# SPACECRAFT ORBIT DETERMINATION ENHANCEMENT BY USING LOW-ALTITUDE PLANETARY OPTICAL IMAGES

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## ABSTRACT

A novel technique for trajectory determination of planetary orbiters by using optical images of the planetary surfaces, in addition to standard radiometric observables, is proposed. The methodology is based on relating two sequential views of the same scene of the planetary surface in a mathematical form. This mathematical expression is spacecraft trajectory dependent, therefore allows to define an optical observable.

The characteristic features selected in sampled images and used in the described method are corner points, i.e. points of high photometric contrast in two directions. Those features are matched between two sequential views of the same scene of the planetary surface sampled by the camera. The choice of this kind of features and the difference with respect to a more classical geo-referencing of planetary surface landmarks is also discussed, mainly driven by the fact that a relative-positioning methodology, i.e. a mathematical formulation linking two successive views of the same surface area, does not imply the addition of estimated parameters, thus reducing the degradation of the orbit determination process. This technique is based on a pattern matching algorithm which exploits the presence of an high number of corner points to find a robust transformation linking two views of the planet's surface and is able to manage occlusions between matched images as well as to allow sub-pixel level accuracy. In order to test the feasibility of this method, a simulation framework is developed : it allows to generate synthetic images of the planet surface according to the orbiter position and orientation. This also allows to evaluate pattern matching algorithms best suited to deal with the illumination constraints, i.e. sun azimuth and elevation angles, by which the two views are affected. A synthetic Digital Elevation Model (DEM) is generated by simulating a set of impact craters on a initial terrain model combining Fractional Brownian Motion spectral synthesis and craters fractal details according to data of previous space missions. The resulting DEM is rendered by a ray tracing software according to the orbiter pose and camera parameters. The pattern matching algorithm is then applied to the generated high resolution images to test the proposed method in a realistic scenario. The mathematical formulation of a novel optical observable is exploited using fundamentals of computer vision. The two set of corner points extracted and matched enable to relate the two separate views of the same scene with perspective projections, which results in an homographic transformation accounting for scaling, rotation and translation. The result is an observable expressed as a function of intrinsic and extrinsic camera parameters.

The formulation of the partial derivatives as a function of the spacecraft state is also presented and a statistical analysis is conducted. The proposed algorithms are formulated as “plug-ins” to

classical radiometric orbit determination S/W, where a new set of optical residuals needs to be added to the cost function to be minimized and a series of new partial derivatives are provided to the estimation filter.

The image acquisition planning is designed as a result of an optimization between the main driving factors affecting the effectiveness of optical observables, such as scene illumination due to sun elevation and azimuth, the constraints due to the mission geometry and some guidelines are given in different mission scenarios.

An error budget is presented, as the main tool for an apriori evaluation of the performance expected by the proposed methodology and a comparison between mission scenarios is provided.

The reference scenario for application of the proposed trajectory estimation enhancement method is ESA's BepiColombo mission to Mercury, where radiometric observables alone will already produce a state-of-the-art orbit determination accuracy and where an improvement in the positional accuracy is expected from the additional optical measurements only for some particular mission phases. However, every orbiter spacecraft may potentially take advantage of the proposed method, if a high-resolution imaging system is included in the onboard payload package.

As a matter of fact, every spacecraft using radio tracking from the ground as the main source for orbit determination undergoes an evolution of the estimation weak direction due to inherent informative anisotropy of the observations. The complementarity of the informative directions provided by optical observables is discussed and shown in the paper and some insights are provided on the effectiveness of this methodology.

Preliminary results are also presented by means of a simple orbital model implementation where the main geometries and constraints of BepiColombo's Mercury Planetary Orbiter are taken into account, and simulated ranging, Doppler and optical observables are used in a simplified scenario.