

Sequence matching techniques for GNSS-space based navigation enhancement

Original

Sequence matching techniques for GNSS-space based navigation enhancement / Fiorina, Francesco. - ELETTRONICO. - (2025). (Riunione annuale GTTI 2025 Bologna (Ita) 15-17 settembre 2025).

Availability:

This version is available at: 11583/3003577 since: 2025-10-01T17:20:26Z

Publisher:

Associazione Gruppo Telecomunicazioni e Tecnologie dell'Informazione (GTTI)

Published

DOI:

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Sequence matching techniques for GNSS-space based navigation enhancement.

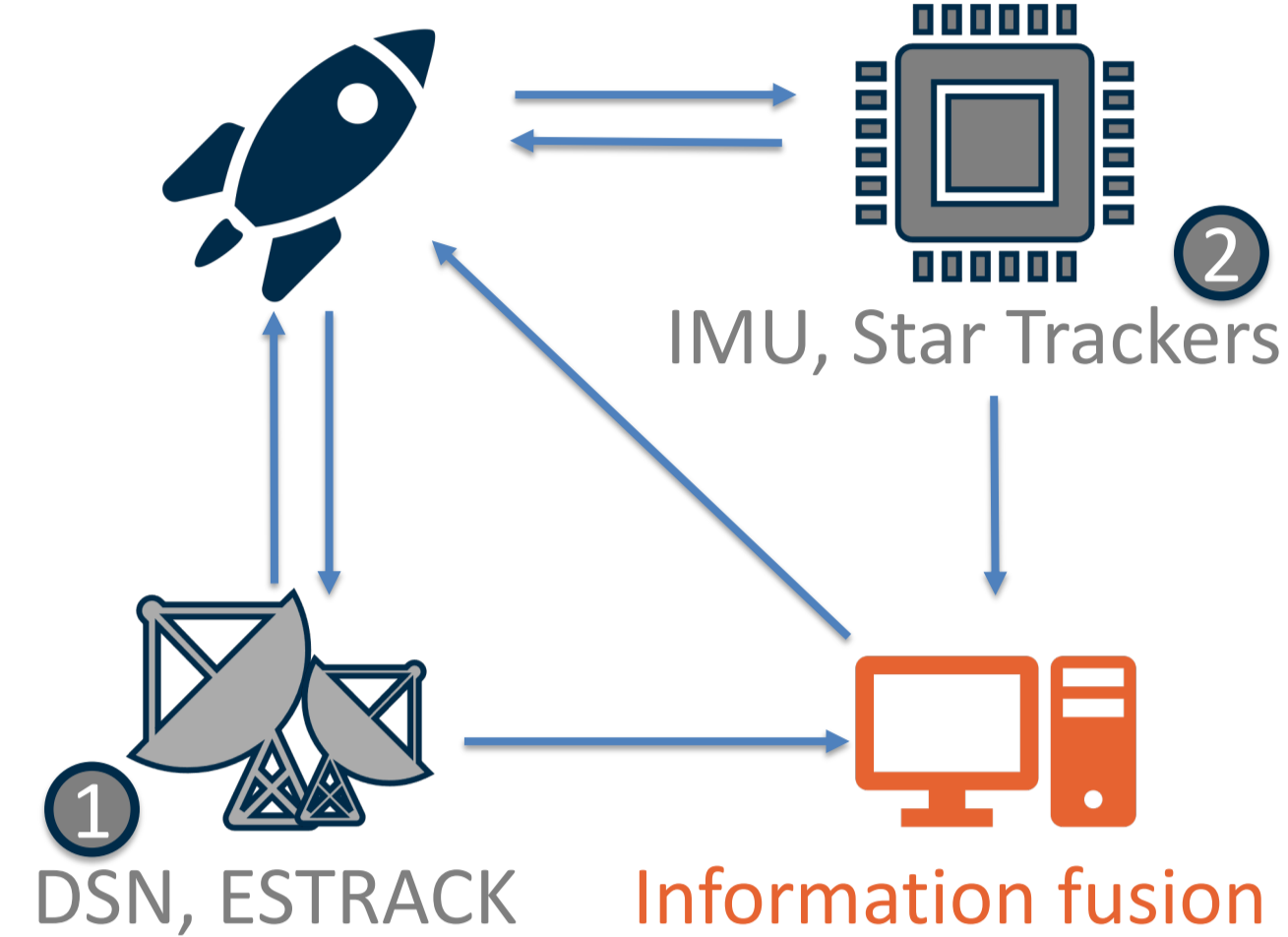
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Introduction

The rapid growth of space exploration has led to more missions targeting deep space and the Moon.

- Accurate OD essential for localization, navigation & maneuvers.
- Current approach: ground systems (1) + onboard sensors (2).



DRAWBACKS

- High operational costs
- Critical delays in real-time operations
- Limited ground resources

ALTERNATIVE

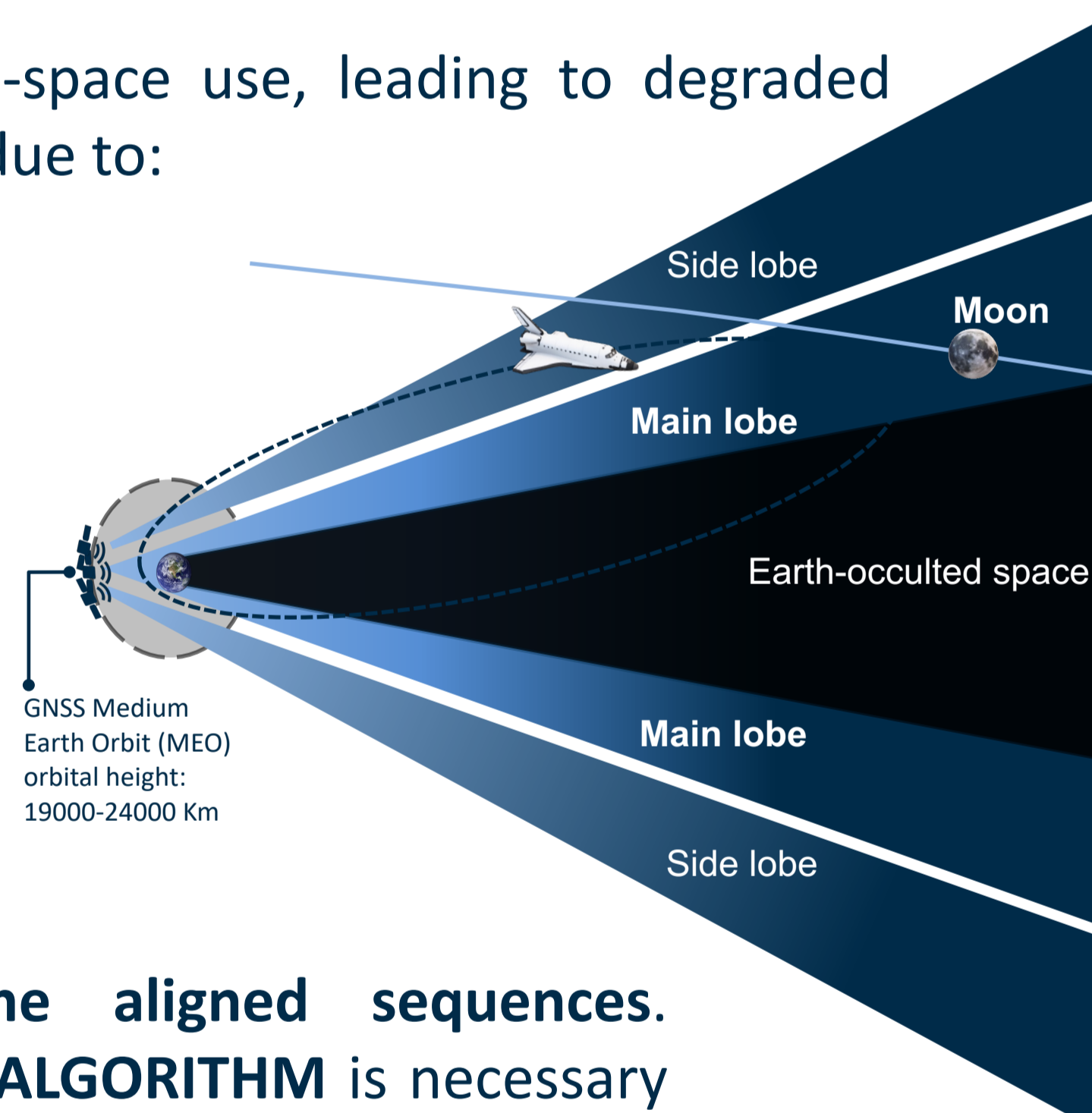
Global Navigation Satellite Systems (GNSS) offers a promising alternative for lunar navigation. In March 2025, the **LuGRE** receiver successfully demonstrated real-time use of GNSS signals at lunar altitudes, estimating its state and collecting data throughout the mission.



Addressed Research Questions/ Problems

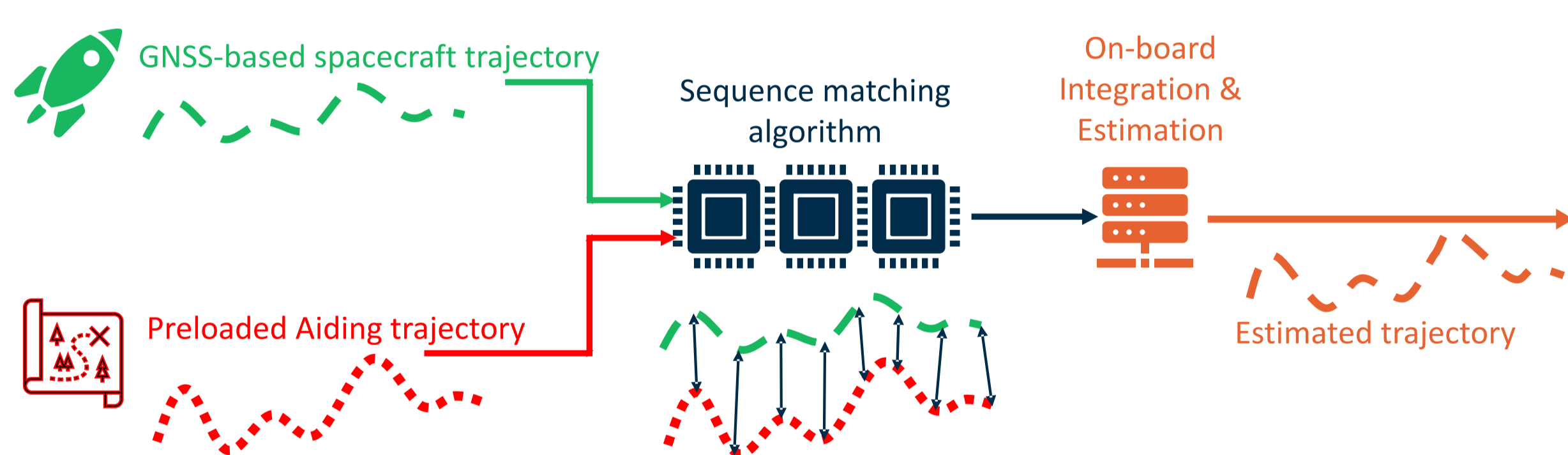
GNSS was not built for lunar or deep-space use, leading to degraded Position, Velocity, and Time estimation due to:

- Poor spatial diversity.
- Path losses and attenuations.
- Signal availability: Earth occultation.



To improve the PVT solution a **GNSS-based spacecraft trajectory** and an **aiding trajectory (AT)** from pre-mission design can be combined.

The two trajectories are **not time aligned sequences**. A reliable **SEQUENCE MATCHING (SM) ALGORITHM** is necessary to properly integrate the two sequences.



QUESTION

Can an orbit-matching adaptation of **Dynamic Time Warping (DTW)** be used as a Sequence Matching (SM) technique to overcome this time misalignment?

Novel Contributions

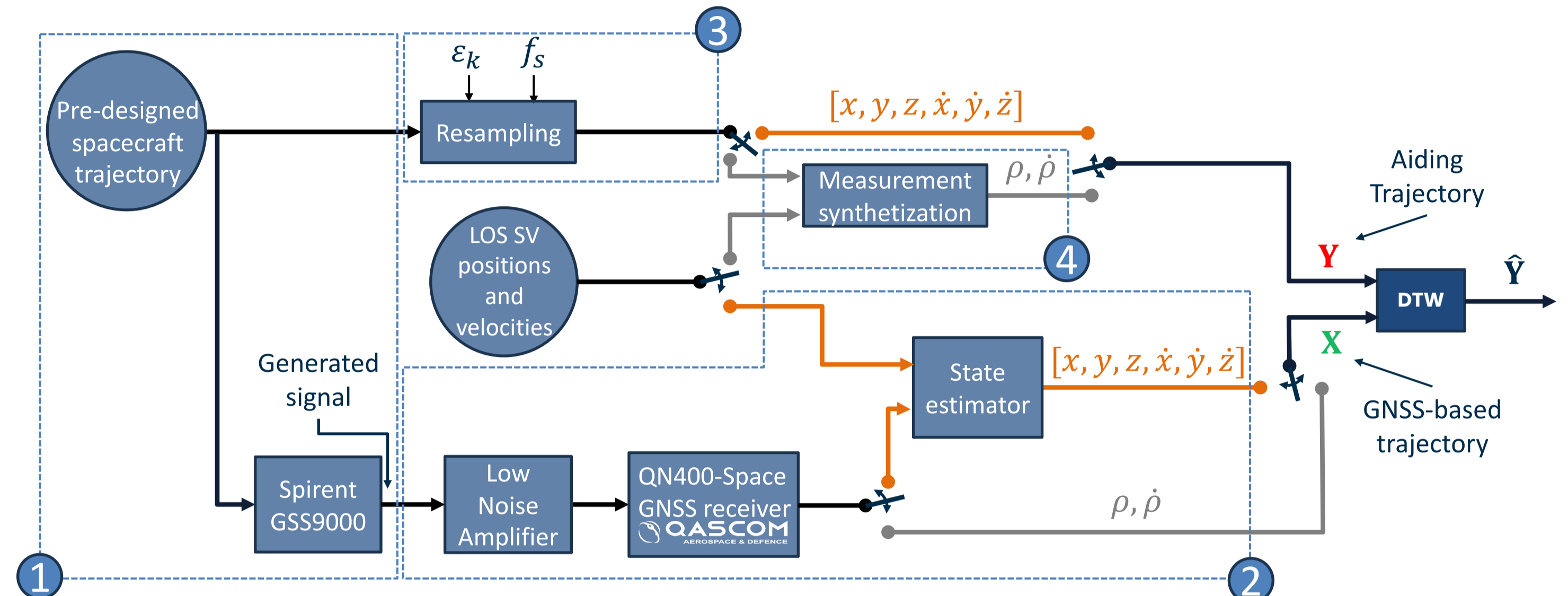
This work proposes a method to handle time misalignment between GNSS data and a pre-designed Aiding Trajectory. Key innovations:

- **Customized DTW** → addresses GNSS-trajectory time misalignment
- **Local weighting strategy** → improves SM robustness & accuracy
- **Dual applicability** → supports both PVT states & raw observables
- **Formalization** → formalization of the SM problem solved with DTW

Methodology and Results

DATA COLLECTION

1. Signal generation in a Hardware In the Loop simulation testbed.
2. **PVT state computation** or Raw measurement extraction.
3. Aiding trajectory resampling at $f_s = 2 \text{ Hz}$ + noise injection $\varepsilon_k \sim \mathcal{N}(0, \sigma_{time})$ on the sampling instants.
4. Observables-Based Aiding Trajectory (OBAT) synthetization.



EXPERIMENT SETTINGS

The experimentation was conducted using different techniques.

Tested techniques:

- Customized DTW
- Locally weighted Customized DTW

Tested Distance functions (DF) :

- L_p distances

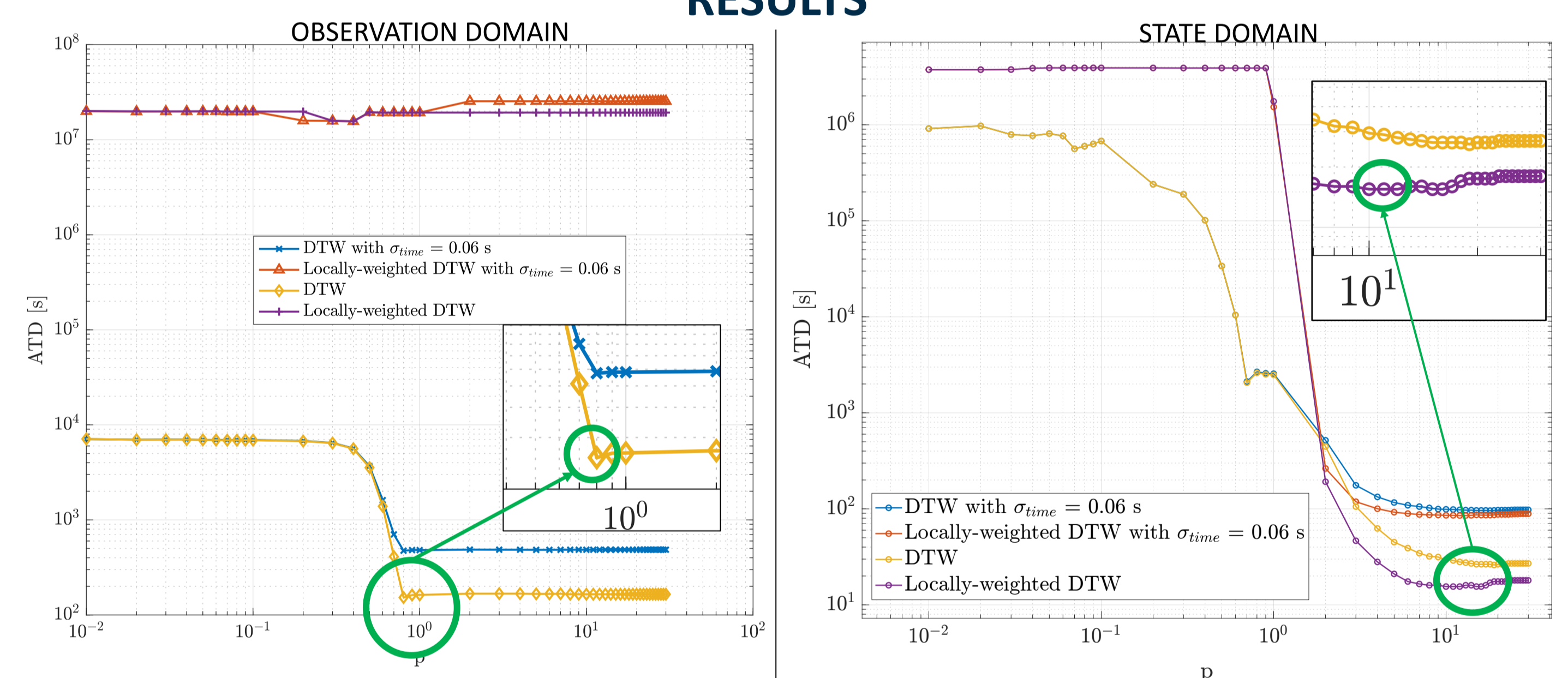
Worse spatial diversity conditions and satellite visibility at lunar distance.

Low Lunar Orbit (LLO)

Distance from earth: $\sim 382260 \text{ km}$ (60 RE)

Different resampling noise on the AT $\sigma_{time} = 0 \text{ s}$ and $\sigma_{time} = 0.06 \text{ s}$.

RESULTS



Accumulated time difference (ATD) between the sampling instants of the matched samples while varying p , a parameter that defines the L_p distance.

Conclusions and publications

GENERAL REMARKS

The customized DTW emerged as an effective method to solve the SM problem

	Observation domain SM	State domain SM
Best technique	DTW	Locally weighted DTW
Best DF	$L_{0.8}$	$L_{10} L_{11} L_{12}$

RESEARCH TAKEAWAY

Customized DTW sequence matching shows promise for extending GNSS applications to deep space and lunar environments.

FURTHER WORKS

Integration of the DTW into the estimation process on real scenario data.

PUBLICATIONS

- F. Fiorina, O. Vouch, A. Nardin, and F. Dovis, "Exploring observation-domain with nonlinear time-series warping for aided GNSS navigation," in Proceedings of the 33rd European Signal Processing Conference (EUSIPCO), 2025, pp. 1273–1277. ISBN: 978-9-46-459362-4.
- F. Fiorina, O. Vouch, A. Nardin, F. Dovis, C. Facchinetti, and M. Musmeci, "A sequence matching approach for gnss-based orbit determination using dynamic time warping," in 2025 IEEE/ION Position, Location and Navigation Symposium (PLANS), 2025, pp. 1055–1065. doi: 10.1109/PLANS61210.2025.11028519.

This study was partially funded within the contract n. 2021-26-H1.0 ASI/Politecnico di Torino "Attività di R&S inerente alla Navigazione GNSS nello Space volume Terra/Luna nell'ambito del Lunar GNSS Receiver Experiment". The author would like to thank NASA, ASI and Qascom for supplying the representative datasets of LuGRE operations that supported this study.