Dynamical Testing and Simulation Methods for Control System of a Lunar Rover

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Abstract

In this paper, a new dynamical analysis method for Lunar/Mars rover is proposed. This method uses testing results of a facility which has a slope softly covered by regolith simulant. It also has gravity compensation function. The slope angle is changed easily, so that hill-climbing testing on various slope angle can be accomplished. In the testing results, the slip factor of the crawler mechanism against the terrain changes owing to the slope angle. A dynamical simulation was performed with applying testing results of the hill climbing to the friction parameter of the surface of divided terrain surface model. This paper describes the testing method and results of hill climbing testing and dynamical analysis using the new method about control system of a lunar rover.

1. Introduction

Aiming at the practical use to base construction and mobile search for rocks and soils on the moon surface, research and development of mobile robot (rover) are furthered by JAXA. The target area of base construction for exploration is mainly the mountains zone of the moon. And the surface of the moon is covered by regolith. A steady run on such irregular terrain is the big technical theme of exploration rovers. A newly developed light weight crawler mechanism is good for driving on such irregular terrain because of its low contact force with ground. This was determined with regard for the mass and expected loading on the rover. In this paper, the technical issues of the mobile robot (in below, called rover) which does inquiry and investigation, and the construction work of a base in respect of a moon planet is arranged, and the results of study about the method of a dynamics testing and analysis which is needed in the development are described.

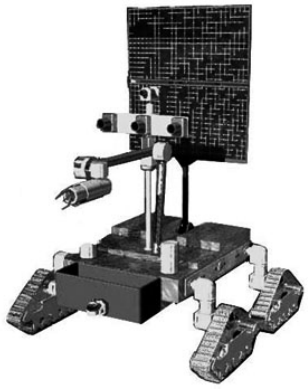

Fig.1 Artist concept of Lunar rover

2. Environment of Lunar/ Mars surface

Comparison of environment on Lunar and Mars surface is shown in the Table 1.

2-1. Environment on Lunar surface

Table1 Comparison of environment with Earth

Items	Earth	Moon	Mars
Gravity	1 G	0.17G	0.38G
Vacant	1 pascal	10^{-9}pascal	0.007pascal
Temp.	-15～40℃	-120～-20	-100～15℃
Soil	Round	Regorith	Round

The moon's surface in the polar region is severe environment, such as a high vacuum, a strong radiation, a big temperature change and a long night. It is far severe environment for a space components compared with an earth orbiter environment.

The degree of slant is distributed from zero inclination to about 40 degrees, and sunlight,

. which produces the domain of a large shadow also by slight ups and downs -- since there are two or more ups and downs with a natural thing, that it is a permanent sunny place

In considered that a day hardly puts a surrounding domain conversely only at a peak with a high crater rim etc., therefore the low mobile vehicle of height like rover.

Unless it chooses and runs a course very much, which does not obtain an idea colander as sun does not put, and the temperature of Polar Regions are said to be -230 degrees in the place of a shadow Centigrade-50--30 degree in the place where sunlight hits.

3. Composition and Technical Issues of Moon Planet Rover

The conceptual figure of moon planet Rover is shown in Fig.1. Moreover, the composition block diagram of moon planet Rover which assumes is shown in Fig.2. It states below about the composition outline and technical subject of main portions.

3-1. Run System

When the regolith has piled up 10cm or more and reaches the inclination ground, the surface of the moon generates slipping and being buried by the regolith, and serves as an obstacle of a run. A run of the slope where the regolith piled up is not easy. The rigid body wheel is used for Rover for Mars. The stack of such a rigid body wheel is carried out frequently. In the climbing performance of the slope covered with the regolith, the good testing result is obtained by the crawler type run system which has low-pressure grounding and the low-pressure bundle hardening effect. By the crawler type run system, crawler-belt, optimization of a suspension mechanism, etc. are development subjects. The regolith contains the detailed particle, and since it is the square outside, it acts like an abradant. Since wear is intense, the measure against wear is required for the run system component which touches a regolith.

Moreover, the measure against protection against dust of an actuator is required.

3-2. Position Identification and Measurement

Deduction of the self-position by the radio wave of an earth circumference GPS satellite is difficult on the moon. Moreover, since sunlight is not necessarily put very much to a local run as stated previously, it cannot depend for direction measurement on a solar sensor.

For this reason, it is thought that the radio wave or the optical sign formed on the direction measurement by start lacquer and a lander etc., and the sensor which detects it are effective in self-position identification of Rover. Moreover, since dead reckoning based on the actuator rotation information on a run system has the slipping by the regolith, it generates a large error.

Moreover, position measurement of Rover from a lander becomes effective only when Rover is seen.

for this reason, the moon's surface from Rover -- it is indispensable to calculate a self-position and its amount of change by measurement of geographical feature As a sensor of geographical feature measurement, a laser range finder and a stereo visual sensor are promising. Since there are many domains of a shadow, the lighting by LED or the stroboscope is required for a stereo visual sensor.

3-3. Operation / Control System

There is change in the time zone the moon appears from Japan, and the time zone which is not visible. The round trip of the command telemetry to the moon's surface takes the time for 4 seconds - about 8 seconds by space transmission time, the processing time in a ground station computer, etc. That is, the time for about 8 seconds is taken for a reaction to come on the contrary at the maximum. For this reason, Rover needs to perform automatically and autonomously steering control in the Rover run, rotation control of each ring corresponding to slipping, etc. It is effective to acquire a visual information and to send it because of the monitor of a situation. It is necessary to constitute detailed moon's surface 3-dimensional map on the ground, and to update every moment based on visual information or the information measured from the lander. Although large autonomy is not required of the Rover control in order to send instructions of a run course from the ground based on this, the partial autonomous function is required and effective. The outline of a functional assignment of the ground and lander Rover of operation / control system of Rover is shown in Fig.3.

3-4. Robot Arm

On the moon, there is one sixth of terrestrial gravity, and there is terrestrial gravity of 40 percent, and in a Mars surface, though it is looser than the ground, a robot arm needs to support the weight of prudence or a handling payload, and needs to operate. For this reason, compared with the robot arm and drive mechanism on an orbit around the earth, the load of an actuator is large. According to load, contact pressure of bearlings increases according to the increase of contact pressure of a reduction gear, and gravity.

The lubricant of mechanisms is big issue for lunar rovers because of intrusion of the regolith.

In the wiring (cable construction and attaching of connector) work in respect of a moon planet, or a structure assembly, relative positioning with an object and control of force are needed.

Since it becomes the work from Rover by which a scaffold is not stabilized, consideration is required also for the load which joins a robot arm at a dynamic interference with a run mechanism, or the vibration under run.

Moreover, in force control, a characteristic setup which considered interference with the dynamics of a run system is required.

4. Testing of Run System

4-1. Testing Item

Since running the whole distance of the moon's surface covered by the regolith, the inclination ground of Mars, and the irregular ground is called for, it is thought that a run system needs a function and to be performance verified dynamical about the following items.

a. Drive mechanism performance test
b. Run system modal survey
c. Climbing performance test

d. Irregular ground testing

4-2. The Testing Method

In testing of a run system, imitation of the following matters serves as a subject.

a. The characteristic of a regolith

b. Imitation of low gravity of a moon planet surface

The characteristic of a regolith can be mostly imitated by using this by being made from volcanic rock, since stimulant which imitated density, and the square form and a particle size is manufactured.

There is a method using 1/6 scale model as the imitation method of the run characteristic in the low gravity environment of the moon's surface.

However, since it is necessary to set the particle size to one sixth, with the form of regolith stimulant maintained, difficulty is in implementability.

Moreover, neither the payload system nor actual size can apply also to testing of the engineering model which is foundations. It is necessary to imitate the low gravity environment of a moon planet surface by gravity compensation in testing using the engineering model of the system or system size.

To an irregular ground run, the attitude of speed, its direction, and the body is changed sharply.

Therefore, a passive gravity compensation system has the large influence of the addition inertia of a mechanism, or friction, and it is not suitable. For this reason, it is necessary to use the active gravity compensation equipment which follows a motion of the body by the high response by active control of a broadband. The concept of this testing is shown in Fig.4. The result of testing is evaluated and estimated as the characteristic of each part by colliration with the kinetics simulation advanced in parallel. A climbing performance can perform quantitive evaluation efficiently by using the slope run testing equipment made to incline the slope covered with regolith simulant at arbitrary angles. This testing equipment is shown in Fig.5. Although the gravity of 1G is acting on regolith simulant also by this testing method, evaluation is divided about the influence on that rate of slipping, and compensation of the direction which increases the rate of slipping to slope run testing data depending on future evaluation is needed. The crawler mechanism in which low contact pressure in the irregular ground is realizable by high adaptability is promising for a run mechanism. Slope climbing testing equipment is effective also in roadability ability testing in a crawler single unit. The situation of the testing is shown in Fig.6. The grounding force equivalent to arbitrary gravity acceleration is realizable with adjustment of counter weight. Although vacuum environment influences durability, such as a lubricous mechanism part, to a run, it is a grade which influences winding up of sand slightly, and is considered that the influence of the kinetics characteristic on a run is not large. Therefore, it is thought that the durability, characteristic testing, etc. of an actuator simple substance can fully estimate the influence of vacuous.

4-3. Kinetics Simulation

In the computer simulation of the kinetics of the Rover run, a subject is in imitation of the slipping in the regolith surface of a run system. It is clearer than the testing result in slope run testing equipment that the rate of slipping at the time of a run changes according to an angle of inclination on the slope covered with the regolith. Then, the ups-and-downs geographical feature model which imitated the moon planet surface was incorporated in the simulation, and the system which carries out a simulation in the form where the friction coefficient of the surface is changed according to the degree of slant of a slope was developed.

The form of a model and the example of an analysis result which imitated the crawler run system by the locker bogey mechanism of eight flowers are shown in Fig.7. A kinetics simulation needs to stuff especially flexibility allocation of the suspension of the run system corresponding to allocation and a mass distribution of payload equipment and a setup of the characteristic and a drive servo system in detail.

5. Testing of Measurement / Control System

5-1. Testing Item

Especially in measurement and operation / control system, the check of the function and performance of the measurement sensor for a run is important.

As main testing items, it is quoted of the following items.

a. A measurement sensor simple substance function and a performance test

b. Measurement / control system open loop testing

c. Measurement / control system static closed loop testing

d. Measurement / control system dynamic closed loop testing

e. Operation employment system static closed loop testing

f. Operation employment system dynamic closed loop testing

5-2. The Testing Method

In testing of the function and performance of a measurement sensor, or an integrated function, imitation of environment, such as light environment and geographical feature, and its quantification are important subjects. Testing [environment / light environment needs to constitute the environment of the lighting state united with the sunshine of the latitude of the landing point to assume, and] supposing various cases influenced by ups and downs of solar geographical feature etc. In the difficult object of such quantification, it must verify quantitatively and it becomes indispensable to measure the geographical feature of the object to measure separately and to consider as a standard. Since functions, such as geographical feature map generation and a course setup, are due to be assigned to a ground system, they are included in employment

equipment and verified by dynamic closed loop testing by combination with the kinetics simulator of a payload system.

The kinetics simulator used for dynamic closed loop testing is built into employment equipment as it is, and is used as an employment simulator used for prior verification of an employment command. Although various irregular grounds are formed in the inside-of-a-house field (Fig. 9) and being used for closed loop testing of measurement / control functionality ability of a run, outdoor field testing (Fig.10: run testing at the Nakatashima sand hill) is also effective in the purpose which verifies measurement / control performance to the long-distance run in the natural feature which is not artificial. However, in the outdoor field, it is under 1G gravity, and since it is difficult to use regolith stimulant further, the relation of a run system, soil, and gravity acceleration cannot be imitated.

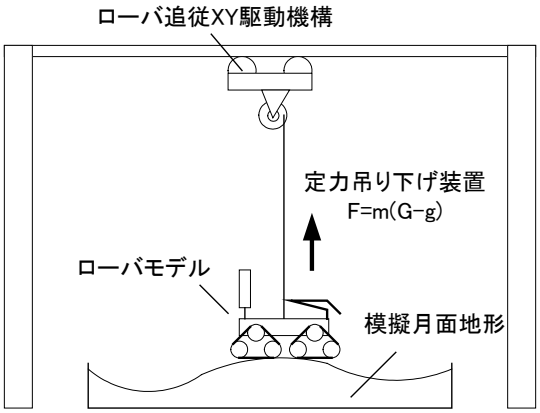

Fig.4 Gravity compensated rover testing configuration

Fig.5 Testing configuration of hill climbing performance

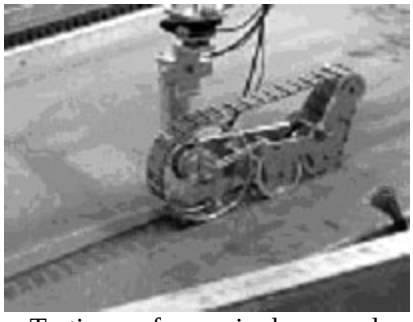

Fig.6 Testing of a single crawler module performance

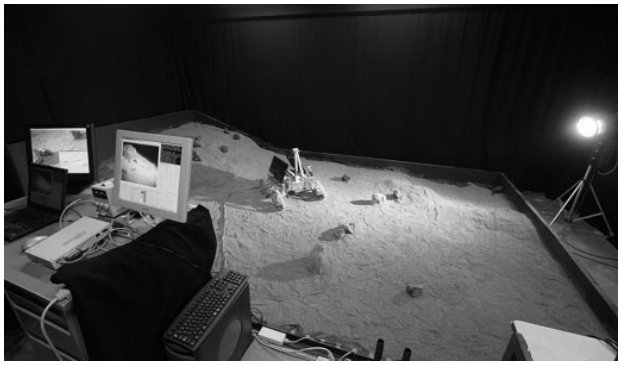

Fig.9 Lunar/Mars rover testing facility

Fig.10 Field running test at Nakatajima-sakyu

6. Testing of Robot Arm

6-1. Testing Item

About action and control of a robot arm, since it is the complicated motion under the low gravity of a moon planet, evaluating according to a kinetics simulation becomes testing under 1G has many restrictions, and main. However, the characteristic acquisition for colleration, a check of operation in various kinds of control modes, etc. are required also as testing using hardware. As main testing items, it is quoted of the following items.

a. Joint simple substance characteristic testing
b. Robot arm modal survey
c. Robot arm static closed loop testing
d. Robot arm dynamic closed loop testing
e. Robot arm work functional testing

6-2. The Testing Method

Simple substance characteristic testing of a joint actually drives a joint within vacuum チャンバ, and acquires data, such as change of output torque, consumption current and rotation speed, or temperature.

This performs valuation modeling-ization of the mechanism characteristics, such as friction of a joint mechanism, and elasticity.

For a certain reason, the influence of the nonlinear nature of the twist elasticity of the reduction gear of a joint also carries out testing using the real hardware of robot arms, such as a modal survey and dynamic closed loop testing, where the gravity of a moon planet surface is imitated by gravity compensation etc.

Under the present circumstances, colliration with a testing result is performed using the computer simulation model which added addition mass, such as compensation equipment, and the kinetics simulation under the gravity environment on a moon planet surface is carried out by the simulation model except such addition mass. The same technique is applied also with an engineering test satellite VII type robot arm, and it is verified that the modal survey result and kinetics simulation result in an on-orbit are in agreement good. The Rover main part which is the attachment base of a robot arm, and the structure and the mechanism element of a run system are also modeled and combined with a kinetics simulation, and the simulation and analysis evaluation also of the dynamical interference with these are carried out.

7. Conclusion

The technical subject of Rover which does inquiry and investigation, and the construction work of a base in respect of a moon planet was arranged, and the result of having studied the method of kinetics testing, such as a run system which is needed in the development, and measurement and control, a robot arm, was described. About a non-fixed thing, detailed examination and preparation are due to be advanced from now on. It states below about the composition outline and technical subject of main portions.

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