frontiers | Frontiers in Space Technologies

TYPE Editorial
PUBLISHED 31 October 2024
DOI 10.3389/frspt.2024.1493494

OPEN ACCESS

EDITED AND REVIEWED BY
Mark Sephton,
Imperial College London, United Kingdom

*CORRESPONDENCE
P. Reiss,
p.reiss@tum.de

RECEIVED 09 September 2024
ACCEPTED 23 October 2024
PUBLISHED 31 October 2024

CITATION
Reiss P, Abbud-Madrid A, Arm P, Bickel VT, Kehl F, Kolvenbach H, Ligeza G, Lomax B and Zabel P (2024) Editorial: Technologies for prospecting, extraction, and utilization of space resources.
Front. Space Technol. 5:1493494.
doi: 10.3389/frspt.2024.1493494

Editorial: Technologies for prospecting, extraction, and utilization of space resources

P. Reiss[1]*, A. Abbud-Madrid[2], P. Arm[3], V. T. Bickel[4], F. Kehl[5,6], H. Kolvenbach[3], G. Ligeza[7], B. Lomax[8] and P. Zabel[9]

[1]Department of Aerospace and Geodesy, School of Engineering and Design, Technical University of Munich, Ottobrunn, Germany, [2]Center for Space Resources, Colorado School of Mines, Golden, CO, United States, [3]Robotic Systems Lab, Department of Mechanical and Process Engineering, ETH Zürich, Zürich, Switzerland, [4]Center for Space and Habitability, University of Bern, Bern, Switzerland, [5]Space Science and Technology Group, Department of Earth and Planetary Sciences, ETH Zurich, Zurich, Switzerland, [6]Space Instruments Group, Department of Astrophysics, University of Zurich, Zurich, Switzerland, [7]Department of Environmental Sciences, University of Basel, Basel, Switzerland, [8]European Space Research and Technology Centre, European Space Agency, Noordwijk, Netherlands, [9]Institute of Space Systems, German Aerospace Center, Bremen, Germany

KEYWORDS

space exploration, space resources, technologies, instruments, moon, in situ resource utilisation

Editorial on the Research Topic
Technologies for prospecting, extraction, and utilization of space resources

Introduction

Our solar system holds an abundance of resources that can be utilized to support space exploration missions and sustain a future human presence beyond Earth. These resources include solar energy, water ice, volatiles, hydrates, minerals, metals, rare earth elements, and the regolith on various celestial bodies. The *in situ* resource utilization (ISRU) approach encompasses the production of life support consumables, such as oxygen and water, propellants, in-space manufacturing, or the construction of large structures based on these locally available materials. ISRU reduces the amount of resources needed to be supplied from Earth, thereby enabling long-term missions and permanent outposts.

The studies presented in this Research Topic showcase advancements in instrument development for the detection and characterization of space resources, as well as technologies to process feedstock and obtain valuable products such as water, oxygen, and metals. Additionally, they address the critical need for suitable terrestrial regolith analogues to support the development, testing, and validation of ISRU systems, as well as the construction of infrastructure to enable sustainable, long-term operations.

Prospecting

Various prospecting missions are currently planned to reduce uncertainties in estimated lunar resource occurrences and concentrations. The European Space Agency's PROSPECT instrument package combines the acquisition and detailed analysis of lunar samples on a lander. Trautner et al. present its design and capabilities and the recent development status.

Equipped with the ProSEED drill and ProSPA analytical laboratory, the instrument package primarily aims to extract and analyze surface and subsurface regolith samples, targeting volatile-rich areas. It also features an ISRU demonstration mode, in which regolith will be reduced with hydrogen to produce water. A multispectral imaging system allows the characterization of the surface at the landing site, and a drill-integrated permittivity sensor supports the determination of subsurface ice and the monitoring of its potential loss during sample acquisition.

Characterization of the soil properties, as well as its ice content, is essential for identifying resource-rich areas, especially for surface-bound vehicles. Gscheidle et al. present their concept of novel dielectric permittivity sensors to map water ice deposits in the lunar regolith. Such sensors could be attached to rover wheels and lander footpads and present a power- and mass-efficient instrument for exploration missions. The study discusses the sensor's functional concept and data processing techniques and demonstrates its performance in detecting ice in lunar regolith.

Laser-induced breakdown spectroscopy (LIBS) and Raman spectroscopy are emerging as powerful tools for *in situ* planetary exploration. The feasibility study by Rammelkamp et al. showcases how LIBS can effectively identify and quantify the mineral ilmenite in lunar regolith, while Raman spectroscopy can be used to monitor oxygen extraction processes. By providing real-time data on elemental composition and process efficiency, these techniques could be an important tool for future prospecting missions.

The location of feedstock, as well as its accessibility, determines the economic viability of a mining operation and subsequent resource processing. In their study, Steinert et al. investigate the influence of location selection on the viability of an in-space refueling architecture that utilizes lunar oxygen. The results suggest that the selection of oxygen production sites should prioritize resource availability and processing efficiency over transport cost variations to optimize the overall mission cost-effectiveness.

Extracting

Kulkarni et al. demonstrate a three-stage beneficiation system to enrich the feedstock concentration of the mineral ilmenite. Through sequential gravitational, magnetic, and electrostatic techniques, the ilmenite grade was increased by a factor of three, highlighting the potential of beneficiation to enable higher oxygen yields in regolith processing.

The research of Burke et al. explores the effect of reduced gravity on bubble formation and detachment in various electrolysis processes, including water electrolysis, molten salt electrolysis, and molten regolith electrolysis. The findings indicate that reduced gravity, fluid properties, electrode surface conditions, and electrode orientation significantly influence electrolytic efficiency, providing insights for designing and operating effective ISRU oxygen production systems.

Utilizing

Constructing necessary infrastructure on the Moon with locally available resources is vital for sustainable long-term missions. Walther et al. systematically investigate the autonomous construction of lunar infrastructure using unprocessed boulders. They present a promising method for building blast shields to protect lunar infrastructure from the debris of a spacecraft landing or launching. The study shows that this approach requires two orders of magnitude less energy than alternative ISRU construction methods.

One critical aspect of establishing a lunar base is ensuring a reliable supply of clean water. The study by Freer et al. addresses this challenge by characterizing the dissolution behavior of lunar regolith in water. The experiments revealed that lunar dust contamination could significantly exceed the volatile levels allowed by drinking water standards of the World Health Organization and the National Aeronautics and Space Administration, particularly in terms of pH, turbidity, and aluminum concentration. These findings underscore the importance of developing robust water purification systems to ensure the health and safety of future crew.

Terrestrial analogues

Testing ISRU systems on ground is only possible through the use of terrestrial regolith analogues, so-called simulants. Long-Fox et al. present insights into the production methods, equipment, and materials used to create planetary regolith simulants. The authors provide details on the compositional data, particle size, and applications for certain standard lunar, Martian, and asteroid simulants.

The study by Louca et al. presents a virtual model of lunar regolith that can effectively replicate regolith behavior, especially with respect to flowability. This approach offers a cost-effective, safe, and practical alternative to physical testing, particularly for large-scale applications like virtual training and teleoperation systems, and could facilitate the development of robust ISRU systems.

The articles collected on this Research Topic demonstrate the immense breadth and multi-disciplinarity of ISRU. They also highlight how fundamental and applied research complement each other to push the boundaries of space exploration and realize sustained human presence beyond low Earth orbit.

Author contributions

PR: Writing–original draft, Writing–review and editing. AA-M: Writing–review and editing. PA: Writing–review and editing. VB: Writing–review and editing. FK: Writing–review and editing. HK: Writing–review and editing. GL: Writing–review and editing. BL: Writing–review and editing. PZ: Writing–review and editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

10.3389/frspt.2024.1493494

Publisher's note