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XXXVII Cycle

Study and Design of GNSS-based Multisensor Integrated Navigation Units

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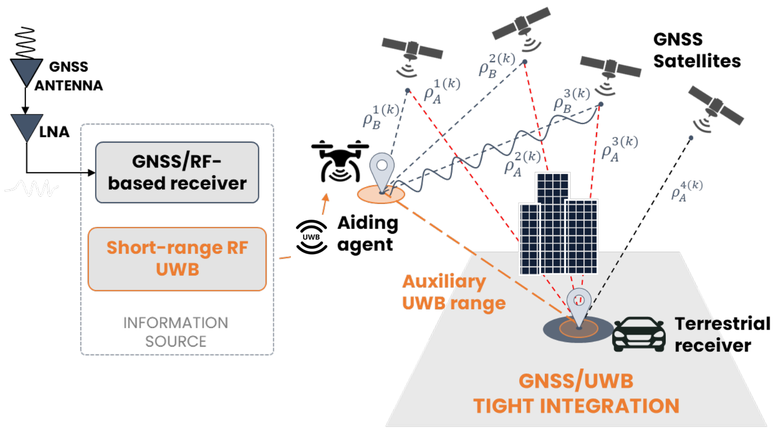
Research context and motivation

- Nowadays, hundreds of applications in the mass-market segment are pushing the demand for **continuous** and **dependable** Positioning, Navigation and Timing (**PNT**) services. However, standalone Global Navigation Satellite Systems (GNSSs) such as **GPS** and **Galileo** cannot satisfy these growing needs, especially in **challenging environments**.
- To overcome these limitations, consumer **GNSS chipsets** are routinely **integrated** with a plethora of **sensors**, both of proprioceptive and exteroceptive natures, and information fusion via well-established **Bayesian estimation** methods is the key enabler to combine additional ranging information from the surrounding environment within the navigation unit.
- Ultra-Wide Band (**UWB**) technology is of growing interest for **hybridisation** with GNSS signals. Over short distances, it has great potential in terms of multipath resilience and can achieve centimetre-level accurate ranging.



AGENT-AIDED POSITIONING

- Assisted PNT via aiding from mobile UWB pseudolite
- Dynamic ranging augmentation to GNSS
- Tight integration with GNSS observables

Novel contributions

ONLINE GNSS/UWB TIME-CALIBRATION

Introduce the time-offset as an additional hidden state in the tight integration filter state-space model.

Statistically infer the time-offset from the available observables jointly with the other navigation states.

COMPENSATION OF STATE-DYNAMICS

LOCAL IDENTIFIABILITY OF TIME-OFFSET

COMPENSATION OF STATE-DYNAMICS leverages a uniformely accelerated motion model to link $\boldsymbol{r}^U_{u,k}$ with $\boldsymbol{r}^G_{u,k}$ and estimate the position displacement:

$$\boldsymbol{\varepsilon}_{r,k} = \boldsymbol{r}^G_{u,k} - \boldsymbol{r}^U_{u,k} = \boldsymbol{v}_{u,k} t_{d,k} + 0.5 \boldsymbol{a}_{u,k} t^2_{d,k}$$

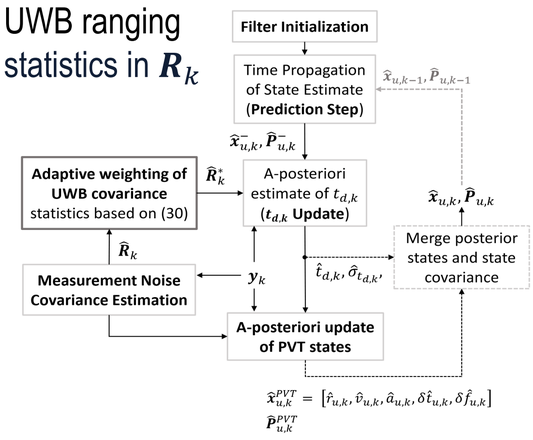
Embed $t_{d,k}$ in the naïve UWB ranging model:

$$\rho_{U,k} = \sqrt{(x_{U,k} - r^U_{x,k})^2 + (y_{U,k} - r^U_{y,k})^2 + (z_{U,k} - r^U_{z,k})^2}$$

$$\boldsymbol{r}^U_{u,k} = \boldsymbol{r}^G_{u,k} - \underbrace{(\boldsymbol{v}_{u,k} t_{d,k} + 0.5 \boldsymbol{a}_{u,k} t^2_{d,k})}_{\boldsymbol{\varepsilon}_{r,k}}$$ Compensated UWB ranging equation

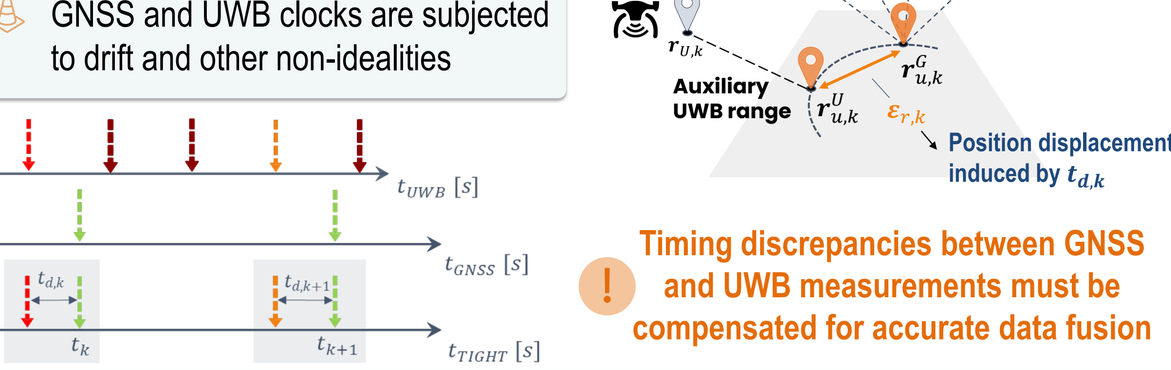
LEGACY EKF MODEL FOR ONLINE TIME-CALIBRATION

LOCAL IDENTIFIABILITY OF TIME-OFFSET is handled by adaptively weighting UWB ranging statistics in $\boldsymbol{R}_k$



DOUBLE-UPDATE EKF MODEL FOR ONLINE TIME-CALIBRATION

Addressed research questions/problems



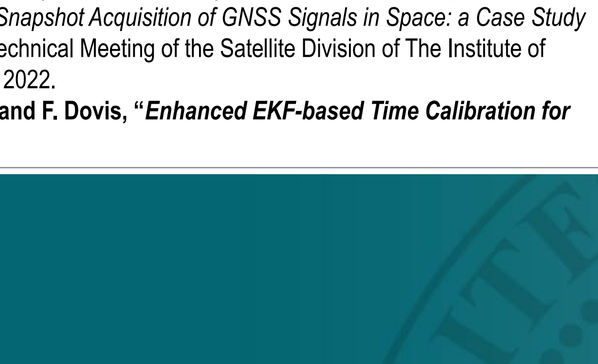
EKF-based GNSS/UWB tight integration filter seen through Discrete-Time Hidden Markov Model (HMM): **Time consistency of GNSS and UWB measurements is required**

GNSS and UWB chipsets have asynchronous clocks and measurements are tagged w.r.t. **different time scales**

- Consumer UWB modules cannot sample at a high-enough rate
- GNSS and UWB clocks are subjected to drift and other non-idealities

GNSS/UWB TIME-OFFSET

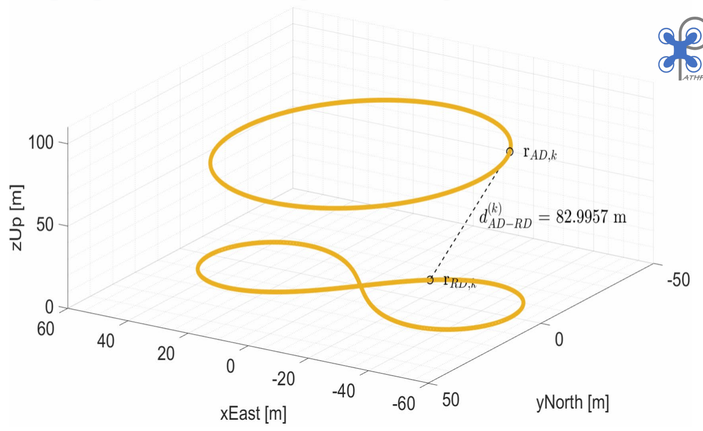
$$t_{d,k} = \delta t_{U,k} - \delta t_{G,k}$$

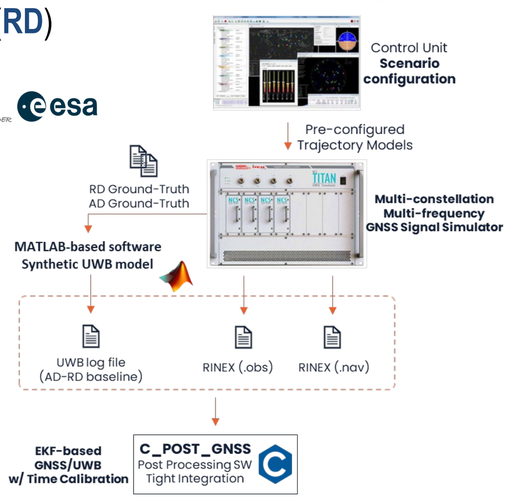


Timing discrepancies between GNSS and UWB measurements must be compensated for accurate data fusion

Adopted methodologies and Results

Simulating a PoC for a flying Aerial Drone (**AD**) as a **mobile UWB pseudolite** enabling relative **ranging** to **aid** the navigation of a ground Rover Drone (**RD**)



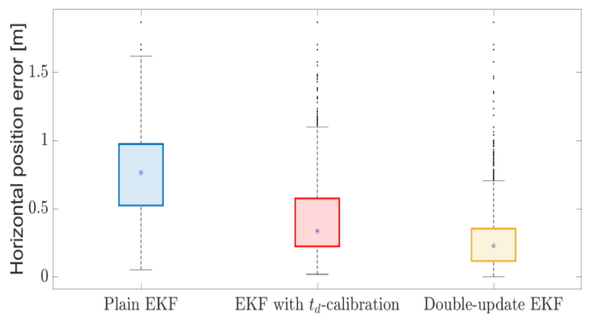


Uncalibrated GNSS/UWB tight integration via **Plain EKF** has **degraded** positioning accuracy performance under **high kinematics**

Horizontal RMSE

t_d [ms] \ Velocity [m/s]	1	2	5	10	15	20
100	0.2297	0.2821	0.2480	0.2896	0.4270	0.7517
80	0.2303	0.2825	0.2476	0.2750	0.3702	0.6405
40	0.2300	0.2817	0.2468	0.2551	0.2837	0.4564
20	0.2293	0.2816	0.2467	0.2500	0.2598	0.4084
8	0.2291	0.2815	0.2473	0.2476	0.2571	0.3981
0	0.2287	0.2810	0.2472	0.2418	0.2601	0.4028

Experimental results highlight **horizontal accuracy gains** up to 42% (95-th percentile) for the EKF-based online calibration models



FURTHER WORKS Optimization of satellite-anchors geometry to maximize the quantity of information in multi-agent scenario. Expansion of the integrated navigation unit to embed additional sensors (e.g., INS, Lidar etc.) and improve positioning performance.

Submitted and published works

- [1] O. Vouch, A. Minetto, G. Falco, and F. Dovis, "*Enhanced Bayesian State Space Estimation for a GNSS/INS Tightly-Coupled Integration in Harsh Environment: an Experimental Study*", in Proceedings of the 34th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2021), St. Louis, Missouri, September 2021.
- [2] **O. Vouch, A. Minetto, G. Falco, and F. Dovis, "*On the Adaptivity of Unscented Particle Filter for GNSS/INS Tightly-Integrated Navigation Unit in Urban Environment*", IEEE Access, Vol. 9, 2021, pp. 144157 – 144170.**
- [3] A. Minetto, F. Dovis, A. Nardin, O. Vouch, G. Impresario, and M. Musmeci, "*Analysis of GNSS data at the Moon for the LuGRE project*" in IEEE 9th International Workshop on Metrology for AeroSpace (MetroAeroSpace), 2022, pp. 134-139.
- [4] **O. Vouch, Y. Guo, S. Zocca, A. Minetto, and F. Dovis, "*Improved Outdoor Target Tracking via EKF-based GNSS/UWB Tight Integration with Online Time Synchronisation*", in Proceedings of the 35th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2022), Denver, Colorado, September 2022.**
- [5] A. Nardin, A. Minetto, O. Vouch, M. Mariani, and F. Dovis, "*Snapshot Acquisition of GNSS Signals in Space: a Case Study at Lunar Distances*", in Proceedings of the 35th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2022), Denver, Colorado, September 2022.
- [6] **Under revision: Y. Guo, O. Vouch, S. Zocca, A. Minetto, and F. Dovis, "*Enhanced EKF-based Time Calibration for GNSS/UWB Tight Integration", IEEE Sensors, 2022.***

List of attended classes

- 01QRPRV - Satellite Navigation signal exploitation for atmospheric and environmental monitoring (23/05/2022, 3 CFU)
- 01QTEIU - Data mining concepts and algorithms (03/02/2022, 4 CFU)
- 01RGBRV - Optimization methods for engineering problems (07/06/2022, 6 CFU)
- 01UJBRV - Adversarial training of neural networks (04/05/2022, 3 CFU)
- 02QUBRS - Statistical data processing (04/02/2022, 4 CFU)
- 02SFURV - Programmazione scientifica avanzata in Matlab (26/05/2022, 6 CFU)
- 01TUFRP - All you need to know about research data management and open access publishing (12/04/2022, 3 CFU)
- 02RHORP - The new Internet Society: entering the black-box of digital innovations (10/01/2022, 1 CFU)
- 01UNXRP - Thinking out of the box (10/01/2022, 1 CFU)
- 01QORKG - Writing Scientific Papers in English (24/03/2022, 3 CFU)
- 08IXTRP - Project management (11/01/2022, 1 CFU)
- 01UNTRP - Managing conflict: negotiation and communication (03/02/2022, 1 CFU)
- TRAINING - ESA/JRC Summer School on GNSS 2022 – Krakow, Poland (18/07 – 29/07, 50 hrs)
- TRAINING - Study and Monitoring of the Ionosphere for Space Weather – Tucuman, FACET-UNT (02/06/2022, 25 hrs)

GNSS Summer School

ION GNSS+ 2022 September 19-23 Denver, Colorado ion.org/gnss I'M PRESENTING

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