Tele-Science by Planetary Rover : Micro 5

Yasuharu KUNII , Masahiro OTSUKA

Dept. of Electrical and Electronic Engineering, Chuo University
1-13-27 Kasuga, Bunkyo-ku, Tokyo 113-8551, JAPAN.
TEL: +81-3-3817-1866, FAX: +81-3-3817-1847
E-Mail: kunii@hmsl.elect.chuo-u.ac.jp

Masaya SUHARA , Yoji KURODA ,

Dept. of Mechanical Engineering, Meiji University
1-1-1 Higashi-mita, Tama-ku, Kawasaki, Kanagawa 214-8571 JAPAN
TEL: +81-44-934-7183, FAX: +81-44-934-7183
E-Mail: ykuroda@capecod.mind.meiji.ac.jp

Takashi KUBOTA

The Institute of Space and Astronautical Science,
3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, JAPAN.
TEL: +81-42-759-8304, FAX: +81-42-759-8304
E-Mail: kubota@cnenet.isas.ac.jp

Abstract

In this paper, we propose the method of constructing the operation environment with the manipulator to gather the sample for the planetary mission, and also describe the development of the 5 Degree-Of-Freedom micro manipulator for the tele-science. Command Distortion Compensation is also presented for Continuous Real-time Tele-driving with the time-delay.

1. Introduction

Recently, it has become easy to construct a cheap, high-speed computer system caused by the high-speed development of the computer technology. As a result, the human interface technology such as the VR technology has been developed rapidly[1][2]. The task operability in the remote environment on Tele-operation has improved by these technologies. However engineers, who have special skills, have still done almost of actual operations by themselves[3][4]. Especially, in the field of a planetary exploration such as the moon and Mars mission, the scientists have requested their own operations by tele-science equipments to the engineers because the operations require high-level skills and the mission can not be failed. In the nature of things, scientists should really operate these equipments by themselves and then it can be expected that we can obtained more good results. Therefore, there are a

Fig. 1 Planetary Rover: Micro 5

Proc. Fifth International Symposium on Artificial Intelligence, Robotics and Automation in Space, 1-3 June 1999 (ESA SP-440)

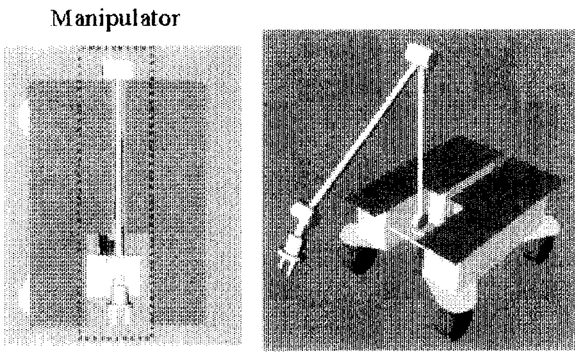


Fig. 2 Image Schematic of 5 DOF Micro Manipulator

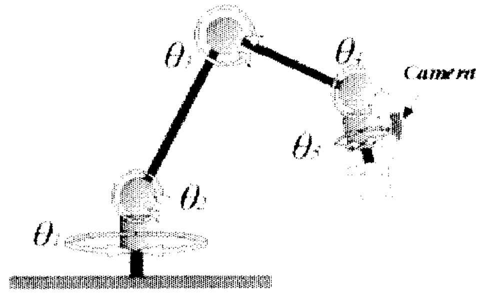


Fig. 3 Structure of Micro Manipulator

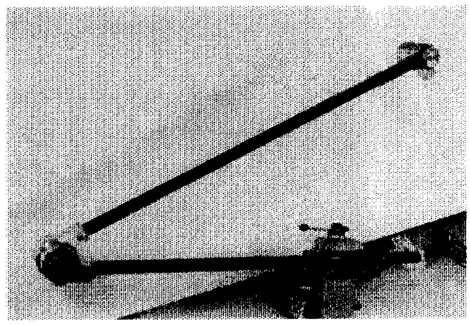


Fig. 4 5DOF Micro Manipulator (under-developing)

Fig. 5 Joint Unit and Actuator (UltraSonic Motor)

lot of demands from the scientist in this point. However an operation environment in a present state is still complex and, moreover, an operation by an engineer is in the situation not avoided because of the existence of the time-delay in the planetary exploration.

In this paper, we propose the method of constructing the operation environment with the manipulator to gather the sample for the planetary mission, and also describe the development of the 5 Degree-Of-Freedom micro manipulator for the telescience.

2. Planetary Rover : Micro 5

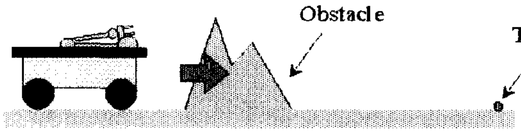
2.1. Micro 5

Developed Micro Planetary Rover : "Micro5" is shown in Fig. 1. Micro5 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]. It has the proposed new suspension system called ***PEGASUS*** *(Pentad Grade Assist SUSpension)*[5]. So the climb-able 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. It's also driven by on-board batteries.

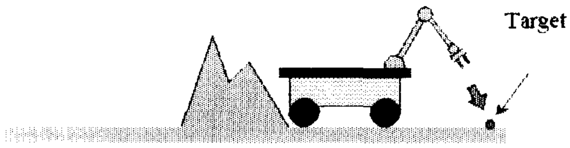
Two CMOS cameras are used as stereo camera for a forward terrain sensor. It also has other cameras around of the body for navigation and scientific observation. The rover is equipped with pitch and roll clinometers for attitude detection and encoders for dead-reckoning. Sensor data processing and control are performed by on board computers, for example, RISC-CPU.

2.2. 5DOF Micro Manipulator

Micro Manipulator is planed to be mounted on Micro 5 (Fig. 2). It has 5 Degree-Of-Freedom (DOF) serial link structure as shown on Fig. 3. It can perform grasping samples, operating some science equipment, scratching sample surface. Moreover, endeffectors based on the mission will be



(a) Target Approach Phase



(b)Target Sampling Phase

Fig. 6 Two Tele-Sampling Phase

able to be installed on the top. Here, the sample collection mission such as small stones is assumed, and a gripper will be equipped. The gripper has a piezo element as a sensor for the grasping recognition of a sample and a small type C-MOS camera is mounted on the gripper. Each joint is driven by Ultra-Sonic Motor (USM) with Harmonic Drive gear, and all of links are produced in a single structure with a carbon fiber. Here, it is forecast that the manipulator is spent much time for a command waiting state etc. In general, USM adopted on this manipulator can drive by a low electric power and has a big geostationary torque. Therefore, the conservation of electric power can be achieved on this manipulator system. In addition, we have much advantage because CFRP used for the main body has light weight and high strength.

3. *Tele-science by Micro5*

Let's assume tele-sampling method is composed of two phases. The first is “Target approach phase” in which the rover is going to the close area of a target (Fig. 6 (a)). That is a short range navigation. Another phase is “Target Sampling phase”, which is approach to a target truly to grasp it by using an endeffector (Fig. 6 (b)).

3.1. Target approach phase

In general, it is difficult to achieve the remote control of the system with the time-delay caused by

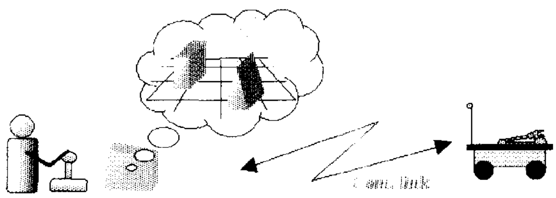


Fig. 7 Direct Tele-Driving System

the communication delay. In such a situation, it is necessary to think about some method to achieve a stable control. Supervisory Control is one of the solutions[3][4]. However, high-level Supervisory Control demands high autonomy ,that is, the performance of high calculation power and the sensor. Actually, in space, it is difficult, in many cases, to install an high-performance computer and various sensors due to problems of the harsh environment, weight of equipments and so on. Therefore, high-level autonomy is not expected in the system, but we develop the system based on human direct and continuous control (Fig. 7).

The virtual rover is controlled in the virtual environment created with received data which have been sent from the real rover, and these data is used for the rover control data, as continuous command data or discrete waypoint data(Fig. 9). At this time, the data received by the real rover are generated based on the data which it measured in the past, because of a time-delay. However, the real rover is updating environmental data which are more reliable at this moment. There is a possibility that operator's environmental data and the latest environmental data on the real rover are different, and it is necessary to change data by using the latest environmental data.

3.1.1. Command Data Compensation

It seems that the difference of these data is mainly caused by the error included according to the distance from the rover. In this case, the reliability of data increases by approaching to the remote area.

In this research, this difference is assumed as a

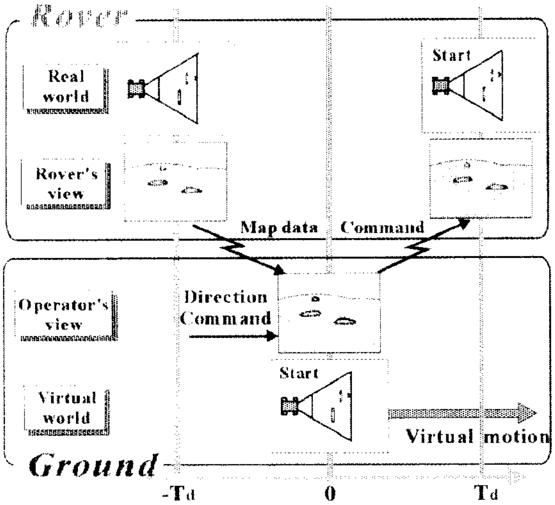


Fig. 9 Time chart of Data Transmission

distortion, and the mapping between old and new data, that is the distortion correction matrix, is acquired. Actually, environmental information is 3 dimensional data. However, it is assumed that the distortion is two dimensions and linear, in an initial stage of the research. And, the distortion compensation algorithm of the camera lens is applied as a method of the distortion compensation.

The Command Distortion Compensation (CDC) transformation is as follow.

$$X = \overline{X}A$$

Where $\overline{X}$ is sampling data of old environmental data, $\overline{X}$ is the last environmental data, and A is the distortion compensation matrix. Actually, we need only three pairs of the sampling point (X and $\overline{X}$), if these measurement data have much accuracy. However, measurement data are including noise which is nonlinear. So it is better to measure a lot of point, and then we use a least mean square techniques to obtain a suitable linear solution.

In the first, we have to make Orthogonal-triangular decomposition by using Householder reflections :

$$\overline{X}P = QR$$

where R is upper triangular matrix, P is permutation matrix and Q is orthogonal matrix. Then the least squares approximate solution is given by

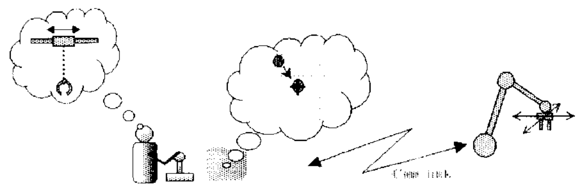


Fig. 8 Tele-Sampling

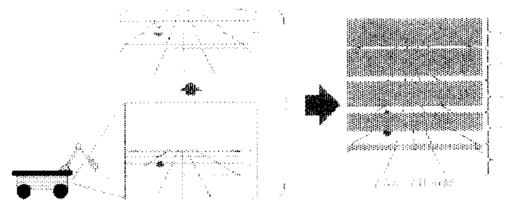


Fig. 10 View Point Transformation

$$A = P(R^{-1}(Q^T X)).$$

Therefore, the command distortion compensation is obtained from

$$Wp_{new} = AWp_{old}.$$

Where Wp_{old} is way-point data matrix sampled data created by operator and Wp_{new} is compensated way-point data matrix.

3.2. Target sampling phase

Target sampling phase is designed by using the above-mentioned manipulator. This phase is basically operated like a X-Y table with a joystick. In the first, we turn a camera and an endeffector equipped on the manipulator to ground. It can be approached to and gathered the target. This operation method looks like the crane game and can be expected that it is easy to accept in general. A detailed operation steps are described as follows.

Step.1: The side-view image which includes the target, and the distance information to the target are acquired by some sensor mounted on the rover, for example the stereo camera, the laser sensor and so on (Fig. 10). These data aren't expected much accuracy in this step.

Step.2: The upper-view image is generated from the side-view image based on distance information. Here, it is composed by using a real

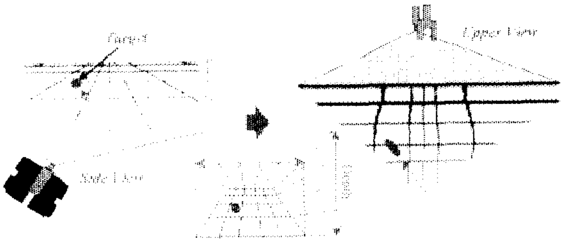


Fig. 12 Example of View Point Transformation

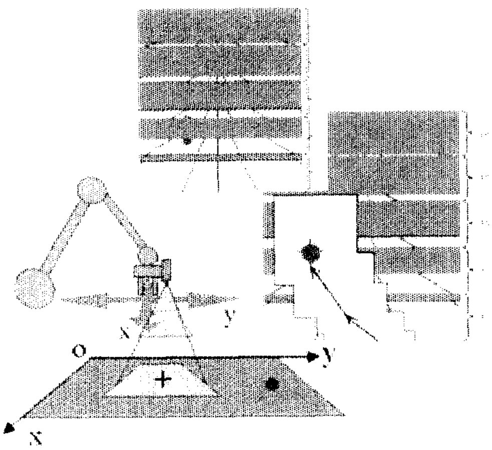


Fig. 13 Motion constrained on X-Y plane

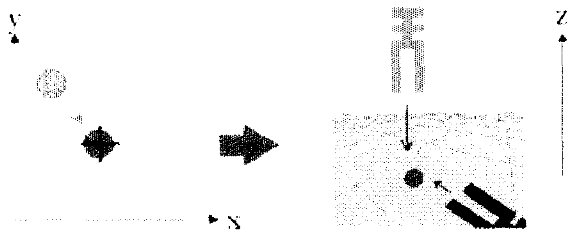


Fig. 11 Target grasping

side-view image and CG(View Point Transformation: VPT, Fig. 10). Fig. 12 is shown a simple example of VPT.

Step.3: The movement of the manipulator is constrained on the X-Y plane, which is a parallel plane to the ground (Fig. 13). The operator is operating a manipulator watching the upper-view image acquired in above step. The generated upper-view image is updated with a real-time real image from a camera mounted on the manipulator.

Step.4: After the target is put in a real upper-view image, the manipulator is guided on the target, that is, the center of the screen (Fig. 11).

Step.5: Next, the direction, to where the manipulator is operated, is constrained to the vertical direction (Z-axis), and it approaches to the target and grasps a sample. Here, a touchdown to the ground is judged by using the shadow, which is coming close to the top of manipulator and also useful for a human-interface.

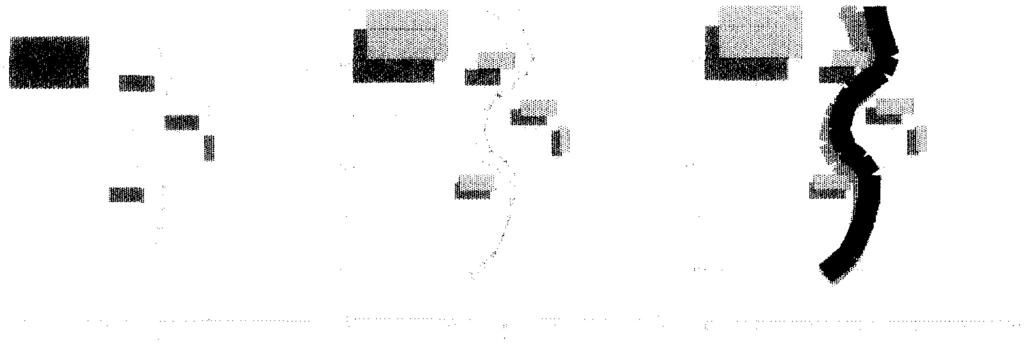
4. Simulation and Experimental Results

Fig. 15 is shown a simulation result of Command Data Compensation. Here, black boxes are obstacles measured as old environment data and gray boxes are new environment data, and, the trajectory (a gray line) in Fig. 15(a) and (b) are command data created by an operator and a black line in (b) is compensated data. Belts in Fig. 15(c) indicate the width of a rover (black belt: operator command, gray belt: compensated data). It's clearly understood that rover's trajectory is avoiding to run against into objects.

An experimental result is shown in Fig. 14. Image (a) and (b) were measured on the start point, and the point of 140cm from the start point, and are images measured by the Tricrops that has three CCD cameras and is a commercial product. The Tricrops can perform the measurement of depth data. The depth data are obtained on points in circles in Fig. 14(a). Fig. 14(c) is a result of command data compensation. The compensated trajectory could be also avoided from objects

5. Conclusion

The micro planetary rover: Micro5 and its 5 DOF Micro Manipulator were shown. These systems are expected to be launched to the moon in the near future (any mission is not authorized yet). In this paper, we proposed the method of Tele-sampling as an example of Tele-Science. This tele-sampling method is composed of two phases: the first is



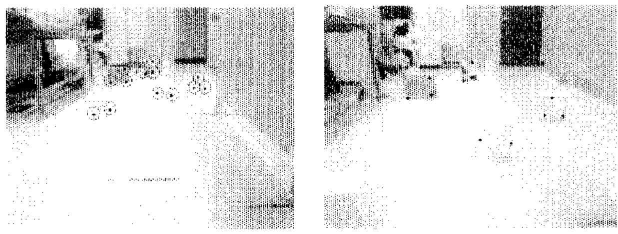
$$A = \begin{pmatrix} 0.9942 & -0.1137 \\ 0.0784 & 1.0642 \\ -0.0473 & -0.0132 \end{pmatrix}$$

(a) Command data (b) Compensated data (c) Trajectory of Rover

Fig. 15 Simulation Results of Distortion Compensation

"Target Approach Phase" and another is "Target Sampling Phase". In Target Approach Phase, we proposed Command Data Compensation and showed simulation and experimental results. In Target Sampling Phase, we proposed the way to operate a manipulator to grasp a target and it works like a crane game.

Finally, we have a lot of future works, for example, the achievement of the total tele-sampling system and its evaluation. Moreover, nonlinear and 3D command data distortion compensation and the use of shadow information are one of future works, too.



(a) Camera Image (b) Camera Image

$$A = \begin{pmatrix} 0.9634 & 0.0763 \\ -0.0700 & 1.0391 \\ 0.2226 & -1.3275 \end{pmatrix}$$

(b) Command Data

Fig. 14 Experimental Results of Distortion Compensation

Reference

[1] S.Tachi: ``ARTIFICIAL REALITY AND TELE-EXIXTENCE", Proc. of Int. Conf. on Artificial reality and Tele-exixtance, pp.7-16,1992.

[2] Karun B.Shimoga:``A Survey of Perceptual Feedback Issue in Dexterous Telemanipulation:Part I. Finger Force Feedback", Proceedings of Virtual Reality Annual International Symposium VRAIS, pp.263--270 ,1993.

[3] L. Matthies, E. Gat, R. Harrison, B. Wilcox, R. Volpe, and T. Litwin, "Mars Microrover Navigation: Performance Evaluation and Enhancement." Autonomous Robots Journal, special issue on Autonomous Vehicles for Planetary Exploration, Volume 2(4), pp. 291-312, 1995.

[4] S. Laubach and J. Burdick, "An Autonomous Sensor-Based Path-Planner for Planetary Microrovers." To appear in Proceedings of the IEEE Conference on Robotics and Automation (ICRA'99), Detroit MI, May 1999.

[5] 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.