A TRACKING ALGORITHM FOR GNSS REFLECTED SIGNALS ON SEA SURFACE

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1. INTRODUCTION

In recent years, the deployment of Global Navigation Satellite System (GNSS) in oceanographic applications such as remote sensing, ocean surface monitoring and kinematics measurements, determination oceanographic parameters like wave height and current speed; has been increasing due to the technological progress in space domain. The use of GNSS reflections such as the Global Positioning System (GPS) for oceanographic observation has been discussed in [1], [2], [3].

In order to study the feasibility of passive systems in the vicinity of sea surface for oceanographers and to develop our platform measure which is the aim of the project MOPS [4] (Marine Opportunity Passive Systems), we have already presented a new approach in using the GPS signals for near-surface applications and coastal observations or monitoring [5]. Concretely, we defined an experiment that deals with the interaction between an electromagnetic wave and a well defined position target.

In this paper, we have extended the problem of interaction to see how we can detect the trajectory of some unknown targets in a defined environment, then to find the reflection points of the direct and the forward scattered GPS signals, and finally to sum them coherently over long periods to extract the useful signal from the noise. To do it, we have considered that we have a weak target tracking problem.

2. TRACKING METHODS

Usually, in a classical target tracking, the process is performed on the basis of pre-processed measurements that are constructed from the original measurements data every time set up. In this case, the common approach is to submit all data to a threshold and to treat those which exceed the threshold as point measurements. This would be acceptable if the Signal to Noise Ratio (SNR) is high. That is no integration over time is performed and information is lost [6].

For low SNR targets, the threshold must be low to allow sufficient probability of target detection. But, a low threshold also gives a high rate of false detections which may cause false tracks [7]. That is why we need to perform a simultaneous detection and tracking using unthresholded data which is known in literature as "Track before Detect" [8]. This same reference explains clearly the use of this method for several applications such as ballistic object, bistatic radar and stealthy targets tracking.

3. PROBLEM FORMULATION

In the maritime environment, we consider that we need to detect the existence of a target on the sea surface. This target may be the crest of a wave approaching the coast. In this case, the emitter is a GPS satellite. The receiver which is an antenna, operating in a passive mode, is located near the sea surface as it is shown in the figure 1. It processes the scattered electromagnetic waves reflected on some targets on the sea surface.

In our approach, we need to estimate target kinematics parameters such as position (Cartesian plan) and velocity from noise corrupted range and Doppler data.

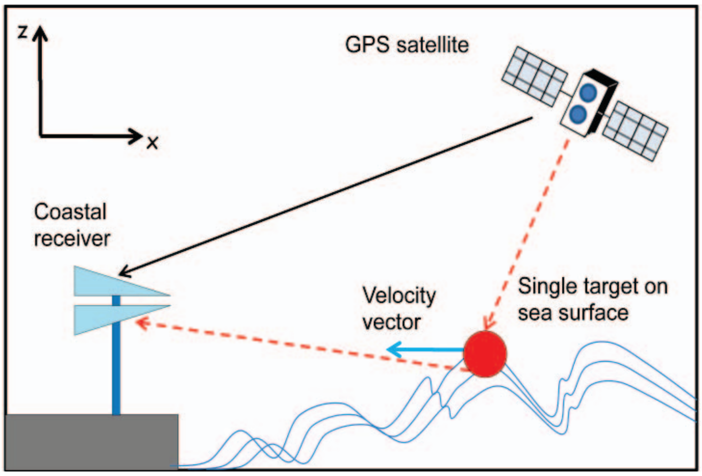

Figure 1: Scheme of the environment

We assume that the target located at (x, z) has a uniform motion with a constant velocity vector $(\dot{x}, \dot{z})$.

The constant velocity model defined in [9] [10] is used to describe the position and velocity using Cartesian coordinates. In addition, the model has an additive process noise term $n_{mod,k}$.

- System dynamics:

The state vector can be defined as: $s = [x \ \dot{x} \ z \ \dot{z}]^T$.

The state equation is: $s_{k+1} = F \cdot s_k + n_{mod,k}$ where $F = \begin{bmatrix} M_F & 0 \\ 0 & M_F \end{bmatrix}$ with $M_F = \begin{bmatrix} 1 & T \\ 0 & 1 \end{bmatrix}$.

T is the revisit time of the GPS signal, it is equal to 1 ms.

- Measurement model:

The measurements consist of the range ρ, the target- receiver bearing angle θ and the Doppler frequency shift δ relative to the carrier signal. In this case, the measurement model can be defined as:

$$z_k = g(s_k) + w_k \text{ where } g(s_k) = [g_\delta(s_k) \quad g_\theta(s_k) \quad g_\rho(s_k)]^T$$

$$g_\delta(s_k) = -\frac{f_c}{c} \cdot \frac{x_k \dot{x}_k + z_k \dot{z}_k}{\sqrt{{x_k}^2 + {z_k}^2}}; \qquad g_\theta(s_k) = \arctan\left(\frac{x_k}{z_k}\right); \qquad g_\rho(s_k) = \sqrt{{x_k}^2 + {z_k}^2}$$

Where the frequency $f_c = 1.5742\ GHz$ is the carrier frequency of the GPS signal, and $c = 3 \cdot 10^8 m.s^{-1}$ is the light speed.

The process noise $n_{mod,k}$ and the measurement noise w_k are assumed to be modeled by a zero mean Gaussian process defined each by its covariance matrix. Thus $n_{mod,k} \sim N(0, \sigma_n^2)$ and $w_k \sim N(0, \sigma_w^2)$.

To estimate the target trajectory, we have implemented a Kalman Filter with a new state vector representing ρ and δ. Then, the estimated values $\hat{\rho}$ and $\hat{\delta}$ are considered as measurements to a new stage of Extended Kalman Filtering in order to obtain the estimated trajectory of the target, more precisely $(\hat{x}, \hat{z})$.

4. FIRST RESULTS

We have performed this simple simulation to see if it is possible to track a reflected GPS signal on sea surface using the Kalman Filtering. This reflection point is referred as a single target. Actually, we used this as a starting point to introduce more complicated scenarios.

In the final paper, we will use two targets: the first one pops up and disappear, the second one pops up and stay in our area of interest. The first one is considered as a fake one and the second one is a true wave crest. Then we proceed by using a particle filter for a Track before Detect (TBD) algorithm in order to find the peaks of reflection. Actually, the particle filter is one of the best used algorithms for TBD especially for root mean square (rms) error position estimation and multitargets detection [7]. To do it, we will consider a jump Markov system since it is often used for tracking applications [8]. The discrete mode represents some hypotheses such as: target 1 is present, target 2 is present, or both of them are present. Also, we can include scenarios dealing with the death of a target while the second one continues to exist.

5. CONCLUSION AND PERSPECTIVES

The main objective of this paper is to join the two theories: tracking targets and long coherent summations, in order to maximise the SNR of the GPS reflected signals to extract them from the noise. These signals provide useful information about the sea state and kinematics as well as the detection of any target on this surface. That is why, in our work, we used a strategy of two main steps: Kalman Filtering for single weak target, Track-before-Detect for multiple target scenarios. In the future, we will validate our results by using real measures of delay and Doppler shift from measurement campaigns that will take place on a measurement dedicated site in Brest, France.

6. REFERENCES

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