Far Approach Optical Navigation and Comet Photometry for the Rosetta Mission

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Extended Abstract:

On January 20th, 2014, the European Space Agency's Rosetta spacecraft woke up after 2.55 years of deep space hibernation. After a re-commissioning period and a series of braking manoeuvers from May to July, it rendezvoused with comet 67P/Churyumov-Gerasimenko in August and successfully delivered the lander Philae to the surface in November. Throughout all these phases, Rosetta relied heavily on optical navigation, first for on-board detection of the comet and far-approach navigation, then for landmark-based proximity operations. Separate papers provide an overview of the Rosetta mission's comet phase from the Flight Dynamics perspective[1] and of the landmark-based processing after[2,3]. This paper focuses on the optical navigation activities carried out before reaching the comet in August and on an analysis of the photometric properties of the comet and the related operational consequences, such as selecting camera exposure times.

Rosetta's optical navigation uses two dedicated navigation cameras (navcams), complemented for special operations or for redundancy purposes by images from both science cameras, the Osiris Narrow Angle Camera (NAC) and Wide Angle Camera (WAC). The first optical operation after hibernation exit was the early detection from the on-board cameras of comet 67P. The NAC was used for this purpose due to its better sensitivity with respect to the navcams (limiting magnitude of 15 against 11). Successful detection was achieved at the first attempted slot on March 24th, when 67P had an estimated magnitude of 15.5. Detection with the navcam occurred in the beginning of May. Ad-hoc image processing software was developed for early detection with the NAC, automatically matching the acquired light sources with the large PPMXL star catalogue, filtering out CCD artefacts and non-stellar objects, leaving only a handful of comet candidates to be manually screened.

As soon as the comet was acquired, far approach optical navigation was started with the purpose of providing as input for the orbit determination process the direction in azimuth and elevation of the centroid of the comet. Three distinct phases can be distinguished: initially, the comet was sufficiently faint to detect enough stars to accurately fit the camera attitude, hence correcting for thermal effects and attitude controller error, resulting in errors below 1 pixel; from July 3rd, at approximately 45,000 km from the comet with a magnitude around 3, separate images with longer exposure had to be taken for the stars, averaging the camera alignment and leading to about 2 pixels accuracy; finally, from July 24th and until the beginning of landmark-based navigation on August 6th, centroiding errors for the extended comet - which was larger than 20 pixels at less than 2500 km - exceeded the attitude errors, thus making star-images useless.

In parallel to the retrieval of optical imagery for the far approach phase, a photometric lightcurve was obtained over 12 days. This data was used to obtain a precise estimation of the comet's

rotational period, later used as input for the attitude reconstruction of the comet. From July 11th until the 31st, photometric data was obtained every 2.5 seconds with the navcam in the coined "asteroid-tracking mode". The rotational period of the comet was obtained through a combination of periodic folding and χ^2-fitting of distance-corrected periodic and bi-periodic Fourier components, the latter needed to determine whether or not the comet had nutation. Results of this analysis are presented in the paper, showing the peculiar light-curve properties of double-lobed 67P with a first estimated period of 12.425 ± 0.013 hours.

Finally, analysis of the photometric properties of 67P was carried out throughout the whole approach and near-comet phases of the Rosetta mission. Operationally, this had the main purposes of enabling the appropriate selection of navcam exposure times and of estimating the values of the photometric parameters necessary for the generation of the maplets for automatic landmark-based navigation[4].

During the approach phase, when the comet was a point light source (until July), a simple H-G magnitude model from Lowry[5] was used as a reference, taking large margins for the definition of the exposure times of both NAC and navcam. *A posteriori* analysis showed that the comet was consistently slightly fainter (0.3-0.5 magnitude) with respect to the Lowry model, except for an outburst of activity from 67P in late April.

After the comet was resolved in the navcam, two main methods were followed: to start with, the navcam integration times were manually defined at each phase angle and sun distance based on previous experience, maintaining consistent margins (i.e. 80% of saturation); as Rosetta was flying around the comet in many different orbits from August to December, an empirical table model was built for all phase angles, normalized at 1 AU.

In parallel, a modified version of the theoretical Lunar reflectance model was developed, using the ever increasing imaging information to fit three main parameters. Consistency of the modified Lunar reflectance model was verified both through the successful application of the maplets methodology used routinely for automatic landmark observations generations and through comparing with exposure times derived from the empirical table method. The Lunar model is now being used also for the automatic computation of the navcam exposure times.

All details of the developed photometric model for comet 67P are provided in this paper, including results from the fit of the model parameters, quantitative assessments with reference to comet images and the comparison of exposure times obtained with the theoretical and empirical table models.

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