ScuDo
Scuola di Dottorato - Doctoral School
WHAT YOU ARE, TAKES YOU FAR

XXXVII Cycle

Cooperative GNSS positioning in Space

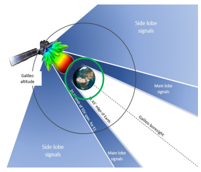
Anaïs DELÉPAUT

Supervisor: Prof. Fabio DOVIS, with support from Alex MINETTO

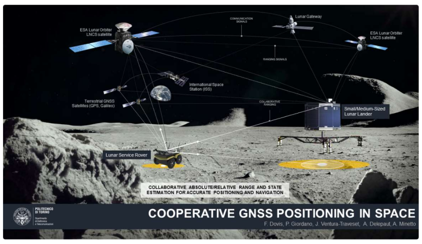
Research context and motivation

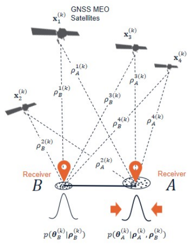
- There is a great interest in **extending the use of GNSS in Space** as witnessed by past studies that are addressing not only the use of GNSS on board of LEO, MEO and GEO satellites, but also to support cislunar missions and initiatives.

Space Navigation Technology	Autonomy	Order of Accuracy [km]	"Real Time"	Cost	Size
Radiometric Tracking (DSN)	✗	$1e^{-3}$	✗	✗	✓
X-Ray Pulsar Navigation	✓	1	✓	?	✗
Celestial Optical Triangulation	✓	10	✓	✓	✓
Full-Disk Optical Navigation	✓	10	✓	✓	✓
GNSS Navigation	✓	$1e^{-2}$	✓	✓	✓
Inertial Navigation	✓	✗	✓	✓	✓

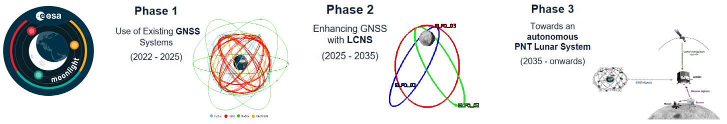


- The concept of **GNSS Cooperative Positioning (GNSS-CP)** is quite effective on Earth when the number of visible GNSS satellites is limited. It is based on the estimation of the baseline between a pair of networked GNSS receivers which can rely on a communication link, one of which benefiting from favourable visibility conditions. Such a baseline is integrated as an additional range measurement.





- Theoretical studies showed that the improvement of precision and accuracy of the position depends on the quality and synchronization of the GNSS measurements, the latency of the channel, but also on the relative position of the cooperating receivers. This opens the door to optimized designs (orbits, communications, GNSS receiver, smart integration, etc.) for new communication and navigation Space systems exploiting this concept.
- In the context of a next generation of Space initiatives, the innovative concept proposed here could be of interest to different ESA programmes planned for this decade.



Addressed research questions/problems

- Could the concept of GNSS-CP be applied to Space and, in particular, to lunar missions despite the considerable challenges related to the very low signal to noise ratio and the very poor geometry of the Earth GNSS constellation from a lunar user point-of-view, with all satellites appearing to come from the same point, resulting in a very high value of the DOP? How could GNSS-CP help overcome these limitations?
- The lunar scenario being different with respect to the terrestrial scenario also in terms of inter-users distance magnitude, how much does the algorithm previously defined for terrestrial receivers have to be revisited to compensate for these differences? Do the assumptions taken for the Earth scenario still hold for the lunar scenario? If not, to which extent?
- How could the proposed concept fit in the ESA Moonlight initiative and support each of the three phases of the Lunar Communication and Navigation System?

Submitted and published works

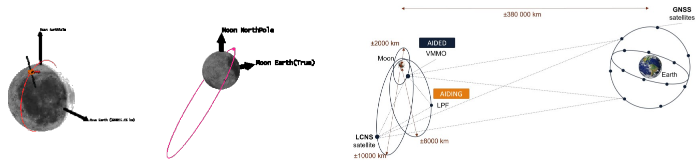
- Delépaut, A., Minetto, A., and Dovis, "*The potential of the Cooperative Positioning paradigm to improve GNSS-based positioning in Space*", Navitec 2022, ESA, Noordwijk, the Netherlands
- Delépaut, A., Minetto, A., and Dovis, et al., "*Enhanced GNSS-based Positioning in Space exploiting Inter-Spacecraft Cooperation*", International Technical Meeting of The Institute of Navigation (ION ITM 2022), Long Beach, California
- Delépaut, A., Minetto, A., and Dovis, et al., "Cooperative GNSS Positioning in Space: Modeling and Application to Space Missions", IEEE AeroSpace Conference, Montana, USA - *Abstract Submitted and Accepted*

Awards

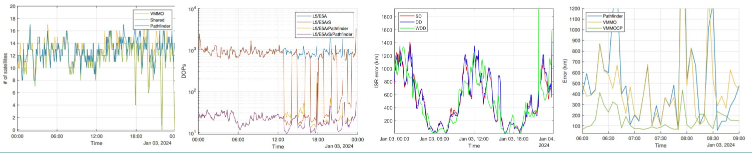
- Navitec 2022 Conference - Best Student Presentation Award (Technical soundness, Novelty, Presentation skills)
- ESA/JRC International Summerschool on GNSS 2022 - Project Competition - Rank No. 2

Novel contributions

- For the first time, the use of GNSS-CP was assessed for Space applications. In particular, realistic data were generated using Systems Tool Kit (STK) for two planned missions, that are the VMMO cubesat mission as well as the lunar Pathfinder mission.

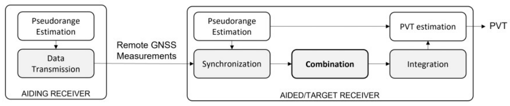


- The Inter-Agent Range (IAR) was estimated using single, double and weighted double differences of the raw pseudorange measurements made at both receivers. This distance was then tightly integrated through a least squares estimator with the pseudorange measurements to improve the positioning accuracy of each user independently. This allowed to prove the potential of GNSS-CP to improve GNSS positioning performances in Space under specific configurations.



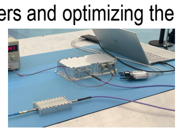
Adopted methodology

- After an exhaustive review of the literature to isolate the most adapted techniques for Space for each block shown on the below block diagram, the STK simulator is used to generate raw measurements, which are then post-processed in Matlab, with the LunavSim software built at ESA, to estimate the quality of the GNSS-CP algorithms and subsequently adapt them to the Space scenario. Once this is completed, the algorithm is cross-validated using the raw measurements made by a real high-sentivity receiver, the NaviMoon receiver in the ESA navigation laboratory. Finally, a dedicated GNSS-CP receiver will be designed.



Future work

- The future steps will consist in proceeding with the concept definition of GNSS-CP for the Space scenario. This includes the definition of an IAR estimation technique bypassing the linearisation challenge met when using the terrestrial GNSS-CP algorithm, the technique for synchronizing the measurements made at the cooperating receivers and optimizing the integration strategy of the pseudorange measurements with the IAR.
- Using the Spirent simulator at ESA combined with the NaviMoon Rx to test the GNSS-CP algorithm based on realistic measurements.
- Designing a user receiver for GNSS-CP in Space.



List of attended classes

- 02PIKLX – Lingua italiana III livello (16/2/2022, 30.00)
- 01TUFRV – All you need to know about research data management and open access publishing (12/4/2022, 15)
- 01RISRV – Public speaking (25/5/2022, 6.67)
- 01UNYRV – Personal branding (31/8/2022, 1.33)
- 02LWHRV – Communication (20/9/2022, 6.67)
- 01TRARV – Big data processing and programming (31/3/2022, 26.67)
- 02SFURV – Programmazione scientifica avanzata in matlab (21/4/2022, 40.00)
- 01RGBRV – Optimization methods for engineering problems (7/6/2022, 50.00)
- 01QRPRV – Satellite Navigation signal exploitation for atmospheric and environmental monitoring (30/6/2022, 20.00)
- EXTERNAL - STUDY AND MONITORING OF THE IONOSPHERE FOR Space WEATHER (7/12/2021, 20.00)
- EXTERNAL - ESA/JRC International Summerschool on GNSS 2022 (18/7/2022, 50.00)

PhD program in
Electrical, Electronics and Communications Engineering