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Multipath and NLOS detection based on the combination of CNO values and a fish-eye camera

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Abstract: For land transport environment and railways in particular, the main limits of GNSS signal exploitations for an accurate and safe positioning comes from the local environment surrounding the vehicle. Obstacles induce multipath and non-line of sight signal reception that need to be detected for railway line characterization or feared event mitigation. In this paper, we show that the use of two techniques based on CNO and camera respectively, can help detecting and labelling faulty events along a trajectory. The methods have been applied on a test run performed during the ERSAT GGC project in Spain. This paper presents first the techniques, then an analysis of the detections for evaluation.

1. Introduction

Despite all the GNSS receivers and constellations evolutions, NLOS (Non Line Of Sight) and multipath remain major limits of GNSS performance in most of the transport environments such as urban areas or railway trenches.

Multipath and NLOS have the same original causes, which are the surrounding obstacles that reflect or diffract satellite signals before signals reach the antenna. In transport environment, these obstacles are numerous: the vehicles itself and, in land transport, all the built and natural environment crossed by the vehicle. The difference between multipath and NLOS is the presence or not of an obstacle between the antenna and the satellite. With only the green LOS signal represented in figure 1, one talk about LOS optimal signal. As soon as echoes can also reach the antenna, multipath occur. And when only the reflected signal reaches the antenna as represented in red on the figure, the signal is considered as NLOS.

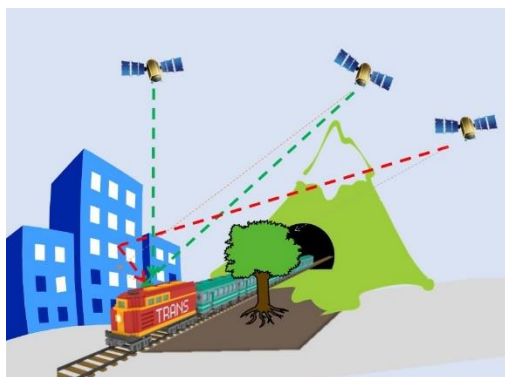


Figure 1. Multipath versus NLOS reception

At receiver level, it is sometimes difficult to distinguish between multipath and NLOS. Detection techniques relying on the detection of auto-correlation function distortion can detect multipath but not NLOS. However, their consequence on pseudorange estimation and the mitigation techniques differ [1]. NLOS will most of the time induce a larger delay in the pseudorange estimation.

The literature focused on multipath and NLOS has different objectives: a good understanding and modelling of these two effects first, the development of detection and identification techniques then, and its final goal, mitigation and/or correction. Furthermore, we will see a growing need to characterize and bound their effects for new applications such as autonomous vehicles, where integrity is one of the main challenges [25].

Indeed, one can show that a good detection or a proper estimation of the pseudo-range errors can increase accuracy of the estimated position.

Detection techniques allow the receiver to mitigate the effect of multipath and/or NLOS. [1] enters into the baseband signal processing in order to detect NLOS based on vector tracking loop. As a NLOS signal produces a delay in the pseudo-range measurement, they can also be detected and excluded as a faulty measurement by RAIM techniques as developed in [2]. NLOS detection based on the use of a fish-eye camera can result in NLOS satellite exclusion in position estimation. The results of [21] previously conclude that exclusion in a classical least square solution can increase accuracy but not always depending also on LOS satellite geometry. With a similar technique, [22] reduces horizontal error in a solution composed of a GNSS RTK receiver and a gyroscope.

One can also mention the shadow matching approaches that use LOS and NLOS classification in order to improve cross-track positioning accuracy in urban canyons. The principle relies on the comparison of visible satellite prediction with the measured satellite visibility to determine position [23].

The multipath or NLOS error estimation can rely on models extracted from collected data [11], rely on Bayesian framework [3] or on 3D models [12][13][14]. The development of realistic pseudo-range error is specifically addressed by some other studies relying in the use of a massive collection of data [4][5] or in specific environments [24] or exploring the potential of machine learning for signal classification [10]. Based on a set of parameters among which CN0, pseudorange residuals or satellite elevation, [6] proposed a gradient boosting decision tree based classification algorithm, [7] neuro-fuzzy inference or [8] convolutional neural networks.

The research presented in this paper addresses the need of detecting the multipath and NLOS signals as an objective expressed for the European ERSAT GGC project. In this project, GNSS is expected to be used for railway signalling applications. In order to limit the degradation that the local effect may cause on the system, a railway track characterization has been developed in order to determine where the probability of having local effects degrading the performances were the lowest. After characterization, the system must provide a map identifying the area where GNSS signals will be received with optimal conditions. The objective is here thus not to mitigate, but to detect as a prevention tool.

In the framework of the project, a special attention has been paid on multipath and NLOS detection techniques with a set of methods: CMC (Code Multipath Carrier), CN0 (Carrier-to-Noise Ratio), and image-based detection. CMC is the topic of a separate paper. In this paper, we will investigate the complementarity of CN0 and image-based techniques. Section 2 will briefly introduce the two techniques. Section 3 will analyse the detection performed along a railway line before conclusions and perspectives.

2. Detection techniques applied for multipath and NLOS detection

2.1. CN0 based detection

Carrier-to-noise density ratio (C/N0) indicates the signal strength of the different satellites tracked. Local propagation effects affect CN0. A multipath echo can be overlay with the LOS-

signal in a constructive or destructive manner depending on the phase of the reflected signal with respect to the direct signal. NLOS causes a fading due to the reflection attenuation coefficient as well as the longer path. Moreover, one shall notice that C/N0 depends on the satellite elevation.

CN0-based detection technique developed in this paper is inspired by [16] and [17] proposed to detect strong multipath. It requires dual frequency reception (L1 and L2).

CN0-based detection flag is the result of the detection of an abnormal situation observed at the CN0 level. The nominal situation is calibrated a priori depending on the satellite identity and its elevation as illustrated on figure 3. A threshold is fixed to detect when the value is out of this nominal zone, here below as, for each elevation the mean $\Delta CN0_{m_{el}} \pm 3\sigma$.

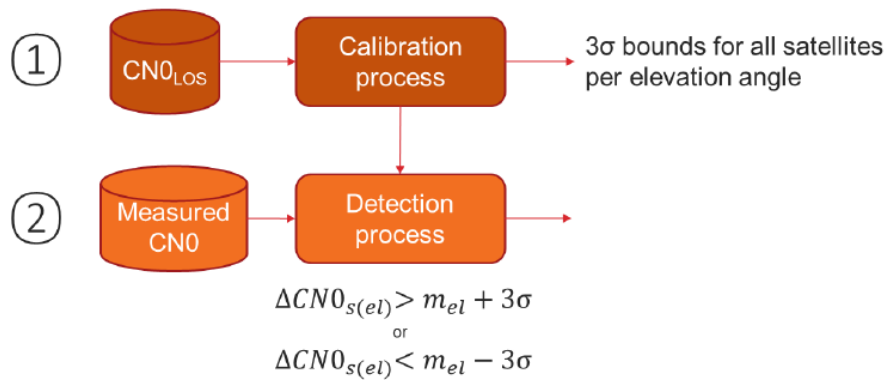


Figure 2. Two-step process for the multipath detection with CN0

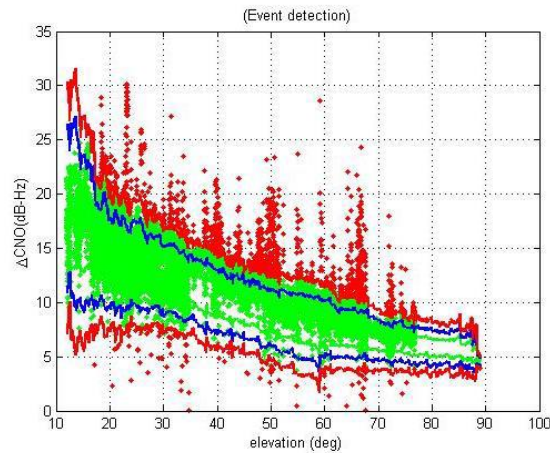


Figure 3. Elevation dependent Delta-CN0 modelling and 3-sigma bounds

The output of the CN0-based tool is a result file containing all satellite states of reception along time.

2.2. Image-based detection

The image-based detection techniques originally presented in [18] relies on the comparison of satellite positions with sky area classification. The image processing first presented in [21, 28] and improved afterwards allows classifying the regions of interest of the fish-eye image into sky and non-sky areas and the satellite position is compared to the corresponding area of the image. A satellite recognized as placed in a sky area is labelled as Line-Of-Sight (LOS), otherwise NLOS. This concept has been used for accuracy enhancement [20]. This paper uses the recently prototyped system for the ERSAT GGC project [19]. Figure 7 illustrates an

example of the image processing result. The output of the image-based tool is a result file containing all satellite states of reception along time.

2.3. Limits and complementarity

The CNO distributions between LOS and NLOS satellites are different but not fully separated. Indeed, a strong NLOS can be received with a high signal strength depending on the reflective surface. Empirical studies illustrate such distributions [26][9]. Similarly, the distinction between multipath and NLOS is not always reliable as different effects can have similar impacts. In order to differentiate between NLOS and Multipath, a GNSS LOS/NLOS signal classifier has been presented in [9] especially for shadow matching where this classification is the heart of the algorithm.

In this paper, our objective is to benefit from the two detection techniques proposed as complementary techniques in order to detect and classify the multipath and NLOS effects.

3. Application and analysis

3.1. Data used for this paper

Both CNO and image-based detection techniques have been applied along a railway line in Spain during experimental campaigns organized in the framework of ERSAT GGC project. The line links “Almorchón to Alhondiguilla” through 94 km. The campaign covers 10 days (20 to 24 and 27 to 31 of May 2019) running under different epoch conditions (day and night). The line mainly crosses open sky areas with some bridges and low elevated obstacles as illustrated in figure 4.

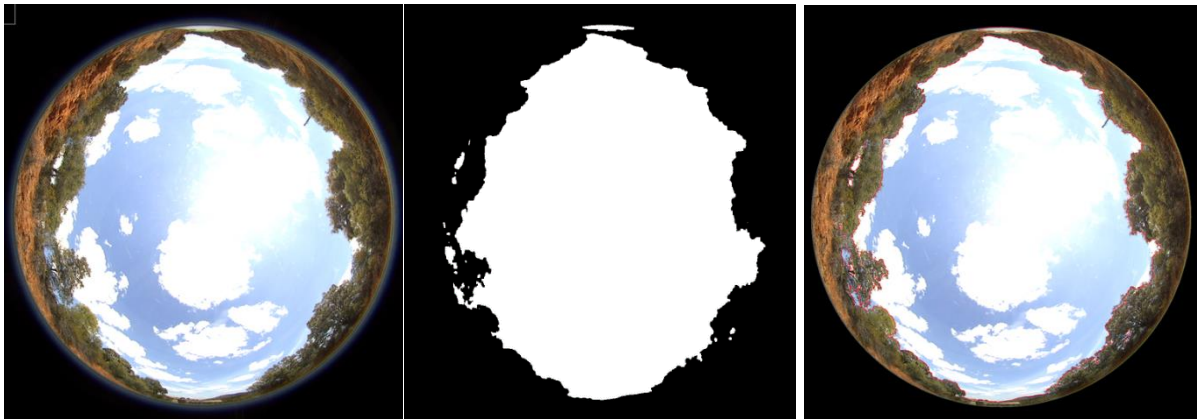


Figure 4. Fish-eye Image representing a typical area along the track, a/original image aquired, b/ classified regions (sky in white vs not-sky in black) , c/ original image with the detected horizon line in red.

Nine GPS satellites can be received along the run, among which two are considered with a too low elevation for being used in confidence (number 6 and 31 on figure 5).

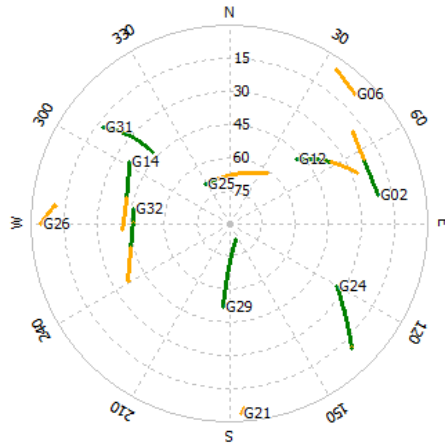


Figure 5. Skyplot of the satellites received during the campaign (green dual frequency, orange single).

Figure 6 plots the satellite visibility along the train run. Green lines represent the reception of L1 and L2 signals; orange the reception of L1 only. This information is important to understand the availability of the ΔCN0 method, which requires both.

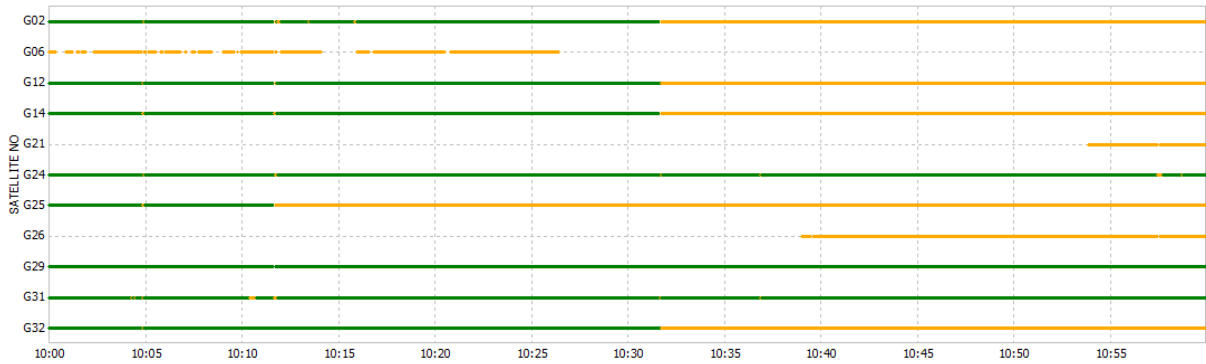


Figure 6. Skyplot of the satellites received during the campaign

3.2. Detection results

The objective of this section is to present first the detections along one run with both techniques in order to evaluate their redundancy and complementarity.

Satellites 6 and 31 are received with a low elevation angles and are not considered by the CN0 detection techniques.

Figure 7 plots the detected event for each of the considered satellites along time. A mark signify that an event has been detected: blue is a NLOS satellite according to the image and green signify that ΔCN0 was out of the thresholds. One can immediately see that the detections are not redundant and that NLOS is often detected without any detection on CN0.

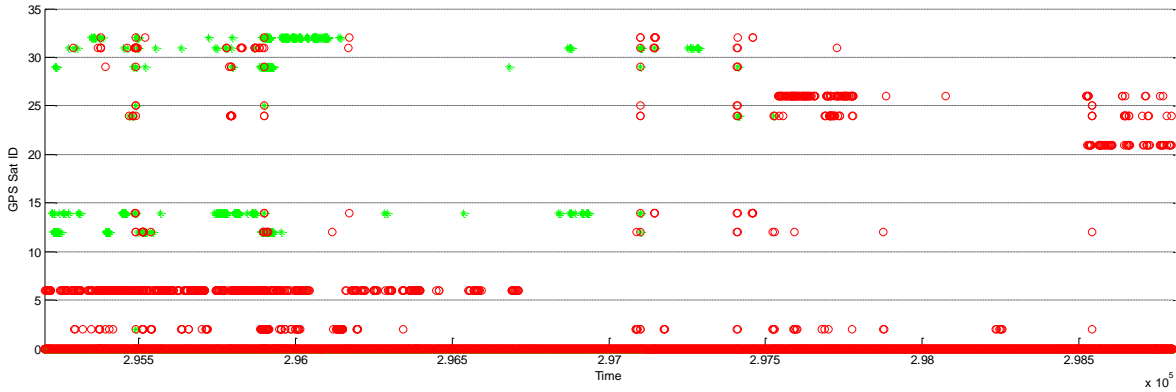


Figure 7. Image-based (red) and CNO-based (green) detections along the run for each satellite.

As illustrated on figure 8, main obstacles along this line are small trees along the track. Considering optical rays as done with the image-based detection, satellites hidden by trees are considered as NLOS. However, depending on the foliage density, it is highly probable that they only be slightly affect the signal. This consideration will be of major interest for the development of the tool enhancement where it is planned to distinguish between built obstacles and vegetation.

Due to the environment of the line, the probability of having real NLOS has reflected signal is low (2,3% epochs are concerned with NLOS along a 1h run). Except some very short ones when the train crosses the metal bridges of figure 8b.

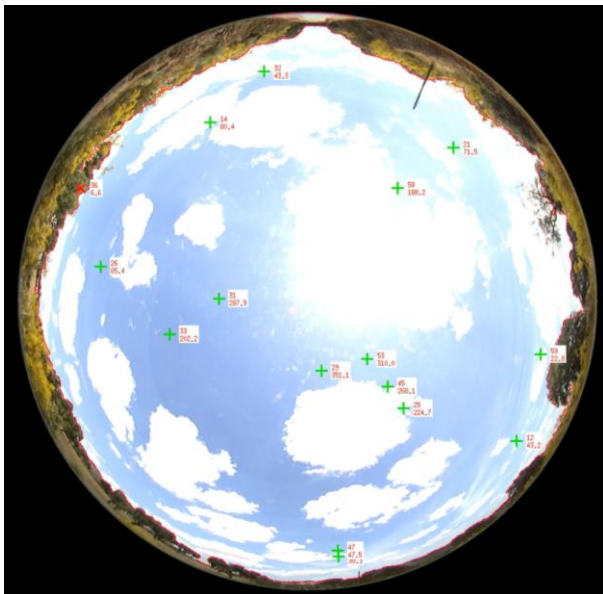


Figure 8a. Example or typical low elevated masking environment along the Spanish line.



Figure 8b. Metallic bridge with NLOS satellites

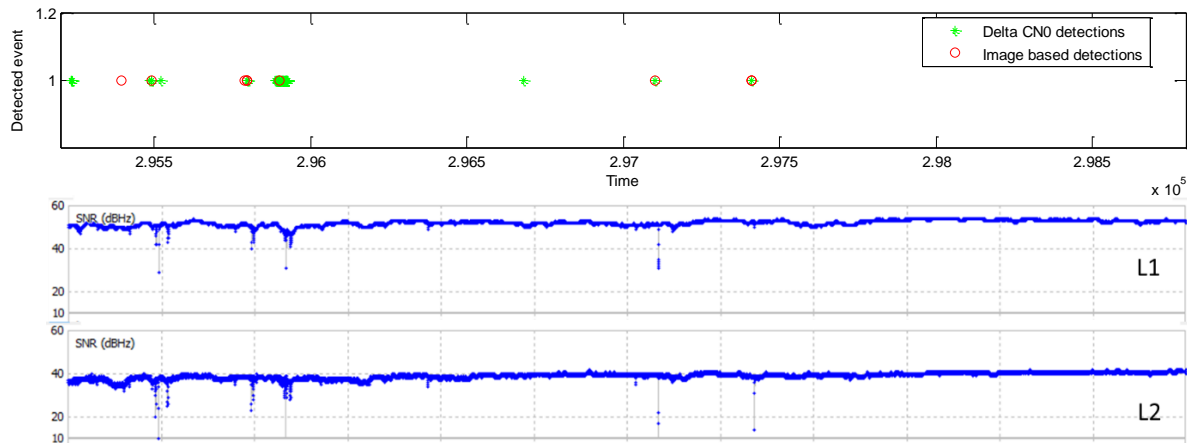


Figure 9. Focus on satellite 29 characteristics. On top: detections obtained with Δ CN0 and Image. Below L1 and L2 SNR variations vs time.

Satellite 29 has a high elevation angle ($>50^\circ$) and is rarely subject to multipath or NLOS events along the path. As represented in figure 9, a couple of SNR variations can be observed along time that conduct to detected events thanks to the Δ CN0 method. These events are often synchronized with a camera-based detection. This double check reinforces the confidence that a real event happens.

On the contrary, satellite 31 has a lower elevation angle (from 18 to 43°) and as shown on figure 10, its SNR is much more noisy. For such conditions, one can see that the CN0-based detections are more frequent than the image-based.

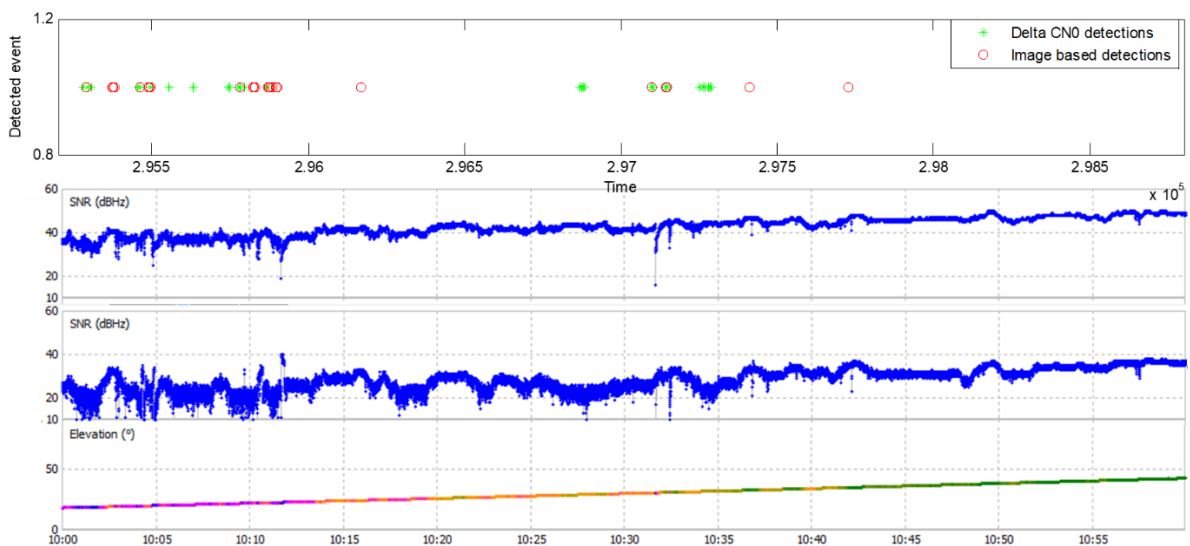


Figure 10. Focus on satellite 31 characteristics. On top: detections obtained with Δ CN0 and Image. Below L1 and L2 SNR variations vs time, and elevation variations.

4. Conclusions and perspectives

First results show that on such a line, the NLOS and CN0-based techniques offer very different detected events. Image-based NLOS detection indicates here the presence of optical obstacles

between the satellite and the receiver but not really the presence of reflecting obstacles. The detection relates more an attenuation than a masking effects for vegetation. It will be of prior interest to have this distinction in the future version of the image processing. The results will for sure be very different in urban areas where the type of obstacles is different.

Globally, the line is not subject to strong multipath. This is why the detection based on CN0 also shows some limits here.

In the toolset developed for ERSAT GGC, some more detection techniques have been proposed as presented in [27] in order to benefit from heterogeneous methods and limit the drawbacks of each of them. As no perfect solution exist to detect the local effects on GNSS signal, it will be of particular interest to refine, in the future, each of these techniques separately but also define how deep learning can help taking the best use of each of them in a decision logic.

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