New Concept of Passive Measure using GNSS Reflected Signals in Oceanographic Applications

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Abstract- **Today, one of the methods in monitoring oceans is the use of radar systems or more generally the use of electromagnetic diffusion. Thanks to the deployment of satellite navigation systems (GNSS), such as GPS, GNSS signals are being used more and more as an opportunity source for this kind of observation. This paper assesses the measurement of oceanographic parameters within a few meters near the surface. The oceanographic phenomena that is currently available for recording is limited. That is why we propose a much finer analysis of the diffusion and the scattering of GNSS signals near ocean surface, by employing very fine time steps and integration over the long periods of code. The final goal is to be able to perceive very fine phenomena, among which the ocean surface kinematics. In order to achieve this, the application of sophisticated processing algorithms is needed. In this work we simulate and highlight the observable effects expected as a result of use of such a method. The work is realized as a part of the MOPS project.**

I. INTRODUCTION

Research concerning oceanographic issues is increasing. One of the most important research topics is ocean surface monitoring and remote sensing. Through the last years, many scientists and research groups have been working on ways to get more precise measures of several oceanographic parameters, always by means of reflectometry radar systems.

Indeed, the signals reflected from the ocean surface offer a very powerful source of advanced oceanographic information, as these signals are affected by water roughness, currents movements, dielectric properties and ocean surface altimetry. From the same reasons, the reflected signals can be used for remote sensing purposes. For instance, wave height, wind speed and direction can be determined from the surface roughness characteristics [1].

Moreover, technological progress in space domain, especially in satellite navigation systems, provides basic help concerning the remote sensing of ocean surface. Without a doubt, the GNSSs (Global Navigation Satellite System) such as the American GPS (Global Positioning system), the European Galileo and the Russian GLONASS could be successfully used not only for positioning purposes but also for ocean surface monitoring. The use of GNSS reflected signals is a powerful and potentially innovative technology for remote sensing. Its characteristics are wide coverage, a passive and precise, long-term, multi-purpose use in all-weather conditions [2].

In this paper, we address the feasibility of passive systems that could be exploited by oceanographers, in the vicinity of sea surface. This work is a part of the project on Marine Opportunity Passive Systems (MOPS) [3].

Next Section presents the geometry and advantages of GNSS allowing them to be used in a passive measure context. Section III addresses the structure of a GPS signal. The studied scenario is introduced and the results are discussed in Section IV. Finally, the last Section concludes the document.

II. USING GNSS SIGNAL FOR PASSIVE MEASURE IN OCEANOGRAPHIC CONTEXT

The GNSS satellites are deployed in relatively high orbits and large inclinations. This provides a global and a wide coverage of the Earth. For instance, the GPS satellites are distributed on specific circular orbits at 55 degrees of inclination and 20,000 Km of altitude [4]. In addition, the GPS ground compound contains the augmentation systems providing additional information for a more precise measure.

Today, only the GPS is fully deployed and operational. However, the systems such as Galileo (launching phase) and GLONASS (revitalization phase) are announced to be deployed in following years. This means that in the following decades the number of satellites in the satellite infrastructure will reach the number of about 80.

The reflection of the GNSS signals on the sea surface induces modifications of the signal characteristics. The use of GNSS reflection for the ocean observation has been already discussed in [5] and [6].

In 1993, Martin-Neira has suggested the use of scattered signals from the existing constellation of GPS satellites in the same purpose [7].

He has also worked on sea surface height estimation from low distances [8] and high distances, where he has improved the passive radar altimetry concept [9]. In addition, Komjathy et al. have worked on the retrieval of wind speed and direction [1]. Other scientists have even developed specialized receivers to gather GPS reflections from a suitable surface. The most important among them are the Delay-Mapping Receiver (DMR) developed by NASA [10] and the GPS Open Loop Differential Real Time Receiver (GOLD-RTR) by the CSIS-IEEC, Spain [11]. Note that during these experiments, the receiver was held by aircrafts, while radars, stratospheric balloons and space platforms have been used, too.

The reflection process induces modifications of the GNSS signal which depend on the sea surface conditions, such as directional roughness and receiver-emitter-surface kinematics.

This is highlighted by inferring a comparison between the measured waveforms and the predicted one theoretically. This is performed by using a model function of geometrical and environmental parameters [12].

Another monitoring type is the coastal monitoring where the receiver is located a few meters above the ocean surface. This type of receiver provides the additional information about the oceanographic environment. For instance, Starlab already developed a coastal receiver called OCEANPAL. The accuracy of this model in determining salinity and height has been proven during the experiments held in Brest, France, and Barcelona, Spain [13].

III. STRUCTURE OF THE GPS SIGNAL

In this paper, the GPS signal is used for costal monitoring. To understand how it works, we are going to present the GPS signal structure.

The GPS satellites emit their code on two carriers, with frequencies L_1 and L_2, defined by the fundamental frequency $F_0 = 10.23$ MHz:

$$\begin{aligned} L_1 &= 154\, F_0 \\ L_2 &= 120\, F_0 \end{aligned} \qquad (1)$$

L_1 wave is modulated by two codes: a civil code C/A and a military one, P(Y), whereas L_2 wave is modulated by the code P(Y). The signal spectrum is spread using a BPSK modulation, as shown in Fig. 1.

In this paper, we will only consider the C/A code. It is composed of the Pseudo-Random Noise sequence (PRN) which is known and unique for each satellite [4]. The C/A code is a sequence of +1 and -1. It has a length of 1023 chips, corresponding to a period of 1ms.

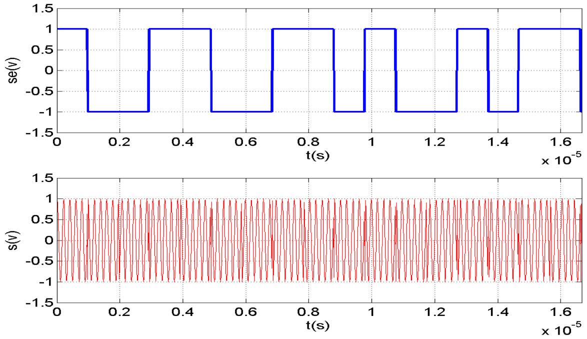

Figure 1. Example of the PRN code (up), and a GPS modulated signal (down)

By measuring the cross correlation product of the reflected GPS signals and the receiver generated replica PRN code, for a particular satellite, we show the peak corresponding to the direct signal emitted by the satellite. The secondary peaks, corresponding to the reflection phenomena are highlighted as well. Some oceanographic parameters may also be extracted from the characteristics of these secondary peaks. Nevertheless, the analysis of the signals remains difficult because the reflections are affected by the sea surface kinematics, roughness and marine environment. In addition, these signals have a low signal to noise ratio, which further complicates its analysis.

To overcome these difficulties, we integrate signal coherently or incoherently over many code sequences.

IV. THE MOBILE-FIXED TARGET EXPERIMENT

The interaction between an electromagnetic wave and a rough and moving sea surface is a particularly complicated phenomenon that makes the processing of the GPS reflected signal very hard. To illustrate this problem we have carried out a simple experiment simulating ocean surface particle movement and the power spectrum evolution through the signal integration over long periods.

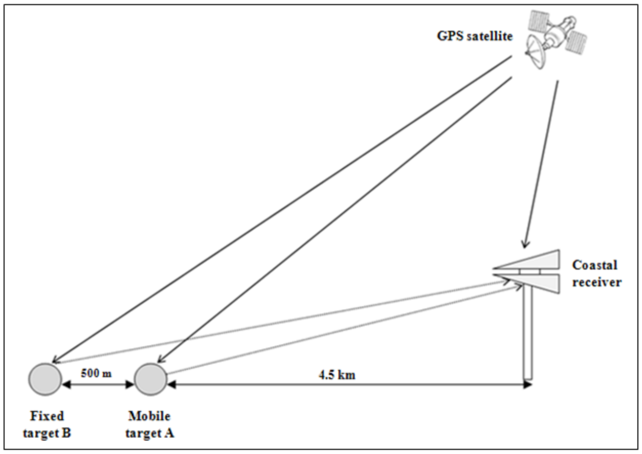

Figure 2. Scheme of the Mobile-Fixed Targets experiment

We address a GPS emitter-receiver scenario. The receiver is considered to be the reference of the system. Two punctual targets are considered: the first one (A) is moving and is located at distance of 4.5 km from the receiver, while the second one (B) is fixed. The range between A and B is 500 m as shown in Fig. 2. We suppose that particle A moves vertically with a velocity of 36 km/h and that the reflected signal is sampled over 60 MHz. Indeed these values do not express the real case where the target A velocity is about 0.5 km/h and the range between A and B is much smaller.

Algorithm description

We simulate the signal received by the antenna. It is composed of three main compounds: the direct signal coming from the satellite without being reflected on any surface, the signal reflected on the fixed target and the signal reflected on the mobile target. These reflected signals are defined with their own SNR (signal to noise ratio) and the delay from the reference point. We should notice that all these signals are synthetic: they have generated by the algorithm as well. A white Gaussian noise is then added to this signal.

A replica of the GPS signal is then generated by the receiver and correlated with the resulting signal. Actually the correlation process is to multiply bit by bit the two signals, to shift the first signal after each multiplication and to sum the resulting product for each time.

In our case, the signal is generated of a certain number *L* of PRN code and the replica is generated on 1 ms. For each period *i* of 1 ms of signal, the correlation is performed in the following way:

$$r_i(t) = s_i(t) \otimes p(t) \qquad (2)$$

where $r_i(t)$ is the correlation result for the i-th period, $s_i(t)$ is the corresponding segment of the received signal and $p(t)$ is the replica.

Since the correlation is performed on a large number *L* of periods, the result will be:

$$r_L(t) = \sum_{i=1}^{L} r_i(t) \qquad (3)$$

The integration over long periods is limited by the phase variation inside the GPS signal. That is why, we have to sum coherently the $r_i(t)$ as seen in the following equation:

$$R_L(t) = |r_L(t)|^2 \qquad (4)$$

In order to evaluate the system performance, we have measured the algorithm gain in different scenarios.

The gain is defined as:

$$G(L) = 10\ log_{10}\left(\frac{R_{L_{max}} - \mu_n}{\sigma_n}\right) \qquad (5)$$

where $R_{L_{max}}$ is the resulting correlation peak value, μ_n and σ_n are the mean and the standard deviation of the noise respectively.

Experiment

1. *Scenario 1:*

In this case, we consider only the direct signal. This signal is integrated over 50 ms (*L*=50)

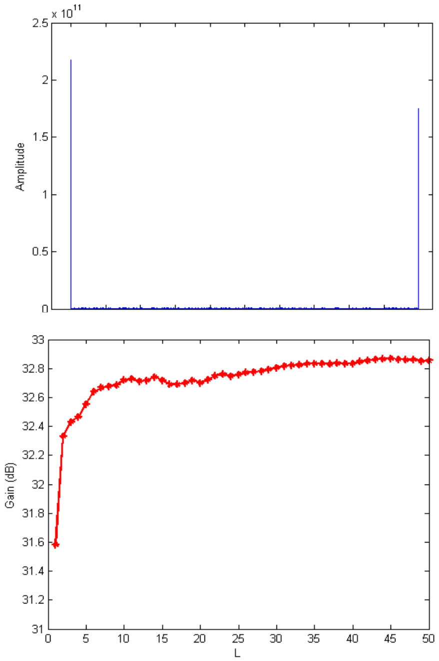

Figure 3. Direct signal correlation (up), gain for the scenario 1 (down)

2. *Scenario 2:*

In this scenario, the signal reflected on the fixed target is included. It is also integrated over 50 ms (*L*=50)

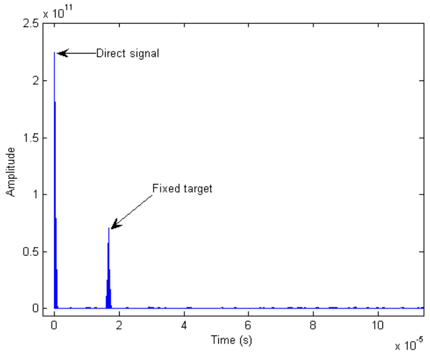

Figure 4. Correlation result showing both the direct and fixed target signals

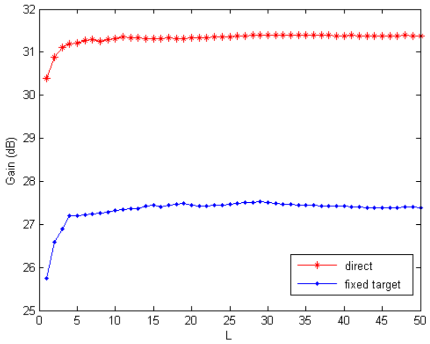

Figure 5. Comparison of the gain for the 2 signals

3. *Scenario 3:*

Now, we will introduce the mobile target. In a first case, we will evaluate the gain for a velocity equal to zero, and in another case, the velocity is 36 km/h.

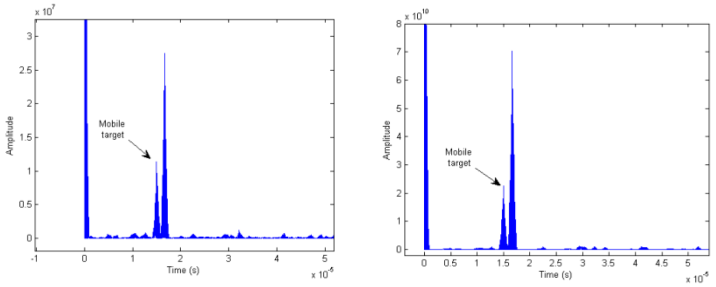

Figure 6. Correlation result for *L* = 1 ms (left) and *L* = 50 ms (right)

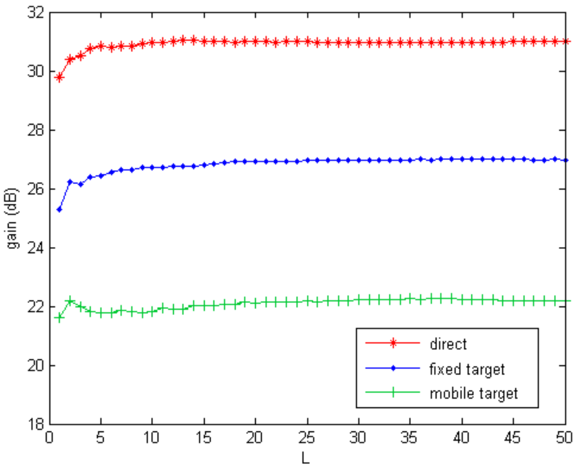

Figure 7. Comparison of the gain values for the 3 scenarios, mobile target velocity = 0

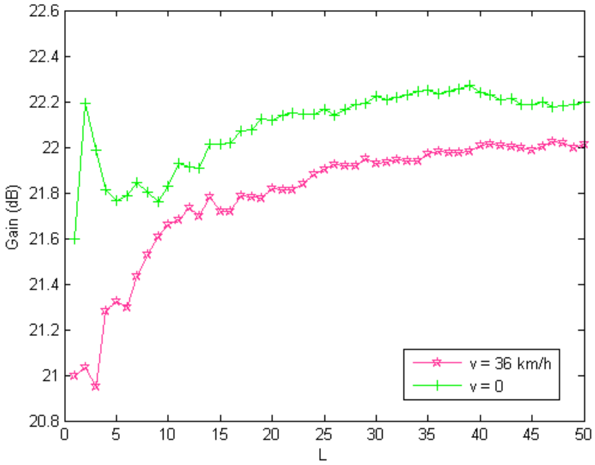

Figure 8. Gain for the mobile target signal
with v = 0 and v = 36 km/h

Results and interpretation

The correlation process allows the identification of signal kind (direct, reflected fixed or mobile) depending on the position and amplitude of the corresponding peak (Fig. 3 up, Fig. 4 and Fig. 6).

Moreover, correlation over many periods of signal increases the SNR. Actually, we can see in Fig. 3 (down), Fig. 5 and Fig. 7 that the gain increases logarithmically in function of the number of periods *L*.

This is useful especially to extract the weak signal reflections from the whole received signal. Thus, in the Fig. 6, we can see how the noise level has been reduced significantly compared to the peak amplitude when integrating on 50ms.

In addition, the simulation in the third scenario shows that the gain variation of the mobile target depends on its velocity: the more this value is high, the more the gain is small (Fig. 8). That is due to the peak spreading and its position variation during the integration over a long time.

V. CONCLUSION AND PERSPECTIVES

The main objective of this paper was to show how the integration of the GNSS signals scattered by some targets over long time can provide relevant information about them. More precisely, we have highlighted the relationship between the gain, calculated from the correlation result, and some main characteristics (SNR and velocity) of the target.

In the future, this work will be continued with more scenarios and real values simulating the kinematics of the sea surface and suitable for oceanographic observation: they have been chosen here to show how the system works at larger scale. We will use later a sophisticated oscillator of 8GHz.

Then, we will study the possibility of measuring other parameters such as temperature, dielectric properties of the surface, currents and tides height, gas exchange on the surface. This would include mainly the surface roughness and its dynamics.

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