

Matteo Capitanio*, Michele Maestrini, Mauro Massari

* Corresponding author: matteo.capitanio@polimi.it

INTRODUCTION

A significant fraction of Resident Space Objects (RSOs), including debris or damaged satellites, are uncooperative and poorly characterized, thus requiring in-orbit inspection for debris mitigation and in-orbit servicing. In this context, **Distributed Space Systems (DSS)** offer a promising approach by providing scalability, robustness to single-agent failures, and multi-view observations. This work presents a preliminary analysis of a distributed navigation architecture in Low Earth Orbit (LEO), where two cooperative chasers, equipped with monocular cameras, collaborate to inspect a large **uncooperative target**.

METHODOLOGY

The primary chaser estimates its relative position, velocity, attitude error, and angular velocity with respect to the target object, via a combination of **Extended Kalman Filter (EKF)** and its **Multiplicative**^[1] variant (**MEKF**). However, monocular vision alone limits navigation accuracy in close-proximity operations. To overcome this, a secondary chaser operating at a larger distance supplies complementary measurements via **Inter-Satellite Link (ISL)**, assuming that the target's shape and inertial properties are known.

Within the simulation framework, modeling the acquired measurements (Fig. 1) is fundamental to evaluate the proposed navigation architecture in a quasi-realistic environment. The measurement model considers:

- 2D pixel coordinates of target's features
- Relative camera pose via **Efficient Perspective-n-Point**^[2] (EPnP)

Realistic visibility constraints are included, such as Field Of View (FOV) limits, self-occlusion, and illumination conditions. Moreover, the architecture relies on **auxiliary measurements**, which include target's orbit, chasers' inertial attitude, and their mutual position, assumed to be provided by external systems.

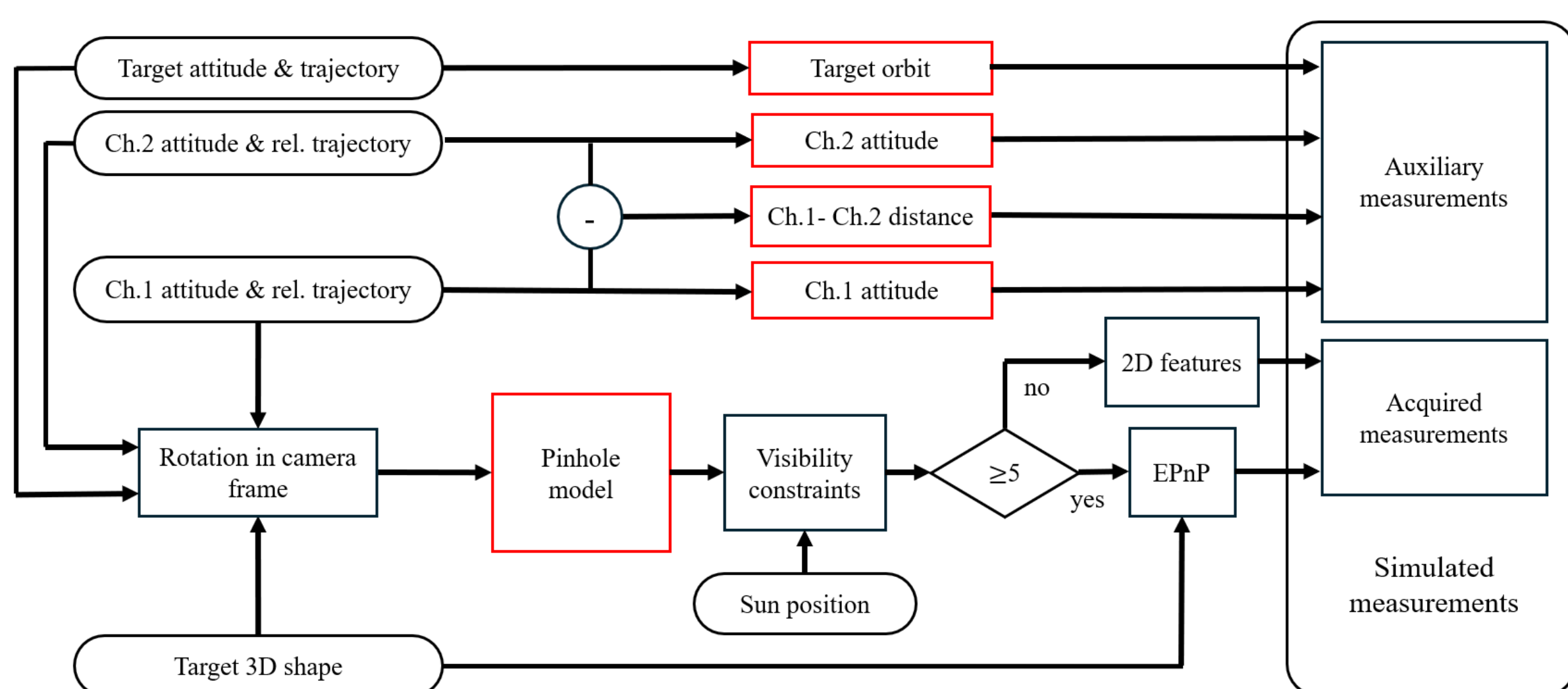


Fig. 1: Diagram of synthetic measurements modeling. Measurement noise is indicated by red boxes.

As the focus of the analysis is on navigation performance, the chaser's control torques to point towards the target are precomputed from ground-truth trajectories and attitudes, and thus are not updated in the loop. In detail, the camera axis is aligned to target's relative position, and related quaternion and angular velocity derivatives are approximated using finite differences.

At each iteration, the filter (Fig. 2) elaborates either the direct measurements acquired by Ch.1, the secondary ones provided by Ch.2, or both simultaneously. The expected measurements \hat{z} are modeled to match the available ones:

- If EPnP measurements are used: $\hat{z} = [-\hat{R}_{CiI}\hat{R}_{IL}\hat{r}_{Ci} \mid \hat{a}_{Ci}]^T$
- If 2D features are used: $\hat{z} = K\frac{1}{Z}(\hat{R}_{CiI}P_T - \hat{R}_{CiI}\hat{R}_{IL}\hat{r}_{Ci})$

with \hat{R} rotation matrices linking i -th chaser body frame C_i , inertial frame I , Local-Vertical Local-Horizontal (LVLH) frame L , and target body frame T . \hat{a} is the relative attitude error and \hat{r} the relative position from the target, while matrix K represents the camera intrinsics, and p_T is a generic target feature. Furthermore, the auxiliary measurements uncertainties are included in the innovation matrix employing the **Consider Covariance approach**^[3].

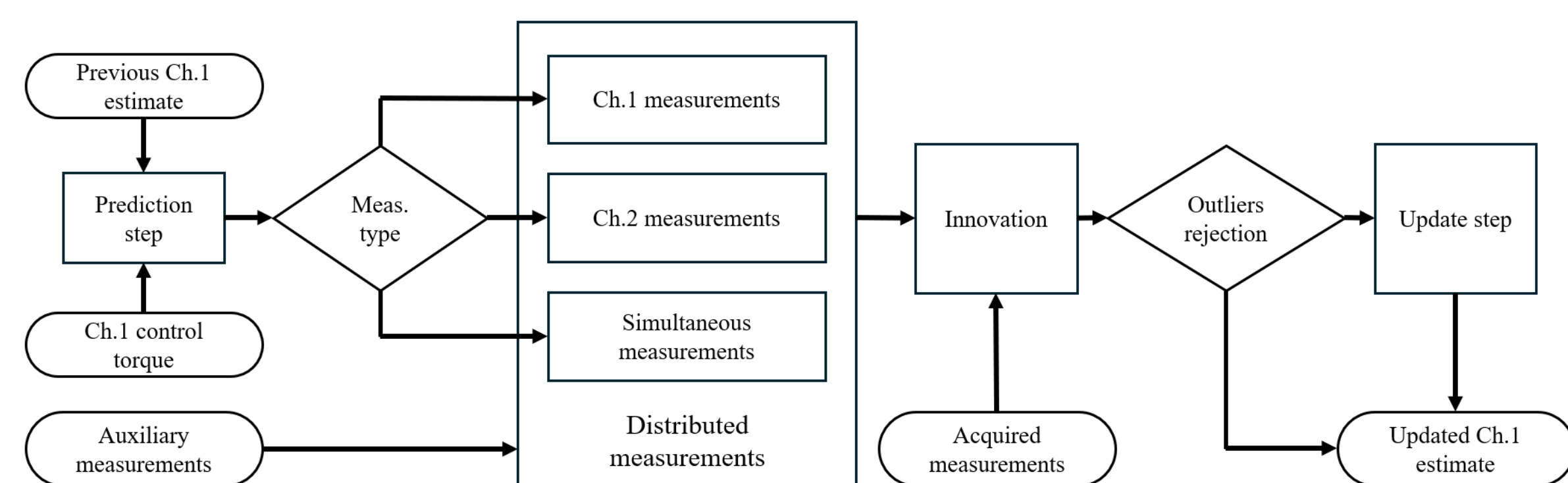


Fig. 2: Diagram of the distributed navigation filter architecture.

TESTED SCENARIO AND RESULTS

Several assumptions are considered to assess this preliminary approach. The target object is modeled as a cuboid, with dimensions $10 \times 3 \times 5$ m and 8000 kg of mass. It orbits a **quasi-circular polar LEO** at 700 km altitude, starting from a random initial orientation. The primary chaser is positioned close to the target object to simulate the close-range inspection mission, maintaining a minimum relative distance of 15 m (Fig. 3). The trajectories are propagated including **air drag** and **Solar Radiation Pressure (SRP)**, to highlight ballistic coefficient difference between the satellites. Both chasers are equipped with a **monocular camera** (20.59° FOV, 4.2 MP), operating at 0.1 Hz and 0.07 Hz, respectively.

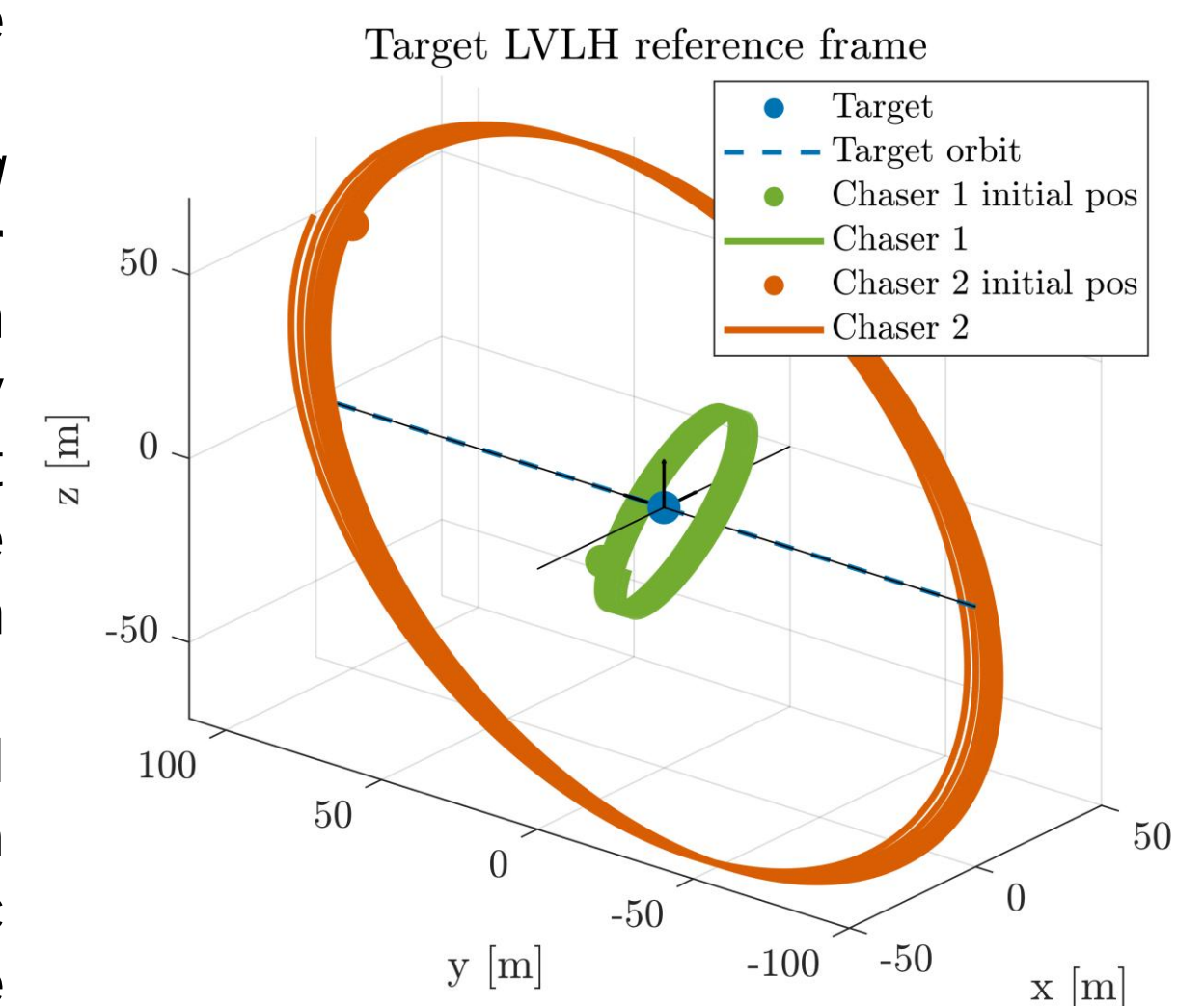


Fig. 3: Chasers' relative orbits.

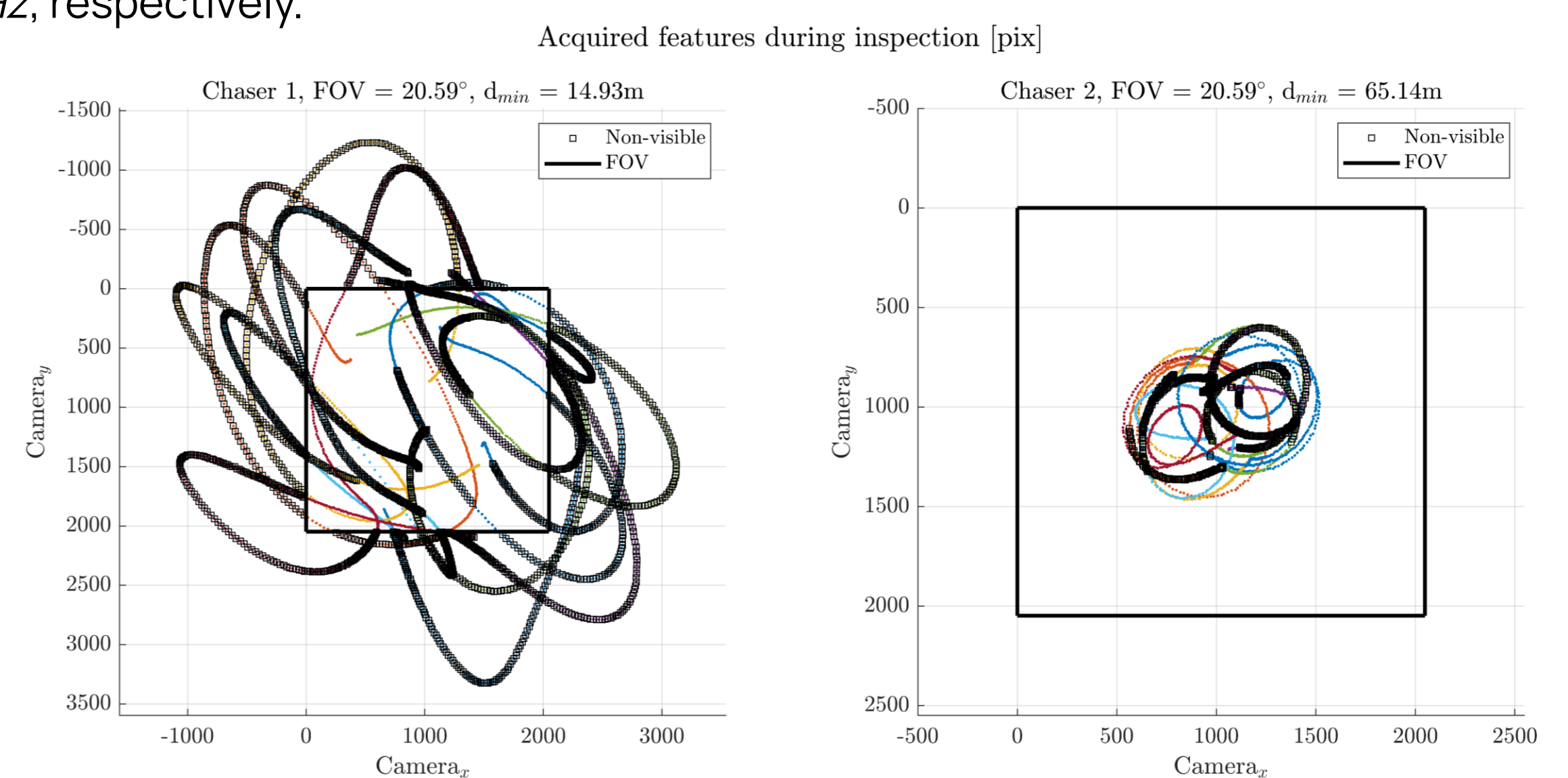


Fig. 4: Acquired features from chasers perspectives. Colored points denote visible features.

Monte Carlo (MC) analyses (Fig. 5) validate the approach under both **nominal** and **degraded conditions**, in which Ch.1 relies only on data provided by Ch.2 to maintain relative navigation around the target object: uncertainties remain bounded, enhancing overall redundancy and robustness.

Variable	Uncertainty (3σ)
Camera noise	5 pix
Target orbit in ECI	100 m, 0.5 m/s
Ch.1 & Ch.2 inertial attitude	$1e-3$
Ch.1 & Ch.2 relative distance	0.10 m
Ch.1 relative pos. & vel. at t_0	1 m, 0.01 m/s
Ch.1 relative att. & ang. vel. at t_0	$1e-2$, 0.057°/s

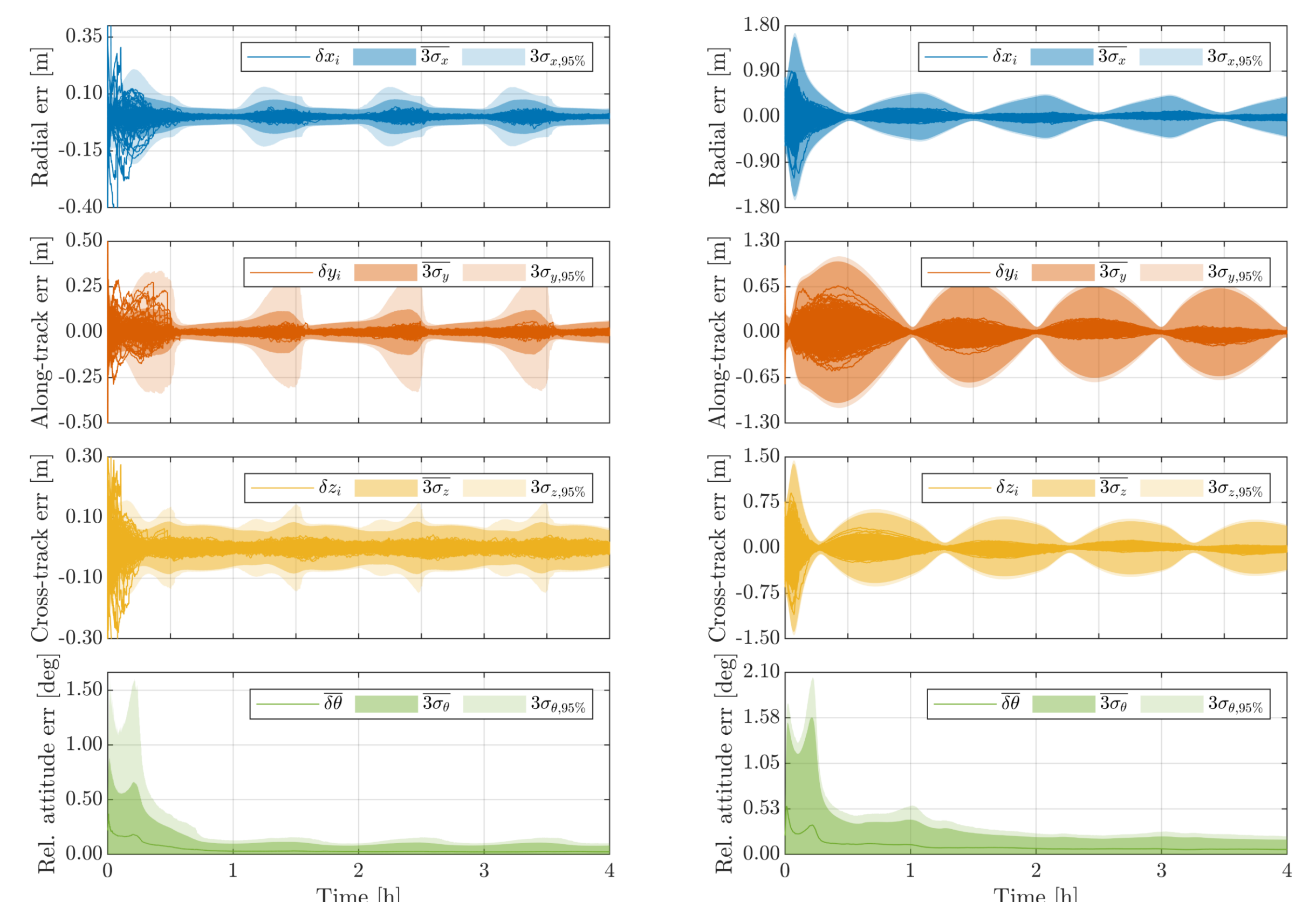


Fig. 5: MC realizations of relative position and attitude errors in nominal conditions (on the left) and degraded conditions (on the right).

Future developments:

- Extend the approach to more realistic scenarios and acquisitions.
- Develop a realistic ISL module, to account for delays and errors.
- Analyze navigation performance with more than two chasers.

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 [2] V. Lepetit et al., EPnP: An accurate O(n) solution to the PnP problem, International Journal of Computer Vision, 2009.
 [3] F. L. Markley et al., Generalized linear covariance analysis, Journal of the Astronautical Sciences, 2009.