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SOIM (Simulator for Operation of Imaging Missions)

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Abstract

The experience accumulated by INAF in international space missions has demonstrated the significant impact and scientific value of imaging tools. These instruments have necessitated the development of software tools across all mission phases to simulate data acquisition, verify and optimize observation strategies, and define essential operational parameters. The Simulator for Operations of Imaging Missions (SOIM) will be a versatile software tool designed for the simulation of these payloads. It will serve as a cross-functional resource, supporting multiple research lines, optimizing performance, and enabling the validation of scientific requirements in collaboration with the scientific community. The contribution of the INAF team is crucial not only in preparing for the planning operations of global mapping and target acquisition for the BepiColombo mission, but also as a tool that can be extended to any imaging instrument for planetary surfaces. This effort involves the collaboration of INAF-OAPD, INAF-IAPS, and CNR-IFN and the LAPD (Laboratorio di Astroinformatica e Planetologia Digitale).

1.Objectives and results

Almost all imaging instruments in planetary science can be modelled as pinhole instruments (analogous to a pinhole camera). These instruments are crucial for planetary exploration, providing images that allow both morphological and radiometric analysis of solar system bodies. Our group's experience with planetary exploration missions has highlighted the lack of an operational simulation tool for such instruments within INAF, which is essential from the early design phases to verify and simulate the acquisition capabilities, impacting risk factors, timing, and precision in payload development.
To address this, the development of the SOIM (Simulator for Operations of Imaging Missions) software began, which is currently being used for the MCAM and SIMBIO-SYS instrument on the BepiColombo mission.
For the operations of a planetary mission, many necessary parameters are defined based on the following inputs: ephemerides, the instrument model, the target model.

1.1 Models

For ongoing missions, ephemerides are directly provided by the relevant space agencies in the standard SK format. For future missions, the development of SKs can be supplemented with the definition of potential new scenarios.
The geometric target model could be a DSK already present (i.e. Phobos) or not (i.e. local MOLA models on Mars) in the Spice Kernel (SK) pool.
Once the orbit is defined and a 3D model (even an approximate one) of the target body is integrated, the illumination angles for each region within the instrument's field of view can be calculated. This, in turn, determines the incoming flux to the instrument, enabling the validation of an operational timeline.
The instrument model is formalized through two sub-models: the geometric model and the opto-electronic model. The geometric model defines the camera's projection system. The opto-electronic model describes the sensor's response to incoming flux in terms of gain (related to filters and aperture) and dark current (or an approximation verified during calibration). While the geometric model is defined during calibration, the opto-electronic model, which can be approximated with a few parameters, is deducible from the early phases of optical and sensor design.
The target model is essentially the radiometric model of the observed body. This can be defined generically for less well-known bodies or specifically if data from previous missions is available. For example, the BepiColombo mission will use knowledge of Mercury from earlier missions as an initial estimate for the radiometric models.

1.2 Overview of the Products

The primary outputs of the software are related to image quality and target visibility. Regarding image quality, the system allows the definition of integration times to avoid saturation or smearing. Concerning target visibility, it enables the estimation of repetition times needed to ensure a defined overlap of images and provides mapping of planetary acquisitions as well as a synthetic simulation of the expected data. Outputs related to this task include shapefiles of each acquisition.
With the current version of the simulator, it was possible, for example, to simulate images at the closest approach of the first 4 Mercury flybys by BepiColombo's MCAM cameras. This enabled the creation of acquisition timelines and the validation of geological features captured during these phases.
The same process was used to optimize the camera models by correcting the pointing of these cameras as predicted by the SKs, as detailed in INAF Technical Report 125.

2. Conclusions

Planetary research requires constant updates and experimentation with new technologies, demanding rapid problem-solving and necessitating consistent funding for training and access to basic research resources. The SOIM faces two main challenges: scalability and dissemination.

1. Scalability: The SOIM tool must be adaptable to various imaging instruments, whether under development (e.g., the HYPSOS stereo hyperspectral camera for lunar observation) or in operation (e.g., the SIMBIO-SYS instrument on the BepiColombo mission). This requires a modular architecture, platform-independent language, and the ability to operate in virtual environments.
2. Dissemination: SOIM must meet both INAF's technological needs and the scientific community's requirements. Effective dissemination involves creating a process that facilitates scientific visualization and interpretation, such as projecting a camera's footprint in a GIS environment to assess observational opportunities and data quality

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