DELAY SUPER RESOLUTION FOR GNSS-R

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1. ABSTRACT

Global Navigation Satellite System Reflectometry (GNSS–R) is a new approach for earth observation using signals of opportunity in a bistatic configuration [1]. The GPS system is presently used for experimental applications related to the ocean surface scatterometry and indirect retrieval of ocean surface parameters [2, 3]. These new features are due to the availability of a long Pseudo Noise (PN) sequence transmitted by the satellites of the GPS constellation. The transmitted signal is reflected by the ocean surface and received at a different site (airborne or spaceborne). A deeper insight into the time-frequency structure of the signal, would reveal that it resembles a superposition of many small contributions having different delay and Doppler shifts. This structure is due to both the system geometry and the surface properties: the interest is to draw out the surface contribution as clearly as possible. At the current state of the research, the received signal is used to generate a Delay–Doppler (DD) map by correlating the received signal with a frequency shifted replica of the transmitted signal.

The time–frequency resolution of the DD map is entangled with the structure of the transmitted signal and with the processing strategy. It is well known, in fact, that the correlation method allows to separate only those relative delays that are greater than the duration of the sequence chip. Improving the resolution in the delay domain may produce more accurate maps and finer information on the ocean surface.

The aim of this work is to provide a new processing framework for producing DD maps with improved delay resolution. We will show that this is possible at the cost of a moderate increase in the computational complexity [4].

We present here a brief sketch of the theory behind the concept of superresolution delay profile.

The signal trasmitted from a GPS can be stated in the form

$$s(t) = [c(t) \oplus p(t)]e^{j(2\pi f_0 t + \phi_0)}$$

where $c(t)$ is the C/A code, $p(t)$ is the navigation code, f_0 and ϕ_0 are the carrier frequency and phase, respectively, and $\oplus$ denotes modulo-2 sum. The C/A code is a 10-bits pseudo-noise periodic sequence that, for usual GPS systems, is repeted every T =1ms with a chip duration τ_c of about 0.97μs. The scattered signal is a superposition of many *effective* contributions from specular facets; each contribution undergoes an attenuation A_k, a delay τ_k and a frequency shift f_k. It can be represented as

$$y(t) = \sum_{k=1}^{D} A_k s(t - \tau_k)e^{j2\pi f_k t} + n(t)$$

where D is the number of effective scatterers and $n(t)$ is the additive white gaussian noise. The received signal is correlated with a replica of the transmitted one and a *delay profile* $z(t)$ is generated. This is the usual *matched filter* processing. We proceed now by applying the *subspace approach*, that is, by performing an eigendecomposition of the Toeplitz matrix $\mathbf{R} = E[\mathbf{z}\mathbf{z}^H]$, where $\mathbf{z} = [z(t_1), z(t_2), \ldots, z(t_N)]$ is obtained by sampling the delay profile $z(t)$ with a period that is a small fraction of the chip rate and $(\cdot)^H$ denotes conjugate transpose. The set of D eigenvectors corresponding to the largest eigenvalues spans the signal subspace, whereas the remaining set of $N - D$ eigenvectors spans the noise subspace. It can be shown that the noise subspace is ortogonal to the so called *steering vector* $\mathbf{r}_s(\tau) = [r_s(t_1 - \tau), r_s(t_2 - \tau), \ldots, r_s(t_N - \tau)]$, that is the sampled autocorrelation function of the PN sequence, when it is evaluated at the true delays $[\tau_1, \tau_2, \ldots, \tau_D]$ produced by the effective scatterers.

The Superresolution Delay Profile (SDP) is a measure of the ortogonality of the vector of samples to the noise subspace. It is defined as

$$SDP(\tau) = \frac{\mathbf{r}_s^H(\tau)\mathbf{R}_n^{-1}\mathbf{r}_s(\tau)}{\sum_{i=D+1}^{N} |\mathbf{r}_s^H(\tau)\mathbf{e}_i|^2}$$

where $\mathbf{R}_n$ is the noise autocorrelation matrix and $\mathbf{e}_i,\ i=1,\ldots N$ is the set of eigenvectors arranged in descending order. Thus the SDP exhibits marked peaks in the presence of scattered energy.

Figure 1 shows the normalized delay profiles given by the classical method and the SDP. At the left and right hand figures we have used 10 and 20 samples per–chip respectively. The solid line plot shows the superresolution delay profile and the dot line plot represents the delay profile. For both cases two delays have been introduced at the instants $\tau_1 = 2.42\tau_c$ and $\tau_2 = 2.50\tau_c$. The close delays are not resolved by the correlation method that shows a peak situated at an incorrect delay value but it is, instead, apparent that the SDP, for the case of 20 samples per chip, exhibits two marked peaks at the correct delay values. It is also evident that, for the other case, the SDP samples are too widely separated and the achievable resolution is not sufficient to show two separate peaks.

The method is under check with a simulator of DD returns from the ocean surface. It is also under consideration a design study for the optimum value of the sampling frequency in an optimized satellite receiver.

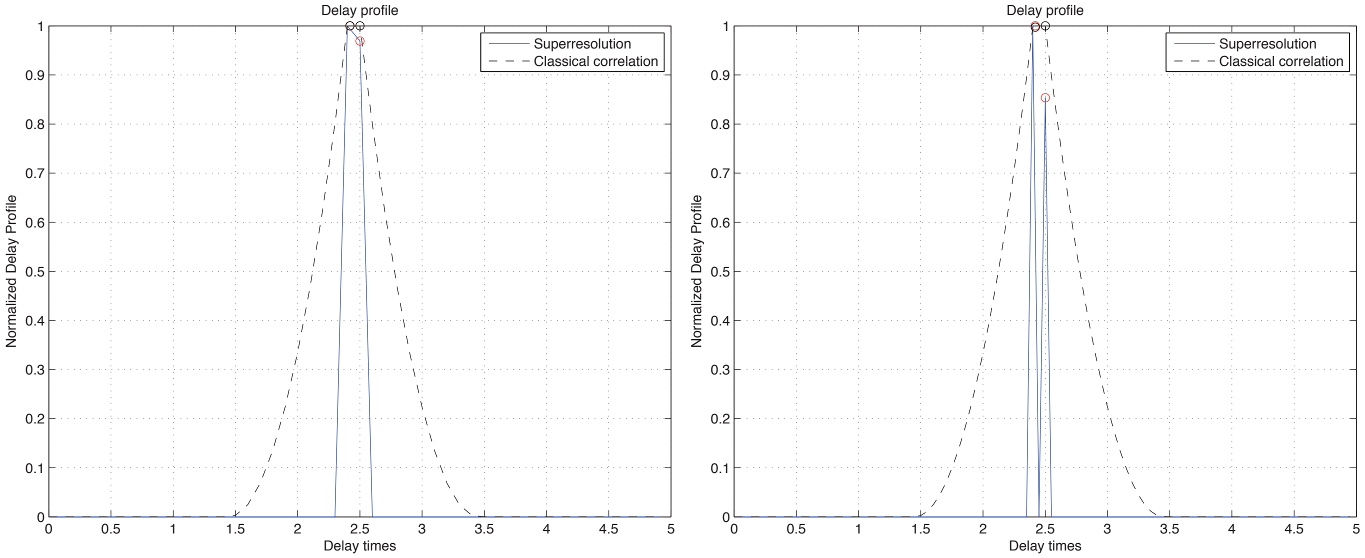

Fig. 1. Normalized delay profiles using different signal samplings: left: 10 samples per chip, right: 20 samples per chip.

2. REFERENCES

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