DESIGNING OF LUNAR ROVERS FOR HIGH WORK PERFORMANCE

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ABSTRACT

NASDA, office of R&D, has been studying key technologies of planetary rover for years in the fields of a study of remote driving methods by the 6-wheel chassis and mobility performance evaluation by the 3-wheel chassis. Since these studies were related only to the moving capability on the surface, study has begun in the useful rovers that has high work performance in various exploration missions, as candidates for the coming lunar surface initiative mission of Japan. This paper describes some study results of elemental exploration tasks and designing of small lunar rovers. As for elemental studies, specimen-observation technique was tested with computer aiding analysis, and a compact laser range finder was developed and tested for terrain recognition. As for designing of small rovers, two concepts are studied; ground test model of mutually co-operating 2-rover-system has been designed, and capability of re-fuelable flying-rover-system were analyzed preliminary.

1. INTRODUCTION

We developed the 6-wheeled rover (Fig.1) and the 3-wheeled rover, the TRISTAR-II (Fig.2) for the studies of remote driving methods and mobility performance [1, 2]. Since these studies were related only to the moving capability on the surface, designing has been begun in the useful rovers that has high work performance in various exploration missions, as candidates for the coming lunar surface initiative mission of Japan.

FIG. 1 6-wheeled rover

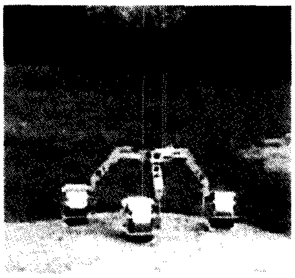

FIG. 2 the TRISTAR-II

And the focus was in the study of how to execute basic exploration tasks effectively. In section 2, observation technique with computer aiding analysis, and a compact laser range finder for terrain recognition are described. In the exploration mission, the allowable total mass to be shared for rovers is considered to be about 100kg, and more effective system as a total exploration device is required. The multi-rover-system is to be more robust and attractive than single system with redundancy in the unknown environment. A mutually co-operating 2-rover-system was proposed, and designed: 40kg rover; 20kg for the bus system, 20kg for the mission equipment. As for night hibernation on the moon, there are three kinds of system concept; (1) system with RTGs (Radio-isotope Thermal Generator), (2) system with big thermal assistant device like a water tank or fuel cells, (3) landing vehicle base system with no self-dedicated thermal assistant device. In the study landing vehicle base system was assumed, in which rovers are activated in noon and return to the landing vehicle at evening for night hibernation. Under these conditions, two types of rover were desinged for high work performance. In section 3, the concept of the systems and some results of the design are described.

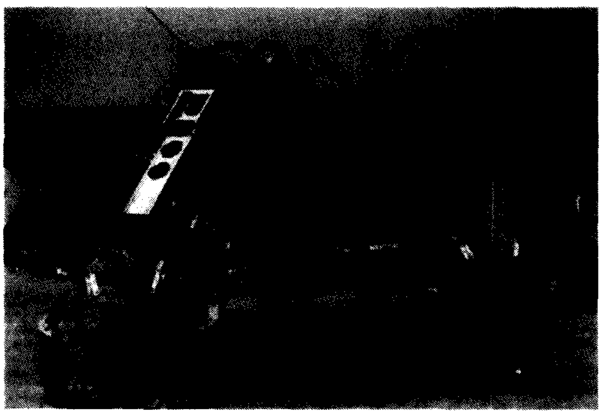

FIG. 3 the TRISTAR-II with a 4-DOF manipulator

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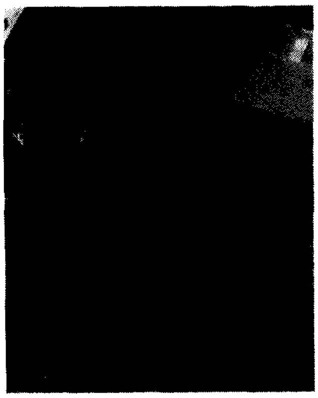

FIG.4 Manipulator with camera

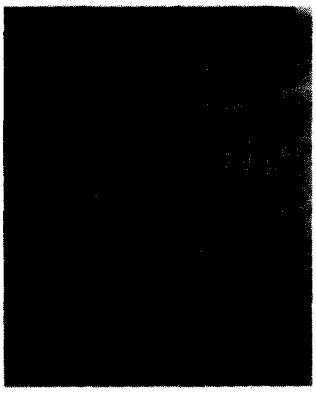

FIG.5 Manipulator with scoop

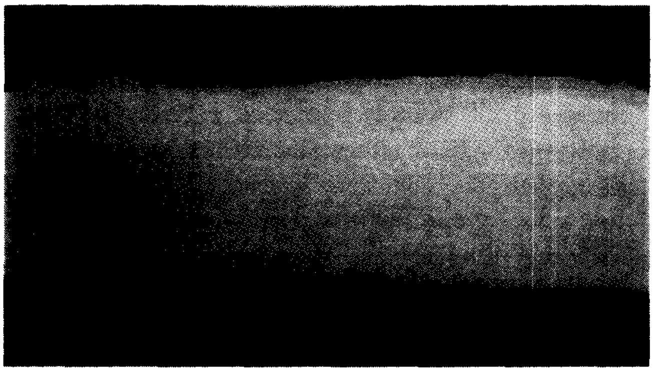

FIG.6 Visibility in the forward lighting

FIG.7 Visibility in the inverse lighting

2. ENHANCEMENT OF WORK PERFORMANCE

2. 1 COMPUTER AIDED OBSERVATION

Observation of surroundings and rock specimen is one of the basic tasks of planetary rovers, and computer aiding analysis can enhance the performance. Tests were conducted using the modified the TRISTAR-Ⅱ. Fig.3～Fig.5 show the rover with a 4-DOF manipulator, cameras and a scoop. The followings are added functions to the TRISTAR-Ⅱ.

a) 3-CCD camera for observation of surroundings
 (Horizontal resolution: 750TV lines, SN: 62dB)
b) High magnifying power camera for rock observation
 (Horizontal resolution: 560TV lines, SN: 54dB)
c) 4-DOF (Degree Of Freedom) manipulator
 3 Ultrasonic motor -joints, Linear-actuator on the top
d) Scoop for digging and sampling

1) Wide-viewed display of the surrounding

It is considered very difficult to operate a rover in unknown environments, and the high contrast on the lunar surface will make the task even difficult [3]. Fig.6 and Fig.7 show the visibility in forward and inverse lighting on the pseudo-lunar surface. The results were examined using wide-viewed display which was generated by connecting multi-images by pattern matching. Fig.8 shows the wide-viewed image consisted of 8 images. The field of view is equivalent to 240 degrees, and the pixel resolutions are 2488 horizontally and 480 vertically.

2) High resolution observation of a rock specimen

In the high-resolution observation of uneven surface of rock specimen by a high magnifying power camera, there exist focused regions and unfocused regions within an image. The field of view of the camera is narrow and its depth of focused field in optical axis

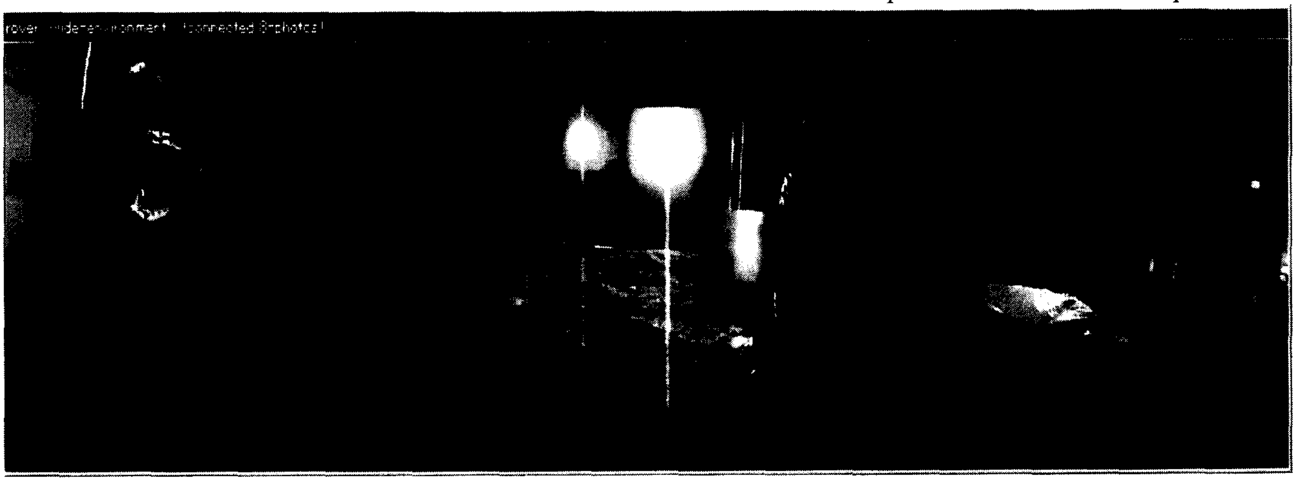

FIG.: 8 Wide-viewed image consisted of 8 images (Horizontal Pixels: 2488, Vertical Pixels: 480) direction is very shallow. Fig.9 and Fig.10 show the images of the Fassaite pyroxene by high magnifying power camera. The former is the image of concave surface and the latter is the image of convex surface. We examined the method in which the focused regions from each image are extracted, and connected to get a fully focused wide image data.

Fig.11 shows the connection of 2 images, and Fig.12 shows that of 6 images, which resolutions are 1495 horizontally and 480 vertically. By enabling onboard processing, the specimen observation tasks would be executed effectively even in the low communication rate to the earth station [4].

2.2 A COMPACT LASER RANGE FINDER

A laser range finder (LRF) is considered key sensor for navigation and environment recognition. A small-size scanning Laser Range Finders was studied for space applications for years, and a new compact model developed for small rovers [5]. Fig.13 shows the photo of the laser range finder, and Table.1 shows its main characteristics. Fig.14 shows the schematic figure of optical and scanning module in which the optical system consists of a polygon mirror and two parabolic reflectors.

A direct vertical driving of polygon's mount, without belt/gear, is adopted and the upper flat mirrors are eliminated for further compactness, which enabled to minimize the optical system as a designed feature.

Fig.15 shows sand field scenes of 1～5m range. It shows that the LRF can clearly measure the terrain for the lunar/planetary rover application. Because the mounting height of sensor head will be restricted to be less than ～1m for small rover and the sensor spatial resolution is limited,

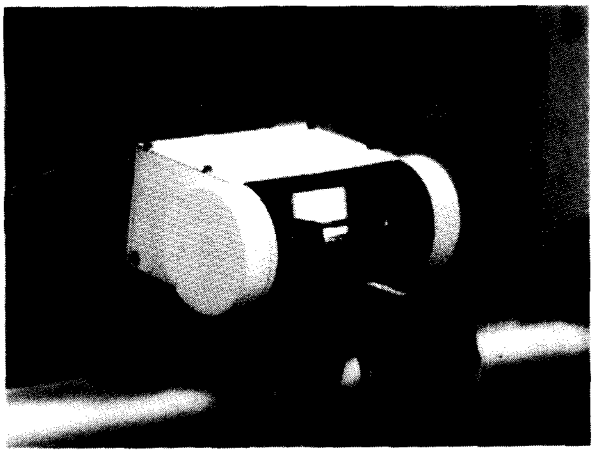

FIG. 13 Photo of the Laser Range Finder

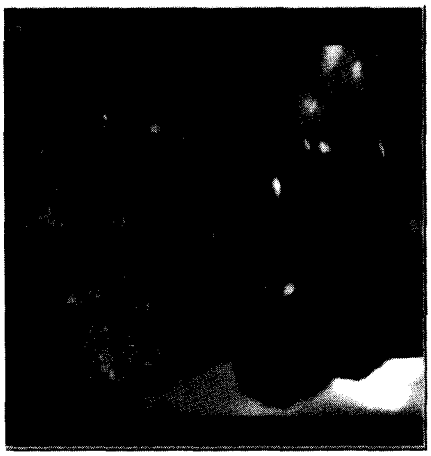

FIG. 9 focused on the left

FIG.10 focused on right

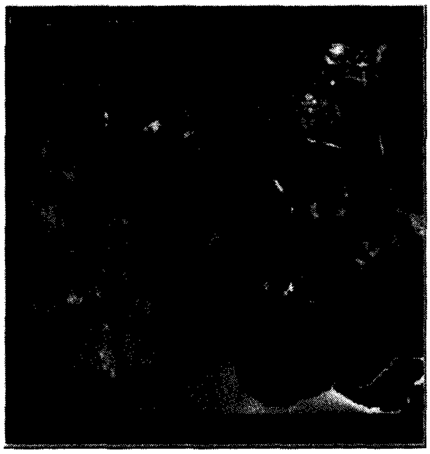

FIG. 11 focused on both

FIG.: 12 focused on 6-images (Horizontal Pixels: 1495 pixels, Vertical Pixels: 480)

TABLE.: 1 Main Characteristics of the LRF

Items	Specification	Unit
Technical method ranging H.scanning V.scanning	Phase detection on AM modulation CW Mechanical scanning by a 4-facet polygon Mechanical scanning of horizontal scanning module	
total field of view(H×V) instantaneous FOV emitted beam incident beam	90×45 5 10	deg mrad mrad
spatial resolution	(256, 128, 32, 8)×64	pixel
data frame rate	4	Hz
operational range objects CCR	0.5～5 >100	m m
resolution range radiance	16 8	bit bit
Peak LD power(λ =780mm	150	mW
CW modulation frequency (90%)	10 and 1.5	MHz
effective optical aperture	15	mm ϕ
polygon mirror rev. speed driving mechanism of vertical scan	4800 direct drive	rpm
range measurement circuit temperature compensation	full digital direct coupling or optical fiber	
size(W×H×L) scanner electronics	100×81×42 150×80×120	mm mm
weight scanner electronics	0.18 1	kg kg
power consumption	15	W

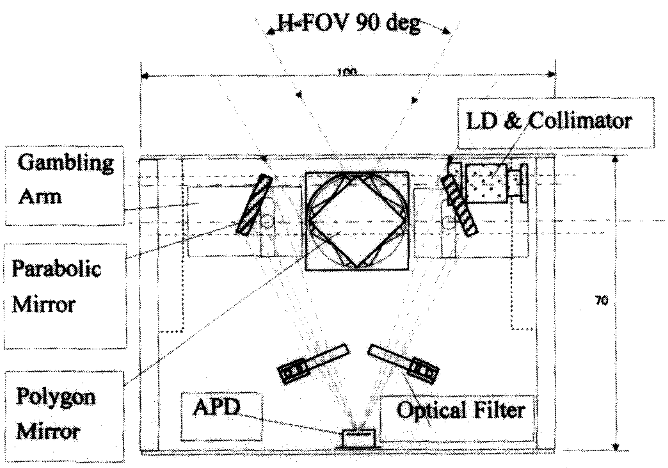

FIG. 14 Schematic figure of Optical and Scanning Module

the measurement range area of 1～5m is adequate for its autonomous navigation and/or map registration. And the high frame rate of this LRF enables the on-board supervision during high speed remote driving. This compact sensor is applied to a small rover described in the next section.

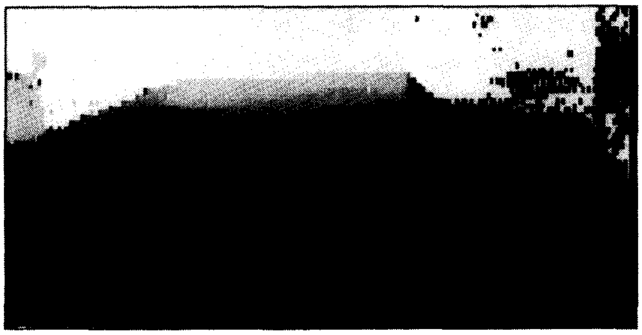

FIG. 15 Range Image Data of a sand field scene

3. DESIGN OF SMALL EXPLORATION ROVERs

3.1 MULTI-ROVER-SYSTEM

The multi-rover-system is to be more robust and attractive than single system with redundancy in the unknown environment. In the study a mutually co-operating 2-rover-system was proposed, and a concept of the small exploration robot is shown below. The chassis concept is 3-wheeled type derived from the TRISTAR-II. The wheels can be folded under the rover's body by the wheel rotation and be expanded to gain high mobility performance.

a) The improved chassis has low center of gravity of mass and shelter covers for the night hibernation.

b) The rover has a 4 degree-of-freedom manipulator for exploration tasks such as observation and sampling of specimens. And it also can be used for reconfigurations of rover itself.

c) The system consists of 2 rovers, each has same configuration with different mission equipment. It is possible to connect the rovers for long distance traverse over the relatively moderate terrain and to operate separately for cooperative works, such as investigation of a small deep crater, recovering from stacked condition, and measurements that need active-roll and passive-roll.

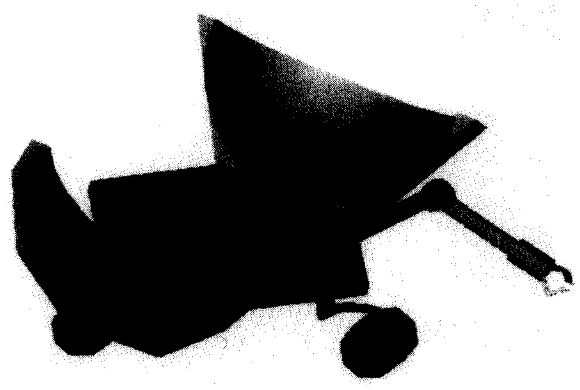

FIG. 16 Overview of Small Exploration Rover

A ground test model was designed with following characteristics from the viewpoint of evaluation on its

working performance and its operability.
a) Dust-proof and waterproof feature for experiments on various areas
b) Variable communication capacity within the range of 32Kbps-10Mbps for advanced operability
c) On-board intelligence of perception for evaluation of its effectiveness

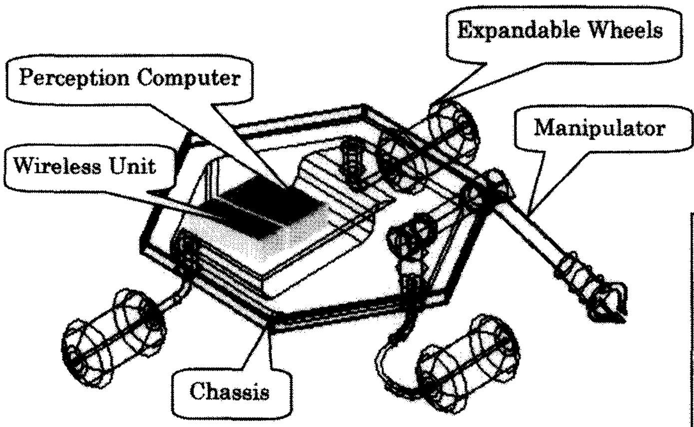

FIG.17 Small Exploration Rover for Cooperative Works

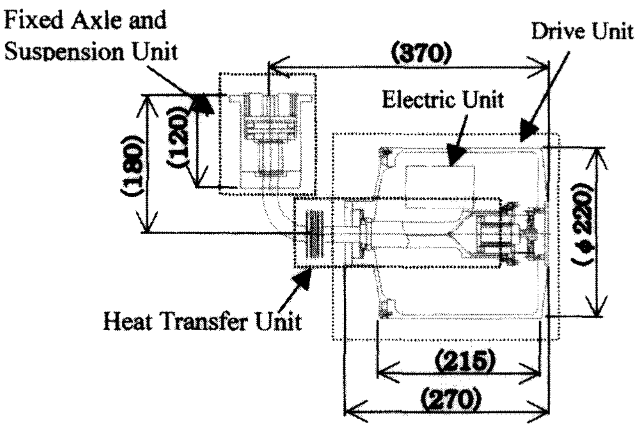

FIG. 18 Wheel System [mm]

Fig.16, Fig.17, Fig.18 and Fig.19 show the ground test model. The model is 1.0m(W)×1.0m(L)×0.8m(H) size and 40kg weight for the bus system for 1G environment. The distributed control systems are implemented, which use the RS-485 (5Mbps) as the internal communications for command/event data, and the Ethernet (10/100Mbps) as the internal and the external communications of the heavy sensory data. All data are collected at the onboard note-PC to interface the operational station. In a wheel hub system, there are
a) Motor control unit
b) High power DC-motor and HD-gear
c) Heat transfer unit by passive heat pipe
d) Perception processing unit

The shaft mounting system with suspension and rotary mechanism is located at body interface. A 4-DOF manipulator by step-motors is located on the top of rover.
As for cooperative tasks, such as pulling the mission equipment (Fig20), pulling-up the other rover (Fig.21), and tasks which need separated transmitter and receiver in particular observations, mutual force and various methods in the viewpoint of the operational technique and driving technique must be considered.

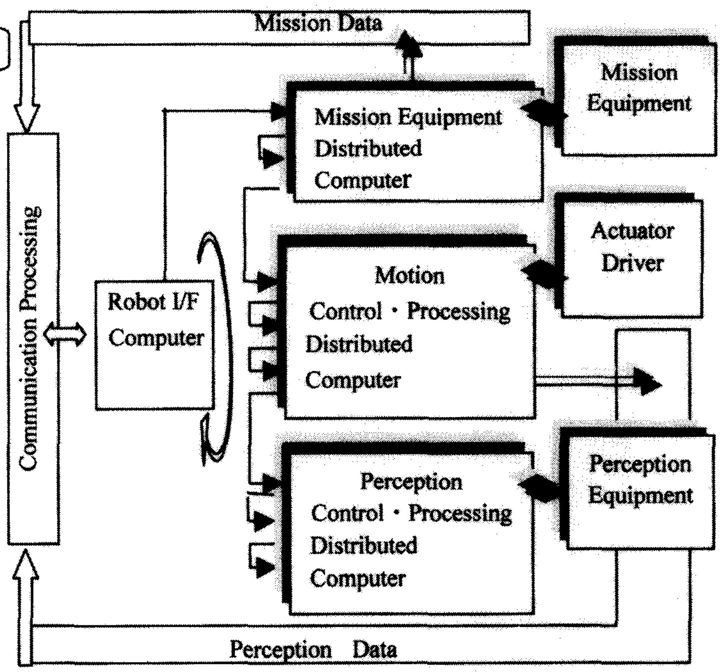

FIG. 19 Distributed Control Systems

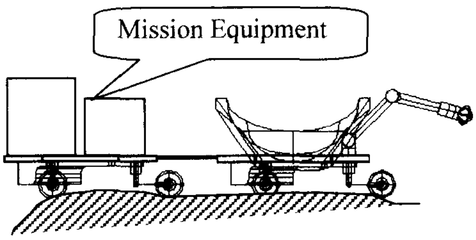

FIG. 20 Works in Connected mode

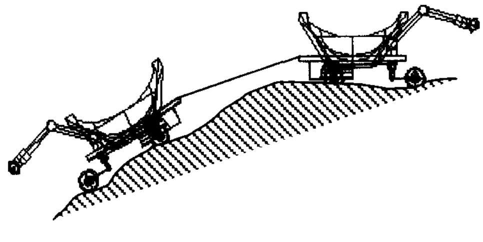

FIG. 21 an Example of cooperative Works

3.2 THE LUNAR FLYING ROVER

A rover with appropriate system could fly around on the lunar surface relatively easily because of its small gravity. There have been many studies related to such systems, but it has shown that self-contained or stand-alone system can not be realized because of weight restriction. Since the mobility performance of rovers is originally limited, a flying probe is remarkably useful in the exploration system that consists of mother base system with small probes. In the study, the flying rover system was designed, which returns to the landing vehicle at night for hibernation and re-fueling, and flies again for several times during noon. The system is designed to fly to ~ 25km in horizontal one way or to ~ 1km in vertical one way during a single day mission, when (amount of propellant) / (total mass of the rover) = 2 / 5; for example, 40kg rover with 16kg propellant. Fig.22 shows the horizontal flight time vs. the ratio of (amount of propellant) / (total mass of the rover). Fig.23 shows the flight control simulation, the results suggested the possiblilty to operate from the ground with 7sec delay supported by the ground computer.

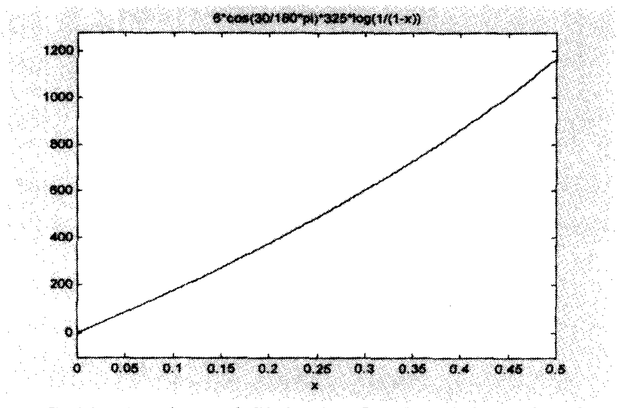

FIG. 22 Horizontal flight time[sec] and the ratio of (Amount of propellant) / (Total mass of the rover)

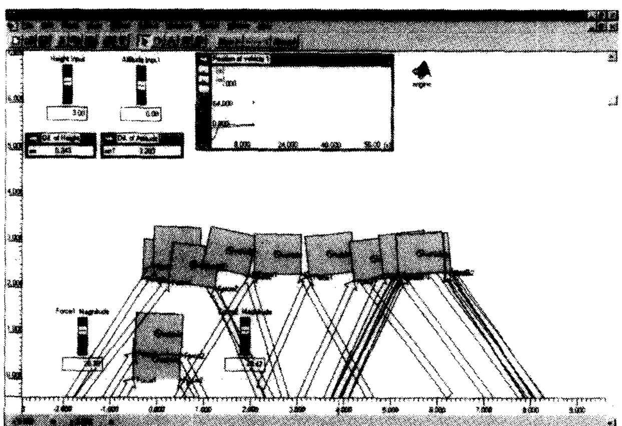

FIG.23 The flight simulation of the flight exploration robot

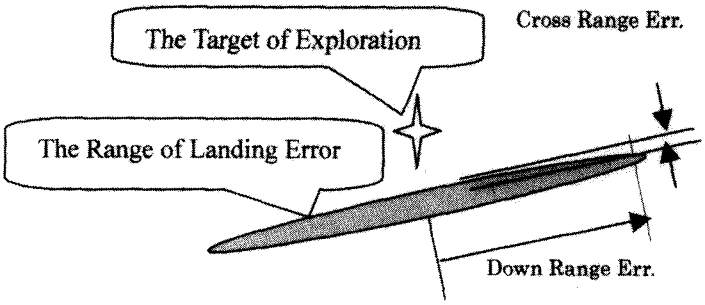

FIG.24 The target of exploration and the landing point error

Such a flying rover is suitable for the mission to the specific target of exploration (Fig.24), and exploration of more dangerous, vital regions such as inside of deep craters, far-side of the moon. The system also has an advantage that it can be operated at the target area in long duration sinse it requires very short flight time.

4. CONCLUSION AND ACKNOWLEDGEMENTS

For the effective lunar surface mission, NASDA, office of R&D, has been studying basic technologies and system concepts, which is useful for the exploration tasks, and attractive as technical targets. The paper described the research feature of basic computer aided observation, a new laser range finder, the small exploration rovers, which are operated in coordination, and the lunar flying rover system.

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