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Image Processing Simulations for the BepiColombo Rotation Experiment

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Abstract

One of the major objectives of the Radio Science Experiment hosted on-board the Mercury Planetary Orbiter of the ESA mission BepiColombo is the retrieval of Mercury's rotational state, fundamental to gather information on its interior. This consists in a system-level experiment envisaging the collaboration among different payloads. The experiment relies upon precise orbit reconstruction and observations of the same landmarks on the surface at different epochs enabling to infer the planet's obliquity and librations. Since the experiment is rather complex, the implementation of a global simulator is under development to identify optimal observation criteria. In particular, this abstract will focus on two modules of the simulator, one producing a surface map of possible image pairs and a tool for the generation of synthetic images aimed at the selection of optimal pattern matching strategies.

1. Introduction

The scientific interest in exploring Mercury is especially motivated by the puzzling outcomes of the Mariner 10 mission flybys performed in 1974-75 unveiling the existence of a magnetic field on the planet. In order investigate on this discovery and address other important studies in geodesy and geophysics, ESA is currently preparing for the launch of the BepiColombo mission planned to reach Mercury in 2020.

A possible theory explaining the presence of a magnetic field could be the existence of a liquid outer core generating a dynamo effect. While Earth-based observations support this theory [3], the planet's high uncompressed density more likely suggests a core made of pure iron. As it was shown by Peale [1], the knowledge of the rotational parameters of a planet, i.e. obliquity and librations, is of primary importance in order to constrain its interior structure. The obliquity of a planet represents the inclination of its spin axis direction with respect to the normal to the orbital plane. Mercury's annual forced librations consist in a longitudinal motion characterized by a sinusoidal wave with a period of 88-day, caused by a Sun gravity-gradient effect. Since the estimated amplitude of this phenomenon is only 400 m at the equator very precise measurements are needed.

2. The BepiColombo Rotation Experiment

The BepiColombo Rotation Experiment is accomplished via the collaboration among different payloads, thus implying a rather high level of complexity. In particular, it makes use of the images acquired by the High Resolution Imaging Channel (HRIC) part of the SIMBIO-SYS payload, star-tracker precise orbit reconstruction, gravity field determination thanks to radio tracking data provided by the Ka-band transponder (MORE) and estimation of large non-gravitational accelerations detected by the Italian Spring Accelerometer (ISA).

The rotational parameters are estimated by the observations of landmarks on Mercury's surface taken at different epochs, so as to generate a useful number of observables consisting in the displacement of a target point. During this process, several aspects must be taken into account such as the selection of the most favourable epochs for the observations and the most suitable features to be captured as well as the optimal pattern matching algorithms and the implementation of realistic error models.

In order to address the issues presented above, a global simulator of the entire experiment is currently under development with the final aim of identifying the optimal mission observation planning and test all the critical parts of the estimation process.

In particular, two of the modules composing the simulator consist in a software tool producing a map of all the possible image pairs, fundamental for later selection of observations, and a second one generating synthetic images simulating the optical observations that will be captured by the camera.
In Figure 1 a typical output of the coverage map of Mercury's surface is shown. The software tool, implemented using Fortran programming language, takes as input the MPO trajectory kernel, makes use of NAIF SPICE routines computing the ground tracks and giving as output a database of the observations for post-processing analyses.

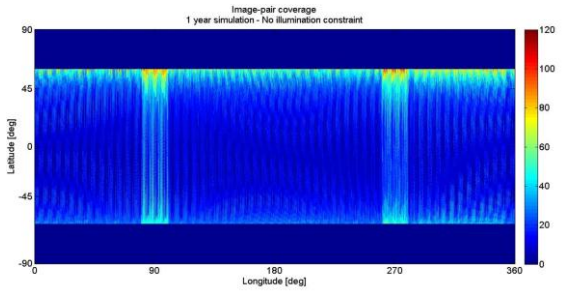

Figure 1: Map of possible image pairs

Several constraints must be taken into account in the process of the images selection. The peculiar 3:2 spin orbit resonance of Mercury and the fact that librations depend on the value of its mean anomaly result in the impossibility to obtain image pairs characterized by the same illumination conditions [4]. The constraints usually imposed consist in limiting the change of scales and illuminations in order to make the pattern matching process feasible, as well as selecting images showing appreciable differential libration amplitudes for the estimation process. Since this significantly decreases the number of useful observations, new pattern matching and observational strategies were investigated in order to relax some of these constraints.

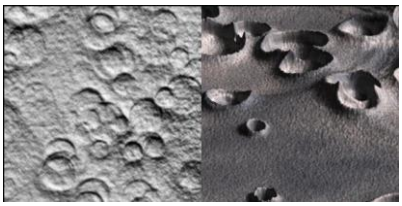
Figure 2: Example of synthetic image generation

In order to assess the goodness of the proposed strategies and build ad-hoc pattern matching algorithms as well as quantifying the associated errors, a tool generating synthetic images was developed (Figure 2). Images can be generated depending on desired values of altitude and illumination angles so as to simulate a real observation. The idea of the global simulator is to select a certain number of image pairs, generate the relative synthetic observations and investigate the best pattern matching algorithms. At the moment only algorithms robust to changes of scale have been studied leading to sub-pixel accuracy in the feature tracking stage. An output of the tracing process is shown in Figure 3.

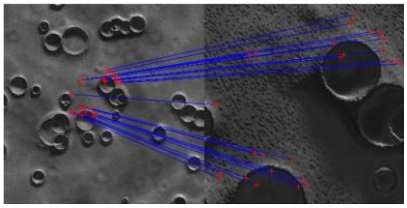
Figure 3: An output pair of the ray tracing algorithm and the subsequent feature tracking

6. Summary and Conclusions

The implementation of pattern matching algorithms suitable also for abrupt changes in illuminations condition is currently under development. In parallel, a sensitivity analysis to derive statistics of the main parameters variations in each image pairs is being carried out in order to help in the definition of selection criteria to be integrated in the overall process. Successively, a test campaign is foreseen to test the end-to-end global simulator.

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