RADIO FREQUENCY INTERFERENCES SUPPRESSION FOR ULTRA WIDE BAND RADAR

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ABSTRACT

In this paper, a time domain processing of Ultra Wide Band SAR (Synthetic Aperture Radar) data and an algorithm to remove the Radio Frequency Interferences (RFI) measured with this kind of radar are described and tested. Usually a SAR is a narrow band system, but in our case it transmits nanosecond short pulses without carrier which have a spectral content from 100 MHz to 1 GHz. We investigate the possibilities of Ultra Wide Band radar imaging in order to scan the advantages over conventionnal radar. One of the potential advantage is the accurate target discrimination because of the short pulse duration, but one problem that we encounter is the RFI present in the UWB return. An algorithm based on Least Mean Square method is developped to extract and cancel these RFI.

1 INTRODUCTION

A radar image is representative of the electromagnetic reflectivity of terrain surfaces and targets. In widespread use throughout both civil and military observation systems, narrow band SAR imagery based on Chirp signals is limited (mainly in terms of resolution). Thanks to the broad instantaneous spectrum of UWB signals (very short pulses of about a nanosecond), the UWB radar may gain in resolution and penetrate the natural screens as the low frequency radars. Such systems combine the penetration enhancement associated with UHF frequencies with the resolution of wide bandwidth. Today, interest in UWB radar is growing. Measurements became possible due to fast response equipment which could generate pulses of nanosecond duration. It is accompagnied by the appearance of new applications, such as ground penetrating radar, construction control, pipe and cable detection. Analyses from the results of the processing that emerged from the initial UWB trials, carried out at CELAR (French Technical Center for Armament Electronics) using a prototype radar, show that electromagnetic noise level is very high because the required bandwidth share some RF bands occupied by other communication systems (0,1 GHz - 1 GHz). The advance of telecommunications technology creates an increasingly hostile environment for radio frequency interference, called RFI. The RFI can obscure the target response and make detection difficult. If we want a good Signal to Noise Ratio (SNR) on SAR image, RFI must be extracted and removed. An algorithm to remove RFI, based on Least Mean Square method, is then tested.

2 UWB SAR EXPERIMENTATION

2.1 UWB SAR imagery processing

The geometric configuration of a SAR mounted on a vehicle travelling at speed v is shown in figure 1. The short pulse, with its wide instantaneous spectrum, is transmitted using UWB antenna and then backscattered by the elementary target reflectivity *sigma0*.

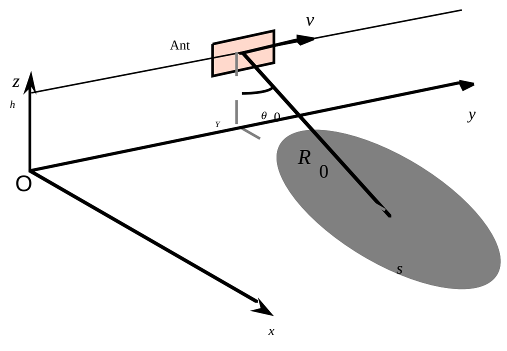

Figure 1 : Geometric configuration of a SAR

The algorithm developed for data processing is based on focusing by time domain back projection [1]. The method involves the coherent summation of sampled pulse responses of targets and terrain measured over the angular sector corresponding to radar displacement. Unlike the narrow band radar, UWB responses termed as pulse result directly from the measurement. The coherent summation can be summarised by the following formula :

$$I(x_i, y_i) = \sum_{k=1}^{N} R_x\left(d\left(x_i, y_i\right), p_k\right).$$

Image computation is carried out pixel by pixel. For each pixel $I(x_i, y_i)$, the algorithm identifies, for each pulse response R_x, and using the real distance $d(x_i, y_i)$ between the antenna and the pixel under consideration, the corresponding range bin. As this point is most unlikely to correspond exactly with a measured range bin, its value is calculated by linear interpolation between the values of the two nearest bins. A value for each pixel is obtained by summing these values obtained from all the pulse responses which made up the measurement and which correspond to the N various aperture positions of the radar p_k (hyperpola of range migration).

2.1 UWB SAR experimentation results

A trial programme took place at CELAR [2] in december 1996 with a prototype UWB radar installed on the external STRADI platform. The principle of the measurements was to emit a UWB pulse, for a given position, and to digitize the signal reflected from the scene directly in the time domain. The operation was then restarted every 60 cm on the trail, and for various scenes. Only largest targets as trihedral could be detected in the scenes. Other areas were measured, but they were made of clutter and electromagnetic noise. As a results, RFI appears in the received signal. Thus, interference extraction and removal is needed. Interferences are now studied and RFI suppression are developped in the section 4 to increase the probability of detecting while keeping the output power requirement low.

3 ELECTROMAGNETIC INTERFERENCES

The frequency range of the UWB signal is also used extensively by many radio frequency services : TV, radio, cellular phones, etc, which are relatively narrow-banded, as can be seen on figure 2 where a spectrum of typical RFI is shown in the band from 0 Hz to 1 GHz. The electromagnetic noise was measured at CELAR through an UWB antenna with a spectrum analysor. The envelop shows that peak levels on analysor reach - 11 dBm. High levels are located in FM and TV band around 100 MHz and from 400 to 700 MHz. Two other bands are detected : 160-200 MHz and 930- 960 MHz.

In the section 4, we present an algorithm developped by Miller, McCorkle and Potter [3] for the removal of narrow band interferences from Ultra Wide Band signal.

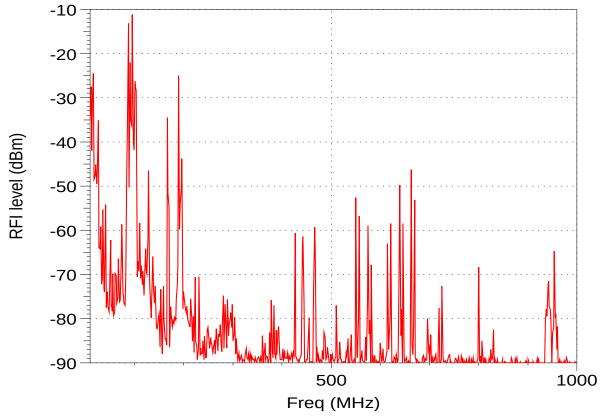

Figure 2 : Radio Frequency Interference spectrum

4 RFI SUPPRESSION ALGORITHM

In this section, the UWB received signal [3] is assumed to be $x(k) = s(k) + n(k) + r(k)$, $k = 0, \ldots, N-1$, with $s(k)$ the UWB signal, $n(k)$ a white noise, $r(k)$ RFI signals, and N the number of points of the measured signal. If M values of interference frequencies w_i are assumed to be known and theirs levels $\{a_i, b_i\}$ unknown, $r(k)$ is given by $r(k) = \sum_{i=1}^{M} a_i \sin(w_i k) + \sum_{i=1}^{M} b_i \cos(w_i k)$, $\mathrm{k} = 0, \ldots, \mathrm{N}-1$.

We want to estimate the signal $r(k)$ in a way to minimize the quadratic error criterion $\sum_{k=0}^{N-1} \left| x(k) - r(k) \right|^2$. In this objective, it gives $\underline{r} = A\underline{z}$ with A a matrix Nx$2M$ containing terms $\sin(w_i k)$ and $\cos(w_i k)$ and z a column of $2M$ lenght containing coefficients a_i and b_i. Least mean squares problem is $A\underline{z} = \underline{x}$, with :

$$A = \begin{bmatrix} \sin(w_1 k_1) & \cos(w_1 k_1) & . & . & . & \sin(w_M k_1) & \cos(w_M k_1) \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ \sin(w_1 k_N) & \cos(w_1 k_N) & . & . & . & \sin(w_M k_N) & \cos(w_M k_N) \end{bmatrix}$$

$$\underline{z} = \begin{bmatrix} a_1 \\ b_1 \\ . \\ . \\ a_M \\ b_M \end{bmatrix}, \qquad \underline{x} = \begin{bmatrix} x(k_1) \\ x(k_2) \\ . \\ . \\ x(k_N) \end{bmatrix}.$$

The solution consits of finding $\hat{\underline{z}}$ to minimize $J(\underline{z}) = \left\| \underline{x} - A\underline{z} \right\|^2 = \left(\underline{x} - A\underline{z}\right)^t \left(\underline{x} - A\underline{z}\right) = \underline{x}^t \underline{x} - 2\underline{x}^t A\underline{z} + \underline{z}^t A^t A\underline{z}$.

The derivative expression $\dfrac{\partial J(\underline{z})}{\partial \underline{z}} = -2\underline{x}^t A + 2\underline{z}^t \left(A^t A\right) = 0$

leads to $\hat{\underline{z}} = \left(A^T A\right)^{-1} A^T \underline{x}$ and the Least Mean Square solution gives $\hat{\underline{r}} = A\left(A^T A\right)^{-1} A^T \underline{x}$. Next $\hat{\underline{r}}$ is substracted to the signal *x*. LMS method has only a solution if $A^t A$ is a non-singular matrix. We also must verify $\dim(\underline{z}) < \dim(\underline{x})$ that's to say more equations than unknowns.

5 RESULTS AND PERFORMANCES

First, ten RFI frequencies corresponding to figure 2 with a random phase and the same level were added to an UWB indoor ISAR measurement of a target. Figure 3 presents the simulated signal with RFI and the signal obtained after RFI removal. This algorithm allows to find the initial UWB signal without distorsion.

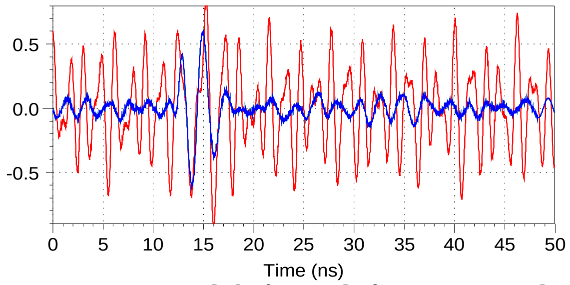

Figure 3 : Signals before and after RFI removal

If the RFI signals haven't a stationnarity characteristic, the estimation of the frequencies can be biased. It can give the consequence that frequencies are not removed. For example, we have an UWB signal (-18 dB SNR) with 15 RFI frequencies and the figure 4 shows the SNR after RFI suppression when *Nber* frequencies are removed. Here, we can note the inportance to have a good estimation of all the RFI frequencies before removal algorithm. We seek maximal reduction of interferences energy, minimal loss and distorsion. Losses for the maximum of the signal are represented on figure 4. We can conclude that the losses increase with the number of removed frequencies. It may be a limitation of this processing.

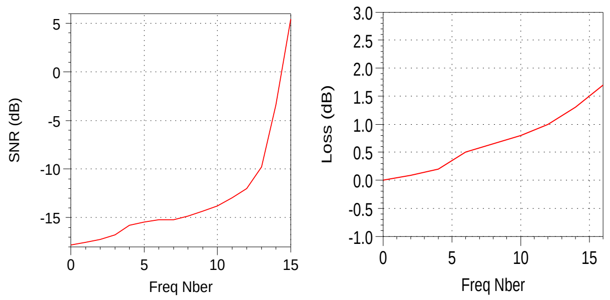

Figure 4 : SNR and loss after RFI removal

Then, the figure 5 represents simulated images of a target (small missile) before and after RFI suppression and shows the capability to detect the target after RFI removal.

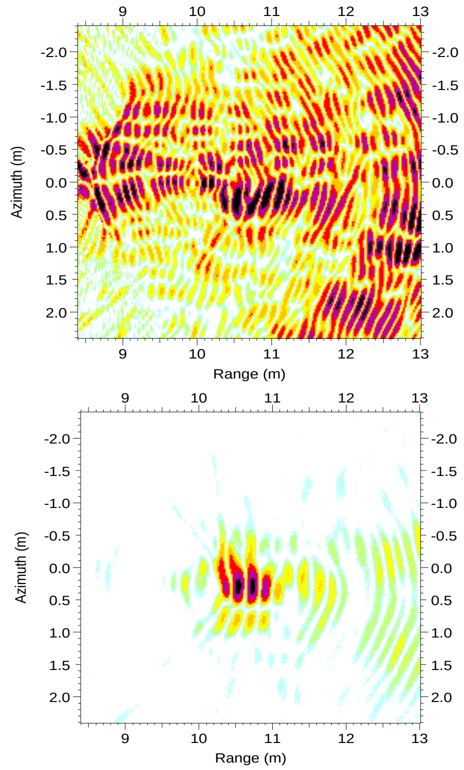

Figure 5 : Images before and after RFI suppression

6 CONCLUSION

In this document, back projection algorithm dedicated to Ultra Wide Band signals is described. The time domain aspect is all the more important that the transient nature of UWB signal supplies a vast amount of information on the electromagnetic scattering mechanisms. But, during UWB measurements, radio frequency interferences can appear and obscure target detection. We have described how RFI can be an important noise source in UWB system and how they can be suppressed. The Least Mean Square method for extracting RFI give good results, which are quantified with simulated data. Next, we would like to improve our sinusoidal model of the RFI to include a more complete description of the RFI signal and to apply the LMS algorithm to measured data.

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