Multi-arc Orbit Determination to determine Rosetta trajectory and 67P physical parameters

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The ESA Rosetta spacecraft followed comet 67P/Churyumov-Gerasimenko around the Sun for two years from August 2014 to September 2016. The spacecraft was navigated using Earth-based radiometric tracking data (2-way range and Doppler) augmented with space-based optical navigation data (directions to landmarks). The orbit determination program was solving simultaneously for the spacecraft state and for the comet orbital and rotational states [1]. For routine planning short observation intervals were used and the comet spin direction, its gravity field coefficients and the navigation landmark coordinates were kept fixed. In order to obtain good estimates of those parameters, long orbit determination arcs were used. Convergence was then difficult to achieve and it was usually necessary to pre-set the values of many dynamic parameters from the results of preliminary runs using e.g. shorter observation intervals. Since the filter was also using dense matrix operations, each iteration was taking a considerable amount of CPU time.

During the last two months of the Rosetta mission, the spacecraft was to fly 3-days orbits with low pericentres. In preparation for this flyover phase, it was necessary to increase the surface density of our navigation landmarks and to improve our knowledge of the comet gravity field. More than ten thousands landmarks were identified on the comet. An orbit determination setup using multiple disjoint arcs and a decomposition in landmarks subsets to make use of the sparsity of the landmark observable modelling problem was used to determine the gravity field and the many landmark coordinates.

The flyover phase itself would provide important data for estimating the gravity field. However because of the many low pericenters, convergence of long interval orbit determinations would not be possible. A multi-arc approach was used instead. Matching constraints for the trajectories at arc boundaries were added as observations equations. The multiple shooting strategy not only made convergence easy, reducing the number of iterations, but also increased the sparsity of the problem making each iteration faster. Multi-arc orbit determinations were run regularly during the final phase of the mission to update the gravity field coefficients and the direction of the comet spin vector in inertial frame and in body frame.

For navigation purposes, it was necessary to monitor the evolution of the comet dynamical parameters. In October 2014, orbit determination runs had already shown that the activity of the comet was modifying its rotation period. Later as the comet was approaching perihelion, significant changes were also observed in its inertial spin direction and its orbital elements. After perihelion, a change in the spin vector direction in body frame was measured. The body frame had previously been conveniently defined so that the canonical Z axis was along the spin direction. With the parametrization used in the orbit determination software, this made it possible to solve for spin phase and spin period with exactly two parameters. But with the change in spin direction, spin direction constraints in routine planning orbit determinations could not be enforced by parametrization but had to be implemented as heavily weighted observation equations.

The proposed paper will describe the Square Root Information Filter (SRIF) used in Rosetta orbit determination, the multi-arc strategy and associated decomposition between local and global parameters, and the implementation of the matching constraints at arc boundaries for the spacecraft and comet trajectories. How the results were then incorporated in Rosetta routine navigation will also be explained. Moreover, it will discuss the observability of the 67P gravity field as well as the observability of the evolution of Churyumov-Gerasimenko dynamical parameters during the two years Rosetta spent at the comet.

References

[1] Bernard Godard *et al.*, Orbit Determination of Rosetta around Comet 67P/Churyumov-Gerasimenko, *Proceedings of the 25th International Symposium on Space Flight Dynamics, Munich*, 2015.