Newly Developed Microrover System for Lunar Exploration

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Abstract : This paper describes a newly developed microrover with small size, lightweight, 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 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

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[1][2][3] for unmanned surface exploration of planets. 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 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].

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[11]. 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[12]. The authors also have done a long-range test for the perfect autonomous rover at a slag heap in Izu-Ohshima in Japan[13].

The authors have studied a lunar rover that can travel safely over a long distance on rough terrain. The authors have developed a small, lightweight microrover with a new mobility system, which is called "Micro5". This paper describes the design and implementation of a small rover for future Lunar 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 exploration is explained. Then a new mobility system is proposed in Section 4. Section 5 discusses some experiments and demonstrations for Micro5. Finally, Section 6 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's 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. This paper here describes science missions by rover, requirements from scientific viewpoint, and engineering techniques to be developed.

2.1 Science missions

Candidates for rover missions here, not all of which, though, will be accommodated by 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 □-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 rovers are expected to travel in wide areas and explore the surface in detail. Exploration requirements for lunar 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 rover missions 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 the specification of the developed Micro5 are shown in Fig.1 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 0.15[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.

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. On-board computers perform sensor data processing and control. 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, and scientific data to the ground system. Operators can control the robot based on image data by teleoperation techniques. Micro5 has the sampling system. The lightweight manipulator with a CMOS camera has been developed, which will be attached to the front of the rover. Some scientific instruments are under development.

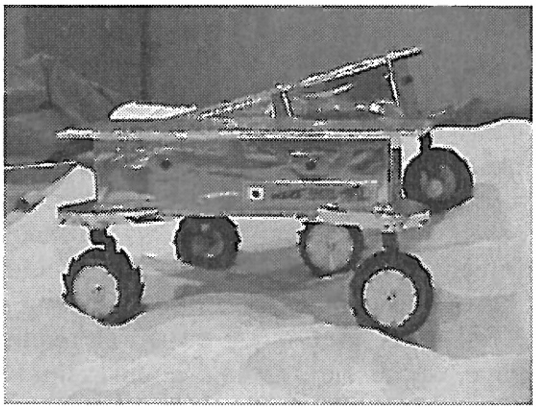

Fig.1 Overview of Micro5

Table 1 Specification of Micro5

Size	0.55[m] (length) 0.53[m] (width) 0.25[m] (height)
Weight	About 5[kg]
Mobility System	PEGASUS Wheel diameter : 0.1[m]
Mobility Performance	Velocity : 1.5[cm/s] Climbable step : 0.15[m] Climbable slope : 40[deg]
Power Supply	Solar Panel : max 27W Battery : NiCd, Lithium
Power Consumption	Actuator : max 5[W] Computer : max 4[W]
Payload	4 stereo cameras Manipulator

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 lightweight 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[14] as shown in Fig.2 and 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.

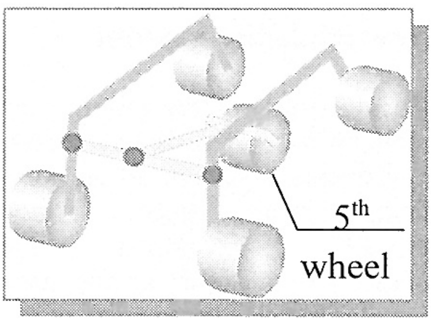

Fig.2 PEGASUS System

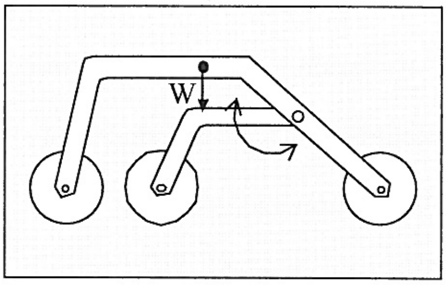

Fig.3 PEGASUS Mechanism

5. Experimental Study

5.1 Energy Consumption Evaluation

In order to evaluate energy consumption performance of Micro5, three types of rover models are tested, which have conventional four-wheel drive, rocker-bogie suspension and PEGASUS, respectively. Energy consumption of each model is defined that each model consumes electricity while they are climbing over the step. Torque generated by each tire can be calculated from the current measured in each motor. For the equality in conditions for each suspension system, the size and the weight of models are set to be the same. The test is carried out in three states of the center of gravity as shown in Fig.4 to examine the position effect of the center of gravity.

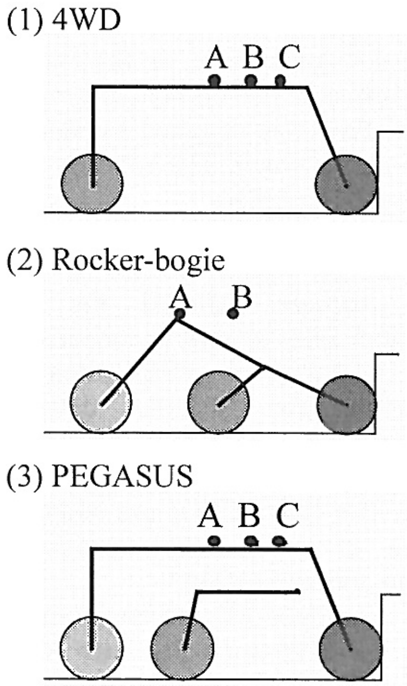

Fig.4 Rover Models

Figure 5 shows the experimental results of three rover models, while climbing over the step. In Fig.5(1), the rear wheel of 4WD model slipped and could not climb the step because the center of gravity is located very behind. However PEGASUS could climb over the step smoothly as shown in Fig.5(3). Figure 6 shows the total energy consumption calculated by the summation of the current of the whole tires, while each model is climbing the step. The experimental results show that PEGASUS and rocker-bogie suspension were better than 4WD, because their load distribution capability. Furthermore, PEGASUS consumes 20% lower than rocker-bogie suspension, because the number of wheels of PEGASUS is five.

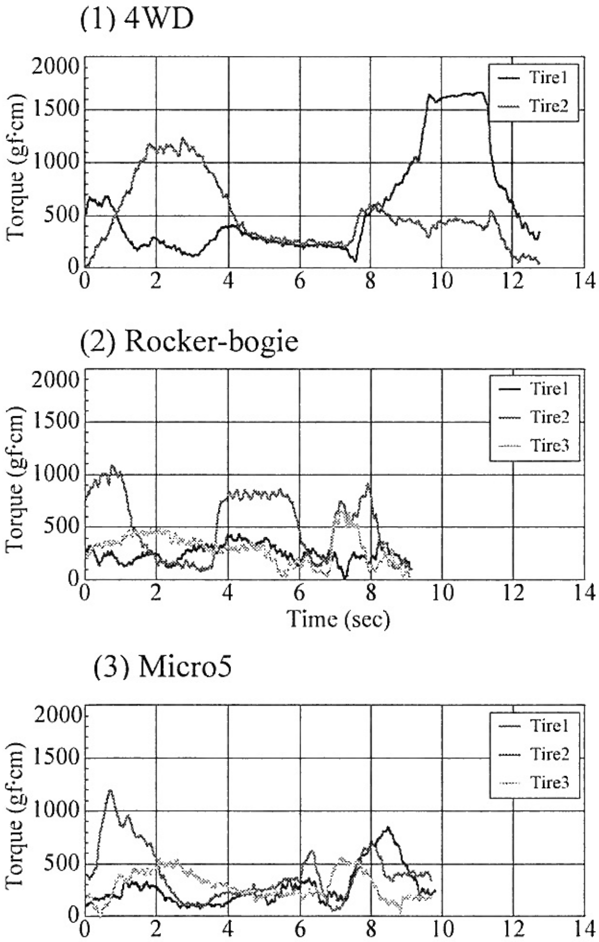

Fig.5 Energy Consumption

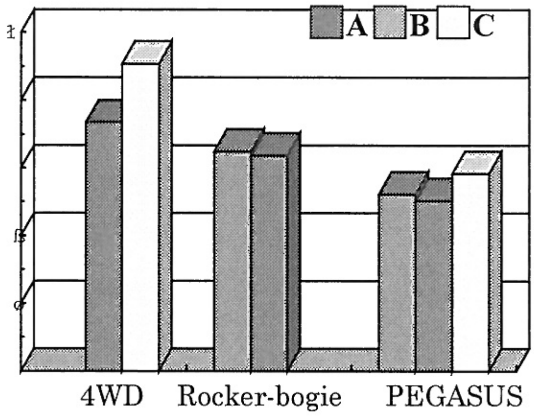

Fig.6 Total Energy Consumption

5.2 Micro5 Mobility Demonstration

Micro5 navigation strategy is based on both tele-operation and autonomous behavior. The performance on the mobility of Micro5 is demonstrated by teleoperation. Micro5 does not have any active steering mechanism. The surface of the moon is covered with regolith like sand. So the steering is controlled by differential of left and right wheels. To turn easily, special tires with spiral fin are developed as shown in Fig.7.

Figure 8 shows the image sequences of outdoor experiments. Micro5 can get over small crater and step. The experimental results show the good performance of the developed micro-rover.

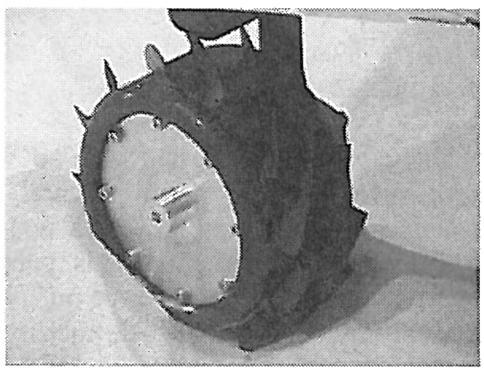

Fig.7 Tire with Spiral Fin

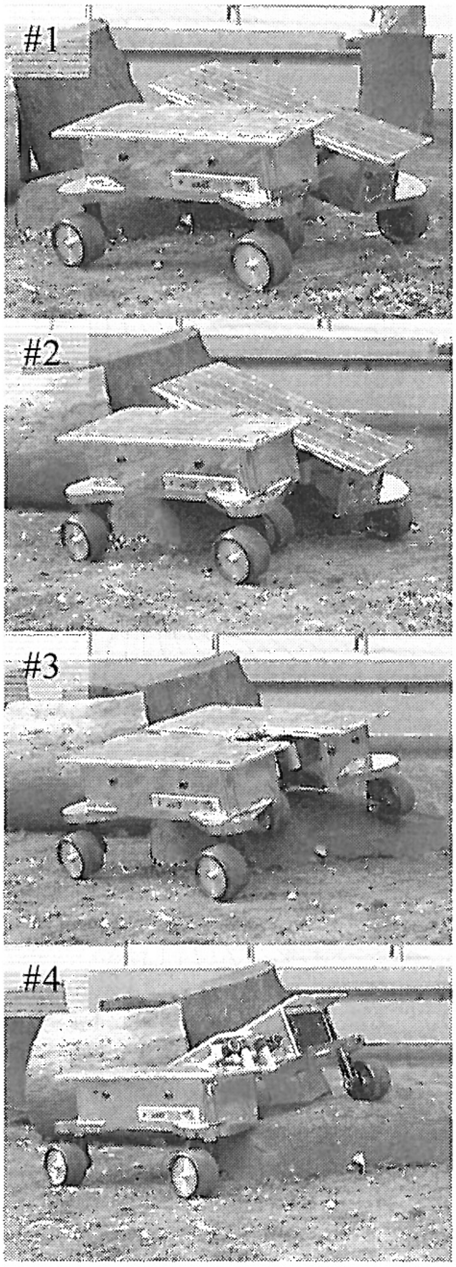

Fig.8 Field Experimental Results

6. Conclusions

This paper has presented a developed microrover "Micro5" for future Lunar missions requiring long traverses and rover-based science experiments. This paper also proposed a new design concept on the small lightweight rover with a novel mobility. Some experiments and demonstrations showed the good performance of Micro5.

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