Micromanipulator with Lightweight and Low Power Consumption by using Ultra-Sonic Motor for Planetary Explore Mission

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Abstract

Japanese space agencies are planning SELENE mission series, that will launch an orbiter and a lander mission to the moon in the next decade. One of candidates in SELENE 2 missions is a rover mission. A manipulator has strong possibility to be one of equipments mounted on a rover, though. It is to be a periscope and a sampling tool, and can operate other scientific equipments. In this paper, we discuss a manipulator for our rover system and introduce a developed micro manipulator. It has 5 degrees of freedoms and each joint is driven by a Ultra-Sonic Motor (USM) which needs no electrical power to keep a posture of a manipulator. In general, a manipulator spends almost of working times to maintain to its posture, so that is stopped. However, in that time, each actuator makes a torque by using electrical power and also CPU power. That is huge energy loss in the very severe energy environment like the space, and we need some countermeasure on this problem. We strongly believe that the best solution of this problem is to apply USM to an actuator of a joint to solve this problem. To make a torque on a rotor, it should have a large friction on a interface between a stator and a rotor. It means USM can have a large static friction during an idle state, so that works like a clutch. Furthermore, we don't need any electrical and CPU power to stop a rotation of a joint, and it is very light.

1. Introduction

Toward the next decade, several schemes sending an unmanned mobile explorer to the moon or Mars are being planned for scientific exploration [1][2][3]. In recent years, many researchers have studied and developed lunar or planetary rovers for unmanned surface exploration. Especially micro-rover missions, for example, Sojourner rover (1997), have received a lot of attention, because small, low-cost missions are typically constrained by mass, budget and schedule.

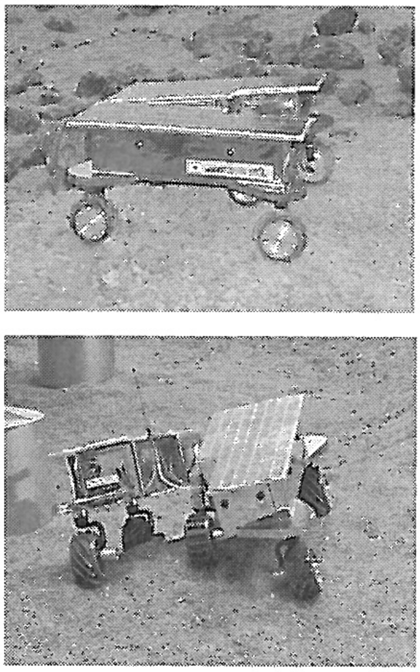


Fig. 1 Lunar Rover: Micro5-01

In the case of Japan, Japanese space agencies are planning some missions launching unmanned scientific explorers to the moon in the next decade. For example, one of them is SELENE 2 mission series that include an orbiter and a lander mission to the moon. One of candidates in SELENE missions is a rover mission. On the standpoint of a mission area, there are much advantages to send a rover to the moon surface. A mission scope of a lander, which doesn't have mobility, is just a point. However, if we can have a rover, the mission area can be expanded to two dimensional mission area. Object of a rover mission is scientific investigation, therefore, a rover system is not a mobile engineering system but a part of scientific equipments. Low cost missions have furthermore been required by Japanese space agencies, because of their budget and a performance of their rockets in these missions. So a design of a rover should be consider as total scientific system including some scientific equipments for each mission. But scientific missions depend on each mission; so, it is difficult to discuss about mission equipments. A manipulator has strong possibility to be one of equipments mounted on a rover, though. In other words, a manipulator should be mounted on a rover system. A manipulator is to be a periscope and a sampling tool, and can operate other scientific equipments.

In this paper, we introduce a micro-rover called "Micro5" which has new suspension system: PEGASUS for high mobility performance, discuss a manipulator for this rover and introduce a developed micro-manipulator. The manipulator is mounted in the middle of Micro5 without a disturbance of a power generation by solar panels. The manipulator is designed after discussions of scientific mission requirements and an evaluation of its joint driving rates. It has 5 degrees of freedoms and each joint is driven by a Ultra-Sonic Motor (USM) which needs no electrical power to keep a posture of a manipulator. The manipulator is operated with a virtual world simulator and images sent from a hand eye camera by a joystick located on a remote site.

2. Lunar Rover: Micro 5

Developed Micro Planetary Rover: "Micro5" is shown in Fig.1[4]. It can perform a lightweight, a small size, a low electric power and high mobility.

Micro5 is driven by five wheels controlled independently. The steering is controlled by differential of left and right wheels. We have 3 types of Micro5s and each one has a different type of small actuators such as a DC motor, a DC brushless motor and an ultrasonic motor. The velocity of the rover is about 1.5[cm/s]. It has the proposed new suspension system called PEGASUS (PEntad Grade Assist SUSpension)[5]. So the climb-able step height is 0.15[m] and it is 1.5 times of the wheel diameter. The climbable slope is about 40[deg]. An electrical power is supplied by two solar panels on the top of the rover. Each panel has 36 solar cells and total maximum electrical power is 36[w]. It can be also driven by on-board batteries, which are charged by solar panels when the rover gets much solar power. Two CMOS cameras are used as stereo camera for a forward terrain sensor.

It also has other cameras around of 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, for example, RISC-CPU.

3. Design of Manipulator on Rover

3.1. Manipulator as Rover System

In general, it is necessary and indispensable in the science mission to install science observation equipments. However, it is generally difficult to discuss features of science equipment, because it has strong relationship to a mission and that depends on each mission. We can develop some manipulator for specific mission, but then again it becomes important that a manipulator have enough generality to be applied to many missions in the limited weight. It has much advantage to install a manipulator, which is not for specific work, on a rover for the operation side and the science side. For instance, it is a manipulation of the science tool such as a sampling tool and the spectrum cameras etc., and it is an active camera for 3D measurement and periscopes (observatory) for the navigation and the science observation. As for a manipulator on a rover, it is expected as a sensor system combined many kinds of functions.

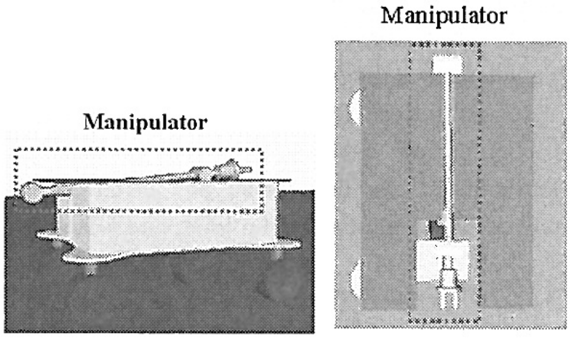


Fig.2 Location of Manipulator on Micro5

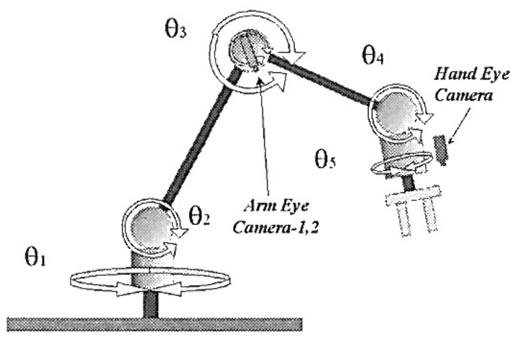


Fig. 3 Structure of Micro Manipulator

3.2. Requirement and Feature of Manipulator

Functions of a manipulator in the rover mission are as follows:

- Observation of a remote place (by a camera, etc.)
- Observation of an environment surrounding a rover (including itself)
- Collecting a samples for the scientific observation
- Approaching and touching to a soil and rocks with an science equipment such as a spectrum camera
- Digging the ground & Breaking samples into pieces (development of an endeffector)
- Removal of dust from a surface of a sample
- Functions as maintenance tools such as the cleaning tool for the solar panels etc.
- 3D space measurement sensor, etc.

On the other hand, it is a very severe energy situation in space and on the planet (surface of the moon) , therefore, we have to make any efforts saving total power consumption for a rover system. A manipulator is not exception of that too. In addition, it needs to consider a lot of demands including above mentioned functions and the weight limitation, as follows.

- Down sizing and lightening
- Low electric power consumption
- Long links for large work space and observation of remote place
- Enough degree of freedom for missions
- Installation of sensors such as a camera
- Installation of endeffector

3.3. Design of Manipulator on Rover

We considered above mentioned demands and requirements, designed and developed a manipulator for the micro lunar rover: Micro5 in Fig.1. We have many choices of locations to put a manipulator on Micro5. We decided this location is the center of the rover with a

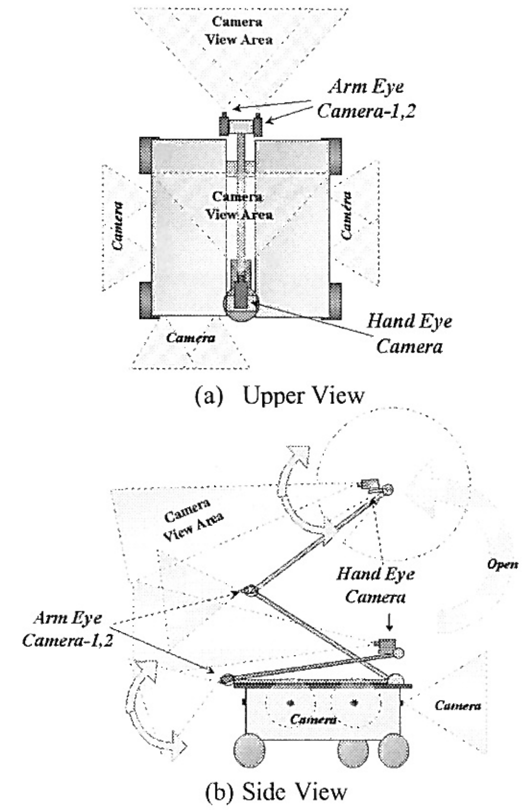
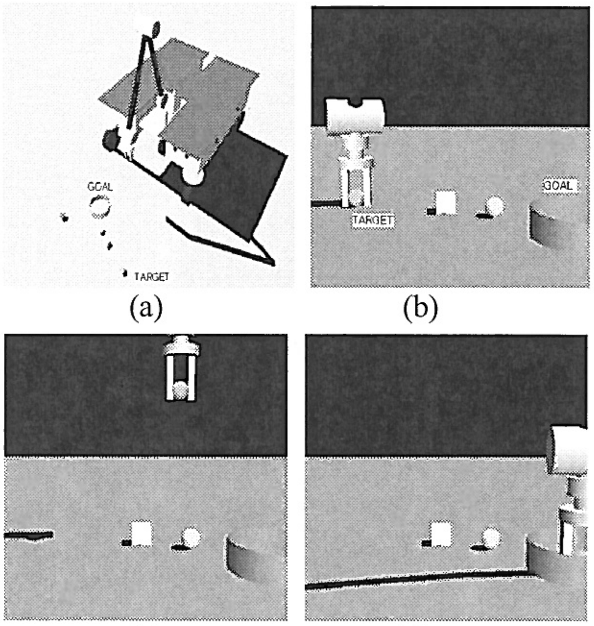


Fig. 4 Camera System of Micro5

weight balance and without disturbance of a power generation of solar panels (Fig.2). Structure of developed manipulator is shown in Fig.3. It has 5 Degrees-Of-Freedom (DOF), because of assuming some operations, for example, picking up samples and inserting a science equipment into topsoil. However, it is also possible to extend the number of DOF to 6 DOF ac-cording to the mission.

3.4. Manipulator as Camera System on Micro5

This manipulator system is providing another important function to the rover, and that is a function as one part of visual sensor systems on Micro5. Whole of visual sensor system on Micro-5 is planned as shown in Fig.4. Four stereo camera systems are located on the each side of the body. Three small size cameras are planned at the elbow and the top of this manipulator, but in this time, it has only one camera as a hand eye camera on the top(Fig.3). A hand eye camera and stereo arm eye cameras can be located at high position by expanding the manipulator, and these work like an observatory. We are planning the elbow joint on which the arm eye cameras and the third joint can be moved separately. It can be operated for various missions with other cameras



(a) (b) (c) (d)

Fig.5 Tele-Sampling Simulation

(a) Mode1 (b) Mode2

Fig.6 Operation Method

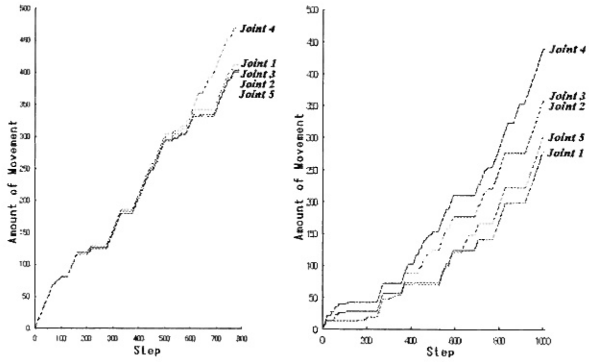
on Micro5. This camera system is useful for the autonomous navigation, the tele-driving and the tele-science. Especially, an environment and elevation map data is acquired by this system, during navigation and tele-driving of the rover.

4. Joint driving rate & Actuator

4.1. Joint driving rate

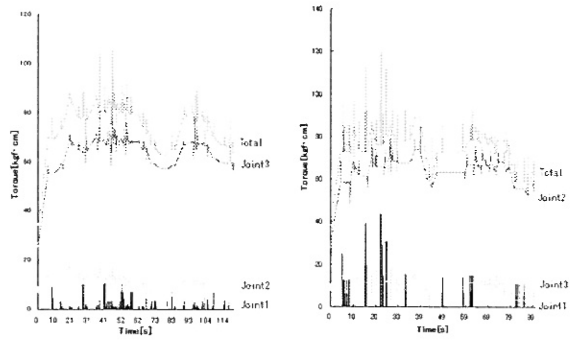
In general, a manipulator spends almost of working times to maintain to its posture, so that is stopped. Therefore, it is forecast that the energy of a manipulator spends on each command waiting time by keeping of some posture.

Here, we assume that a manipulator is working on an operation in which it grasps a sample and puts it into a bucket by tele-control. This operation is realized with a computer simulation as shown in Fig.5, and an operator uses a joystick to control it during an operation. In the first step of an approach phase, which a manipulator comes upon a sample, a manipulator is constrained into



(a) mode1 (b) mode2

Fig.7 Joint Movement



(a) mode1 (b) mode2

Fig.8 Joint Torques (Joint 1-3)

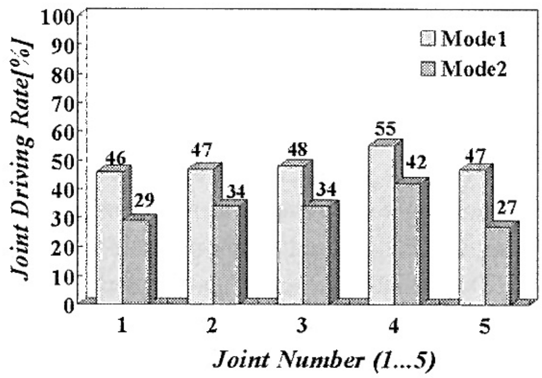
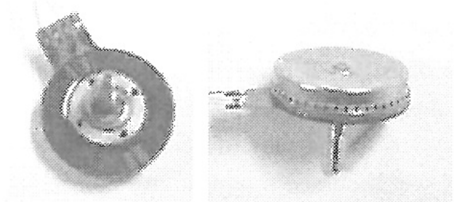


Fig.9 Driving Rate of Actuators

Total Length	920[mm]
Total Weight	1.45[Kg]
Conveyable weight	300[g](on the earth)
Actuator	Ultra-Sonic Motor
Reduser	Harmonic Gear

Table.1 Specification of Micro Manipulator



(a) Appearance

Rated Speed	250[rpm]	Max. Torque	1[Kgf-cm]
Rated Torque	0.5[Kgf-cm]	Hold Torque	1[Kgf-cm]
Rated Power	1.3[w]	Weight	20[g]

(b) Specification

Fig. 10 Ultra Sonic Motor - USM

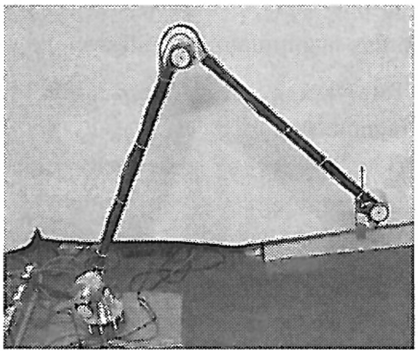


Fig. 11 Micro Manipulator with USM

a parallel plane to the ground. An operator can approach to a upper point of a target by two operational methods, namely, orthogonal mode (mode1) and polar mode (mode2) in Fig.6. When a manipulator arrives at there, it will go down to and grasp a target sample. After grasping at a sample, it will be moved into a bucket (Fig.5(d)).

Now, let us check a stopping time of a manipulator during its operation. We recorded each transition of joint angles and torques as shown in Fig.7 and Fig.8. The transition of joint angles in Fig.7 is integral summation of each joint motion, and those even part of each transition indicate that each joint are stopping. It is easy to find an even part on each operational mode in this operation. Drive rate of each joint, that is actuator, is shown in Fig.9. Each joint doesn't work for more than half of operational time. However, in that time, each actuator makes a torque by using electrical power and also CPU power. This idle time might be increased more in an actual science operation. That is huge energy loss in the very severe energy environment like the space, and we need some countermeasure on this problem.

4.2. Ultra Sonic Motor

One of solutions of this above-mentioned problem might be a clutch put on a joint but it increases a weight of each joint and makes complexity of joint structures. High gear ratio is also one solution but it is difficult to guarantee to keep joint angles without control. We strongly believe that the best solution of this problem is to apply Ultra-Sonic Motor (USM) to an actuator of a joint to solve this problem. The principle of USM is a ultra sonic wave, which make a traveling wave on the surface of a stator. This traveling wave makes an elliptical orbital motion on a contact surface to a rotor, and a rotor is carried to the direction of the traveling wave. It works like a wave, which can carry garbage to somewhere, in the sea. To make a torque on a rotor, it should have a large friction on a interface between a stator and a rotor. It means USM can have a large static friction during an idle state, so that works like a clutch. Furthermore, we don't need any electrical and CPU power to stop a rotation of a joint. USM and its specification are shown in Fig.9. They indicate that USM is the best solution on the point of low electrical power consumption and its weight.

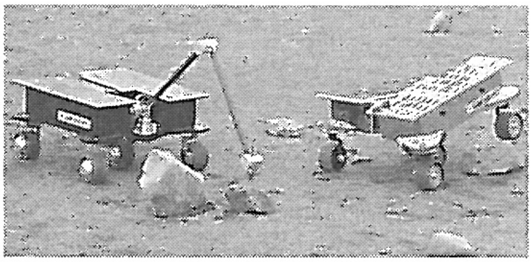


Fig.12 Micro5-01(right) & Micro5-02(left)

5. Development of Micro Manipulator

The prototype of micro-manipulator is shown in Fig.11. It is mounted on the middle of Micro5, and that is in the space between right and left body, where it is not disturb a generation of solar panels, as shown in Fig.12. The feature of this manipulator is described in Table.1. Ultra-Sonic Motor (USM) drives each joint with Harmonic Drive gear, and almost all of links are made of carbon fiber plastics (CFRP). The manipulator is automatically oper-ated between the closed mode and the opened mode. When the manipulator is in the closed mode, the direction of a hand eye camera is into the forward of Micro5. Therefore we can get a front view sending from Micro5. On the other hand, the workspace is mainly to be at the back of Micro5, when it is in the opened mode. It can also touch solar panel side, so it is possible to clean up dusts on panels.

Advantages of a manipulator actuated by USM were indicated by this prototype model. In addition, we are

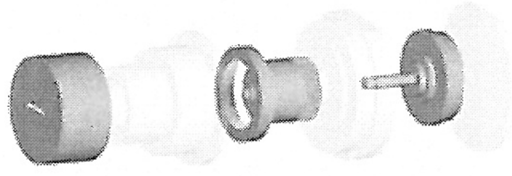


Fig.13 New USM Drive Unit for Joints

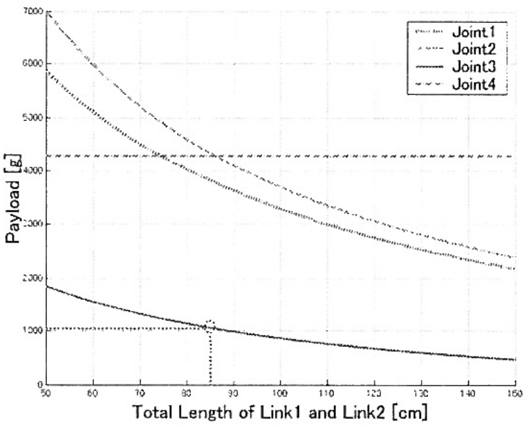


Fig.14 Payload by total length for a manipulator mounted new USM unit.

redesigning the USM drive units of each joint, to improve a performance of a conveyable weight. It should be small and lightweight, and the design of new USM drive unit is shown in Fig.13. It also consists of Harmonic Drive and USM, and we are designing three sizes of drive units, such as large, middle and small size. The first and second joint from the basement are large size, the third joint unit is middle size and the fourth and fifth joints are small size. Simulation result about a conveyable weight, that is a payload by a total length, is indicated in Fig.14, and it was simulated using nominal torque. In our design, the payload limitation comes about torque capacity of third joint, and that is 1.05[Kg] including a weight of an endeffector(0.4[Kg]), when total length of manipulator links is 0.85[m] consisting of Link-1 (0.45[m]) and Link-2 (0.4[m]). Here, total link length is consisting of link1 and link2 and those links have the difference of 0.05[m] as clearance, to close manipulator. Its maximum payload will be about 2.4[Kg] with a repeated peak torque that is dangerous and not nominal value. If a large size unit is used on the third joint, we can have two or three times of payload in exchange for total weight. And also, we have a tradeoff between the payload and the total length, shown in Fig.14. However, they are considerable choices for the design depending on the science mission.

This new design will be appeared in the near future.

6. Conclusion

The object of a rover mission is scientific investigation; therefore, a rover system is not a mobile engineering system but a part of scientific equipments. In this paper we discussed scientific mission requirements of a manipulator, an evaluation of its joint driving rates, and showed a developed micro lightweight manipulator, which has 5 DOF and is actuated by a Ultra-Sonic Motor (USM) that needs no electrical power to keep a posture of a manipulator. Furthermore, we are redesigning the USM drive units of each joint, to improve a performance of a conveyable weight, and some results were shown in this paper. However, we still have some problems on this manipulator as follows:

- Total design and its optimization of a rover and a manipulator
- Development of endeffector for each mission scheme, etc.
- Technical feasibility in Space environment

We should step up to the next research stage for an actual mission under consideration. It was for that purpose that the most important thing on our research situation is an establishment of a technical feasibility in the space.

This work was partially supported by the Ministry of Education, Culture, Sports, Science and Technology of Japan, Grant-in-Aid for Scientific Research (B)(2), 12450173.

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