New Concepts for Relative Navigation at Planetary Approach

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This paper reports selected results of a study, where we combined within the ESA orbit determination software new radiometric and optical measurement types with previously existing ones in order to improve the orbital knowledge for celestial body approaches of upcoming interplanetary missions.

We address these combinations of measurement types as ‘Navigation concepts’ and define them specifically as combinations of measurement types complementing each other in terms of:

- Required resources
- Information content
- Timing during approach

We applied these combinations to specific mission scenarios of previous and new missions of ESA, taking into account the individual mission design and constraints, in order to find combinations which

- provide high accuracy with less resources in normal situations

- recover the orbital knowledge of the spacecraft state quickly when it is degraded during contingencies
- provide reasonable accuracy in difficult observation conditions, e.g., during solar conjunction
- counter the effect of ephemeris errors on the relative state of the spacecraft to the celestial body

In the past ESA mainly used the radiometric measurement types Range, Doppler, and Delta-DOR which provide absolute measurements. Radiometric measurement types not yet used by ESA, hence 'new', include Satellite to Satellite/Lander Tracking, Differenced Doppler, and Same Beam Interferometry.

For the approach of asteroid Steins by the Rosetta spacecraft in 2008 and again for the asteroid Lutetia in 2010, ESA employed optical measurements, where the inertial direction (right ascension and declination) from the spacecraft to the target was determined by comparing the position of the asteroid to positions of background stars on images taken by the navigation and science cameras. For point-like targets like these asteroids, the use of defocused images permits the determination of the direction with sub-pixel accuracy. For extended objects, like planets, and especially for the very close approach of Rosetta to comet Churyumov-Gerasimenko a different approach needs to be taken, which uses positions of discernible surface features (landmarks) on camera images. Both optical types provide relative measurements of spacecraft and target body.

All these measurement types have specific information content and a specific demand of resources (number of stations with spacecraft visibility, 2nd spacecraft/lander availability, and on-board cameras). Therefore immediately questions arise such as:

- Which combination of them is feasible for a given mission scenario?
- Which combination offers the highest information content?
- Which combination allows the quickest recovery after loss of orbital knowledge?

In selected approach scenarios of BepiColombo, ExoMars, Mars Express and Rosetta we illustrate the applicability and usefulness of the individual measurement types above and compare the advantages of their various combinations in order to find the best navigation concept for the given situation. Our findings may be also useful for other missions as some of the scenarios arise from quite general situations.