Mercury rotational state estimation applied to the BepiColombo Mission: an optimized approach on the selection of optical observations

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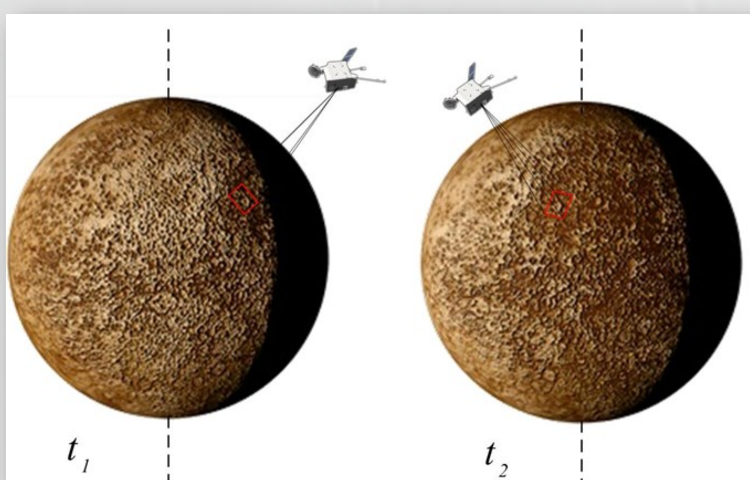
Abstract

One of the objectives of the Radio Science experiment hosted on-board the BepiColombo mission is the retrieval of Mercury's rotational state, a key parameter to gather information on the core of the planet. Mercury's obliquity and librations will be measured at unprecedented accuracies (<1 arcsec).

The experiment is accomplished thanks to data provided by different payloads: precise orbit determination (MORE), accelerometer measurements (ISA) and high resolution images (SIMBIO-SYS/HRIC). The correlation of surface landmarks extrapolated by two images of the same area taken at different epochs constitutes the observable to be fed into an end-to-end simulator, built up at the final aim of defining the images optimal acquisition scheduling. The optimization is performed via a genetic algorithm, employing a simplified estimation process of the rotational state for evaluating the goodness of the solutions. Results obtained from this simulator have been validated using a setup developed in MONTE, where a global multiarc software employs both optical and radiometric simulated observables.

Rotation Experiment Simulator

Observation strategy



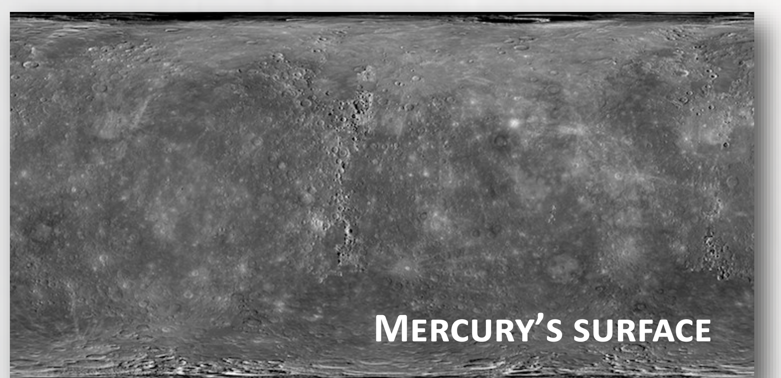
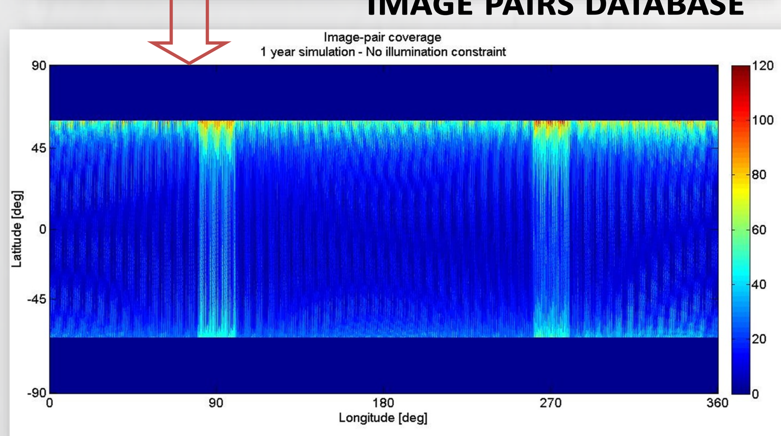
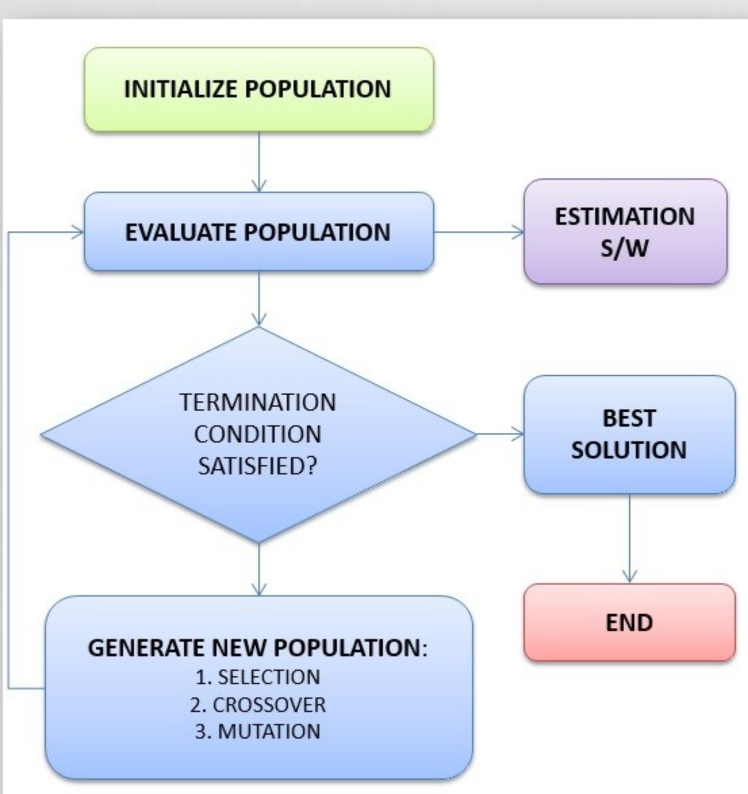


Image pairs database



Optimization

Genetic algorithm

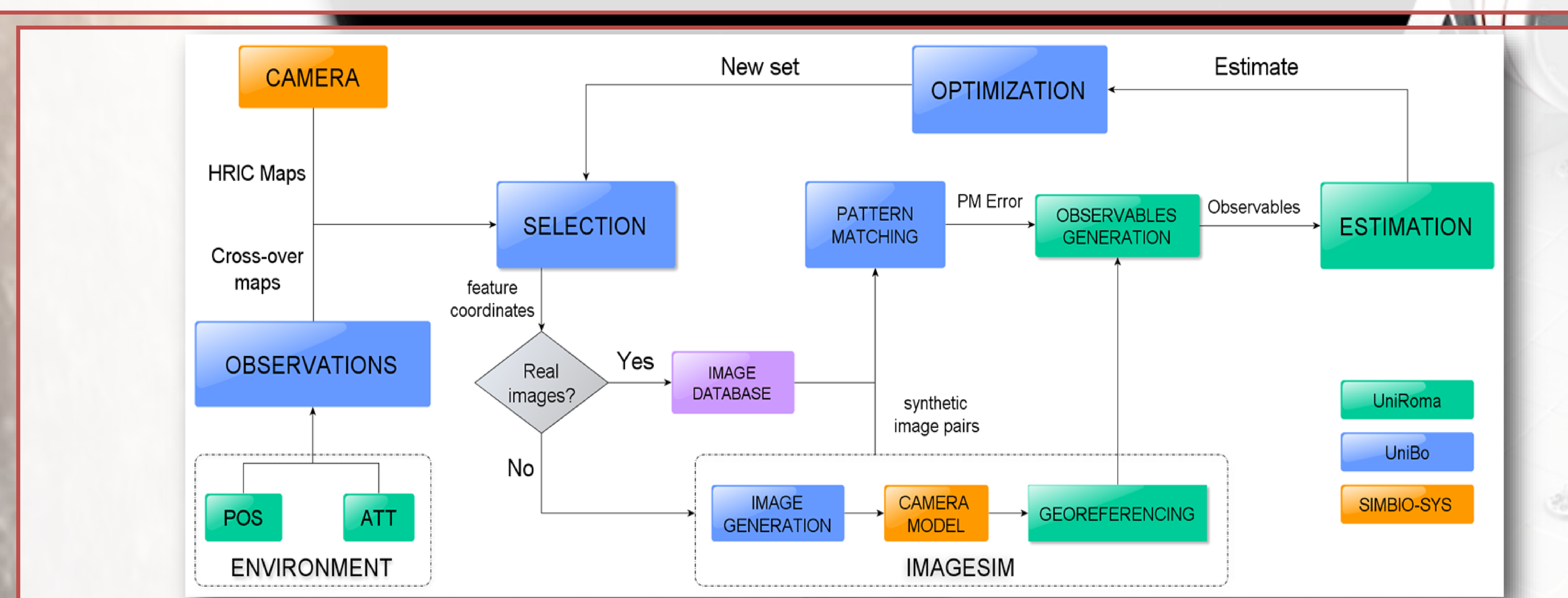


The optimization procedure is based on a genetic algorithm, evaluating the individuals of the population depending on the accuracy obtained in the estimation of rotational parameters. A fitness function is associated to each chromosome:

$$\text{FITNESS} = \frac{1}{\sqrt{\left(\frac{\sigma_{RA}}{\sigma_{RA\,exp}}\right)^2 + \left(\frac{\sigma_{DEC}}{\sigma_{DEC\,exp}}\right)^2 + \left(\frac{\sigma_{LIB}}{\sigma_{LIB\,expected}}\right)^2}}$$

Optimization settings:

- 10 individuals
- 300 iterations



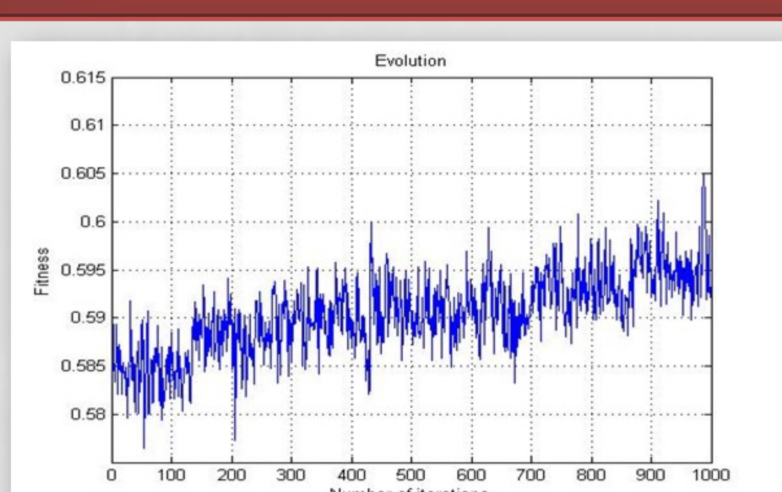
Orbit Determination Simulation Setup

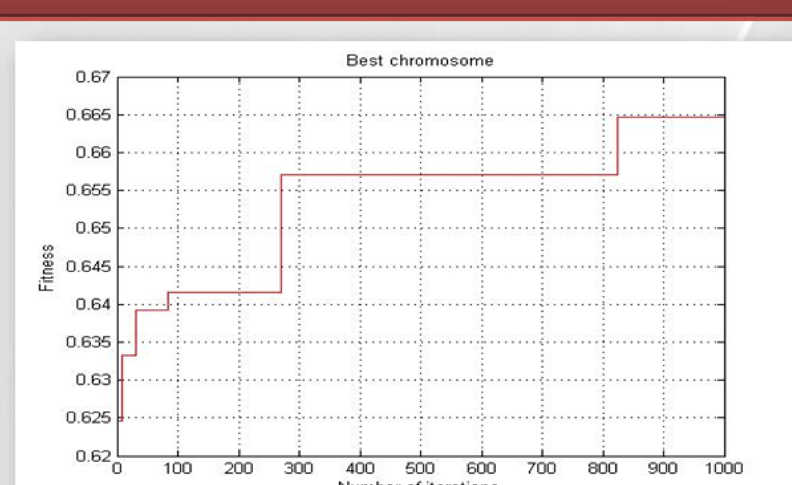
A consolidated orbit determination software (JPL/MONTE) was employed for a set of simulations for the MPO (Mercury Polar Orbiter).

Simulation Setup:

1. 365 days simulation
2. Position apriori sigma of 0.1 km and Velocity apriori sigma of 1e-6 km/s
3. Doppler observables with ADEV of 1.8e-14@300s
4. 100 pairs of optical observables in one year(both random and optimized)
5. Pointing error on three axes in consider sigma with 5 arcsec error
6. Images pattern matching error of 0.01 pixel
7. Landmarks apriori uncertainty of 10km in longitude and latitude

Optimization output





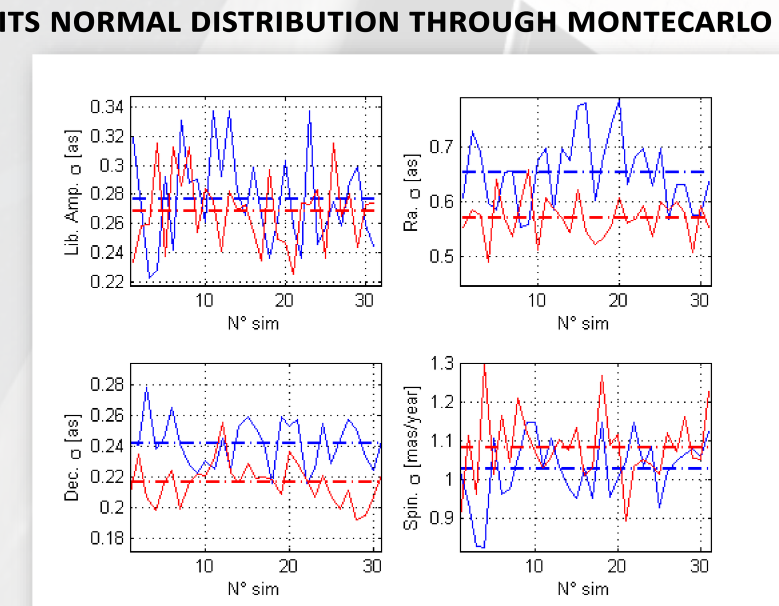
Several simulations have been run in order to test the S/W. The final validation has been accomplished feeding the results obtained into a setup implemented in MONTE. The optimization procedure always leads to a better accuracy in the estimation of rotational parameters, although the solutions found do not represent a global maximum. MONTE simulations have the objective of demonstrating that all these image sets are improved with respect to random ones, thus confirming the good functioning of the S/W.

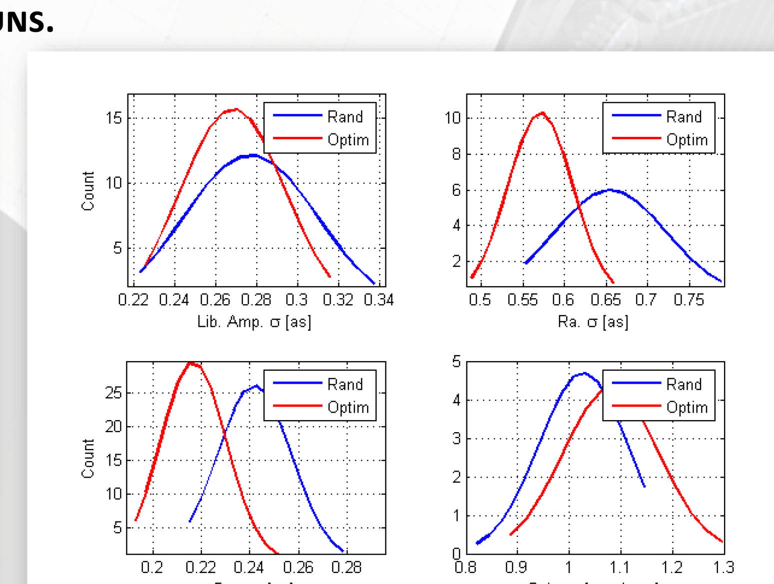
Simulations Results

The simulation of the estimation of Mercury orientation parameters with the aim of validating the optimization procedure has been done on a Montecarlo of 31 runs both for random and optimized schedules of optical observables.

A first result shows that there is variation in the solution from one schedule to the other but that the mean formal sigma is better for the three optimized parameters, i.e. the obliquity (RA,Dec) and the libration amplitude, while the spin rate has been estimated but not optimized.

The STD of the formal sigma is smaller for the optimized optical schedules as shown evaluating its normal distribution through Montecarlo runs.





Mean Improvement on formal sigma of the orientation parameters:

	Lib. Amp.	RA	Dec	(Spin Rate)
Optimization Improvement on formal sigma	3.1 %	12.8 %	10.6 %	-5.3 %
Random solutions STD over Optimal solution STD	1.3	1.7	1.1	0.9

Conclusions

This analysis showed an optimization procedure that may be used to choose the best optical schedule for MPO for the estimation of rotational parameters.

A way to crossvalidate this optimization procedure has been provided, using a different software from the one used for the optimization process, showing, with Montecarlo runs, an improved formal sigma and a reduced variance of the formal sigma for the three optimized orientation parameters of interest in the orbit determination solution, thus confirming the effectiveness of the optimization algorithm.

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