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Small bodies IR imaging for vision based relative navigation and mapping enhancement

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Small bodies have always attracted the scientists community interest being supposed to be the key of life on our planet and a fundamental link in the solar system formation chain. The subset of NEOs family - which are candidates for Earth impacting - targets on-going activities and research for planetary defense. These reasons justify the recently increasing number of missions - either flown or planned to fly - targeted to small bodies, which require specific technologies development because of the harsh and almost unknown environment they have to face particularly during proximity operations. Indeed, the probe is typically asked to orbit close to a small object, unknown in shape and dynamics, to progressively characterize it in terms of geophysical and dynamical properties. To this end, different sensors and techniques are embarked, among which multispectral imaging is fundamental to support both body shape and thermophysical properties reconstruction, as recently shown by Hayabusa2 mission to asteroid 162173 Ryugu [1]. ESA's upcoming mission Hera [2] will strongly rely on optical measurements to characterize the binary system Didymos. Besides the visual camera, the payload package includes a thermal-infrared camera, which is meant to have a primary role as a scientific imager and possibly to play as technological supporter for vision-based proximity navigation.

The proposed paper stresses this approach and investigates the benefits of exploiting scientific IR-imagers already on-board to support relative navigation; in particular, data collected by the thermal-infrared camera, which are primarily devoted to scientific investigation, are fused with visible camera outputs for GNC purposes.

Multispectral data fusion increases the reliability of the navigation scheme in case of shadows and high Sun phase angle, while the combination of shape and temperature information allows a deeper and faster understanding of the asteroid's composition and inertia reconstruction towards its spin history identification. The proposed architecture combines image processing techniques for pose estimation

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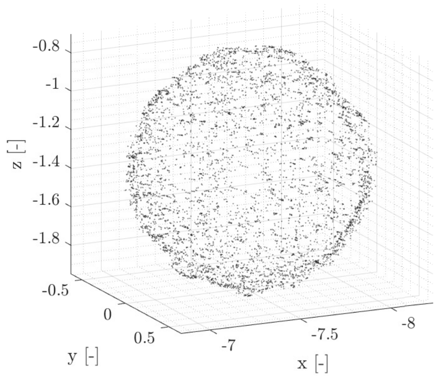
- applied to the VIS-IR raw data - with filtering methods for sensor fusion. An Extended Kalman Filter fuses the image processing outputs with star tracker, gyroscope and altimeter measurements to refine the pose and reconstruct the asteroid's spin state. Adopted sampling rates comply with real hardware performance according to the measurements class: high for inertial data acquisition $(1s)$, low for imaging sensors $(30s)$.

Synthetic images have been generated on purpose using PANGU [3] to almost replicate Hera's on board camera resolution: 1024×1024 pixels for VIS, 512×512 px for IR. An example is reported in Figure 1.

(a) Synthetic thermal-infrared image



(b) Asteroid 3D sparse map

Figure 1: Sample synthetic IR frame (left) and output 3D sparse map (right)

Although IR images offer reduced resolution with respect to VIS data, the adopted approach highlights that the VIS-IR measurements fusion leads to improvements in the order of 40%, 35% and 39% in localization, attitude and spin state estimation respectively, compared to VIS camera exploitation only, as shown in Table 1.

Table 1: Pose and spin state estimation root mean square error

	Position [m]	Attitude [deg]	Spin state [rad/s]
VIS only	18	1.10	1.54e-05
VIS & IR	10.8	0.71	9.4e-06

Validation strategies - which include real IR images acquisition - and models concerning each block of the proposed architecture, from IR images generation to measurements filtering are briefly discussed in the paper, which then focuses on representative cases to critically highlight the suggested approach effectiveness and areas of improvement.

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