview and specification of the developed Micro5 are shown in Fig.2 and Table 1 respectively. The weight of Micro5 is about 5[kg]. The developed rover measures about 0.53[m] wide, 0.55[m] long, and 0.25 [m] high. The wheel diameter is 0.1[m].

The developed rover is driven by five wheels controlled independently. The steering is controlled by differential of left and right wheels. Those wheels are actuated by small DC motors. The velocity of the rover is about 1.5[cm/s]. This rover has the proposed new suspension system. So the climbable step is 0.13[m] and the climbable slope is about 40[deg]. Power is supplied by solar panel on the top of the rover. The rover is also driven by on-board batteries.

Two stereo cameras are used for a forward terrain sensor. This rover also has some other CMOS cameras around the body for navigation and scientific observation. The rover is equipped with pitch and roll clinometers for attitude detection and encoders for dead-reckoning. Sensor data processing and control are performed by on-board computers. The RISC-CPUs are dedicated to the function of environment recognition, path planning and navigation.

The developed Micro5 has communication system to communicate with the ground system. The rover can send obtained images, house-keeping data, scientific data to the ground system. Operators can control the robot based on image data by teleoperation techniques. Micro5 has the sampling system. The light-weight manipulator with a CMOS camera has been developed, which will be attached to the front of the rover. Some scientific instruments are under development.

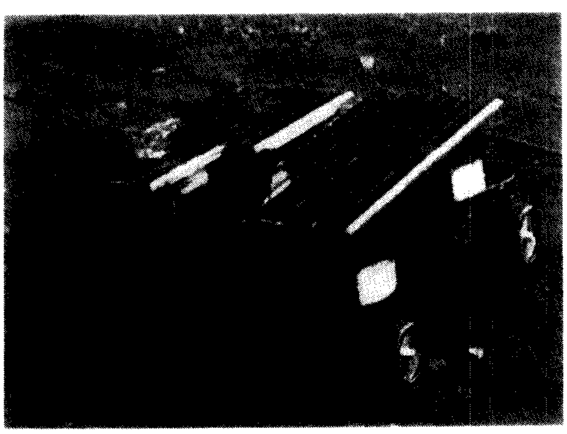


Fig.2 Overview of Micro5

Table 1 Specification of Micro5

Size	0.55[m] (Length) 0.53[m] (Width) 0.25[m] (Height)
Weight	about 5[kg]
Mobility System	Micro5 suspension system Wheel Diameter : 0.10[m] Body Height : 0.13[m]
Mobility Performance	Velocity : 1.5[cm/s] Climable Step : 13[cm] Climable Slope : 40[deg]
CPU	Mupltiple CPUs (32bit, 16bit)
Communication	40[Kbps] UHF
Power Supply	Solar Panel : peak power 27[W] Battery : NiCd
Power Consumption	Actuator: less than 3[W] : less than 5[W] (MAX) Computer : less than 4[W]
Payload	8 cameras Sunsensor etc. (to be equipped) Manipulator (to be equipped)

4. New Mobility System

Various kinds of the mobility systems for traverse on rough terrain have been proposed. The suspension system is the key issue for realizing high degrees of mobility. NASA/JPL developed rocker-bogie suspension in a series of the project called "Rocky". That system consists of a pair of two links called the rocker and the bogie which are attached to each other by a passive rotary joint. This combination of the rocker and the bogie makes it possible for the rover to climb rocks 1.5 times its wheel diameter in height smoothly. The rocker-bogie suspension system provides extremely high degree of mobility for the rover. However this is not a perfect system for smaller rover. The rocker-bogie system of Rocky 7 has six wheels. Many-wheels system needs many motors and gears, that causes to increase the weight. Another problem comes from the structure that wheels are attached on the end of the long links and the links are connected by rotary joints as a chain. So very strong stress would act on the links and the joints, even if small force is acted on the wheels. The structure has to be made heavier to endure the strong stress.

A small long-range rover is required to have both a simple and light weight mechanism like 4-wheel drive system and a high degree of mobility like rocker-bogie suspension system. In order to achieve these opposed requirements, the authors propose a new suspension system[18] as shown in Fig.3. The proposed suspension system PEGASUS consists of a conservative four-wheel drive system and a fifth active wheel connected by a link. The fifth wheel which is attached to the end of the link, and the other end of the link is attached to the body with a passive rotary joint. The proposed system is designed to distribute the load of weight equally to all five wheels whenever the rover climb up or down. It means that the fifth wheel supports the load taken to the front wheels when the front wheels climb up rocks, and it also supports that taken to the rear wheels when the rear wheels climb up the rocks. This system can be realized to be simple and light in weight, because the design is based upon a simple 4-wheel drive system.

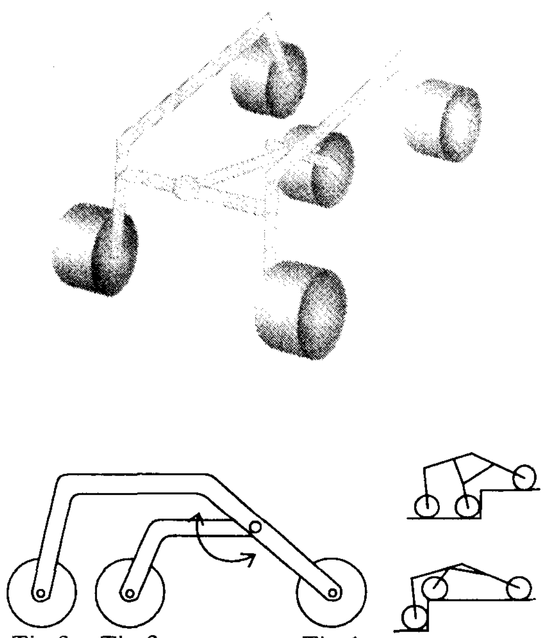


Fig.3 PEGASUS system

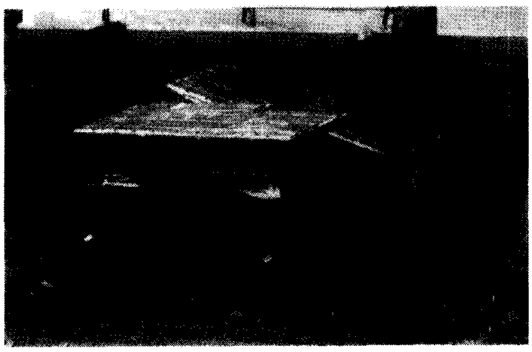
5. Demonstrations

Micro5 navigation strategy is based on teleoperation and autonomous behavior. The performance on the mobility of Micro5 is demonstrated by teleoperation.

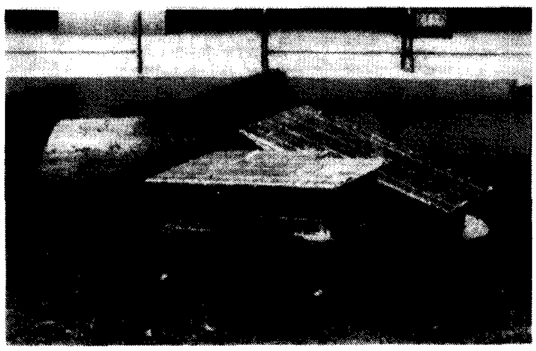
Figure 4 shows the image sequence of outdoor experiments. The experimental result shows the good performance of the developed microrover.

(a) Experimental Image #1

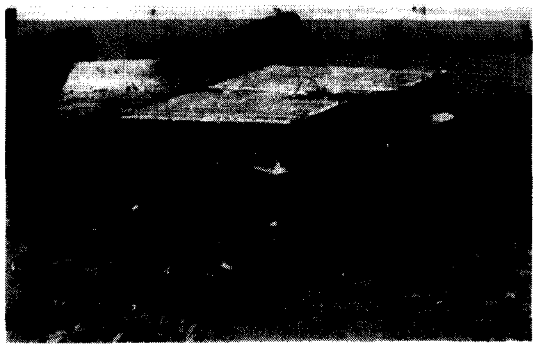
(b) Experimental Image #2



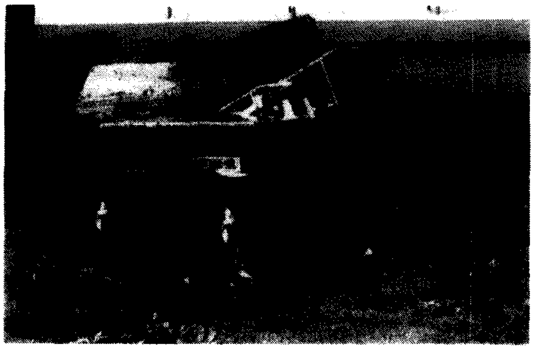
(c) Experimental Image #3



(d) Experimental Image #4



(e) Experimental Image #5



(f) Experimental Image #6

Fig.4 Field Experimental Results

6. Buddy System

The authors are going to design and develop a lunar or planetary rover based on Micro5 architecture according to mission requirements. The authors are also proposing a multiple rovers mission based on buddy system as shown in Fig.5. The proposed buddy system would lead to higher reliability and safety for exploration mission of the moon or planets. The multiple rovers can also make it possible to extend the exploration areas. Various kinds of tasks such as digging, crater exploration, cliff exploration, sample collection can be realized by cooperation of multiple rovers.

7. Conclusions

This paper described a developed microrover "Micro5" for future Lunar or Planetary missions requiring long traverses and rover-based science experiments. This paper also proposed a new design concept on the small light-weight rover with a novel mobility. Some experiments and demonstrations showed the good performance of Micro5. Cooperative exploration by buddy system is also proposed.

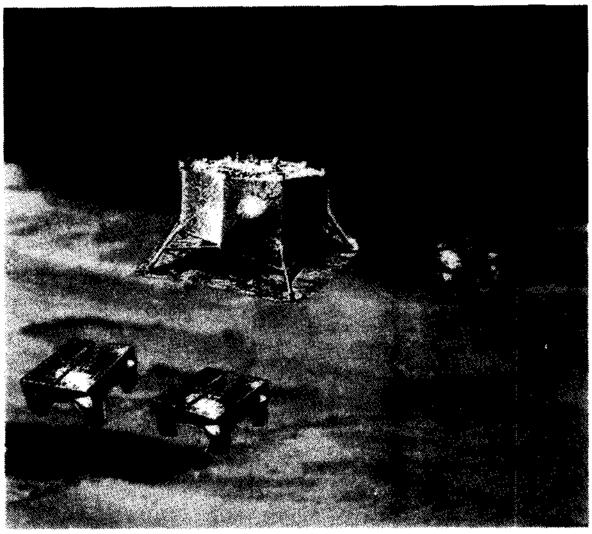


Fig.5 Cooperative Exploration by Buddy System

Reference

[1] J.L.Loch, R.Desai, "Moose on the Loose: Toward Extended Mission Autonomy for Robotic Exploration of Planetary Surfaces," Proc. of ICAR'93, pp.97-101, 1993.

[2] G.Giralt, "Remote Intervention Robot Autonomy and Real World Application Cases," Proc. of IEEE Int. Conf. on R&A, pp.541-547, 1993.

[3] R.Chatila, R.Alami, S.Lacroix, J.Perret, C.Proust, "Planet Exploration by Robots : From Mission Planning to Autonomous Navigation," Proc. of ICAR'93, pp.91-96, 1993.

[4] http;//mpfwww.jpl.nasa.gov/

[5] C.R.Weisbin, D.Lavery, G.Rodriguez, "Robotics Technology for Planetary Missions Into the 21st Century" Proc. of i-SAIRAS'97, pp.5-10, 1997.

[6] L.Matthies, E.Gat, R.Harrison, B.Wilcox, R.Volpe, T.Litwin, "Mars Microrover Navigation : Performance Evaluation and Enhancement," Proc. of IROS'95, pp.433-440, 1995.

[7] D.P.Miller, M.G.Slack, R.J.Firby, "Path planning and execution monitoring for a planetary rover," Proc. of IEEE Int. Conf. on R&A, pp.20-25, 1990.

[8] R.Simmons, E.Krotkov, "Autonomous Planetary Exploration: From Ambler to APEX," Proc. of ICAR'93, pp.429-434, 1993.

[9] E.Gat, R.Desai, R.Ivlev, J.Loch, and D.P.Miller, "Behavior Control for Robotic Exploration of Planetary Surfaces, "IEEE Trans. on R&A, Vol.10, No.4, pp.490-503, 1994.

[10] T.T.Lee, C.L.Shih, "Robust Path Planning in Unknown Environments via Local Distance Function," Proc. of i-SAIRAS'90, pp.251-254, 1990.

[11] R.Simmons, E.Krotkov, L.Chrisman, F.Cozman, R.Goodwin, M.Hebert, L.Katragadda, S.Koenig, G.Krishna-swamy, Y.Shinoda, W.Whittaker, "Experience with Rover Navigation for Lunar-Like Terrains," Proc. of IROS'95, pp.441-446, 1995.

[12] R.Morlanss, A.Liegeois,"A D.T.M based Path Planning Method for Planetary Rovers," Missions, Technologies et Conception des Vehicles Mobiles Planeraires, pp.499-507, 1992.

[13] S.Hayati, R.Arvidson, "Long Range Science Rover (Rocky 7) Mojave Desert Field Tests," Proc. of i-SAIRAS'97, pp.361-367, 1997.

[14] W.R.Whittaker, D.Bapna, M.W. Maimone, E.Rollins, "Atacame Desert Trek: A Planetary Analog Field Experiment" Proc. of i-SAIRAS'97, pp.355-360, 1997.

[15] T.Kubota, I.Nakatani, Y.Kuroda, T.Adachi, H.Saito, T.Iijima, "Izu-Ohshima Field Tests for Autonomous Planetary Rover," Proc. of IROS'98, pp.588-593, 1998.

[16] I.Nakatani, T.Kubota, T.Adachi, H.Saito, "Navigation Technique for Planetary Rover," Proc. of ICAR'95, pp.201-205, 1995.

[17] I.Nakatani, T.Kubota, T.Adachi, H.Saitou, S.Okamoto, "Control Technique for Planetary Rover", 3rd Int. Symposium on Artificial Intelligence, Robotics and Automation for Space, pp.103-106, 1994.

[18] Y.Kuroda, K.Kondo, T.Miyata, M.Makino, "The Micro5 Suspension System for Small Long-range Planetary Rover", ISAS 8th Workshop on Astrodynamics and Flight Mechanics, pp.287-292, 1998.