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# Implementation of an End-to-End Simulator for the BepiColombo Rotation Experiment

**A. Palli** (1), A. Bevilacqua (1), A. Genova (2), A. Gherardi (1), L. Iess (2), R. Meriggiola (2), P. Tortora (1)

(1) Università di Bologna, Italy, (2) Università di Roma "Sapienza", Italy

## Abstract

Fundamental information on the interior of Mercury can be inferred from its rotational state, in terms of obliquity and amplitude of physical libration in longitude. For this reason a dedicated Rotation Experiment will be performed by the ESA mission BepiColombo. A system-level experiment simulator has been developed in order to optimize the observation strategy and is here presented. In particular, this abstract will focus on the estimation process, the optimization algorithms and the selection of optimal pattern matching strategies.

## 1. Introduction

Multiple optical observations of a same region on the surface of Mercury can be used to determine the obliquity and the libration amplitude. An apparent shift (*registration error*) on the surface of evident features can be observed in the georeferenced images if the rotational model used for georeferencing does not accurately describe the rotational state. Different pattern matching algorithms, depending on the light conditions and the image resolution, can be applied to compute the misregistration. The mismatching is also affected by several error sources, from the spacecraft ephemerides and attitude to the camera orientation, calibration and thermoelastic deformations. A weighted least squares method is used to minimize the registration errors, providing the estimated rotational parameters.

This technique will be used in the BepiColombo Rotation Experiment to estimate the obliquity and the amplitude of physical librations in longitude with an improved level of accuracy. Updated estimates of the libration amplitude can be used to constrain the deep interior models and the radius of the outer core [1], while the polar Moment of Inertia (MoI) can be directly inferred from the obliquity.

## 2. The BepiColombo Rotation Experiment Simulator

The BepiColombo Rotation Experiment Simulator can perform complete simulations of the experiment as well as process real data. It will use high resolution images (5 m at pericenter) acquired by the High Resolution Imaging Channel (HRIC), as well as star-tracker attitude data and spacecraft trajectory previously obtained by the gravity field determination.

In the simulations a dataset of optical observables is generated starting from the predicted trajectory. All the crossover areas are detected and observed at different times. The corresponding optical observables are selected taking into account the time span between the first and the second observation and the most suitable conditions (sun elevation and azimuth, S/C altitude) to the application of pattern matching algorithms. Realistic error models for the attitude and the spacecraft ephemerides have been included. Since only a limited number of image pairs will be available for the rotation experiment, the identification of an optimal science planning is a major issue in the pre-mission phase. For this reason, an end-to-end simulator of the experiment (Figure 1) has been implemented, including all involved constraints.

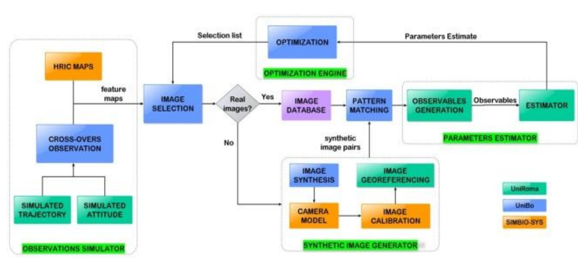


Figure 1: End-to-end simulator of the experiment

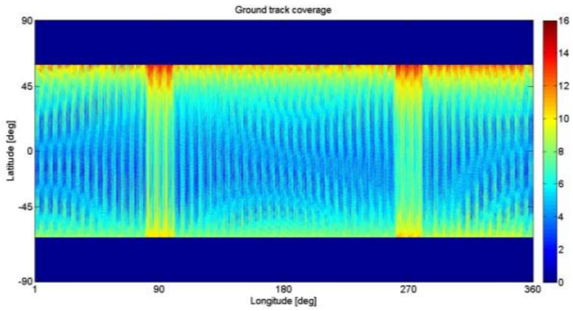


Figure 2: Map of the observations

The first block of the simulator is the observation simulator. the trajectory and the attitude of the spacecraft are used to provide a map of the BepiColombo ground tracks and of all potential crossover areas (Figure 2). All data relative to each observation (epoch, altitude, illumination conditions) are stored for successive post-processing. The database of optical observables is then used to compute the image pairs opportunities and this second database can be filtered according to the desired constraints such as altitude, location, or illumination conditions, in order to drive the pattern matching process. An initial random set was selected from the general database in order to be used for the estimation of the rotational parameters.
In order to reproduce the operational conditions, test the most suitable pattern matching algorithms and compute the error relative to the image processing a Synthetic Image Generator has been developed. For each couple of observations the corresponding simulated images are generated using the previously stored data and a dedicated pattern matching algorithm is applied, providing the relative error. Thanks to the current algorithms this is estimated to be around 1/10 pixel at worst.
Concerning images elaboration, simulations have also been performed in order to identify the optimal pattern matching algorithms.

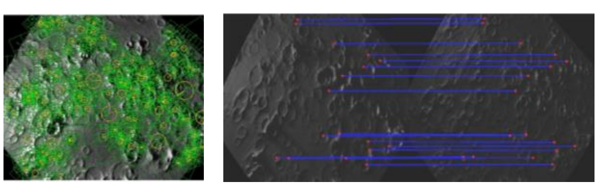

Figure 3: Example of features extraction and matching with a SIFT method

These are strictly dependent on the characteristics of each image and different methods are applied according to their robustness to changes of scales, and sun elevation and azimuth angles. In Fig. 3 an example of feature extraction and matching employing a Scale-Invariant Feature Transform algorithm is shown.
Both pattern matching error and optical observables are processed to generate the simulated registration errors, which refer to a putative. rotational model of Mercury. Errors relative to attitude reconstruction, spacecraft ephemerides, time tagging and thermoelastic deformations are also included. The registration errors are then processed by the estimator which provides the estimated rotational parameters along with the relative accuracies. Further simulations were performed using only the estimation software and randomly introducing sets of observations in order to test the minimum number of couples necessary to reach the desired level of accuracy in the estimation of the rotational parameters.
The entire procedure is iterated inside an optimization routine employing a genetic algorithm which adjusts the current planning of the observations until convergence to an optimum and uses the output of the rational parameters estimation algorithm as a figure of merit for the current solution.
A first release of the software has already been completed and preliminary simulations performed.

## 6. Conclusions

The best observational strategy for the BepiColombo rotation experiment is strictly dependent on different factors such as location of the landmarks, epoch of the observations, light conditions and altitude. Since the number of available observations will be limited an end-to-end simulator of the experiment has been implemented to take into account all mission phases. By reproducing the operational conditions it will then be possible to ensure the optimal scientific return. The simulator is now at its first integration and will be refined and improved in the future, also following the latest mission design updates.

## References

[1] Margot, J. L., Peale, S. J., Jurgens, R. F., Slade, M. A., Holin, I. V.: Large Longitude Libration of Mercury Reveals a Molten Core, Science 316, 710, May 2007