A Novel Observation Strategy for Asteroids Shape Reconstruction

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Abstract. In recent years the space community's interest has been increasingly focused on the analysis of small bodies. Lack of knowledge surrounding the targeted small body's characteristics is a crucial issue during the approach phase. We propose here a new approach for asteroids shapes' reconstruction based on the shape-from-silhouette technique and a novel observation strategy. We demonstrate how this new approach can utilise current state of the art technologies and achieve comparable results to currently adopted techniques.

Keywords: Small Body Exploration · Shape from silhouette · Hovering.

Several recent missions from various space agencies have focused their attention on near-Earth asteroids and comets. There are many reasons for this: firstly, small bodies are the untouched building blocks of the solar system. Therefore, their close observation can be useful to reinforce the existing hypotheses regarding its origin [1] [2]. Secondly, Near Earth Objects (NEOs) exploration is fundamental to identify suitable planetary defence techniques [3] [4]. Lastly, there is a growing interest in exploiting space-born raw materials and several asteroids have already been identified which could be interesting targets for mining [5].

To date, missions that have successfully visited and observed asteroids and comets have achieved this scientific output via heavy input and supervision from ground control teams. With the recent developments in electronics' miniaturization, the development of on-board autonomous operations is expanding and an autonomous navigation system is nowadays considered as an enabling technology for the exploration and exploitation of NEOs [6]. Unfortunately, satellite missions are also challenged by a poorly characterised and very chaotic environment. Because of it, missions are generally divided in a sequence of exploration phases that slowly decrease the distance from the target body the more confident we become with its characteristics [7] [8].

In this "standardized" mission timeline, one of the most complicated tasks is the reconstruction of the small body's shape. A 3D model of a small body is a feature that is difficult to define before reaching the most advanced part of a mission. However, with this information it is possible to make initial estimates of the body's gravitational field, enabling the design of safer and more optimal short range trajectory, which in turn allow a preliminary characterization of its internal structure [9] [10].

Several techniques have been proposed to recover the shape of small bodies: light-curves inversion [11], shape-from-X methods [12], control-point based techniques, stereophotoclinometry [13], SLAM [14] and range imaging techniques [15]. A promising technique which could be integrated into an autonomous navigation system for the reconstruction of a 3D model is the so called shape-from-silhouette procedure [16]. Amongst the many requirements that ensure optimal performance of this procedure in a small body observation mission, the most challenging is the collection of the target's binary silhouettes. The presence of a single source of light, the Sun, and the lack of refracted light caused by the absence of any type of atmosphere, introduce shades on the asteroid. Consequently, depending on how much the spacecraft's approach direction is inclined with respect to the Sun rays direction, the actual silhouette could be confused with the limb terminator. Several techniques have been designed to overcome this problem such as building conservative silhouettes [8] or considering only useful parts of the observed limbs [12]. Alternatively, one could approach the small body along the Sun-body direction, in order to have it fully illuminated upon arrival. However, this approach does not ensure a safe reconstruction of the silhouette owing to potential shadows caused by surface features on the body's surface itself, or due to errors in the positioning along the sun-body direction that can expose the camera to a shaded limb.

This paper provides a novel idea for collecting the needed data for the small body's shape reconstruction which was inspired by our team's Sun-occultation analyses [17]. As an alternative, we analysed whether it was possible to observe the small body's figure inside the Sun disk while hovering from a vantage observation point along the sun-small body line-of-sight. The existence and the selection of the observation point to hover depends on the geometry and physical characteristics of the target body. Its definition is related with the apparent dimension of the Sun at the distance that the small body is orbiting the Sun itself. The process has been tested and validated through synthetic optical camera images simulated employing the software Blender [18] (c.f., Figure 1). With our procedure there is no reason to worry about the kind of errors which have been previously mentioned during the silhouettes extraction process assuming that the small body's obliquity with respect to the orbital plane matches a certain range of degrees and that the spacecraft's camera is equipped with the needed optical filter. Moreover, due to the low accelerations present in this kind of mission, the overall ΔV required to hover these observation points is generally limited and we propose that this approach will be feasible for the majority of NEOs for which data are available.

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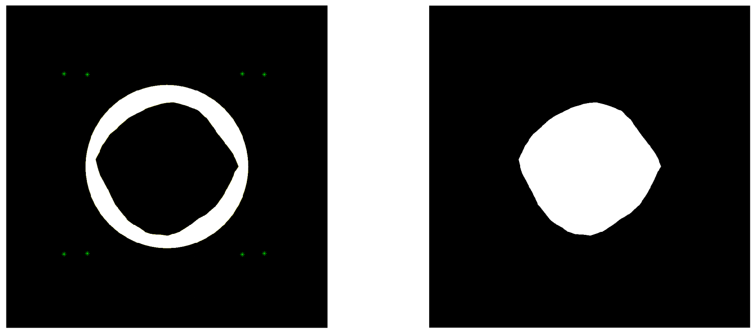

Fig. 1. Asteroid's silhouette reconstruction from binary image.

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