remote sensing

Editorial

Cartography of the Solar System: Remote Sensing beyond Earth

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1. Introduction

Cartography is traditionally associated with map making and the visualization of spatial information. Over recent decades, however, the field has not only been advancing in terms of the depth of knowledge, but also in terms of topical diversity with respect to spatial information. Cartography has successfully made the transition from a traditionally analog field to a digital field with continuous innovations in the areas of spatial data analysis and visualization as a tool for communication and gaining deeper insights.

In the planetary sciences, cartography has been even more strongly related to the domain of map making, but has started to lean towards integrated spatial data analysis, spatial information science, and machine learning as well. In contrast to map making, planetary mapping is rather closely related to the systematic acquisition of data, while cartography consists of turning spatial data into advanced visualizations. As planetary mapping is almost exclusively within the domain of remote sensing, there are also strong ties between remote sensing and cartography. In this sense, cartography deals with three main aspects: data acquisition and management, spatial data analysis, and spatial data visualization.

Across 16 contributions, this Special Issue presents a cross-section of these topics addressed with both conventional and innovative methods, covering topics such as

- Mapping and spectral analysis [1–7];
- Data processing and data products [8–10];
- Impact crater and feature detection [11,12];
- Pose estimation [13,14];
- Research data management and valuation [15,16].

Topics range from fundamental to applied methods and demonstrate their relevance to future planetary exploration and potential resource exploitation.

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2. Topics in Planetary Mapping and Cartography

2.1. Mapping and Spectral Analysis

Thematic and image mapping are foundational tools to support the exploration of planetary surfaces using remote sensing data. Geologic mapping is traditionally based on optical and multispectral image data complemented by local hyperspectral observations. Such thematic mapping depends on the quality of foundational data products which comprise image data mosaics, terrain model mosaics, and potentially other data sources.

In [1], Semenzato et al. present a traditional geologic mapping investigation including crater-size frequency-based age determinations of the Rembrandt basin on Mercury in support of the ESA-JAXA BepiColombo mission. They expand their mapping investigation by introducing morpho-stratigraphic and geo-stratigraphic maps which provided further depth to the mapping investigation. Tognon et al. [2] perform a morpho-stratigraphic investigation of the lunar impact crater Tsiolkovskiy and, using crater-size frequency distributions, demonstrate how at least three igneous periods of volcanic activity have shaped the interior of the impact crater, making it a candidate exploration site on the lunar far-side. Both investigations demonstrate the need for detailed geologic mapping studies and the value of fusing different planetary data sources, even historic ones.

In [3], Ciazela et al. report on their mapping of Mars' surface thermal inertia using a model approach that allows for an approximation of thermal inertia values not only in flat areas but also on slopes, providing a basis to better differentiate geologic units based on their material properties. Luo et al. [4] demonstrate and discuss how the spatio-temporal variation in driving factors associated with Martian surface temperature might have a significant impact on surface operations and emphasise how these effects cannot be neglected.

In two contributions authors take a closer look at the effect of the lunar environment on the characteristics of surface materials as seen in spectra. In Hess et al. [5], the authors investigate how external factors can impact spectral characteristics and address the problems of spectral unmixing without probabilistic methods. In [6], Hess et al. take a closer look at the relationship between TiO_2-bearing minerals, plagioclase, and Mg-spinel, the hydration of the surface material, and the variation over a lunar day.

In their investigation, Wolfarth and Wöhler [7] suggest that the effect of wavelength-dependent seeing, rather than variations in emission angles, might be the cause of the systematic variations in Mercury's normalized spectral reflectance slope.

2.2. Data Processing and Data Products

The basis for future exploration, for the creation of accurate maps, and for performing data analyses are foundational data products that show a high level of consistency and accuracy. Schenk et al. [8] report on the development of topographic and color maps data for Neptune's moon Triton using stereophotogrammetry and photoclinometry, comparing the moon's unique features to objects in the Pluto system with implications for different origins of material and evolution.

In [9], Tao et al. report on a deep learning approach for digital terrain model generation using single images and a coarse global 3D reference. The presented system would be able to reduce the processing times and artifacts in such datasets significantly. In a second contribution, Tao et al. [10] present a data fusion approach in which they merge datasets from different stereo-photogrammetric systems to generate a consistent digital terrain model and an orthoimage mosaic for the entire Valles Marineris region on Mars.

2.3. Impact Crater and Feature Detection

Impact craters have always played an important role in the planetary sciences. They are geologic windows into a planet's past and can be used as chronometers for surface age determinations. They can exhibit a rich variety of materials and erosional processes, and allow for dynamic studies on impact processes. Due to their rich variety of erosional states and complex arrangements, manual selection methods of impact craters have been the most reliable thus far. In [11], the authors present an investigation on the depth/diameter ratio of lunar impact craters at the South pole and implications for harboring water ice.

Impact craters have also been used for testing algorithms to detect these features automatically, and computer vision has started to challenge manual detection methods. In recent years, machine learning algorithms have been playing an important role in improving detection quality. Zang et al. [12] present a novel small-crater detection method based on a region-based convolutional neural network (Crater R-CNN), and demonstrate its operation for selected areas on the Moon.

2.4. Pose Estimation

For spacecraft entry, descent, and landing (EDL), reliable pose estimations are crucial for successful operation. Two contributions in this Special Issue deal with this topic: Chen and Jiang [13] present an impact crater detection method for pose estimation by relying on a high-accuracy network and sequence image information, which is suggested to be an efficient crater detection and recognition method for pose estimation. Zhong et al. [14] take a different route and try to address specific difficulties of effective lunar patch matching, proposing a multi-scale fusion network to achieve lunar image patch matching accurately and robustly.

2.5. Research Data Management

A new ethical awareness regarding the responsible handling of research data has been evolving over recent decades, recognizing that these data are valuable assets that need to be accessible, reusable, and transparent with respect to their creation and lineage. This development affects cartography in particular as data are the foundational building block of any sub-discipline in this domain. Two contributions in this Special Issue address this topic in more detail. In [15], Nass et al. present a prototype to address the evolving need to efficiently query and manage complex data in the world of planetary remote sensing. The contribution introduces a web-based information management system and showcases its concepts and functionality. In [16], van Gasselt and Nass discuss how information and knowledge are built from planetary source data and how model assumptions, constraints, simplifications, and generalization create uncertainties that precipitate into the final map product. The contribution emphasizes the need for completeness in mapping, cartographic data analysis, and visualization.

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