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

XXXVI Cycle

GNSS/UWB integration algorithms development based on filtering techniques

Yihan Guo

Supervisor: Prof. Fabio Dovis

Research context and motivation

- Modern industry, smart cities, and precision agriculture more and more rely on autonomous mobile robots including drones, autonomous land vehicles, goods-to-person picking robots, and so on. **Accurate and robust positioning systems** are the essential component of autonomous mobile robots;
- However, due to the complicated working environments of autonomous mobile robots, one single sensor is difficult to guarantee all the positioning requirements under different conditions. Therefore, **sensor fusion** becomes a potential solution that compensates for the flaws of every single sensor to provide more accurate and robust positioning services;
- The **Global Navigation Satellite System** (GNSS) is essential to autonomous mobile robots due to its worldwide positioning capability. But GNSS signals always suffer from multi-path, non-line-of-sight, and even being blocked because of the mask of buildings and trees. Therefore, integrating GNSS with other sensors is necessary;
- Benefiting from narrow pulse and wide frequency band features, **Ultra-Wide Band** (UWB) has centimeter-level accuracy ranging and strong penetration capabilities. Therefore, UWB is an ideal candidate to integrate with GNSS.

Applications

autonomous land vehicles — drones — goods-to-person picking robots

Positioning components

GNSS SDR — UWB

Addressed research questions/problems

- When implementing the integration navigation, the measurements from GNSS and UWB are fused together to obtain one positioning result. Therefore, **the design of the integration framework** should be considered carefully to make a trade-off between positioning accuracy and computational load;
- Due to different internal clocks and data transmission delays of GNSS and UWB, the **misalignment** (which is named as **time-offset**) between the GNSS and UWB measurements exists and may jeopardize the positioning performance. Therefore, how to evaluate the impact of time-offset and how to mitigate this impact become valuable topics.

Novel contributions

- Formed the **basic integration schemes** for GNSS/UWB tight integration based on EKF and PF, respectively;
- An analysis is carried out to investigate the **error sources** when implementing the EKF as the sensor integration scheme, and indicators are given to reflect the degree of this error;
- For GNSS/UWB tight integration, the factors that may trigger errors in the EKF are analyzed and given;
- Simulated experiments are designed based on the factors triggering errors in EKF to **compare the positioning performances** between EKF and PF for GNSS/UWB tight integration, which provides a reference to decide whether to choose EKF or PF in different applications;
- Investigated the **error propagation** when time-offset exists. Point out in which scenarios, time calibration for GNSS/UWB integration is necessary to be implemented.
- Proposed **a time calibration method** by modeling time-offset as a variable in the state-space model.
- Proposed a **double-update scheme** to further improve the performance of time calibration considering the impact of UWB geometry.

Submitted and published works

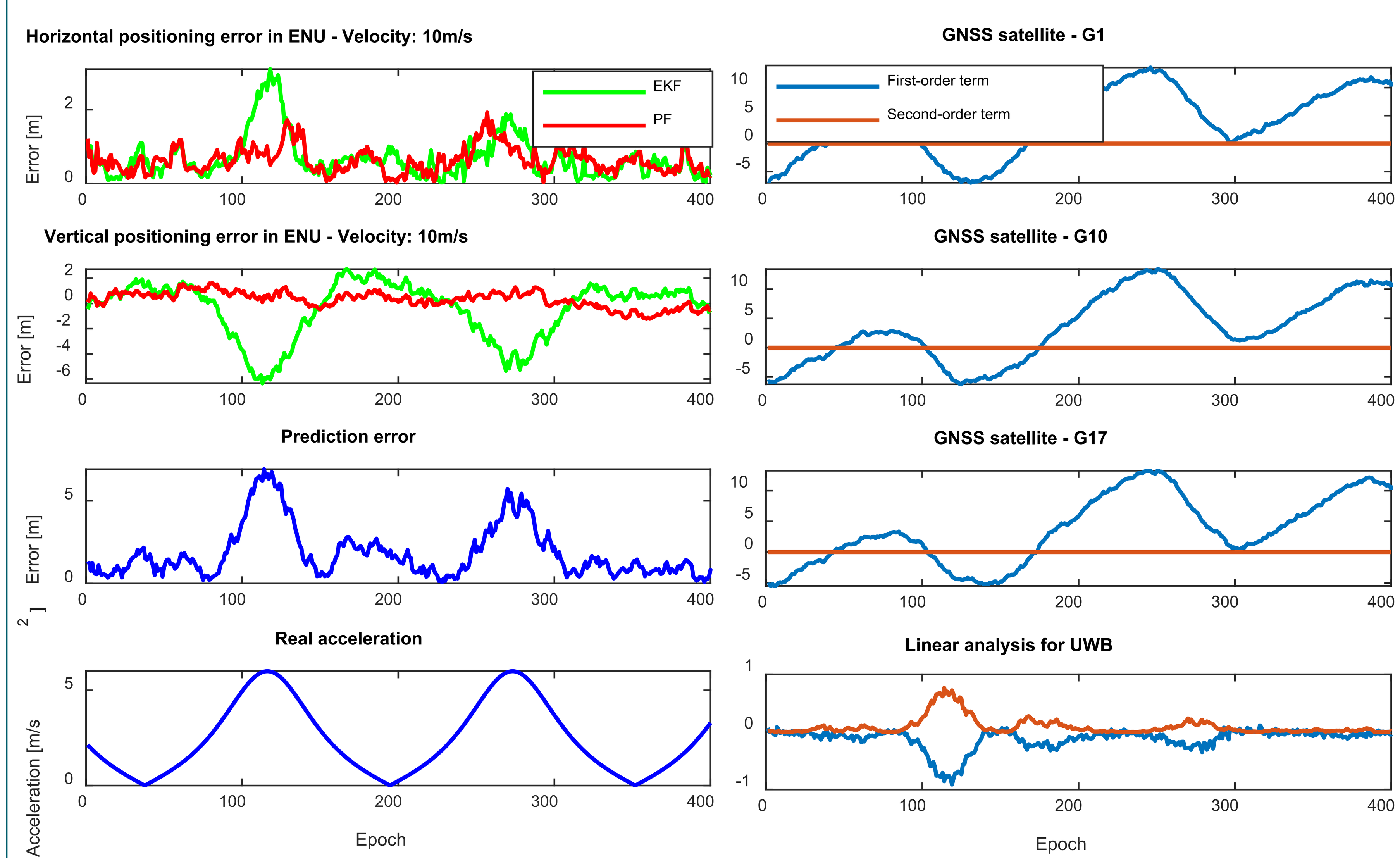
- Zocca, S., **Guo, Y.**, Minetto, A., & Dovis, F., "*Improved weighting in particle filters applied to precise state estimation in GNSS*", GNSS. Frontiers in Robotics and AI. 2022 Aug 11;9:950427.
- Vouch, O., **Guo, Y.**, Zocca, S., Minetto, A., & Dovis, F., "*Improved Outdoor Target Tracking via EKF-based GNSS/UWB Tight Integration with Online Time Synchronisation*", ION GNSS+ 2022, Denver, CO, 2022
- **Guo, Y.**, Vouch, O., Zocca, S., Minetto, A., & Dovis, F., "*Enhanced EKF-based Time Calibration for GNSS/UWB Tight Integration*", IEEE Sensors Journal (**submitted**)

Adopted methodologies

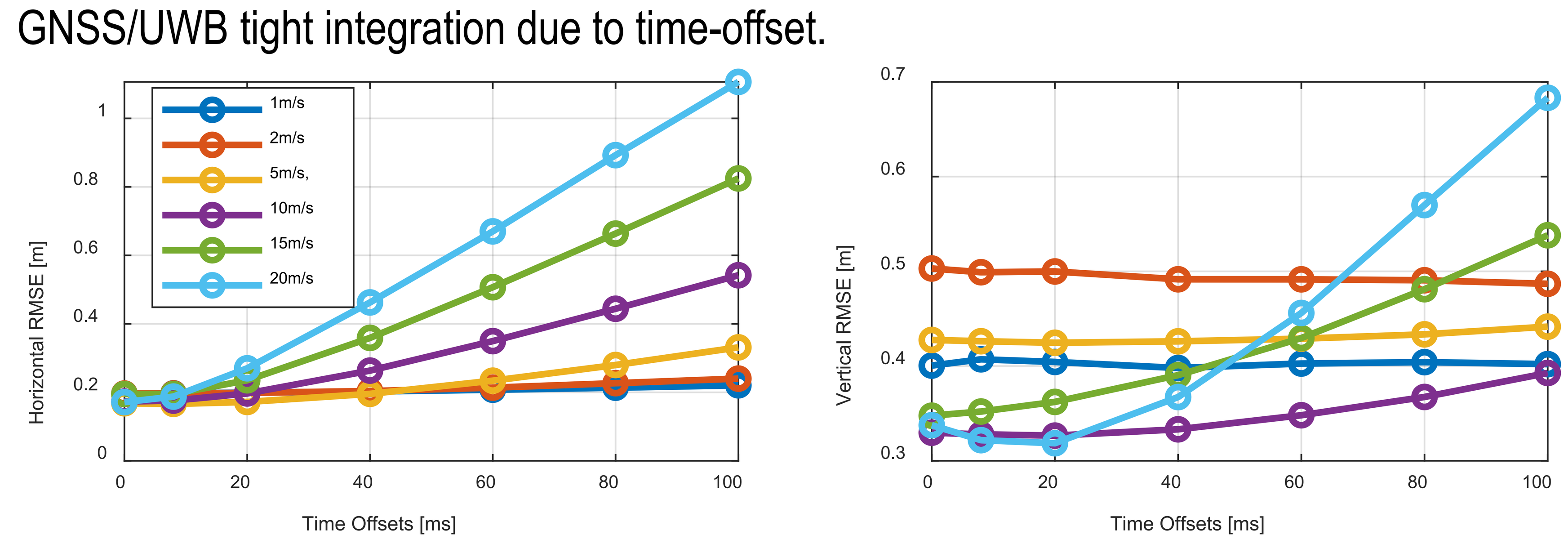
- According to the Taylor expansion, the **linearization error** in the EKF scheme for GNSS/UWB tight integration is analyzed. Consequently, the factors triggering the linearization in the GNSS/UWB state-space model are analyzed and given.

$$y_k = h(\hat{x}_k^-) + J_k(x_k - \hat{x}_k^-) + \frac{1}{2}(x_k - \hat{x}_k^-)^T H_k (x_k - \hat{x}_k^-) + O(x_k - \hat{x}_k^-) + v_k$$

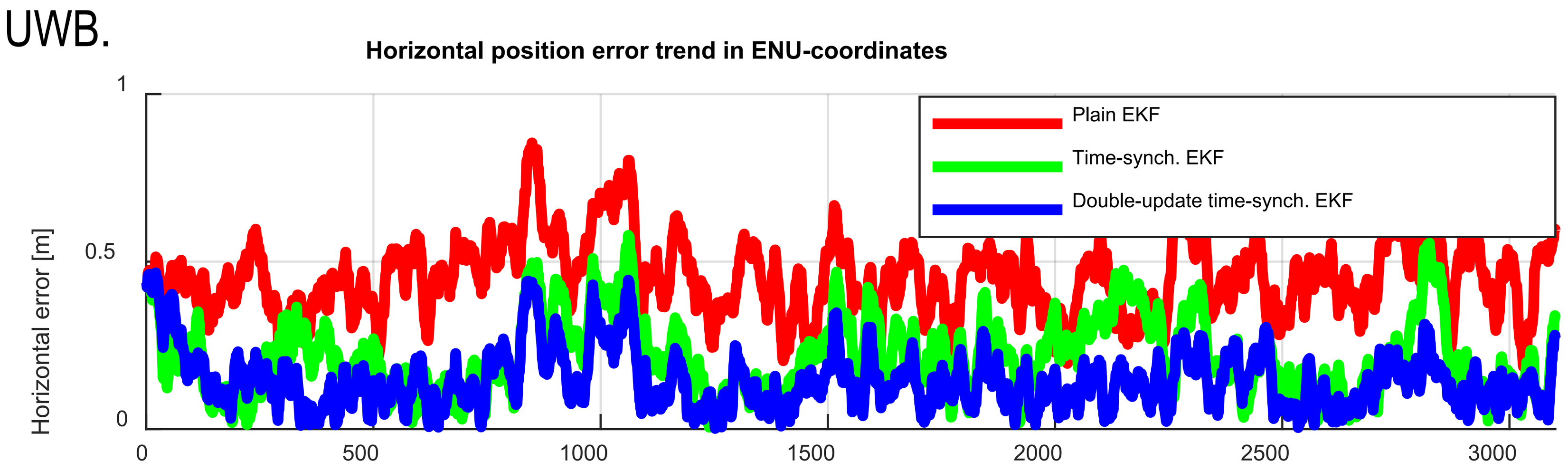
1. **Prediction error**:
   - Dynamic status
   - Sampling interval
2. **Hessian matrix**
   - GNSS pseudorange function
   - UWB ranging function



- From the theoretical aspect, we inferred the **error propagation** in the EKF scheme of the GNSS/UWB tight integration due to time-offset.



- Develop **a time calibration method** to mitigate the impact of time-offset on positioning performance deterioration in GNSS/UWB tight integration. proposed a new **double-update approach** to further enhance the time calibration performance considering the geometry of UWB.



Future work

- Develop advanced integration algorithms for GNSS/UWB integration. **batch processed methods** could be a possible candidate such as the factor graph.
- Include some **other sensors** (Inertial Navigation System, Lidar, camera, etc.) could be into the integration scheme to further improve the positioning performance.
- Develop **data pre-processing** methods to detect and eliminate gross errors for integrated navigation systems.

List of attended classes

- 01QTEIU – Data mining concepts and algorithms (3/2/2022, 33.33)
- External training activity – Study and Monitoring of the Ionosphere for Space Weather(7/12/2021, 26.6)

Politecnico di Torino
1859

PhD program in
Electrical, Electronics and Communications Engineering