

Efficient Deep Space Exploration: Optimizing Lunar Orbit Analysis and Data Processing for TSUKIMI

*Ryodo Hemmi¹, YASUKO KASAI¹, Takayoshi Yamada¹, Suyun Wang¹, Shigeru Sato¹, Hideaki Miyamoto², Hirotaka Horita³, Takashi Eishima⁴, Narihiro Okuma⁴, Hayato Watanabe⁵, Akihiro Shibuya⁵

1. National Institute of Information and Communications Technology, 2. The University of Tokyo, 3. Systems Engineering Consultants Co., Ltd., 4. Axelspace Corporation, 5. Space BD Inc.

In the 2020s to 2030s, as the frequency and commercialization of deep space exploration of the Moon, Mars, asteroids, etc. become a global trend, the challenges of the mission's increasing size, complexity, and cost and a shortage of human resources are seen as bottlenecks. Therefore, it is necessary to promote more efficient and effective exploration and revitalize private space development and the space industry.

This research particularly suggests that it is extremely important from the viewpoint of efficient exploration to conduct a seamless process from orbit design to observation schedule generation, observation mode design, analysis simulation in the observation plan region (prediction, error analysis), actual data acquisition, and downlink data processing.

For example, although there are widely used orbit analysis software (e.g., AGI's STK, NASA's GMAT), they are not designed to continuously analyze science in different situations due to differences in computer specifications and purposes, resulting in a lack of continuity in the overall mission. However, this software can be specialized, making them difficult to use and requiring a high cost of learning, which is not business-oriented.

Furthermore, from the perspective of scientific requirements and resource estimation, existing data display search is suitable for quick search using tools like Quickmap (<https://quickmap.lroc.asu.edu>), Moon Trek (<https://trek.nasa.gov/moon/>), JMARS (<https://jmars.asu.edu/>), etc., but moving from there to exact analysis using actual data requires specialized knowledge and there are numerous technical challenges.

Moreover, a significant amount of data obtained from existing missions is publicly available and accessible, but it has not been subjected to co-registration, georeferencing, mosaicking, or orthorectification, resulting in problems such as the inability to obtain accurate geographical coordinates or easily determine the highest resolution at a particular location.

Given these circumstances, we propose that an interface that effectively combines existing software and exploration data is essentially necessary.

In this study, we aimed to develop a method that directly derives continuous observation footprints and their data from satellite orbit and attitude information and observation equipment information.

The input data used in this study was the spacecraft and planetary ephemerides of the exploration satellite for one Earth year, which was considered in the Moon resource exploration project "TSUKIMI" (<https://www.tsukimi.one/>) using Terahertz waves. We simulated footprints on the undulating moon

surface when the sensor with a field of view (FOV) of 0.25 degrees and 0.35 degrees scanned for 0.5 seconds with a 3-second interval in three different satellite attitudes of roll angles of 20, 40, and 60 degrees. The data analysis mainly used SpicelyPy and Python GDAL/OGR API.

As a result, we found that when using a polar orbit with a periapsis close to the South Pole, especially in the first three months, footprints with high spatial density were obtained centered on the South Pole of the moon. Furthermore, it was found that the footprints overlap in the region when different roll angles are used. Additionally, it was found that the footprints move in a direction perpendicular to the direction of the satellite's progress due to the presence of craters of several tens of kilometers in size, but their impact is not so great from a scientific point of view.

Furthermore, it was confirmed that by using these footprints, surface roughness, mineralogical and elemental abundances, surface temperature distribution, etc. can be obtained on a per-observation footprint basis from existing remote sensing databases.

Thus, by utilizing existing software and datasets and expanding their functions as we did in this study, it can be shown that more realistic exploration and observation information can be efficiently acquired beforehand. In the future, we aim to expand the functionality by using more detailed observation modes and schedules as inputs, expanding the Moon surface database (other spectral data, local exploration data, etc.), and constructing a more user-friendly, business-oriented interface/platform.

Acknowledgments:

This research and development include the results achieved under "Exploration of water energy resources over a wide area on the moon using terahertz waves" (JPJ010777) within the "R & D of ICT priority technology" (JPMI00316) of the Ministry of Internal Affairs and Communications. This research is supported by TOKYO DOME CORPORATION/TenQ.

Keywords: Remote Sensing, Moon, GIS