Technologies for Space Surveillance & In-Orbit Servicing

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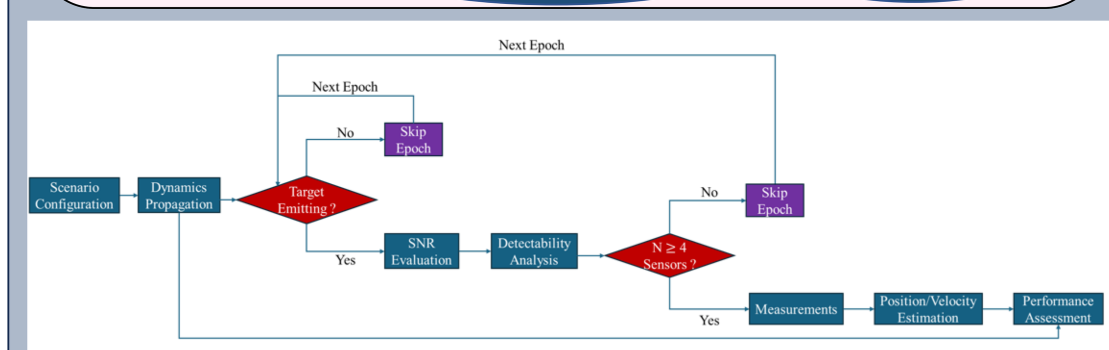
UniNa Contribution

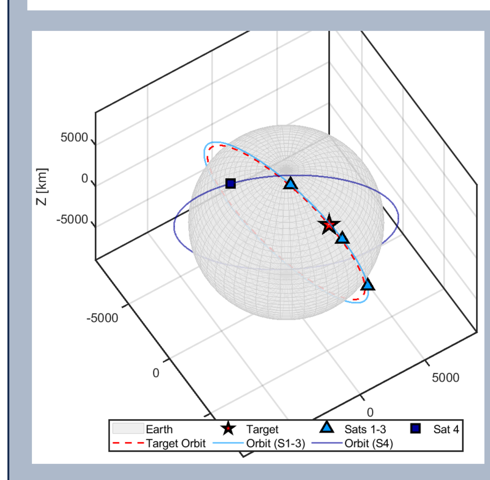
Multi-satellite based Passive Localization of Spaceborne Cooperative RF Emitters: Simulation Framework and Impact of Constellation Geometry

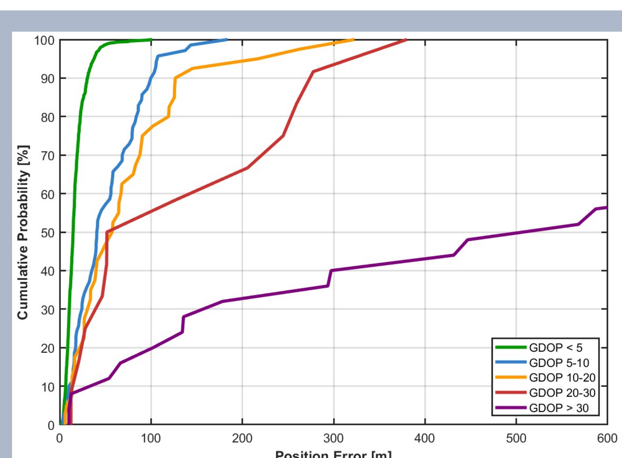
Context & Motivation

- LEO is becoming increasingly crowded, raising the criticality of STM and SSA.
- Current Space Surveillance Networks rely heavily on ground-based architectures and optical telescopes, which face inherent physical and operational constraints.
- A possible alternative technology for localization and tracking of Space objects is the adoption of **Passive Radio-Frequency systems.**

Weather independent | **Exploits *Signal of Opportunity*** | **Simple Hardware**







Problem Statement

- **Space-Based passive satellite constellation** tracking a cooperative LEO spacecraft using RF signals.
- Relying solely on **TDOA** and **FDOA.**
- Receiving constellation of 4 satellites.

Research Outcomes

- Design of a **High-Fidelity End-to-End Simulator** in MATLAB.
- **Robust 3-Stage Estimation Strategy** to handle the non-linearities of the joint TDOA/FDOA problem.
- Quantify how **Constellation Topology** affects the accuracy of joint **Position and Velocity** estimation.

Mean ϵ_{pos} (m)	Median ϵ_{pos} (m)	Std ϵ_{pos} (m)
16.93	**14.68**	**11.24**

Mean ϵ_{vel} (m/s)	Median ϵ_{vel} (m/s)	Std ϵ_{vel} (m/s)
0.80	**0.69**	**0.52**

Architecture Validation

- A configuration of co-orbital and cross-track satellites demonstrated that mean position accuracies of 16 meters and velocity accuracies below 1 m/s are achievable when GDOP remains below 5.

Ongoing activities

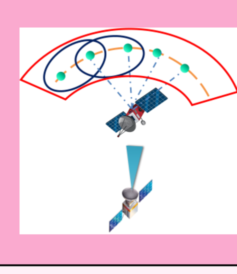
- Identification of RF payload.
- ISL requirements derivation.
- Sequential Estimation.

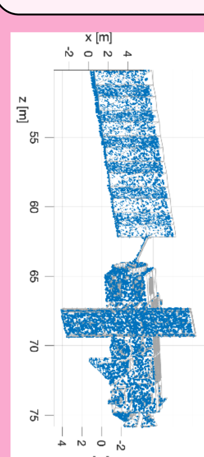
Palescandolo et al., AIAA Scitech 2026 Forum

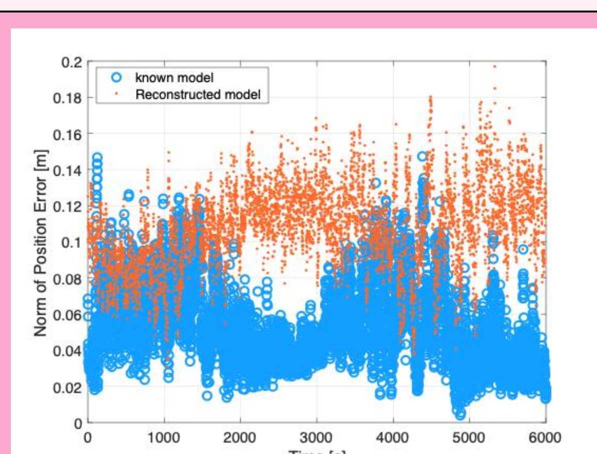
LIDAR-based Relative Navigation and 3D Target Reconstruction for proximity operations with non cooperative and unknown targets

Architecture Design

- **Feature-free** LIDAR-based framework for autonomous relative navigation near space targets of unknown.
- Reconstruction of the target geometric model through iterative registration of LIDAR acquisitions using **Generalized-ICP**, followed by **multi-view registration**.







Architecture validation

- Preliminary validation of the developed architecture on the **ENVISAT spacecraft**, using **synthetic datasets** generated with an **in-house-developed LiDAR simulator**
- **m-level** and **deg-level** accuracy in the **odometry** pose solution
- Target-sensor pose estimated with dm-level accuracy in position and degree-level accuracy in attitude using reconstructed model.

Ongoing activities

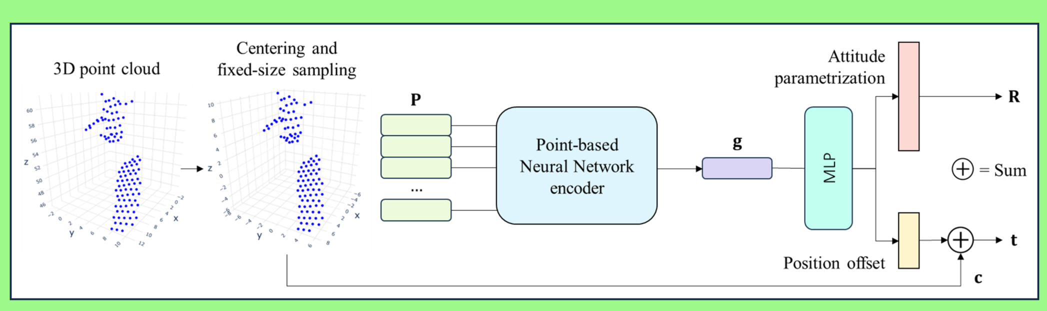
- Validation of the methodology with **real** LIDAR data acquired in a **laboratory facility**

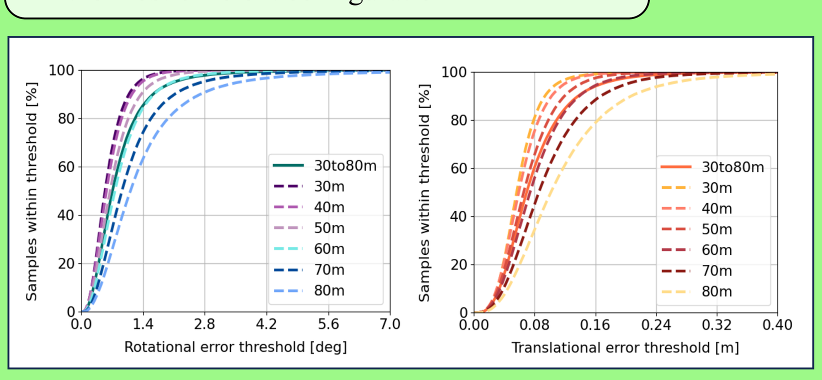
A. **Nocerino** et al., AIAA Scitech 2026 Forum

Deep Learning-based pose estimation system of non-cooperative, known spacecraft using LiDAR data

LiDAR-based pose estimation architecture

- Algorithmic solution that processes **3D LiDAR data** using a **point-based Neural Network** for point cloud global encoding, performing **pose initialization** of an **uncooperative spacecraft**
- **Different neural network encoders and attitude parametrizations examined** to find the most efficient configuration





Architecture validation

- Preliminary validation of the developed architecture on the **ENVISAT spacecraft**, using **synthetic datasets** generated with an **in-house-developed LiDAR simulator**
- **Sub-degree** angle error and **sub-decimeter** translational error achieved on a dataset with **random 30-80 m distances**, with **ICP refinement**, despite point cloud sparseness (**10-500 points**)

Ongoing activities

- **Analysis** and **improvement** of the current algorithmic solution
- Design of a **laboratory facility** for experimental validation

C. **Tecchia** et al., - *28th AIDAA International Congress and the 10th Aerospace Europe Conference (2025)*

Guidance and Control (G&C) strategies for autonomous close-proximity maneuvers with a non-cooperative, tumbling target

Ensuring **safety**, **robustness** and **autonomy** during close-proximity operations

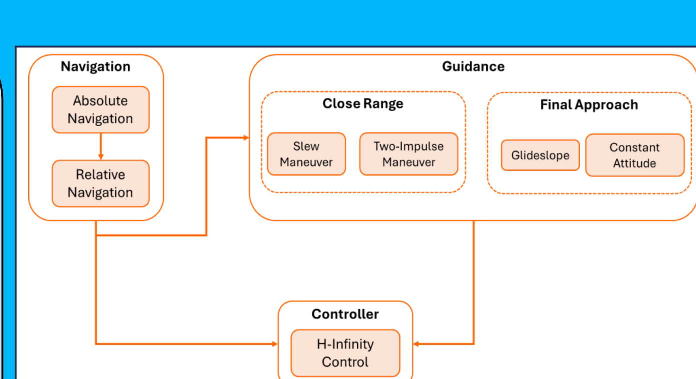
- **Design of optimal G&C algorithms** to define and track a reference trajectory around the tumbling target

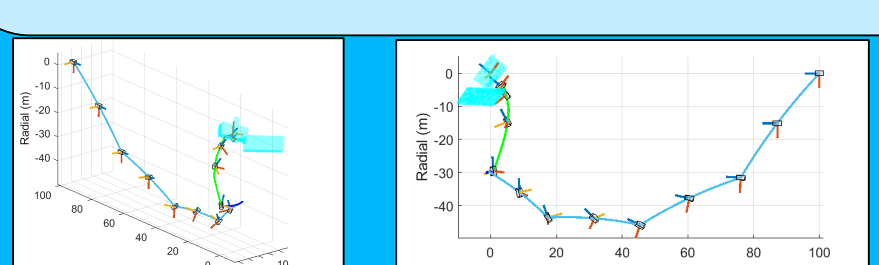
Close Range Phase

- **Translational Maneuver →** drives the servicer to the approach axis
- **Rotational Maneuver →** synchronizes the servicer's motion with the target's rotation

Final Approach Phase

- **Translational Maneuver →** drives the servicer along the approach axis
- **Rotational Maneuver →** maintains constant relative attitude





Architecture Validation

- **High accuracy** at berthing point of the proposed G&C architecture:
  - **Position Errors** are < 10 cm
  - **Attitude Errors** are < 1 deg

Ongoing activities

- Reformulate the guidance function to account continuous-thrust

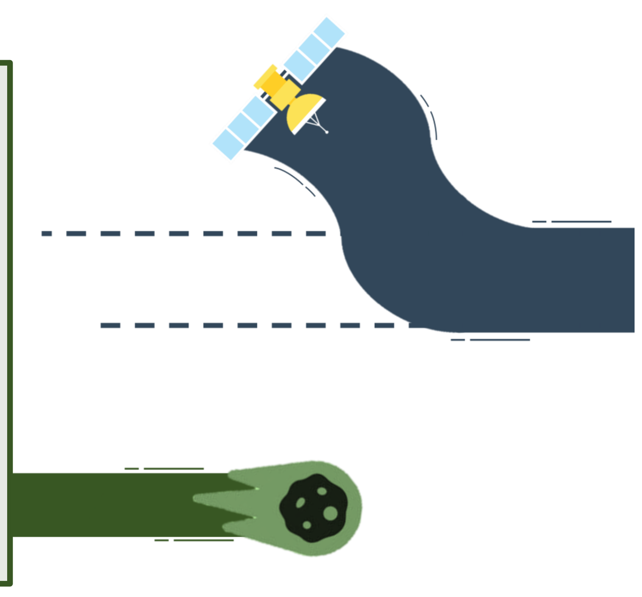
A. **Madonna** et al., - *28th AIDAA International Congress and the 10th Aerospace Europe Conference (2025)*
A. **Madonna** et al., - *11th European Conference for Aerospace Sciences (2025)*
A. **Madonna** et al., - *75th International Astronautical Congress (2024)*

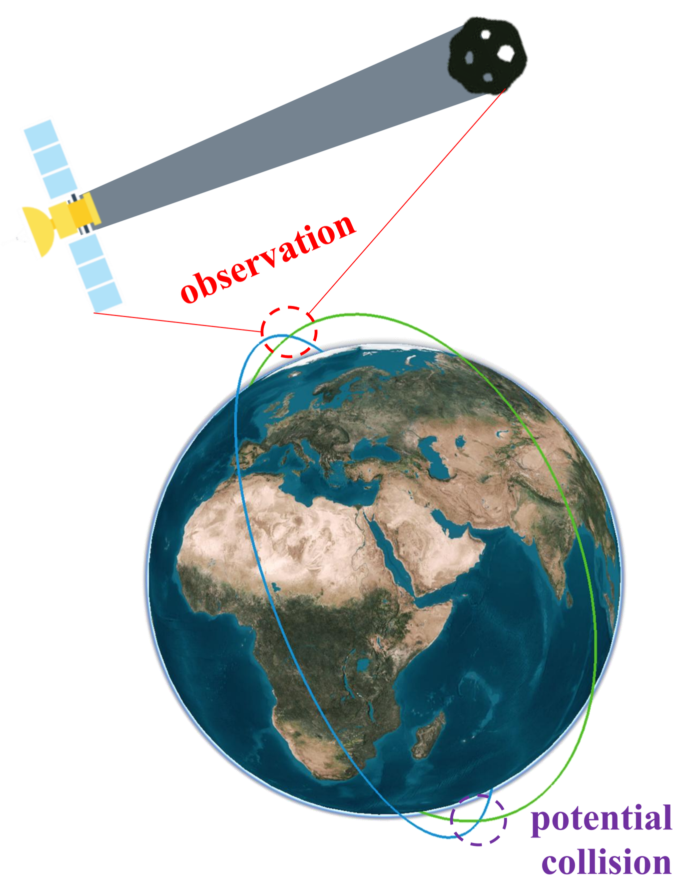
PoliBa Contribution

THE PROBLEM

The rapid growth of objects in LEO is **increasing conjunction alerts**. The current heavy reliance on ground-based tracking leads to large prediction uncertainties, generating a high rate of **false alarms** and forcing conservative avoidance maneuvers.

Over 99% of these **maneuvers are ultimately unnecessary**.



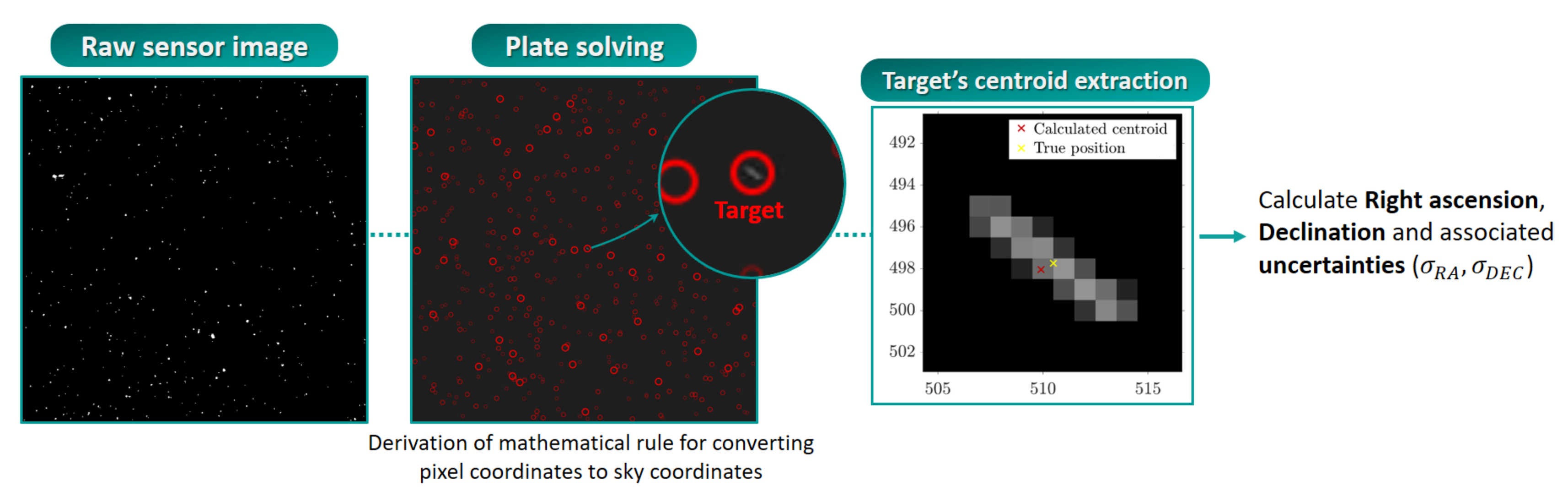


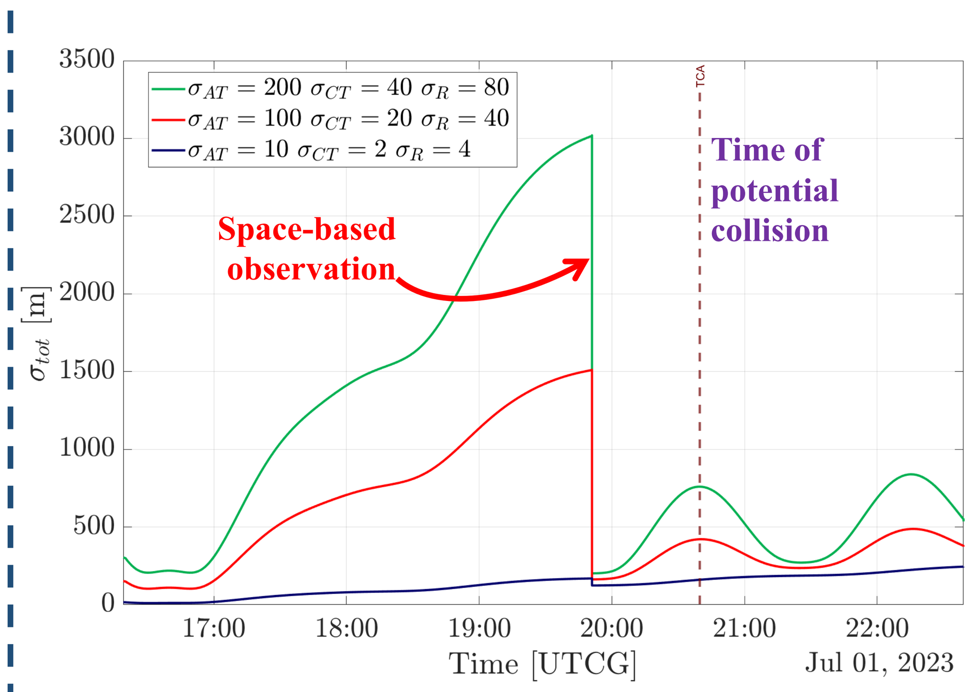
A SOLUTION

In the orbits before a potential collision, the two objects typically experience **multiple close passes.** These encounters are currently not exploited, but they can be used for **autonomous observations** from **onboard sensors** to collect timely measurements of the secondary object and refine its orbit directly onboard, **reducing uncertainty** and before making a maneuver decision.

THE APPROACH

After analyzing the concept from orbital dynamics [1] and sensor detection-limit perspectives [2], we now implement an end-to-end **astrometry and orbit-determination pipeline** [3]. Realistic conjunctions are simulated, optical measurements with uncertainties are extracted, and an onboard EKF is used to **assess the resulting uncertainty reduction**





RESULTS

- For debris-level initial uncertainties, onboard observations can **reduce covariance by ~40–60%**, if detections succeed.
- For well-tracked active satellites, only sensors achieving **total angular errors below ~15 arcsec** provide meaningful improvement.

- **Detection capability**, more than astrometric accuracy, is the main operational **bottleneck** for small, low-quality sensors.

[1] G. Campiti et al, "Orbital kinematics of conjuncting objects in low-earth orbit and opportunities for autonomous observations," *Acta Astronautica*, 208(1), **2023**

[2] G. Campiti et al "Detectability of potentially colliding space objects through onboard cameras and star trackers," *IEEE Transaction on Aerospace and Electronic Systems*, 61(5), **2025**

[3] G. Campiti et al, "Conjunction Risk Reduction in LEO through Onboard Optical Processing," in proc. *CEAS-AIDAA Joint Conference 2025*, **2025**