Low Power Mobility System for Micro Planetary Rover *"Micro5"*

Yoji KURODA*, Koji KONDO*, Kazuaki NAKAMURA*,
Yasuharu KUNII**, and Takashi KUBOTA***

*Dept. of Mechanical Engineering, Meiji University
**Dept. of Electrical and Electronic Engineering, Chuo University
***The Institute of Space and Astronautical Science

1-1-1 Higashi-mita, Tama-ku, Kawasaki 214-8571, JAPAN
Phone/Fax: +81-44-934-7183, e-mail: ykuroda@isc.meiji.ac.jp

Abstract

In this paper, we propose a newly developed suspension system called "Pentad Grade Assist Suspension (PEGASUS)". PEGASUS has high mobility as well as rocker-bogie suspension, with very simple mechanism called only-one-joint architecture. PEGASUS is able to successfully climb up on the step-alike terrain with low energy consumption by scale model test. The prototype of micro planetary rover Micro5 which has been developed by the rover R&D group of ISAS, Meiji university, and Chuo university, adopts PEGASUS as its mobility system. The Micro5 is under testing on the variety types of land environment.

1. Introduction

A mission which is an investigation of the Moon or planets is one of the most effective methodology to know how the Solar system was born. As the result of those many missions, e.g. sensing their surfaces with orbiter or lander, had been carried out, we were able to gain wonderful knowledge. Now, it can be said that more detailed investigation should be started to solve more wonder. [1] On the other hand, almost all countries had to cut down the budget for the development of the space because of their economical problem. As a total cost of missions has been reduced, mission concepts have to be changed to "Smaller, Faster, Better" from large scale projects like Apollo missions. In order to carry out the missions with low-cost, using a small unmanned roving vehicle (shown as 'rover' hereafter) is one of the fascinating ideas.

On July 4, 1997, NASA succeeded to carry out the mission Mars Pathfinder which the rover called Sojourner [2][3][4] was launched to the surface of Mars. Since the mission was the first challenge to explore the surface of Mars by using a rover, Sojourner was just tested it's technical capability to rove near around a lander station. In spite of that, this success was good news because it was proved that the rover was very useful for the surface investigation. Thus, the rover has been required to explore wider in area during longer term for more scientifically-valued missions. In order to explore wider in area, the rover should have a high degree of mobility to traverse rough terrain.

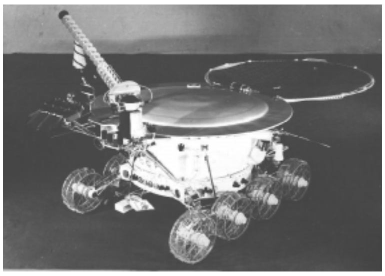
In this paper, we propose a new mobility system called "Pentad Grade Assist Suspension (PEGASUS)" especially for the small long-range rover.

2. Micro Planetary Rover

The next generation micro planetary rover is required to carry out scientific measurement at many points on wide planetary surface during its limited lifetime. The requirements are not clearly defined, but it could be said that total mass of the rover would approximately be less than 30kg because of capacity limitation of launch vehicles.

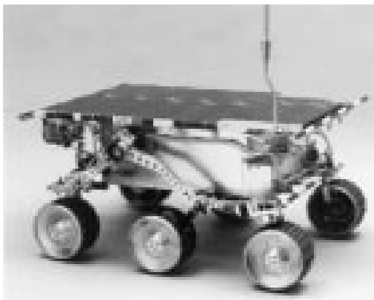
Fig.1 Micro5: prototype micro planetary rover

(a) Nomad: 4 wheeled rover

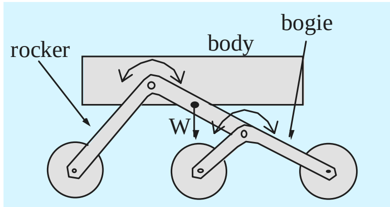


(b) Lunokhod: 8 wheeled Luna rover

Fig.2 Valiety of mobility systems



(a) Sojourner: the Mars rover with Rocker-bogie suspension



(b) Mechanisms of a rocker and a bogie

Fig.3 Rocker-bogie suspension system

In this paper, we discuss the rover system on the premise that the power is supplied from solar cells and batteries. In order to achieve above requirements, the rover *must* have a mobility system which has (1) mechanism to improve its degree of mobility, (2) low energy consumption, and (3) simplicity so as to be embedded in a small body.

These things listed above are showing a tendency to exaggerate when a rover becomes smaller, because a small rover has to pass over relatively big rocks within relatively low power. In order to examine micro planetary rover in a total system, the prototype rover called *Micro5* [14] has been developed in March 1999 by the R&D group consists of the Institute of Space and Astronautical Science (ISAS), Meiji university, and Chuo university. *Micro5* is shown in Fig.1, was designed to have small body sized as a microwave oven, and extremely light in weight as 5 kg excluding scientific instruments. PEGASUS was adopted as a new mobility system for *Micro5* rover.

3. Mobility

Because the suspension system is the key issue of degree of mobility, a variety of mobility systems for cruising rough terrain have been proposed. In this chapter, we'll see some typical systems to know what essential points are for improving mobility.

3.1 Conventional 4-wheel drive system

As you know well, a 4-wheel drive (4WD) shown in Fig.2 (a) is the most popular system for an automobile to traverse rough terrain. We call this conventional 4WD here after. There are many rovers adopted this system for its locomotion, e.g., ISAS/ Nissan rover [5][6], Nomad [7], AMSL Minirover [8], etc. Conventional 4WD has no mechanisms to improve its mobility, but has just one provides torque to each wheel distributively. It's simple and light in weight, however, it doesn't have high degree of mobility compared with following systems.

3.2 Multi-wheel (6 or more) drive system

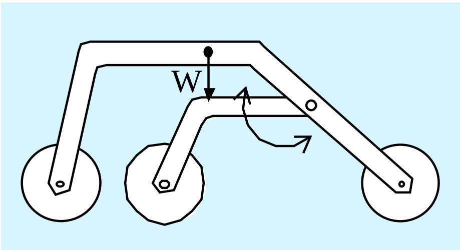
Some Russian rovers [9], e.g. Lunokhod [10], Marsokhod [11], etc., have 6 or more wheels as shown in Fig.2 (b). We classified them as a multi-wheel drive (MWD) system here after. As same as the 4WD system, the MWD system has only the mechanism to distribute the load of weight and torque to each wheel. Though the system has higher degree of mobility because of its load distribution capability, the system is intended to be heavier. Therefore, it is not appropriate to apply for a small rover.

3.3 Rocker-bogie suspension system

Rocker-bogie suspension [2]-[4][12][13] is the system to rove on Martian surface in the mission Mars Pathfinder. NASA has developed this suspension system in a series of the project called 'Rocky'.

As shown in Fig.3, the 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. The rocker, therefore a set of three wheels, is attached to each side of the chassis by another rotary

(a) The Micro5 rover prototype with PEGASUS system in a mobility test on silica sand



(b) Mechanism of PEGASUS system

Fig.4 "Micro5" the prototype micro planetary rover with PEGASUS mobility system

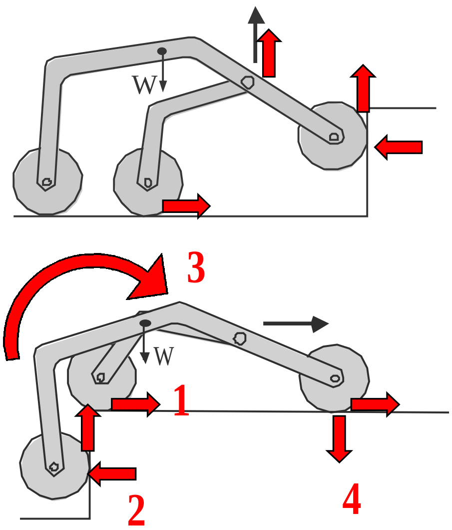


Fig.5 Kinematics of PEGASUS to climb a step

joint. As the wheels are free to move up and down with rotary joints, the system is able to distribute the load of weight to six wheels equality. By this combination of the rocker and the bogie, the rover can climb rocks 1.5 times its wheel diameter in height smoothly.

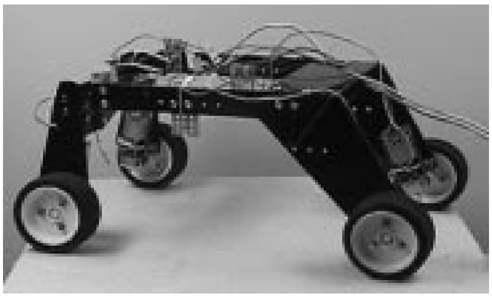
Though the system provides extremely high degree of mobility for the rover as mention before, this is not a perfect system for smaller rover. One is that the rocker-bogie has six wheels. Many wheels it has means many motors and gears are contained. So, many-wheeled system, in general, has easily increased the weight. Another problem comes from its complex structure that wheels are attached on the end of the long links and the links are connected by rotary joints as a chain. A pair of lockers and the body are connected via a differential bar in order to stay pitching angle of the body at the middle of two lockers. Therefore, If small force affected on the wheels, very strong stress would be loaded on the links and the joints because of the lever-like structure. Since the links and the joints have to endure high stress, the structure must be made stronger. This leads the system to be heavier.

3.4 PEGASUS system

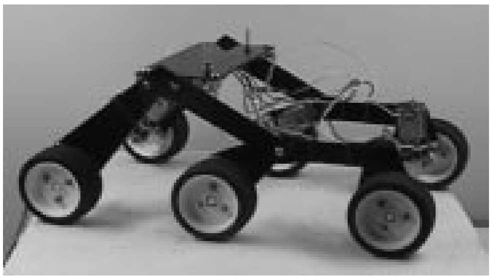
As above, the small long-range rover is required to have both a simple and light weight mechanism like 4-wheel drive system and a high degree of mobility like rocker-bogie suspension system. In order to achieve these opposed requirements, we propose a new suspension system named "Pentad Grade Assist Suspension (PEGASUS)". A newly developed rover prototype *Micro5* equipped with PEGASUS system is shown in Fig. 4 (a). PEGASUS consists of a conventional four-wheel drive system and a fifth active wheel. As shown in Fig. 4 (b), the fifth wheel is attached to the end of a link, and the other end of the link is attached to the body with a passive rotary joint. PEGASUS needs only one joint rather than the rocker-bogie which needs 4 joints. In general, joints are heavy parts and easily lead to trouble in space environment. So, the architecture called "Only-One-Joint" would be one of advantages.

The system is designed to distribute the load of weight equally to all five wheels when the rover climb up on the step-alike terrain. 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. As shown in Fig.5, when the rear wheel climb a step, forward force generated by the traction of the fifth wheel (shown #1 in Fig.5) pushes the rear wheel backward as (#2). These forces produce nose-dive moment (#3), then the moment turns to a vertical force of the front wheel (#4) to support traction. This is the reason why PEGASUS has extremely high mobility. This system realizes such high mobility in simple and light mechanism.

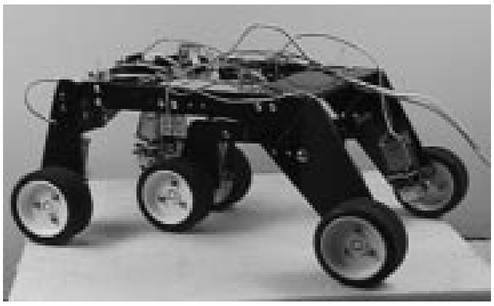
In the following chapters, we discuss how the system is appropriate to the small long-range rover compared with some other typical systems through the



(a) Conventional 4-wheel drive (4WD)



(b) Rocker-bogie suspension



(c) PEGASUS system (consists of the 4WD model with the fifth wheel)

Fig.6 Rover models for energy consumption test

performance evaluation which is carried out by experimental analysis.

4. Energy Consumption Evaluation

In order to compare energy consumption performance with those of typical mobility systems, we made three types of 1/2 scaled rover models which have conventional four-wheel drive, rocker-bogie suspension, and PEGASUS, respectively. The model are shown in Fig.6. An example view of energy consumption test is shown in Fig.7. Energy consumption of each models are defined that each models consume electricity while they are climbing over the step. Torque generated by each tire can be calculated from current measured in each motor. For the equality in conditions for each suspension systems, size and weight of models are set to be same. The test is carried out in three state of center of gravity as shown in Fig.8 to examine the position effect of center of gravity.

Figure 9, 10 and 11 show the results of model test while climbing over the step. In Fig.10 (a), the rear wheel of 4WD model slipped and couldn't climb the step because the center of gravity is located too behind. But PEGASUS could climb over the step smoothly in the case of (a) as shown in Fig.11 (a). Total energy consumption calculated by the summation of current of whole tires while each model is climbing the step is shown in Fig.12. By the result, PEGASUS and rocker-bogie suspension was better than 4WD because their load distribution capability. Furthermore, PEGASUS consumes 20% lower than rocker-bogie suspension. The reason can be considered that PEGASUS has five wheels rather than six wheels.

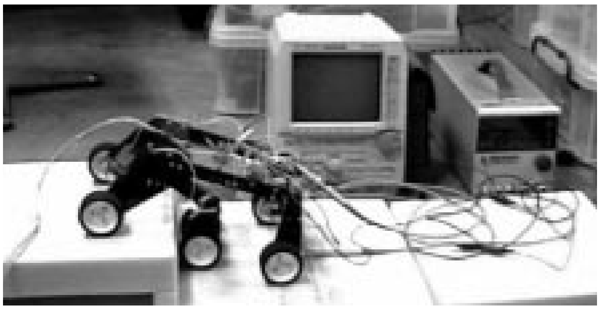
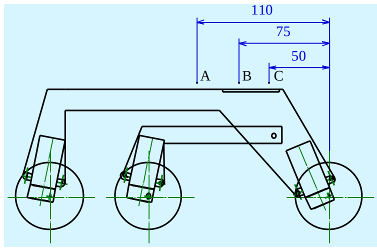
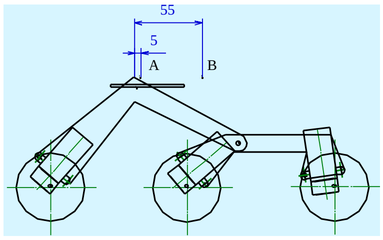


Fig.7 An example view of energy consumption test



(a) Model of 4WD and PEGASUS system



(b) Model of Rocker-bogie suspension

Fig.8 Valiety of the position of center of gravity

5. Conclusion

Micro planetary rover needs to be equipped with the mechanism which actively or passively improve its mobility because of overcoming its physical limitation. In this paper, we proposed a newly developed suspension system called PEGASUS. PEGASUS has high mobility as well as rocker-bogie suspension, with very simple mechanism called Only-One-Joint architecture. PEGASUS was able to successfully move within very low energy consumption

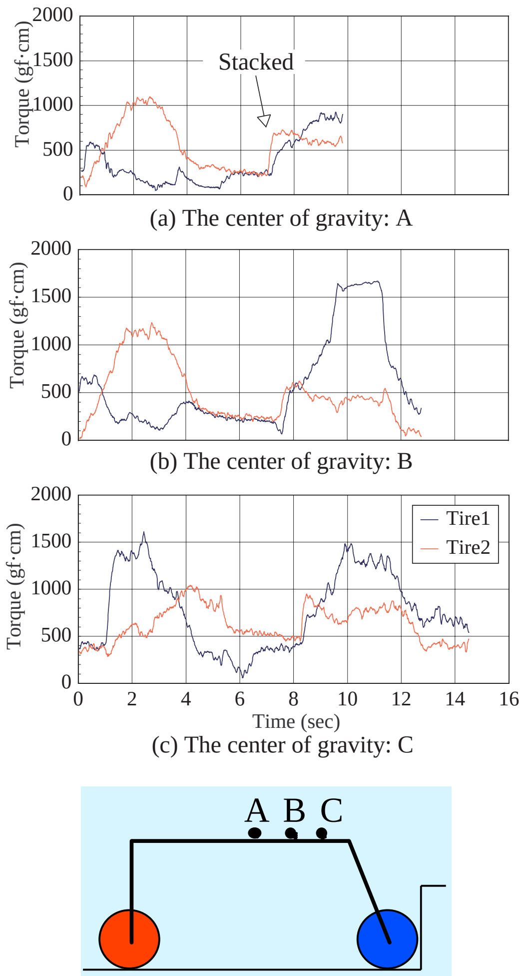


Fig.9 Results of energy consumption experiment Conventional 4-wheel drive

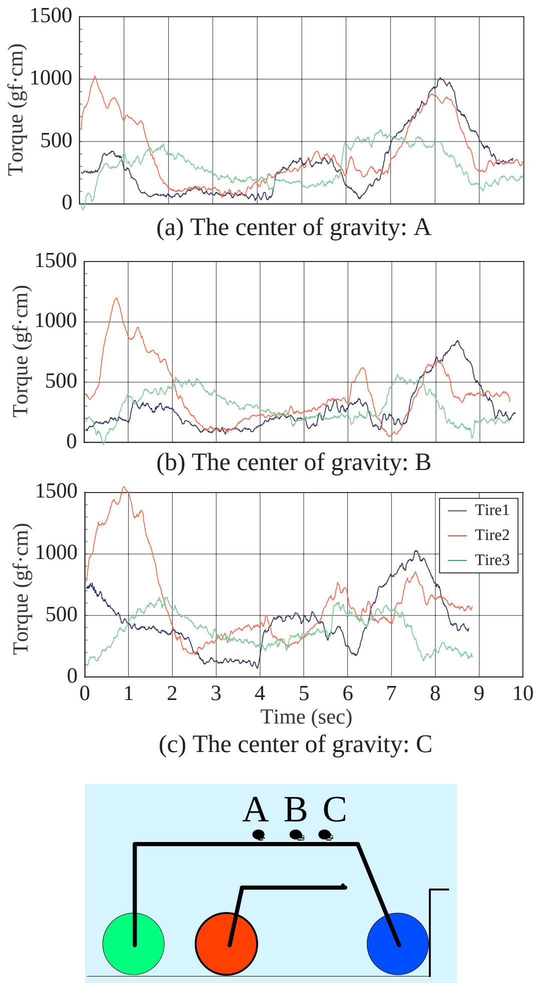


Fig.11 Results of energy consumption experiment PEGASUS system

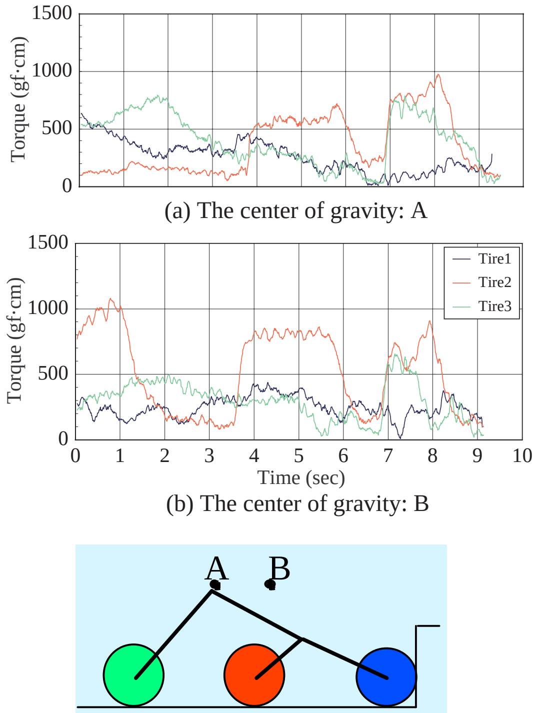


Fig.10 Results of energy consumption experiment Rocker-bogie suspension

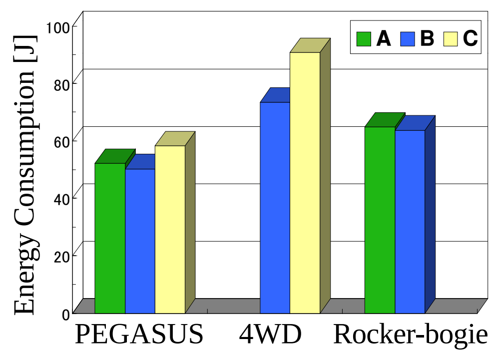


Fig.12 Results of energy consumption experiment comparison of total performance

by scale model test. The prototype of micro planetary rover Micro5 which has been developed by the rover R&D group of ISAS, Meiji university, and Chuo university, adopted with the PEGASUS as its mobility system. The Micro5 is under testing on the variety types of land environment.

Acknowledgments

The *Micro5* prototype planetary rover was developed by collaboration with *GH-Craft ltd.* and *Advanced Circuit Technologies (ACT) Inc*.

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