Japanese Lunar Lander SLIM and Its Optical Navigation for Pinpoint Landing

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Keywords: Lunar lander, pinpoint landing, optical navigation

ABSTRACT

SLIM (Small Lander for Investigating Moon) is Japanese small spacecraft for demonstration of lunar pinpoint landing technology. SLIM aims at achieving accurate navigation to a specific landing point on the moon using innovative optical navigation technology.

1 Introduction

Japan Aerospace Exploration Agency (JAXA) will soon launch a small lander to the Moon soon as shown in Fig. 1. The lander is called SLIM (Smart Lander for Investigating Moon) [1]. Now SLIM is undergoing final tests for the launch in 2023 (Fig. 2).

Aims of SLIM include two challenges. One is to build a small and light landing system. Dry mass of SLIM is as small as about 190kg. The other challenge is to demonstrate precise landing technologies to land on the Moon within up to 100 m error. SLIM is to observe Olivine ejected from a fresh crater on the surface of the moon. The predetermined landing site near the SHIOLI crater in Mare Nectaris (Fig. 3) is highly challenging since the area has steep slopes around 10 degrees and is covered with boulders ejected from the crater. To achieve precision landing a crater-based terrain relative navigation technology is developed in SLIM project.

As shown in Fig. 4, SLIM takes about three months from the launch to LOI (Lunar Orbit Insertion), because it employs fuel-saving orbits with lunar swing-by. After the LOI, 500N thrusters are used to lower the orbit followed by the powered descent phase. Figure 5 shows the sequences of this phase. To update navigation errors, onboard cameras are used to obtain images of lunar surfaces in several areas to collate them with onboard crater maps (Fig. 6). Hazard detection and avoidance is performed just before landing to avoid obstacles harmful to the landing.

2 Optical Navigation for Pinpoint Landing

The main technologies for optical navigation demonstrated by SLIM are described below. All algorithms for optical navigation described in this section are implemented on FPGA (Field Programmable Gate Array) in the actual SLIM spacecraft.

2.1 Making Crater Maps

Onboard crater maps are generated before the launch using image data obtained by the other lunar orbiters.

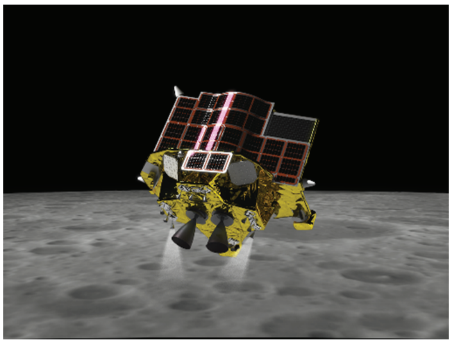

Fig. 1 SLIM (artistic illustration)

Fig. 2 SLIM under the development test

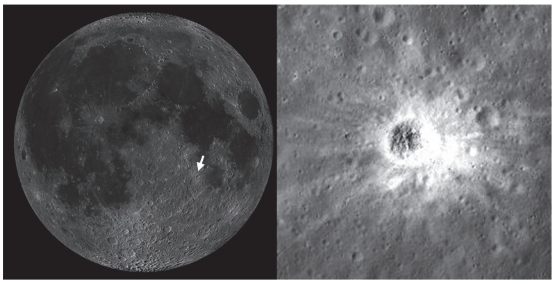

Fig. 3 Landing site of SLIM (near SHIOLI crater)

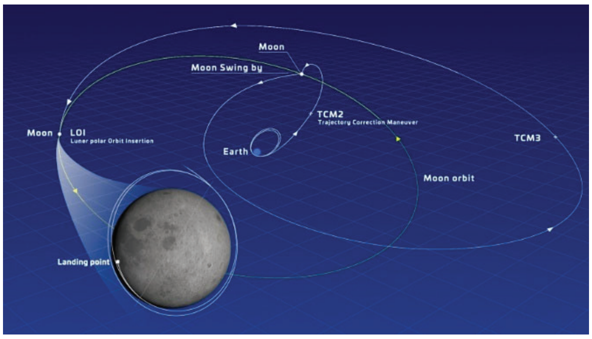

Fig. 4 SLIM orbit to the Moon

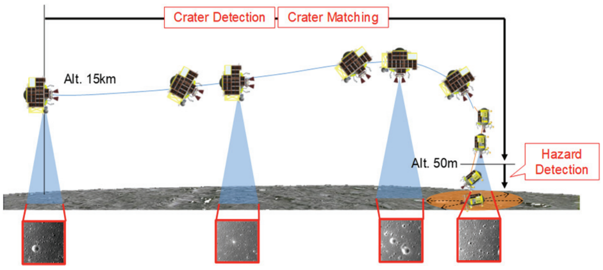

Fig. 5 Landing sequence of SLIM

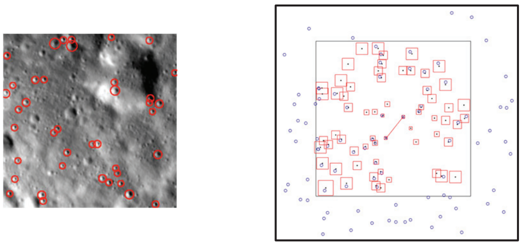

Fig. 6 Crater detection and matching

Digital elevation maps (DEM) are made from obtained high resolution image data, and craters are extracted in advance. Using craters as features makes it robust to illumination changes and possible to reduce map data size. The crater maps are prepared and installed on the onboard computer for each area where crater matching is executed.

2.2 Crater Detection

In the landing phase, onboard navigation cameras [2] are used to obtain images of the surface of the moon. The cameras have the so-called global shutter in order to take lunar surface images without parallelogram-like distortion under high orbital velocity as high as maximum 1 to 2 km/s. The craters in the images are detected by the method based on principal component analysis. The principal component of crater images obtained by the past lunar orbiters is used as a template. Since the method is performed by product-sum operations, it can be designed by fixed-point arithmetic and is friendly to the FPGA implementation. This method is based on the research result by Kamata Laboratory at Meiji University [3].

2.3 Crater Matching

Detected craters are then collated with the onboard crater maps based on spatial relation. This approach searches correspondence of onboard crater map and detected craters to estimate the absolute position of SLIM. In order to find the correspondence, crater spatial pattern such as line segment or triangle features; these algorithms were developed by the research team including Takadama Laboratory at the University of Electro-Communications [4], [5]. Computational complexity of the algorithms is reduced by using on-board navigation information efficiently.

2.4 Hazard Detection

Since SLIM landing site is expected that boulders from the crater near the landing site are heavily distributed, obstacles detection using the camera images at the final hovering altitude (~ 50 m) is carried out. Boulders over 15cm (2px in images) must be avoided for safe landing. A hazard map is generated from the original image using local variance, and the safest area is selected considering the spacecraft footprint, landing error, and body height. Kojima laboratory at Tokyo Metropolitan University collaborated in the development of the algorithm [6].

3 Conclusions

The precision pinpoint landing can bring a paradigm shift in the field of celestial body landing from 'landing where easy to land' to 'landing where desire to land'. Once the technology for pinpoint landing, including optical navigation, has been demonstrated with SLIM, it is expected that various landing missions using SLIM heritage will open up future space activities.

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