OPTICAL MEASUREMENTS FOR ATTITUDE CONTROL AND SHAPE RECONSTRUCTION AT THE ROSETTA FLYBY OF ASTEROID LUTETIA

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Keywords: *Optical Navigation, Asteroid Flyby, Autonomous Tracking, Shape Reconstruction*

ABSTRACT

The ESA interplanetary spacecraft (S/C) Rosetta was launched in March 2004 to rendezvous with comet Churyumov-Gerasimenko in 2014. The overall trajectory contains four planetary swing-bys, three at the Earth and one at Mars. The scientific outcome of the mission is enhanced by two asteroid flybys, one in September 2008 at asteroid Steins, and the second in July 2010 at asteroid Lutetia, after the last Earth swing-by.

For the asteroid flybys, optical measurements taken by on-board CCD cameras were used to navigate the S/C towards the requested flyby conditions and to control autonomously the attitude of the S/C during the flyby phase proper in order to ensure that payload instruments were pointing towards the asteroid. The Steins flyby was conducted successfully, however with degraded performance in the autonomous pointing. An overview of the overall optical data processing, including performance analyses for the various phases of the Steins flyby navigation, was already presented at the ISSFD in 2009. For the Lutetia flyby, a similar approach for the optical data processing was followed, with two new major aspects:

- **Autonomous Asteroid Tracking**

The degraded pointing performance during the Steins flyby was mainly caused by the presence of warm pixels (i.e. pixels with increased dark current) in combination with size and brightness of the target and specific features of the camera software. To improve the pointing accuracy for Lutetia, a different configuration of the on-board camera during autonomous tracking had to be selected. The main parameters to be tuned were the integration time and the detection threshold. This threshold determines the minimum signal in a pixel that is required such that it is considered as part of the extended object.

To avoid disturbances from warm pixels, a warm pixel list was established, and the variability of the signal rate and its dependency on the CCD temperature was measured. This allowed to set an upper limit on the expected disturbances from warm pixels.

Four objects were selected as targets for in-flight tests: two stars (Vega and Spica), the Moon and the Earth during the last Earth swing-by. These targets were to some extent representative of the asteroid during various phases of the approach. Several combinations for

the camera configuration were tested, including automatic vs. fixed settings for exposure and threshold control.

It turned out, that the automatic control was not sufficiently reliable, neither for the exposure time nor for the detection threshold. Instead, optimum fixed values were established that could be used for the flyby. At approach, the configuration was continuously checked against the latest in-flight measurements of the asteroid brightness and the warm pixel list data.

- **Landmarks and Shape**

58 high resolution images were acquired over nearly one hour around closest approach by the on-board narrow angle science camera. These images were processed after the flyby to derive details on the flyby geometry. Due to the fast flyby speed, the resolution at which the surface appeared in the images varied considerably in the range between 55 m to 786 m per pixel. Only in ten images around closest approach, the equivalent size of one pixel was less than 100 m.

Pixel positions of landmarks were determined visually using a graphical user interface in 42 images. In total, 1,788 observations for 89 landmarks were recorded. In addition to the positions, uncertainties were assigned as well. The 1σ values varied between 1 to 9 pixels.

Initial estimates of landmark positions relative to a fixed asteroid frame were determined only based on the landmark observations with a bundle adjustment method.

Based on initial estimates of the landmark positions relative to the asteroid fixed frame, of the initial asteroid and S/C orbits and of the rotation parameters of Lutetia from the literature, a combined estimate of flyby parameters (position and velocity at a fixed epoch), camera attitudes, landmark positions and rotation parameters was achieved. The formal uncertainties in the solution were ca. 1 km in the reconstructed landmark and S/C positions. These uncertainties refer to a frame with its origin on the rotation axis of the asteroid. The formal uncertainties in the estimates of landmark positions relative to each other were much lower and were in the best cases close to the resolution of the camera images. The residuals in the observed landmark pixel positions were in almost all of the cases within the 3σ range. The residuals in the camera attitudes were consistent with the predicted performance of the attitude estimator based on star tracker data. The data content of the observations did not allow to improve the initial estimate of the rotation period as reported in the literature based on ground observations. The estimate of the pole direction could however be refined with a formal uncertainty reduced to ca. 1 deg (3σ).

After reconstruction of the flyby geometry, a coarse shape model was determined from the images. The selected method was a combination of silhouette and shadow carving. Initially, the body was represented by a cuboid, divided into small cubes. Images were processed sequentially to carve out cubes based on information about camera position, camera attitude and Sun direction (all relative to the object). Due to the limited number of images and viewing conditions, the resulting model is actually bigger than the asteroid and reflects the true shape only at specific locations, e.g. which appear as part of the limb in one of the images. For those regions however, the method provides accurate results.

The reconstructions of flyby geometry and asteroid shape were performed with prototype software that was developed for the comet phase where optical navigation relative to landmarks will be used operationally.