LiDAR Navigation for Small Body Exploration

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Abstract

Light detection and ranging (LiDAR) devices are progressively being considered as advantageous navigation sensors for proximity operations in planetary exploration. Future lander missions could introduce imaging LiDAR sensors to support navigation and hazard detection during the entry, descent and landing (EDL) phase.

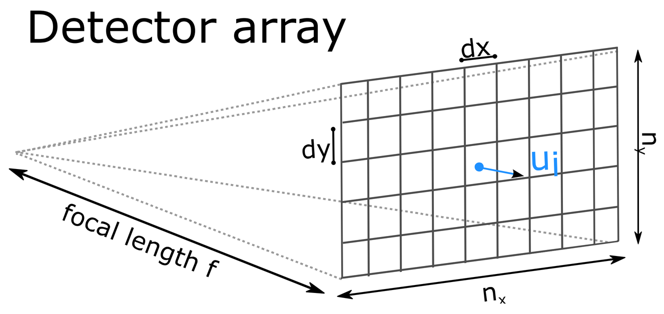
In this poster we present an end-to-end simulation environment for the usage of LiDAR in asteroid-relative navigation. Three main aspects are covered:

- Observation simulation and sensor model
- Navigation concept and related algorithms
- Performance analysis

The overall goal of the proposed simulation environment is to quantify the goodness of state-of-the-art LiDAR point cloud processing methods for surface relative navigation in space.

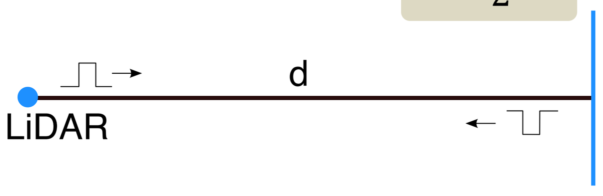
LiDAR observation simulation

Measurement Principle

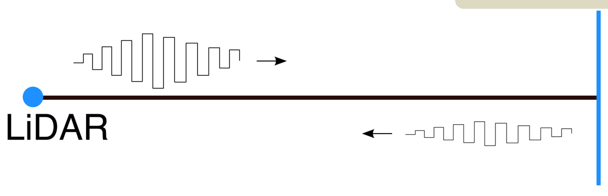


Measurement Type	Technology
LiDAR (large range)	Pulse-based
	Phase-based
	Flash
	Geiger mode (APD)
LiDAR + Structured light (short range)	Time-multiplex
	Colour-stripe coding
	Fringe projection

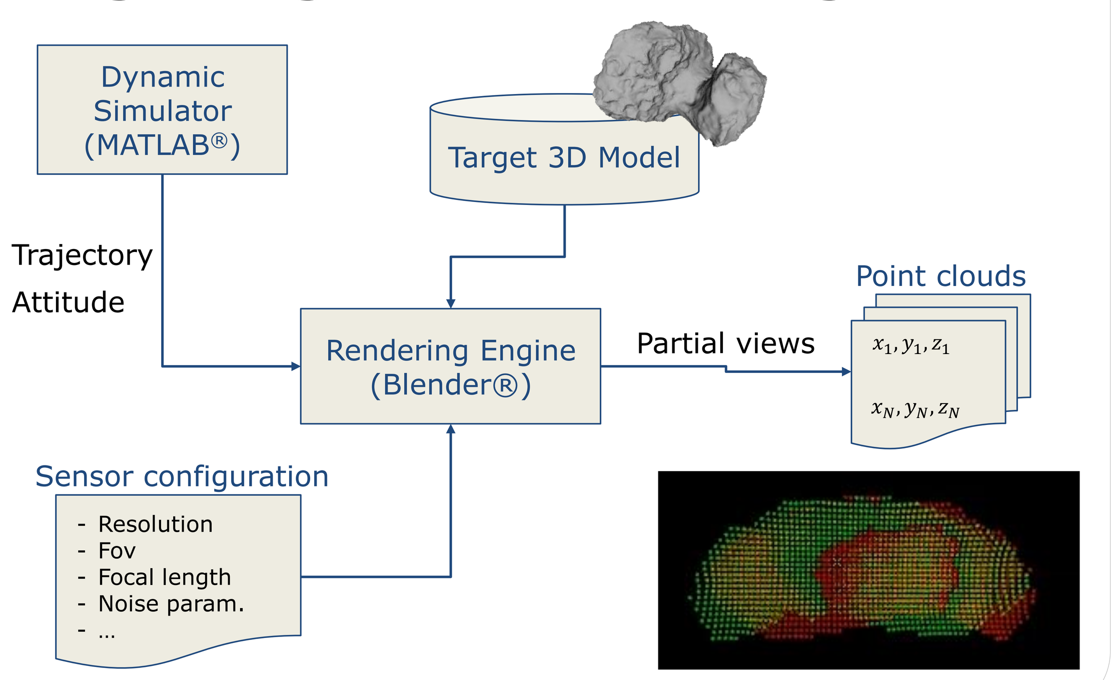
Pulse-based $d = \frac{1}{2} c\, t$



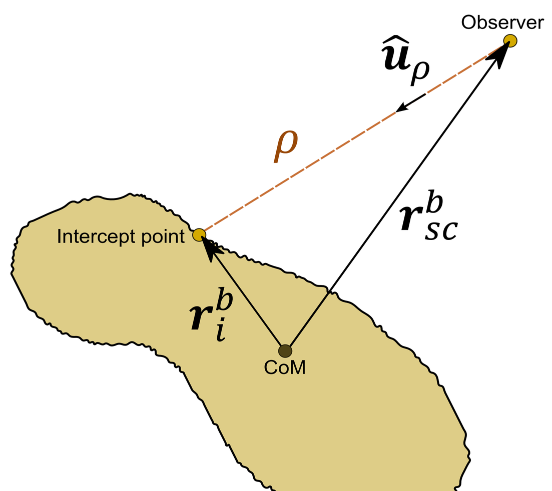
Phase-based $\Phi = \omega t$ $d = c \frac{\varphi}{2\omega}$



Range Image Simulations using Blender®

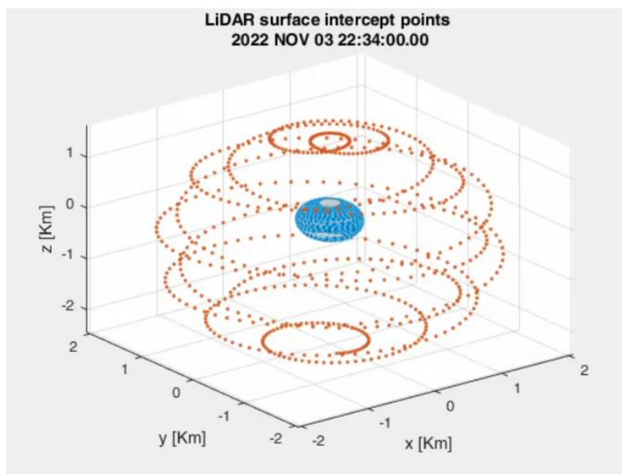


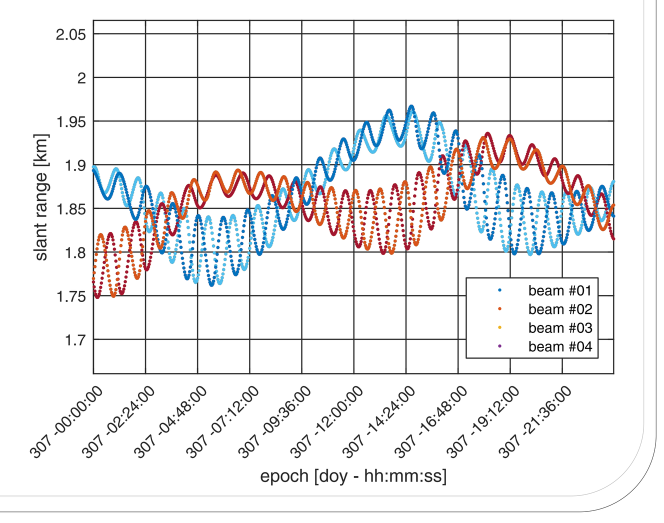
Slant Range Simulations using JPL's NAIF SPICE



$$\rho_i = G(X) = \left| r_{sc}^b - r_i^b \right| + b_\rho + v$$

- Geometric observation calculation
- Intended for multi-beam analysis (3-4 beams)
- MATLAB® based

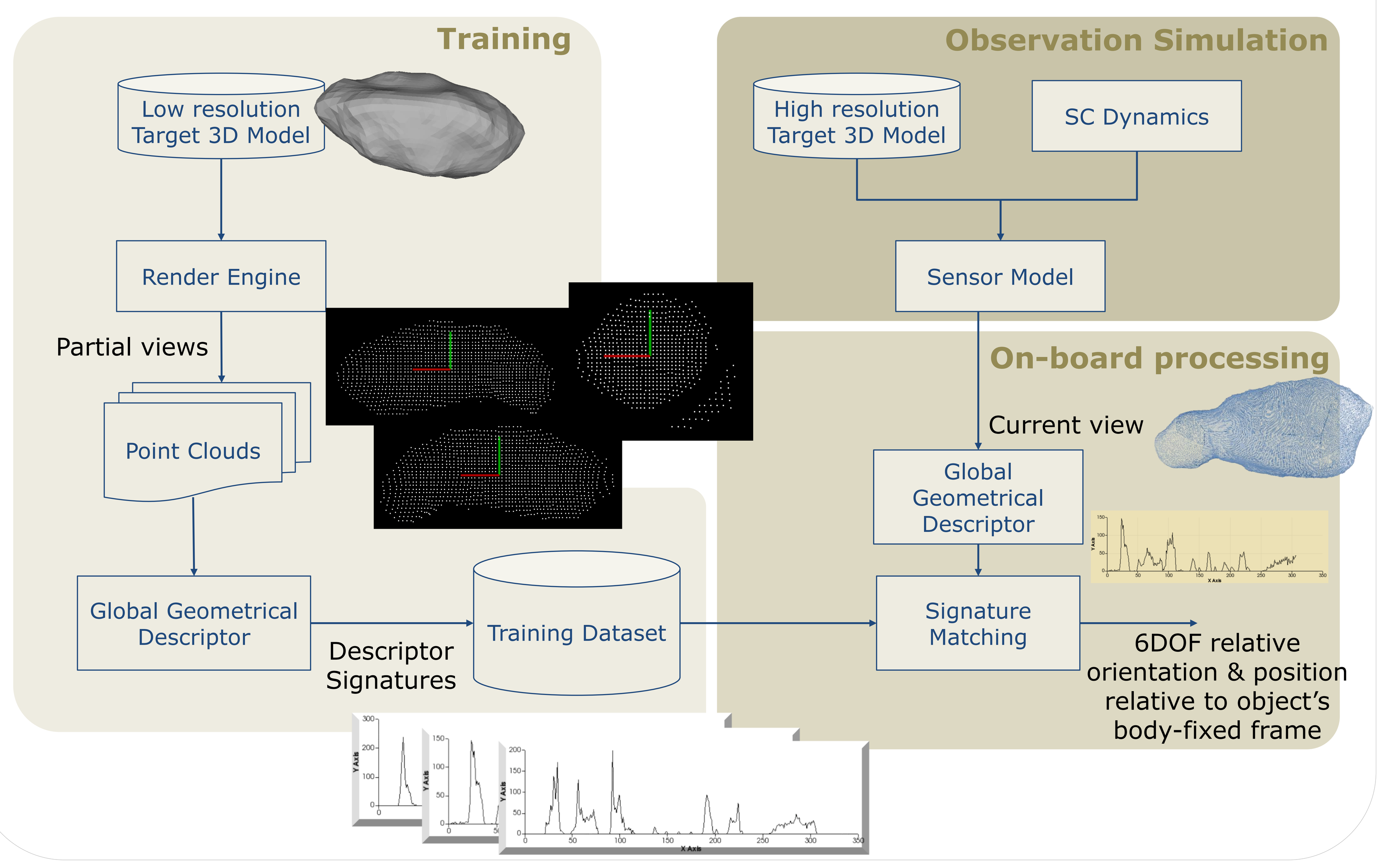




Relative Navigation using Imaging LiDAR

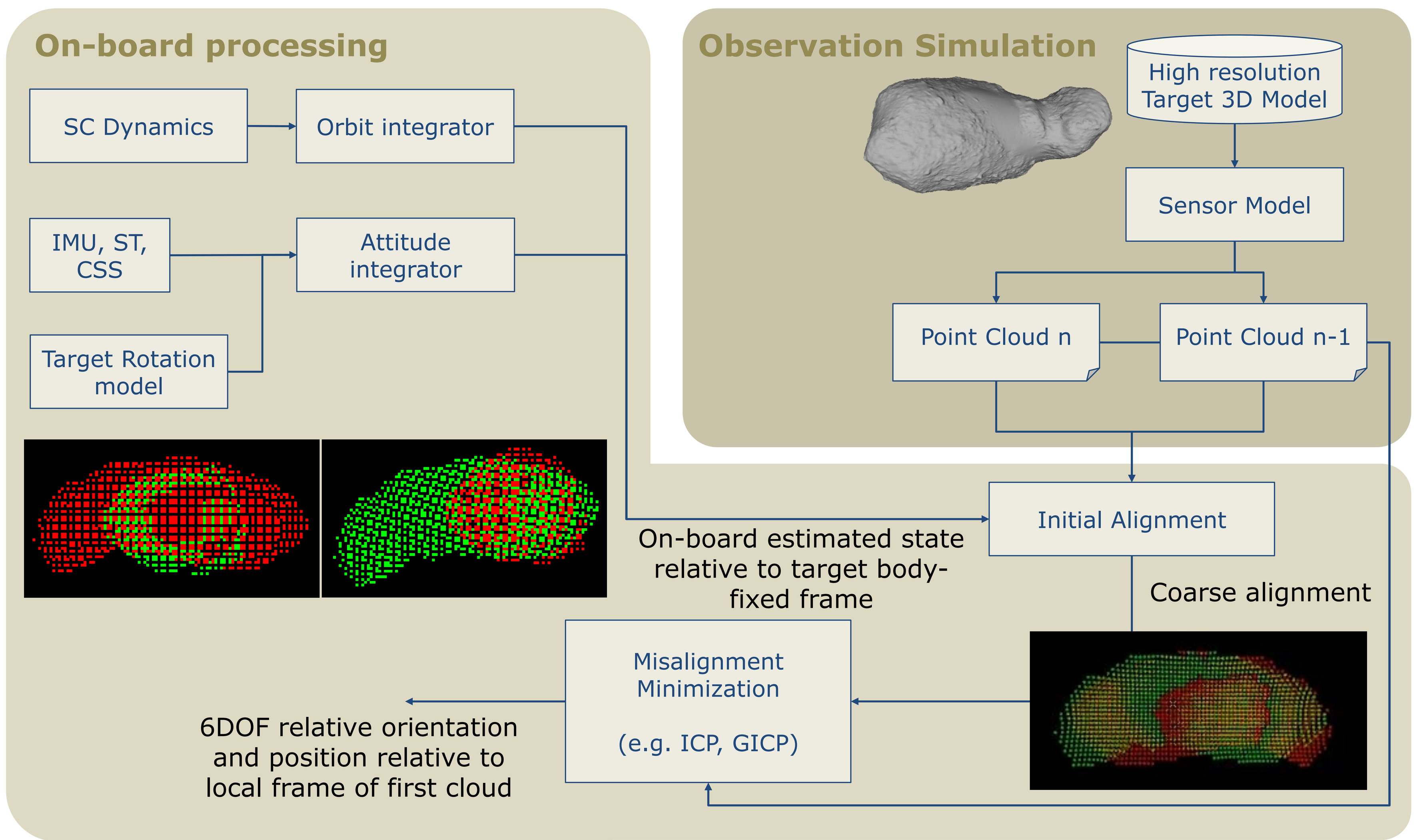
Model Relative Navigation (Global)

An absolute navigation solution (in the target's fixed frame of reference) can be attained by aligning current views to a trained set of partial views, even if the latter were trained on a lower resolution model.



Terrain Relative Navigation (Local)

A relative navigation solution (cloud-to-cloud or view-to-view) can be obtained by minimising the distance between consecutive scans.



Performance of descriptor-based alignment

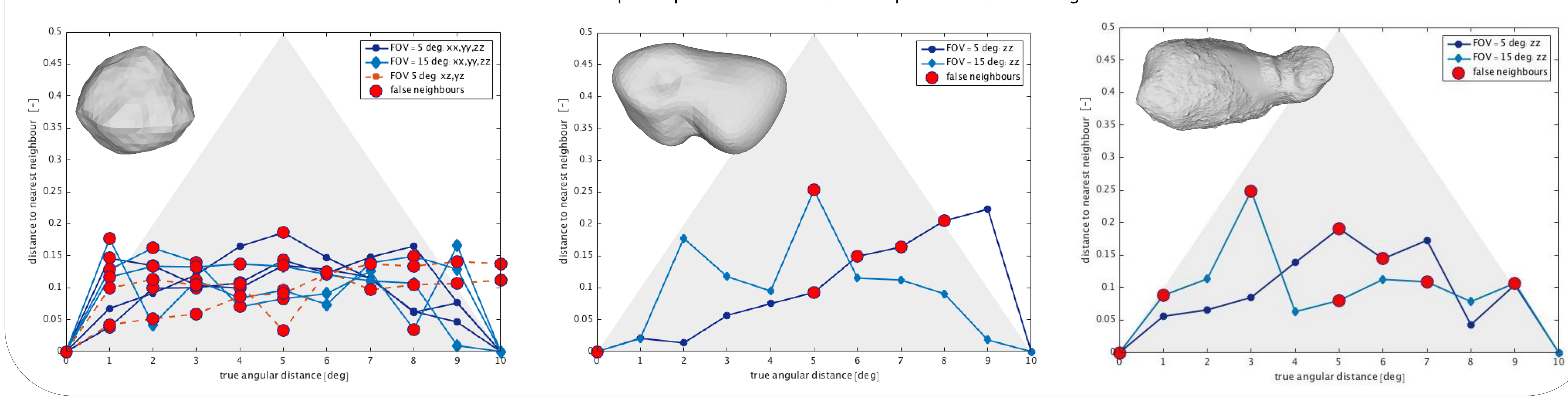
- Training sets of OUR-CVFH* signatures are computed for steps of 10 deg about the model body-fixed axes (128x128 pixels on square FOV of 5 or 15 deg)
- The OUR-CVFH histogram of a test cloud shifted $\phi \in [0, 10]$ deg with respect to a test-set member is matched against the set
- Test clouds are matched to a set about the same body axes (xx, yy, zz) or to a set about a different axes (xz, yz)

- Three asteroid models are evaluated:

1. a typical low resolution spheroid (i.e., a Radar-based model of asteroid Bennu)
2. a dumbbell-shaped body (i.e., a Radar-based model of asteroid Castalia) and
3. an oblate model (i.e., high-resolution model of asteroid Itokawa derived from JAXA's Hayabusa observations)

OUR-CVFH*Alignment Performance on Asteroid Models

*Oriented Unique Repeatable Clustered Viewpoint Feature Histogram



Conclusions

An end-to-end simulation system for the usage of imaging LiDAR in asteroid-relative navigation has been presented.

A complete observation simulation module, capable of generating dense images and multi-beam observables with due error models is included.

We propose two complementary pipelines for surface-relative navigation in absolute (model-based) and local (view-based) sense.

First results of absolute alignments using OUR-CVFH signatures show the need for adapting existing algorithms to the particular application.

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