MULTIPATH MITIGATION BASED ON STATIONARY WAVELET TRANSFORM

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In GNSS based positioning, multipath is the most significant error source. This is due to its random nature since it directly depends on the environment surrounding the receiving antenna. The error on the code measurement can reach tens of meters if not mitigated in the receiver. Multipath mitigation can be performed on different levels of the reception chain. A first solution is to handle the problem at the antenna level where specific antenna design allows to filter multipaths by cancellation (choke ring antenna). A second solution is to consider the problem from a signal processing point of view: in this case, several post-correlation techniques have been designed. Among all these post-correlation methods, one can distinguish the high resolution correlator technique, the Early Late slope (ELS) [18] which is based on a two pairs of additional correlators (with respect to the nominal Early Late Phase (ELP) correlations). Another post-correlation method implemented by NovAtel for GPS receivers is the Maximum Estimation Delay Lock Loop (MEDLL) [19] which is a multipath mitigation technique based on the Maximum Likelihood (ML) principle and requires multi-point cross correlation function (CCF) peak. Namely the ML based technique allows to dramatically reduce the effect of multipaths, but performs moderately well against short multipath rays. In fact, short multipath mitigation assumes that the CCF peak can be sampled finely and that the noise effects can be filtered at very low levels. On the other hand, long integration time assumes a static channel over the integration window which is limited by the receiver/environment dynamic. However, some existing ML techniques appreciably improve the ranging error and thus the positioning.

The main contribution of this paper is to address the problem of multipath mitigation using the wavelet transform (WT) [4,13,15]. Some papers are dealing with the multipath issue based on the WT [1, 2, 3, 4, 8, 9, 10, 11]. In general, the processing consists in filtering the useless coefficients (by thresholding) so that the reconstructed signal appears free of the filtered impairment.

The “classical” WT based processing can be summarized in the following steps:

1- Signal decomposition on a wavelet base: in [5] [13], the best basis decomposition is used, while [15], [6] and [7] suggested a subband decomposition of singular value decomposition (SVD) type which splits into two sub-spaces (signal and noise).
2- Thresholding of coefficients in each sub band [12]. This method is usually what is used when dealing with multipath and interference mitigation issues.
3- Reconstruction (synthesis).

Three main drawbacks can be pointed out in these approaches:

- It is to be noted that the thresholding step assumes the design of the thresholding function as well as the threshold value choice which can be difficult to do.
- Moreover, all these papers are based mostly on the "classical" Mallat algorithm [15], i.e. an orthogonal decomposition with decimation. However, the decimation may be a non-optimal choice when willing to localize precisely events.
- Also, the orthogonality constraint limits the choice of the base decomposition which prevents from designing an adapted basis.

Therefore, in this paper, we are focusing on the use of wavelet decomposition without any decimation, with bi-orthogonal properties which allows to design an adapted filter bank. As far as we know, only one paper has been published on multipath mitigation using a non decimated WT [8]. The present paper extends the idea presented in [8], justifying and designing optimally the adapted filter bank. Moreover [8] is not using all the decomposition levels, while in the present paper, the multipath are estimated on all levels, even on details parts, leading to improved performances validated on simulated and real signals.

The choice of an adapted base, with non decimated wavelets packages decomposition and the estimation of the multipath from the details of this decomposition are the innovations proposed in this article.

This decomposition, often referred to as "dyadic continuous wavelet transform" is particularly suitable for multipath mitigation issues for the following reasons:

- The time variable is continuous,
- A large choice of wavelets is available with less stringent conditions than for an AMR,
- The pyramid algorithm [16], which has a high numerical efficiency, can advantageously be implemented.

Motivation and choice of the filter bank: the choice of the wavelet defines the finite impulse response (RIF) or infinite (RII) filterbank with linear phase or not. Daubechies [14] has shown that a symmetrical or antisymmetric wavelet involves a filter with a linear phase. In the case of GNSS processing, the wavelet must be, as the autocorrelation function, symmetric, as well as the scale function, therefore the filters will have a linear phase.

A linear phase RIF filter bank cannot be orthogonal, unlike an RII filter bank that can combine the two orthogonal and linear phase constraints. As a result, the wavelet basis is not orthogonal but biorthogonal and not decimated in order to have the temporal invariance property for event localization.

Consequence: The biorthogonal analysis allows to build more attractive wavelets at the cost of increased conceptual difficulties. We do not have a single wavelet anymore but two and '. It is the same with the scaling function . As a result, we have two dual families of functions. The filters for analysis and synthesis are therefore different which allows a wide variety of choices in the projection base (wavelets and scaling function).

The "*à trous*" algorithm [17] and non-decimated filterbanks: There are several methods to perform a non-decimated wavelet transform. Unlike the pyramid algorithm, the coefficients of the decomposition have a uniform temporal sampling. The transition from one stage to another is no longer accompanied by decimation of the approximation and detail coefficients, but is performed by the interpolation of the filters, which consists in inserting zeros between the coefficients of the filter to allow to move from the j-1 stage to j stage.

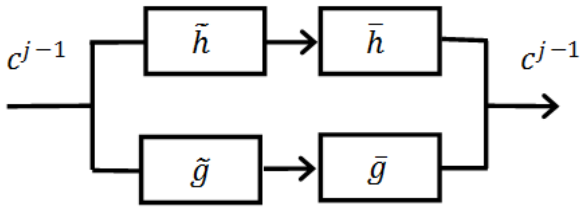

Figure 1: Non decimated filterbank

Details of the proposed algorithm will be given in the paper, with the design of the adapted filters. Figure 2 illustrates the analysis and synthesis bases induced by the choice of these adapted filters.

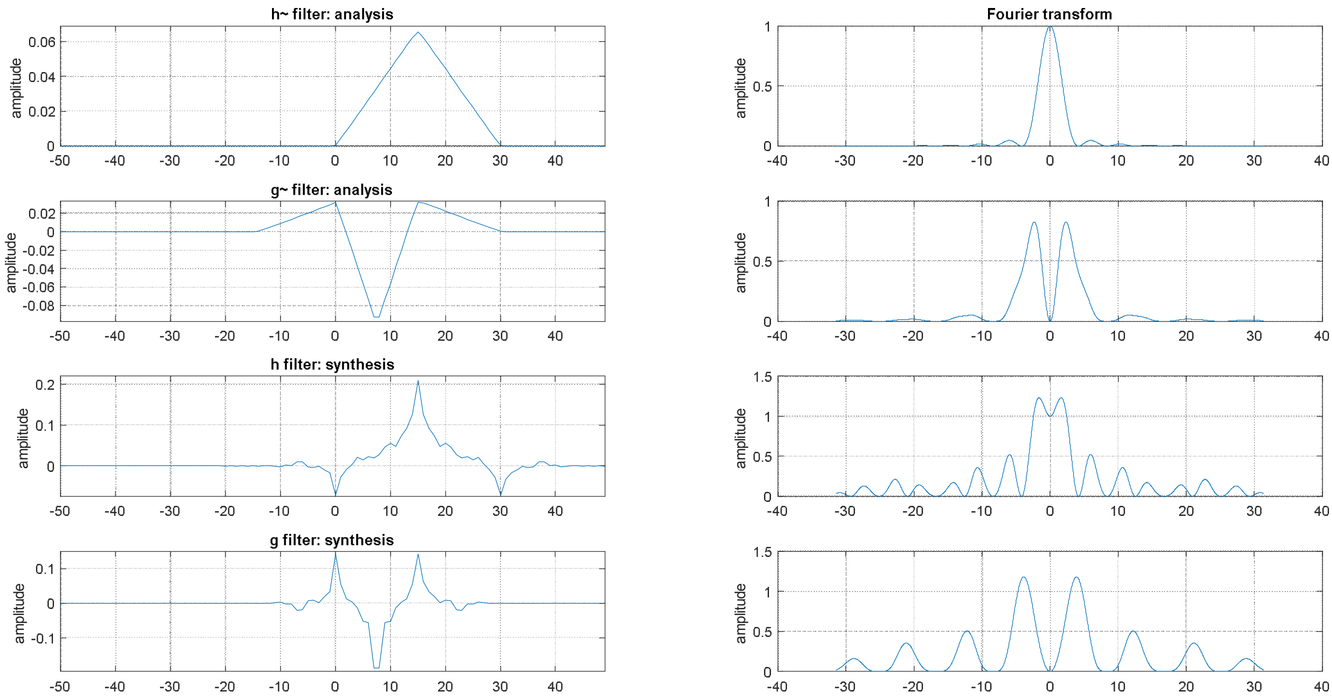

Figure 2: Wavelet and scale function for analysis and synthesis

Validation on simulated GNSS signals

In order to illustrate the decomposition process, a multipath scenario consisting of one direct-signal (LOS) plus three multipath rays is considered.

The analyzed signal consists of a triangular pattern (CCF represented by 39 samples, representing the LOS CCF) to which is added 3 other similar patterns delayed by 10, 12 and 14 samples (representing the multipath rays CCF). The amplitudes are respectively 1.5 for LOS then 0.8, 0.5 and 0.5. On the first subfigure of Fig. 3, the date of appearance of the 3 multipath rays is symbolized by a vertical line marked by a tag on the composite signal (sum of 4 components).

The signature of the various multipaths is seen in the wavelet coefficients. Three scales of the proposed WT decomposition are illustrated on Fig. 3, on the three lines below the first subfigure. In all WT decomposition detail level, the multipath rays are well estimated (see the 3 vertical black lines), especially at the first scale where the 3 peaks (slope change) are easily seen. Note that the signal must be "correctly" sampled in order to be projected on the adapted base; and that the associated wavelet must have at least one zero moment.

Let us remember that the aim of that decomposition is to estimate precisely the LOS delay, which is to be used for code phase tracking preventing the multipath effect to propagate into the measurement and thus into the position solution.

In order to assess the benefit of the WT based multipath mitigation the WT based algorithm has been used as a detector in a multi-correlator Delay Lock Loop. Preliminary simulations show promising results.

The future work is dealing with the improvement of the delay estimation algorithm, before conducting tests on real GNSS signal. Of course, WT based algorithm depends on the autocorrelation function-of the tracked signal. But the concept-could be easily extended to others modulations and consequently to multi-constellation and multi-frequency GNSS signals.

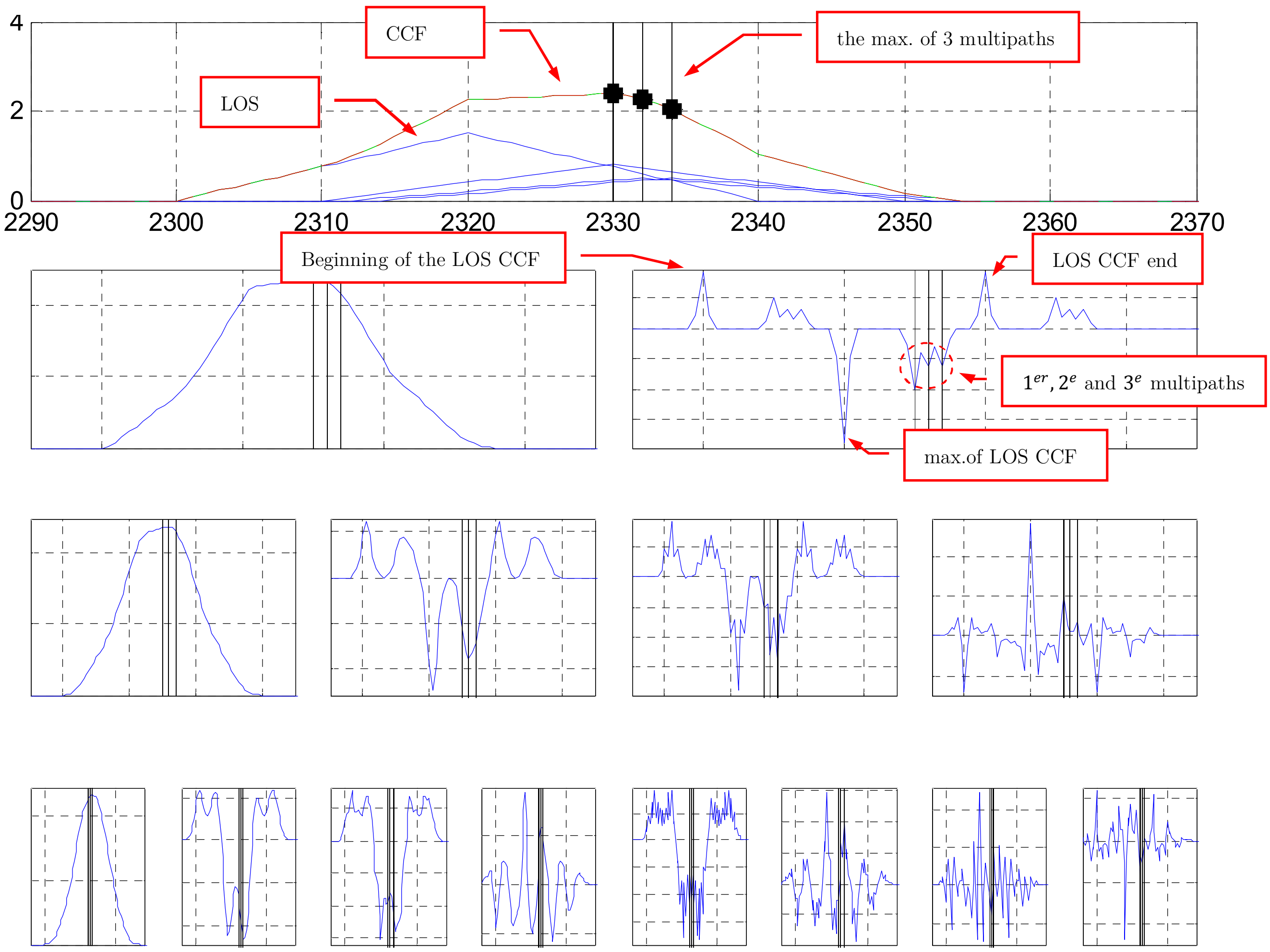

Figure 3 : Original signal with 3 multipath (first figure), results of the proposed WT decomposition at scales 1 to 3 (three figure lines).

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