SMALL BODIES IR IMAGING FOR VISION BASED RELATIVE NAVIGATION AND MAPPING ENHANCEMENT

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Motivations

Small bodies characterization through imaging data

Planetary defense strategies are scenario-dependent. The choice of method for **impact mitigation** is strictly related to the specific target. Small-bodies targeted missions are therefore essential to precisely characterize PHOs in terms of **shape**, **composition** and **rotational dynamics**.

A vision-based GNC chain is here developed to combine information from the visible **(VIS)** and thermal infrared **(TIR)** on-board imager to support **navigation** and **mapping** operations. Vision-aided inertial navigation is then exploited to refine the initial pose estimate and to recover the **asteroid's spin state**.

Synthetic images rendering

Visible images

- Planet and Asteroid Natural Scene Generation Utility (PANGU) rendering software
- AFC camera parameters

Thermal infrared images

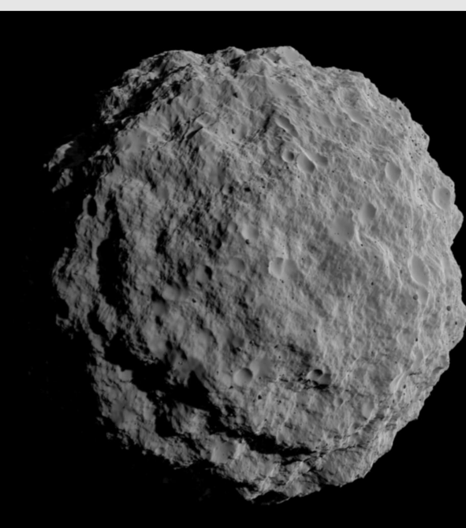
Starting from visible images rendering:

- Synthetic emissivity map
- Asteroid thermal model: equilibrium with solar flux
- Reduced sensor size

Camera parameters

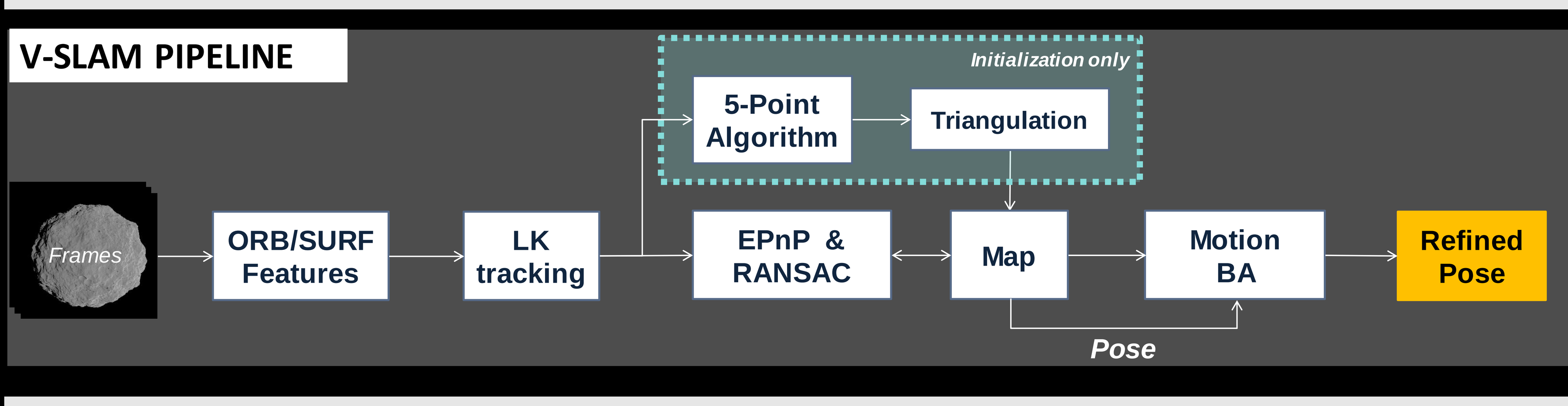
	VIS	TIR
Resolution [px^2]	1024x1024	512x512

Sample VIS



Sample TIR

Image processing: Simultaneous Localization And Mapping (SLAM)

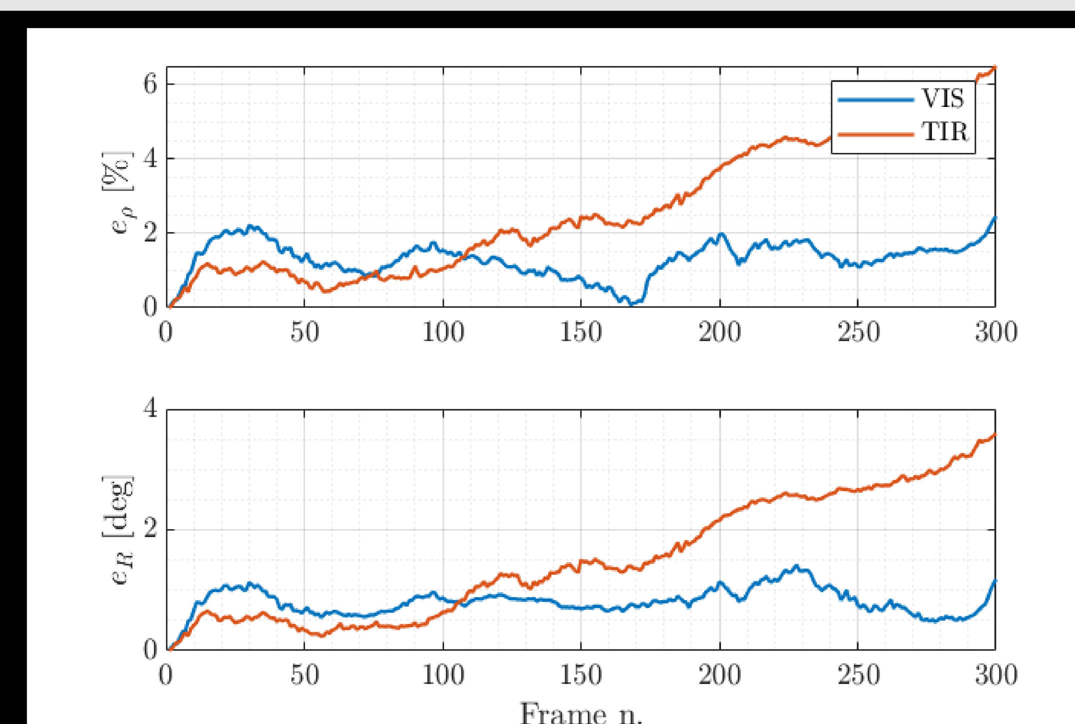


Objectives

Spacecraft relative position and orientation (pose) determination and shape reconstruction exploiting images coming from the VIS and TIR cameras.

Pose determination

- VIS imaging mode shows good results on a long sequence
- TIR image processing is negatively affected by the reduced resolution
- Data fusion will improve the navigation chain accuracy

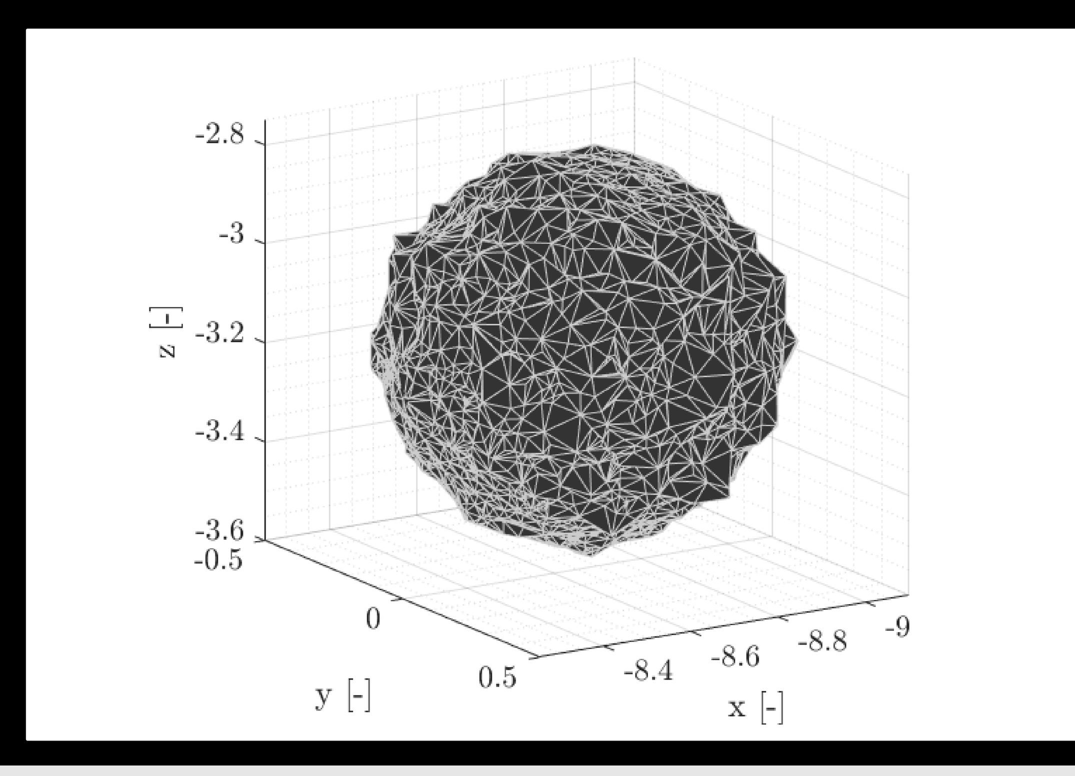


Algorithm description

- Features on the images extracted using **ORB/SURF detector** ;
- Features are **tracked** on subsequent images with *Lucas-Kanade* algorithm;
- *Essential matrix* is retrieved from first two images and features are triangulated to initialize a **3D sparse map**;
- Tracked features are related to the map: a set of **2D to 3D correspondences** is built and used to solve the **PnP problem**, from which spacecraft pose is obtained;
- Pose is finally optimized with **Motion Bundle Adjustment**.

Shape reconstruction

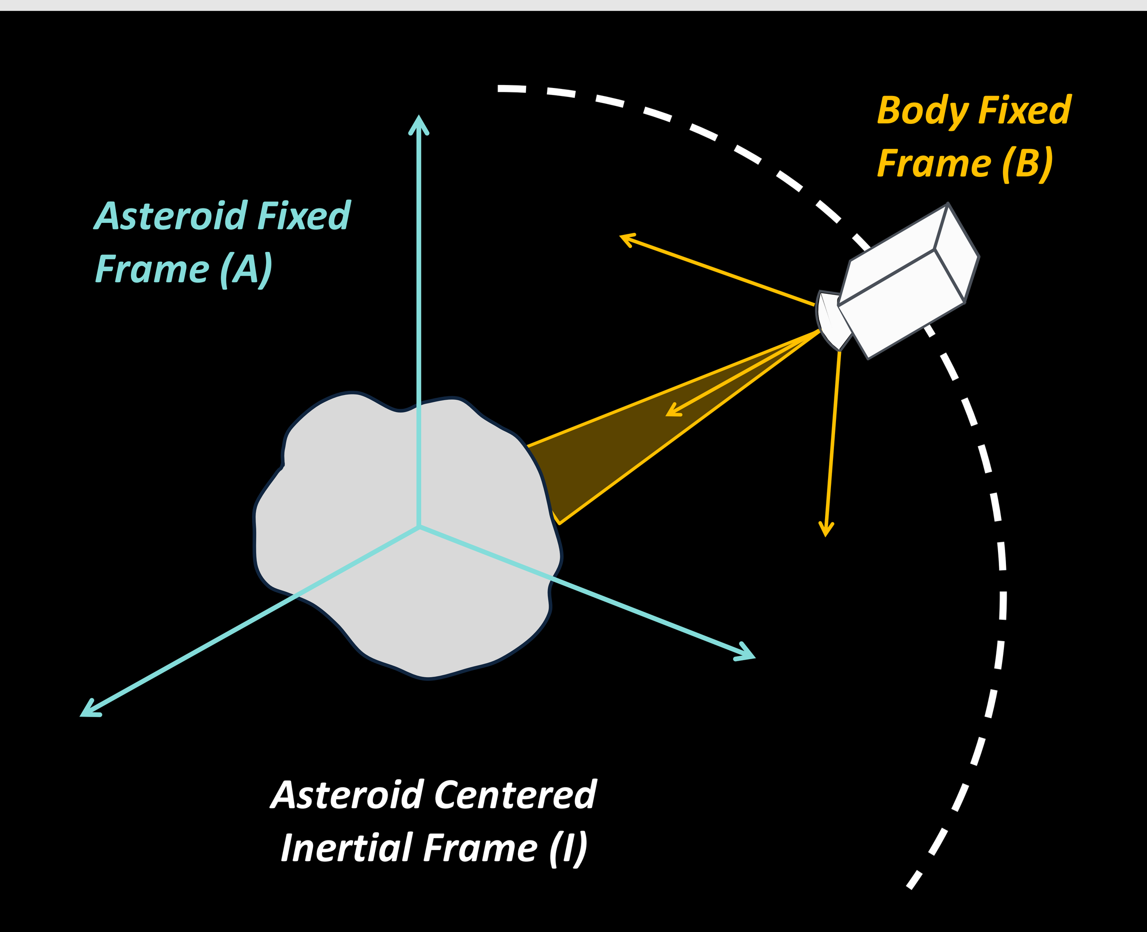
- The V-SLAM algorithm correctly reconstructs the asteroid's shape
- Relative size ratios are respected
- The 3D sparse map is further processed to obtain a polyhedron shape model



Navigation Filter

Objectives

- Refine the vision-based pose estimate
- Characterize the asteroid's rotational dynamics
- Combine **TIR** and **VIS** imaging data to enhance the navigation solution accuracy



Estimation methodology

- An extended Kalman Filter (EKF) fuses image processing (IP) measurements with **star tracker**, **gyroscope** and **altimeter** measurements.
- Gyroscope data are processed as ***dynamic replacement model*** and included in the prediction step.
- The ***null-hypothesis*** test based on the Mahalanobis distance is performed to discard outlier imaging data

Filter State Vector:

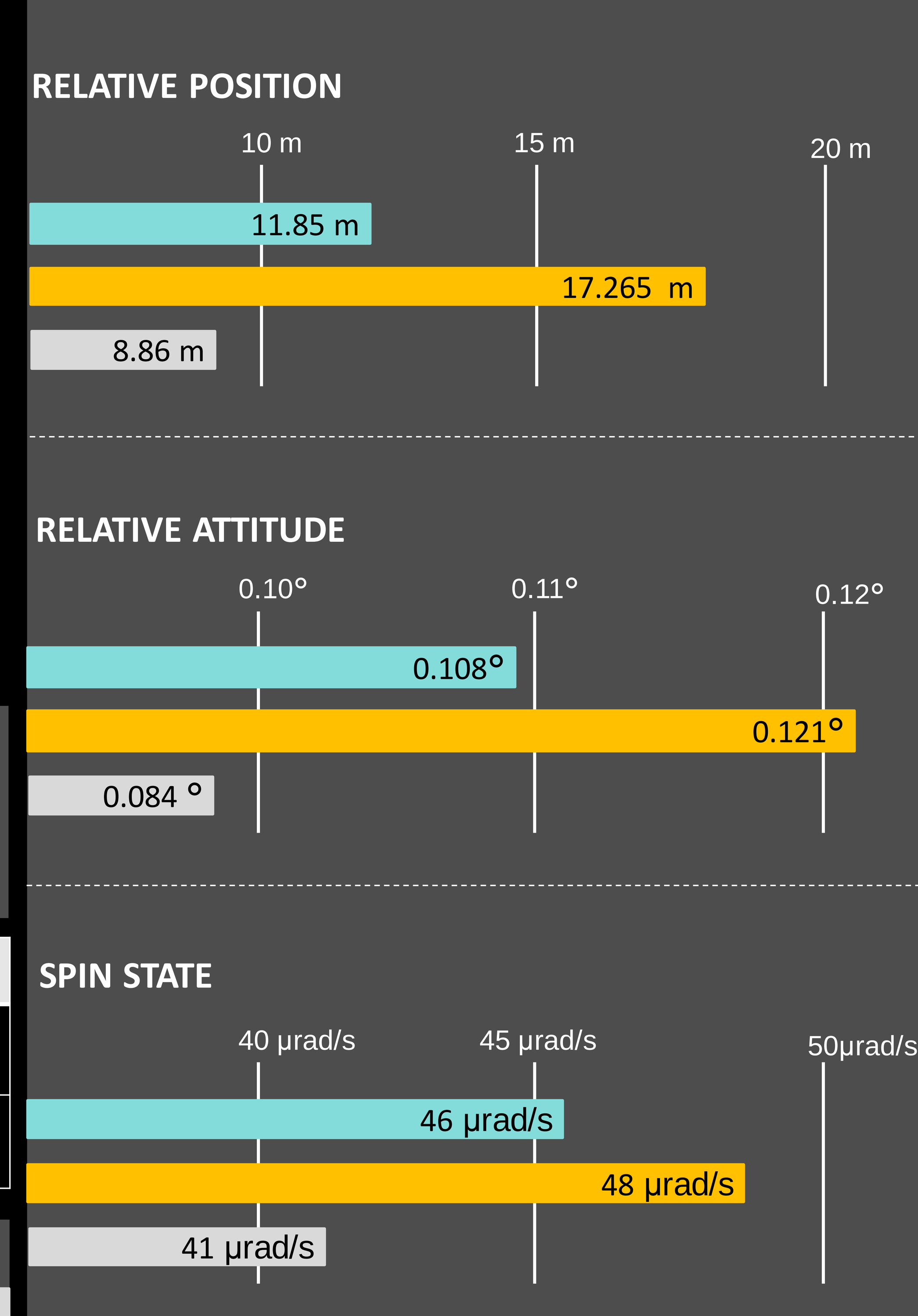
$$X = [\, r_A \;\; v_A \;\; q_{B/A} \, q_{B/I} \;\; \beta \;\; \omega_{A/I} \,]^T$$

Hardware Sampling Time

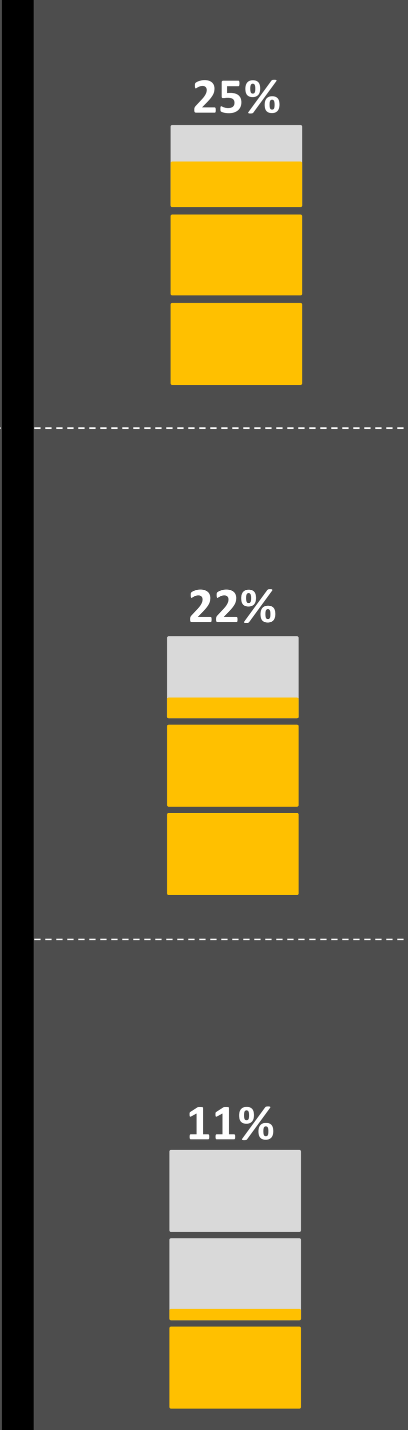
Altimeter	Star Tracker	Navigation Camera
1 [s]	1 [s]	30 [s]

Legend: VIS | TIR | VIS & TIR

RMSE comparison



Performance gain



Subset of Related References

- STAR-Dundee. *Planet and Asteroid Natural Scene Generation Utility*
- H. Durrant-Whyte and T. Bailey. "Simultaneous localization and mapping: part I". In: *IEEE Robotics Automation Magazine* (2006)
- S. Silvestrini, A. Capannolo, M. Piccinin, M. R. Lavagna, J. G. Fernandez, Centralized autonomous relative navigation ofmultiple spacecraft around small bodies, in: AIAA Scitech 2020 Forum
- G. L. Civardi, Multispectral Vision-Based Navigation and Spin State Estimation for Unknown and Uncooperative SpaceObjects, Master's thesis, Politecnico di Milano, 2021