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Transport Research Arena (TRA) Conference

# Contributions to the development of safe and accurate localisation solutions: The LOCSP project

Juliette Marais<sup>a</sup>, Syed Ali Kazim<sup>a</sup>, Zaynab El Mawas<sup>b</sup>, Maan El Badaoui El Najjar<sup>b</sup>,  
Jeremy Skelton<sup>c</sup>

<sup>a</sup> COSYS-LEOST, Univ Gustave Eiffel, IFSTTAR, Univ Lille, F-59650 Villeneuve d'Ascq, France

<sup>b</sup> CRIStAL, Univ Lille, F-59650 Villeneuve d'Ascq, France

<sup>c</sup> M3Systems, B-1300 Wavre, Belgium, Belgium

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## Abstract

GNSS are now in everybody's pocket, embedded in our smartphones and is widely used for informative uses (navigation, leisure...). In future transportation modes, and in particular autonomous vehicles or for safety related railways applications, localisation needs to be accurate and/or safe and trustful. In many of the environments crossed by users, satellite signal propagation is disturbed by buildings, trees or other obstacles that degrade performance. To contribute to the development of safe and accurate localisation solutions in these environments, the LOCSP project intends to evaluate and compare past algorithms on a new shared database but also focuses on the development of two research proposals: through cooperative vehicle localisation using artificial intelligence and with interference mitigation. This paper aims to introduce the project and the first results on these two axes.

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## 1. Introduction

Revolution of the transportation systems, evolving toward autonomous cars or trains in a world where digitalization will be everywhere, implies the development of a panel of embedded technologies among which localisation and communication are key elements. In this framework, the LOCSP project focuses on the localisation function and in particular for accurate and safe positions. Indeed, the new positioning solutions shall provide on one hand the minimum accuracy required by the application (road level, track identification, position of the vehicle on a track...) and, on the other hand, ensure the user that the position can be trusted through the development of integrity monitoring solutions.

However, if satellite-based localisation solutions (GNSS – Global Navigation Satellite Systems) are largely deployed in every day's life, it is well-known and investigated that their performance suffer from propagation

disturbances in most of the land transport environments and in particular in urban areas, where buildings mask or reflect signals before their reception. The detection and mitigation of multipath and Non-Line of Sight signals (signals received only after reflection) are largely studied solutions as done by Groves (2013) or Hsu (2018). Based on observables, thanks to external sensors (cameras or Lidar), or more recently with Machine Learning algorithms, the panel of solutions tested is quite large. In order to enhance accuracy but also availability in land transport environments, some numerous solutions, as reviewed by Yeong (2021), also focus on multi-sensor hybridization in order to benefit from the advantages of heterogeneous sensors and mitigate their drawbacks for a better accuracy and reliability. Hybridization can also benefit from cooperation of several vehicles of a fleet. Indeed, in multi-vehicle system, collaborative localization (CL) can be applied by fusing between the proprioceptive (odometer, inertial centre, Gyroscope...) and exteroceptive (GNSS, vision, LASER range finder...) sensors and others information sources (2D/3D cartographical information system) in order to optimize the position estimation. One of the existing techniques consists in the fact that each vehicle detects the others and calculates relative observations leading to an improvement in the localization integrity of the overall system and in autonomous navigation safety in different situation like intersection and overtaking specially in urban and peri-urban areas. Last, let's mention the increase of interference phenomena, named jamming, that need to be considered if the system developed has to be robust in any environment.

The LOCSP is funded in order to contribute to these developments of safe and accurate localisation solutions in these harsh land transport environments. This paper will present the main results of the LOCSP project that is at its middle term. Two main topics are addressed in particular in this paper: fault tolerant data fusion and cooperative solutions, and interference detection and mitigation. After a brief presentation of the project and the methodology followed, main highlights of these two scientific topics will be presented before conclusion.

## 2. Methodology

The LOCSP project, started in 2020 and funded by the French National Research Agency (ANR) intends to contribute to the development of positioning algorithms capable of computing a position in nominal conditions of reception as well as in the presence of faults. The faults targeted will be system failures, multipath and interferences. The capacity of the system to detect and mitigate these faults is investigated through different research directions and evaluated based on a realistic database under construction extracted from measurements and simulations. The project is a 4 years project, started in 2020. The project aims to answer the two following high-level challenges: 1/ propose new research solutions for a fail-safe positioning and 2/ allow everyone to benefit from a complete and detailed database for evaluation of the different solutions.

Therefore, different tasks are progressing in parallel. The project will contribute on three main directions. The two scientific directions are introduced in the paper:

- First, on fault tolerant data fusion and cooperative solutions. It consists in developing a framework for Fault Detection and Exclusion (FDE) as done by Makkawi (2021) for a Collaborative Localisation (CL) of a multi-vehicle fleet, equipped with multi-sensors solutions. First results will show the distributed architecture selected, and introduce a hybrid diagnostic methodology based on both models and data by Harbaoui (2021). An overview of the progress on a digital twin development for dataset generation will be proposed.
- Second, LOCSP investigates the different techniques for interference detection and mitigation, evaluates and compares their respective performance. In particular, we will investigate the capacity of these different techniques to face RFI and in particular, the one from RAIM algorithms (Receiver Autonomous Integrity Monitoring) as well as the behaviour of fusion algorithms in a PhD work. An illustration of advantages and drawbacks of first pre-correlation signal processing techniques (Notch Filters and Continuous Wavelet Transform) to detect and remove interference signals will be proposed.

The third work axis aims to provide a reference database, composed as a representative set of crossed environments (rural, urban, forests) and feared events (multipath, reflected paths, interferences...). It intends to answer the need to evaluate and compare our algorithms but also allow the community to do so, on a shared database. Most of the data will be collected along experimental campaigns, but will also be complemented with simulated data thanks to the STELLA NGC tool suite. First datasets will be presented during the TRA presentation. This database will be the basis

for evaluation of the scientific contributions proposed but also shall allow everyone (scientific and industrial communities) to compare performance of positioning solutions on a common frame.

### 3. Cooperative vehicles localisation using artificial intelligence

#### 3.1. Fault detection in a collaborative scheme

The developed approach for fault detection, originally based on information theory as done by Al Hage, (2017) is stochastic and non-deterministic. Its main interest is the diagnosis of the vehicle localisation solution via the fault detection and exclusion (FDE) method but for a decentralised cooperative localisation. It is based on the fact that all sensors are prone to errors. They can be represented as gaussian distributions of sensor data whose means are the output of the sensor at the acquisition time and whose variance is obtained by the specification of the technology used in the sensor. Each observation data is fused with all the different non-faulty observations of the environment in order to produce a much more accurate and safe solution. In this work, the novelty of the approach is the use of AI algorithms to enhance the detection of errors by information theory.

This hybrid approach tends to compare the measure of dissimilarity between the distribution of observations, in order to identify the divergent solution and exclude it from the fusion step and declare its sensor as faulty for the ongoing iteration. It uses the diagnosis model generated by learning the different patterns of fault from scenarios provided by the DT and the model-based approach applied through the data acquisition and filtering for the on-going trajectory. In doing so, the safety and the tolerance to faults are increased in the system. That makes the system more available even in faulty cases, giving the most accurate solution it can provide regardless of the case that the vehicle is in. The proposed approach for each vehicle of the system is presented in Fig. 1. It starts by the data reception at each iteration, followed by the filtering and fusion of data, and ends by the diagnosis of the obtained solution in order to exclude faulty sensors and provide the final accurate and safe localisation solution.

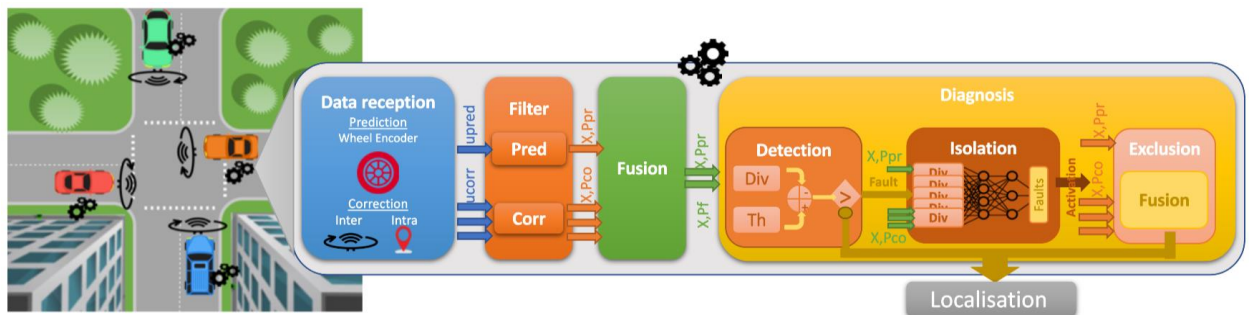


Fig. 1. The Fault detection and exclusion (FDE) applied for one vehicle.

#### 3.2. A Digital Twin for supporting datasets

The development of a multi-autonomous cooperative connected (MACC) vehicle's localisation solution requires the adequate dataset composed of data for several vehicles and sensors simultaneously. Moreover, in order to be exhaustive, many trajectory and fault scenarios should be considered. This is done by the deployment of a Digital Twin (DT) system, which constitutes the main data provider and testing environment for the Artificial Intelligence (AI) method. The DT is composed of two parts: a hardware in the loop component with a GNSS signal simulator coupled with a simulated environment. The DT provides the data entry of the GNSS signal simulator. They consist in GNSS data (KML, Rinex files, pseudoranges ...).

The main benefits of using a DT are the capacity to inject real localisation data provided by a real GNSS receiver in a virtual simulated environment, that also contains additional sensors such as wheel encoders, Lidar, IMU. As a result, the AI generated models from simulated scenarios become more accurate as they are processed back to the virtual environment. Moreover, by comparing the result of the two solutions, simulated and real environment, the difference between the real world and the virtual environment data is minimised, leading to a more realistic result.

This tool also allows the generation of multiple scenarios having sensor failures with fault injection on real and simulated sensor measurements without creating dangerous test situations and without damaging the real prototype vehicles. These scenario trajectories can be created in a continuous way in a very short time for the generation of measurements databases for a significant number of kilometres that is hard to do in a real environment. The DT developed in the CRISAL Lab is presented in Fig. 2, where the GNSS simulator Stella NGC of M3Systems is coupled with the environment simulator CARLA, and the data acquisition is done via ROS (Robot Operating System) platform.

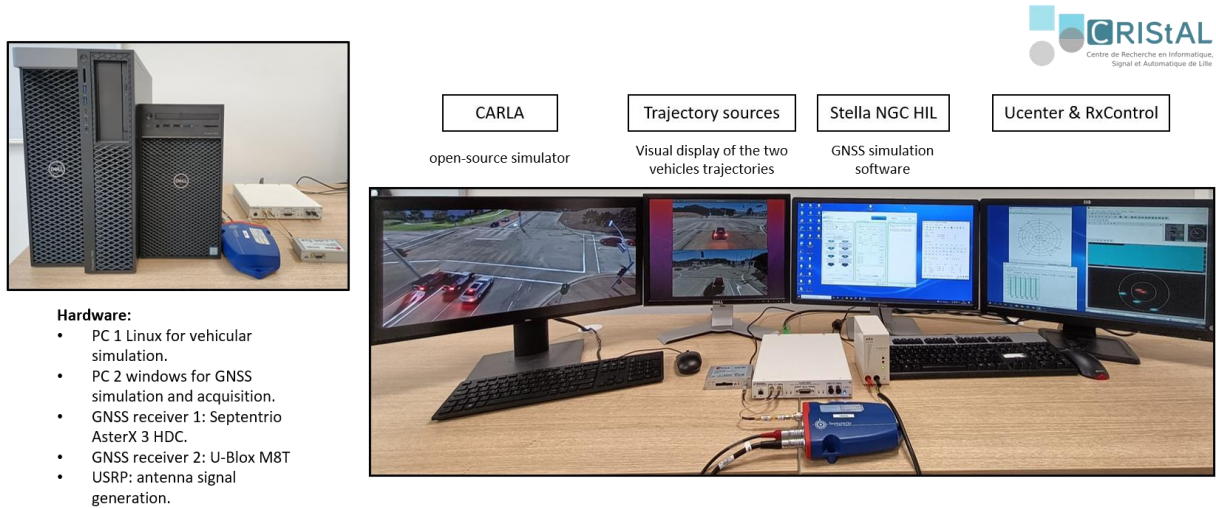


Fig. 2.. Digital Twin for sensors measurements replaying and database generation for learning

The generated scenarios constitute training and test cases for the development of a deep learning algorithm specifically deployed for the detection of simultaneous errors given the pattern of fault in the system. The model generated by the DT is then validated on the real vehicle platform (Renault ZOE robotized car), whose sensor data and configuration is compatible with its DT in the simulated environment. It is also compatible with the GNSS simulator data entry in order to inject faults and compare the solution obtained by the simulator and the behaviour of the developed algorithm in real case scenarios. The equipped sensors and the hardware implementation over the CRISAL Lab experimental vehicle are presented in Fig. 3.

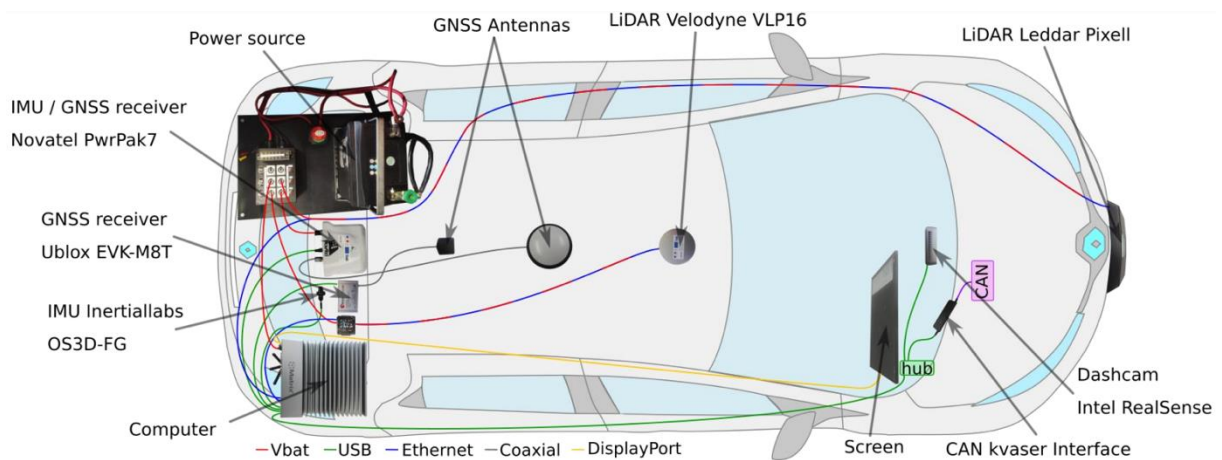


Fig. 3. The Renault ZOE robotized car with the onboard sensors.

### 3.3. First results

The results of this method for a team of three MACC is presented in Fig. 4. In this example, the three vehicles are tb3 robots equipped with indoor localisation sensor Marvelmind providing (x,y) coordinates, IMU providing orientation, encoders for evolution model and Lidar for inter-measurement providing interdistance and bearing angle. The results show that the localisation solution is improved by excluding the detected faulty sensors using the presented method, whereas for robot1, the localisation error decreased in x-axis by 97,6116% and y-axis by 99,0558% after isolation. More numeric comparison is provided in Table I. with the Root Mean Square Deviation (RMSD) before and after isolation.

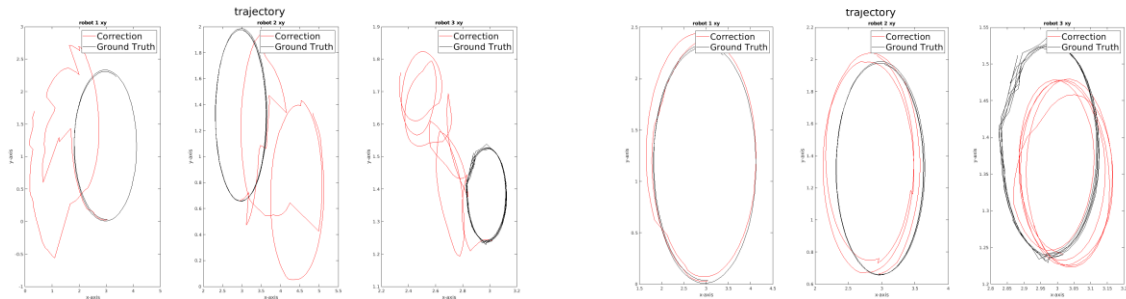


Fig. 4. Trajectory before and after exclusion of faulty sensors.

Table I. Root Mean Square Deviation (RMSD) (in meters and radiant)

	<i>before isolation</i>		<i>after isolation</i>	
<i>Robot<sub>1</sub></i>	x	0.8290	x	0.0198
	y	0.7520	y	0.0071
	$\theta$	3.7844	$\theta$	0.6680
<i>Robot<sub>2</sub></i>	x	0.5648	x	0.0056
	y	0.1110	y	0.0223
	$\theta$	2.6594	$\theta$	0.4664
<i>Robot<sub>3</sub></i>	x	0.1316	x	0.0043
	y	0.0728	y	0.0046
	$\theta$	6.3933	$\theta$	1.2030

## 4. Interference detection and mitigation

### 4.1 Introduction

Radiofrequency interference (RFI) threat has increased significantly in the recent past. It continues to rise due to pervasive use of the radio spectrum as well as due to illegal transmission from the personal privacy devices (PPD's) commonly known as jammers. Such interference sources can endanger any radio systems that rely on low powered signals. Similarly, in Global Navigation Satellite System (GNSS) where satellite signals travel very large distances prior to their arrival at the receiver placed on the ground. These signals are very weak as they are some dB below the noise floor level. It makes them susceptible to such interferences. A subtle amount of interference can induce severe disturbances and if interference power exceeds beyond a certain level it can even block receivers from acquiring signals. This vulnerability of GNSS poses great implications particularly on the safety-critical applications.

There are a significant number of interference incidents reported in the past decade around the world. The main contributor behind these incidents includes spill over signals from the radio systems operating close or within the GNSS band and illegal transmissions to deliberately disturb or detract the receiver. These large numbers of reported incidence confirm RFI as an existing threat to GNSS services. Therefore, it still demands robust solutions to counter interference to meet performance requirements.

The LOCSP contribution on this topic will be a step towards the development of an interference management suite with improved strategies to ensure the resilience of the overall system. It will require robust countermeasures that will incorporate strategies for the detection, characterization, mitigation, and in some cases localization of RFI signals.

## 4.2 Context

In literature, there exist several methodologies to detect and mitigate various types of interference signals (pulsed, continuous wave and chirp signal). Figure 2 shows interference suppression applied at different stages of the receiver chain. They are mainly grouped as the front-end, pre-correlation, post-correlation, and navigation level techniques. This study deals with the interference mitigation at the pre-correlation level prior to satellite signal despreading process. This early stage mitigation could be beneficial especially dealing with strong interferences since techniques in the later stages require normal acquisition and (or) tracking which cannot be guaranteed under such conditions.

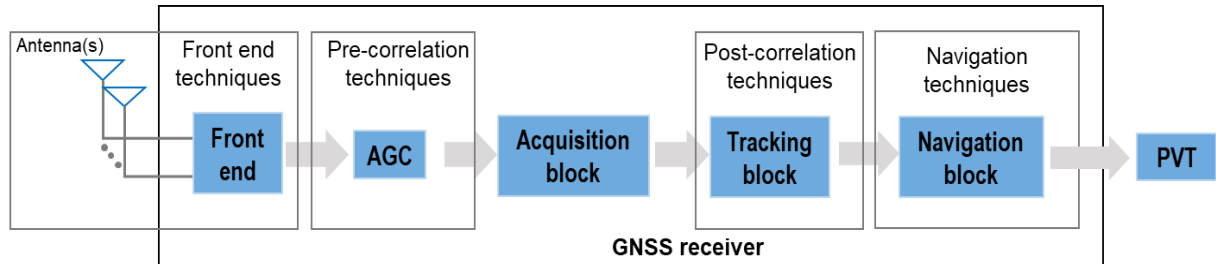


Fig. 2. Block diagram of a typical SatNav receiver inspired by Morales-Ferre (2020). The different stages of the GNSS receiver are shown where interference effects could be suppressed.

The interference suppression techniques at the pre-correlation level have been well investigated in the literature. Pulse blanking (PB) is among the simplest time domain technique. Musumeci (2016) applied pulse blanking method to suppress interference coming from DME/TACAN system. Borio (2016) used PB method to mitigate wideband interference signal. Qin (2020), Gamba (2019) and Borio (2014) studied different Adaptive Notch Filter (ANF) designs, filter parameters affecting mitigation performance while dealing with time-varying frequency of the interference signal also known as chirp interference. Borio (2008) investigated Wigner-Ville Distribution (WVD) to estimate the instantaneous frequency of the interference then the interference content is suppressed with the help of the notch filter. Musumeci (2014 and 2016), Huang (2019), Seo (2019) presented wavelet decomposition method to counter chirp and DME/TACAN interference.

These studies suggest the importance of robust countermeasures to eliminate the effects of interference. It also highlights the fact that the performance of any mitigation technique is very much dependent on the characteristics of interference signal such as power, modulation, bandwidth and others as concluded by Musumeci (2014). All these factors make it very much difficult to have a signal mitigation technique to deal with any kind of interference.

## 4.3 First results

First investigations done in the context of the project concern the suppression of the unwanted signal before the acquisition of the satellites, i.e., at pre-correlation stage.

Two methods have been implemented and tested: the adaptive Notch Filter and the Wavelet decomposition. Adaptive Notch filter (ANF) comprises of an adaptive block that is responsible to track the frequency of the interference signal and derives the notch position of a notch filter (NF) to remove the unnecessary frequency content. Wavelet Packed Decomposition (WPD) is a transformation domain technique that maps a time signal into time-frequency domain. It performs transformation by doing correlation with several candidate functions derived from the mother wavelet by applying shift and scaling operations.

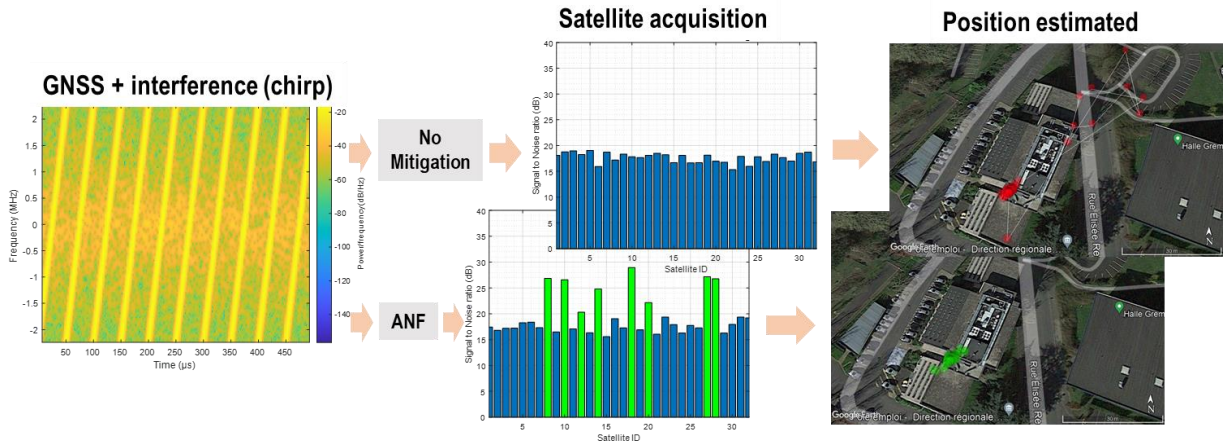


Fig. 3. Interference detection and mitigation. a/Spectrogram of the input signal (GNSS+ITF), b/Signal to noise ratio of satellites acquired c/Estimated position, no mitigation (upper panel) and after suppressing interference by Adaptive notch filter (bottom panel).

Despite most of the papers published evaluate the mitigation performance at the signal level, we consider that it is of particular interest to evaluate how the mitigation applied will affect the user KPIs, and in particular accuracy and integrity, that is a measure of trust the user can have in the position provided.

Kazim (2022) has presented KPI results of three scenarios; 1) without interference, 2) with interference but no mitigation applied and 3) interference with active mitigation technique and the performance indicators such as accuracy, availability and integrity are analysed. The results show, as expected, that interferences when they are not mitigated, can have a bad impact on the availability of the system. Additionally, they cause hazardous misleading information (HMI) which questions the integrity of the provided solution. But they also show that a good mitigation scheme allows from one side to is capable of increasing accuracy but also remove all the HMI which is of main importance for safety related applications.

Fig 3. show some of the initial results from the implemented adaptive notch filter. We can see interference has a noticeable impact on the carrier to noise ratio (CNO) of the satellites. Generally, a minimum of 18 dB is required to ensure successful tracking of the satellites. The impact on the position due to very low CNO is also visible that diverges for a static scenario while inducing a maximum positioning error of 80 meter. After applying the mitigation technique, the signal quality improves (successfully acquired satellites with higher CNO) so as the position accuracy (points are more concentrated around the true position).

## 5. Conclusion and future works

The TRA event will be the opportunity to show the intention and first results of the LOCSP project, being at that time in the middle of its length. A first open dataset will be presented composed of GNSS data, but also images, inertial sensors and a reference trajectory. A first set of results will be available on the two scientific topics (cooperative localisation and interference mitigation). Next steps of the project will consist of completing the dataset, and last year of the project will be used for the definition of KPIs for performance comparison between different types of solution, from the simplest and cheapest (GNSS only without any help) to more complex solutions such as hybrid and/or cooperative solutions.

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