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SAR Processing for Buried Objects Detection using GPR

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***Abstract*—Mine detection techniques require extremely high detection rates. In this paper, signal processing algorithm is introduced to be applied in the ground penetrating radar (GPR) which is more suitable for this application. In GPR microwave signals penetrate into the ground until a buried object reflects them back and the reflected signals are processed in order to extract information about the target. The proposed algorithm generates complex range profiles by applying Inverse Fast Fourier Transform (IFFT) and corrects phase shift due to the system delay. Afterwards in order to improve resolution, synthetic aperture radar (SAR) processing is applied and SAR matrix is formed as GPR moves to the next position. The results obtained show that this algorithm has overcome the problem of the strong reflected signals from the ground and also the other unwanted signals and clutter**

Keywords—GPR; Landmines; IFFT; SAR processing

I. INTRODUCTION

The detection and identification techniques for buried objects have been a great interest to researchers for many years. There are many techniques have been studied. One of them is the metal detector approach (MD) which is still used, but it can't be used for the detection of plastic and low metal landmines. The most important technique to be used is the ground penetrating radar (GPR) which is being used widely in many science fields [1]. In this paper a signal processing algorithm is used which makes use of the synthetic aperture radar (SAR) processing in order to improve the cross range resolution. It also applies first difference and also adaptive subtraction to emphasize the responses of the buried plastic landmines. The results of this algorithm show that it works efficiently in removing clutter and unwanted signals and emphasize the weak reflections from the buried landmine. Thus, the Ground Penetrating Radar (GPR) is used to overcome this problem by using the difference in permittivity of both mine and the surrounding medium to detect the target [2]. However it is difficult for the GPR to detect the target if it has very small dimensions or has a permittivity near to that of the ground. In these cases, the reflected signal of the target is very weak compared to that of the ground and noise, making it difficult to distinguish between both without proper signal processing. Thus, in order to extract useful information about the target, it is necessary to apply proper signal processing by using a stepped frequency continues wave radar (SFCW) to overcome the problem of high instantaneous bandwidth and high sampling rate of the pulsed systems[7]. This paper is organized as follows; section 2 summarizes the GPR transceiver analysis to understand how the Radio Frequency (RF) signals are transmitted and received. In Section 3, the proposed digital signal processing algorithm and how it can achieve the best performance and avoid the unwanted signals reflected from sand surface are presented. Finally in section 4 the results of the proposed algorithm are analyzed to show the efficiency of applying this algorithm in the process of detecting the buried plastic landmines which has a permittivity close to that of the sand permittivity. Conclusion comes at the end of this paper.

II. GPR TRANSCIEVER ANALYSIS

In this work stepped frequency continuous wave ground penetrating radar (SFCW GPR) is used with bandwidth of β= 1 GHZ and operates from initial frequency 1GHZ to 2 GHZ with frequency steps from 2 up to 512 steps. The theory of operation of the SFCW GPR transceiver is presented in this section to understand how the RF signals are transmitted and received [3].

A. GPR Transmitter

The general block diagram of the transmitter is shown in figure (1) below.

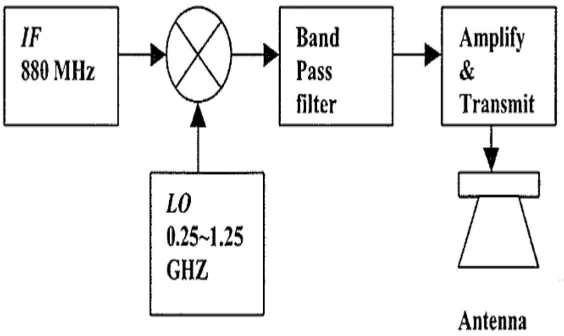

Fig .1. Block diagram of the GPR transmitter

Let the intermediate frequency (IF) and local oscillator (LO) signals be the cosine functions cos(A) and cos(B) respectively. The result of mixing IF with LO is

$$\text{IF} \times \text{LO} = 0.5[\cos(A-B) + \cos(A+B)] \quad (1)$$

Where $$A = 2\pi f_i t \quad (2)$$

$$B = 2\pi f_l t \quad (3)$$

f_i is the intermediate frequency.

f_l is the local oscillator frequency.

By applying bandpass filter to use only the band which is inside the operating range and the output of the filter will be

$$s_t = 0.5 \cos(A + B) \quad (4)$$

By substituting (2) and (3) in (4), we have:

$$s_t = 0.5 \cos(2\pi(f_i + f_l)) \quad (5)$$

B. GPR Reciever

From the block diagram in figure (2) and equation 4 we have

$$s_r = 0.5\Gamma \cos(2\pi(f_i + f_l + \theta)) \quad (6)$$

Where Γ represents the reflection coefficient of the material and θ represents the phase shift. At the output of the mixer we have :

$$s_r \times \text{LO} = 0.25\Gamma [\cos(A+\theta) + \cos(2B+A+\theta)] \quad (7)$$

Again the term cos(2B+A+θ) is eliminated as in the transmitter , and the remaining signal is :

$$\text{IFr} = 0.25\Gamma \cos(A+\theta) \quad (8)$$

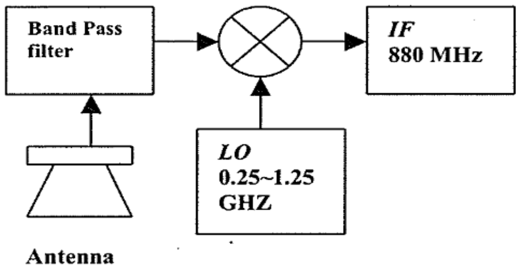

Fig .2. Block diagram of the GPR reciever

In order to extract the useful information from the target , the IFr is compared to the reference signal IF to detect differences in amplitude and phase of the transmitted signal due to the reflector's material and distance. This comparison is done by the use of inphase quadrature(IQ) synchronous demodulator. There are two mixers inside the demodulator, one of them produces the I signals and the other is phase shifted by 90 degrees which produces the quadrature Q output. The inphase output can be expressed as follow :

$$I = (1/8)\Gamma [\cos(A-A-\theta) + \cos(A+A+B)] \quad (9)$$

$$I = (1/8)\Gamma [\cos(-\theta) + \cos(2A+B)] \quad (10)$$

After low pass filtering:

$$I(\theta) = (1/8)\Gamma \cos(-\theta) \quad (11)$$

In similar way the quadrature Q signal is obtained as:

$$Q(\theta) = (1/8)\Gamma \sin(-\theta) \quad (12)$$

C. Mapping Phase Shift to Traveled Distance

After the I and Q signals are sampled at the demodulator , it is desirable to translate the phase shift θ into a physical measurable quantity such as distance[10] .

$$I(\theta) = (1/8)\Gamma \cos(-2\pi(2ds/c)f) \quad (13)$$

$$Q(\theta) = (1/8)\Gamma \sin(-2\pi(2ds/c)f) \quad (14)$$

From the previous equations, it can be observed that I and Q signals are functions of three variables:

The distance ds, the travelling speed C which depends on the medium characteristics and the transmitted frequency f .The higher the magnitude of the reflectivity, the higher the amplitude of the I and Q signals [10].

III. THE PROPOSED DIGITAL SIGNAL PROCESSING ALGORITHM

The objective of this proposed algorithm is to be able to extract useful information from the received signals in order to be able to detect and build an image of the buried object which is in this case the plastic landmine. In order to achieve this we have some problems that need to be addressed:

- The reflections from the surface of the sand are much stronger than those of the buried objects.
- The dielectric constants of the sand and plastic are close to each other, which cause a small reflection coefficient, hence producing a weak response.

So, useful signal processing is required in order to solve the problems cited above.

A. I&Q signals sampling

The expressions for the I and Q signals are given by:

$$I(d,f) = (1/8)\Gamma \cos(-2\pi(2ds/c)f) \qquad (15)$$

$$Q(d,f) = (1/8)\Gamma \sin(-2\pi(2ds/c)f) \qquad (16)$$

The Sampling is actually performed in the frequency domain, and the Nyquist criterion is followed by properly selecting the frequency step Δf by using:

$$\Delta f = \frac{C\,sand}{2dmax} \qquad (17)$$

Where Δf is the maximum frequency step, $C\,sand$ is the speed of light in sand and $dmax$ is the maximum distance to be imaged. Hence by collecting the I and Q samples for each transmitted frequency, an approximation of the frequency response of the medium is obtained for that bandwidth. Once N samples of the I and Q signals are available a complex data vector S is made as:

$$S = I + jQ \qquad (18)$$

From (15) and (16),

$$S = A.e^{-i2\pi df/C} \qquad (19)$$

Where A= Γ/8 is the magnitude of the phasor, which is proportional to the object reflection coefficient and d is the total distance the microwave signals traveled.

B. Transmission Line Correction

The signal travels distance d including the length of the GPR cables. Therefor the distance d is expressed as:

$$d = d_{sys} + 2d_s \qquad (20)$$

Where d_{sys} is the distance traveled including the GPR internal and external cables, and d_s is the distance between the antenna and the reflecting object.

Then by substituting (20) in (19),

$$S(ds,f) = A.Es.e^{-i2\pi df/C} \qquad (21)$$

Where

$$Es = e^{-i2\pi dsysf/C} \qquad (22)$$

Hence, an exponential vector E is generated with opposite sign and multiplied point by point with Es to obtain corrected signal Scorr.

$$Es = e^{i2\pi dsysf/C} \qquad (23)$$

$$Scorr = S.E \qquad (24)$$

$$Scorr(ds,f) = A.e^{-i2\pi df/C} \qquad (25)$$

C. IFFT and removal of unwanted signals

By multiplying the signal S by the correction exponential Es in the frequency domain, a time (range) Shifting will be produced when the Inverse Fourier Transform is applied to the signal. In figure (3) shows the range profiles (absolute value of the IFFT of the data) of a sampled signal S and the corrected signal Scorr are shown.

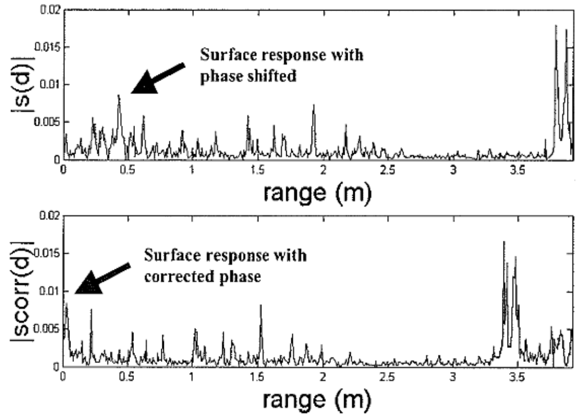

Fig. 3. (Top) sampled signal range profile, (Bottom) corrected signal range profile generated for a buried plastic landmine in sand

In order to obtain responses at different distances, the IFFT is applied to the phase corrected complex data vector Scorr.

$$\mathrm{Scorr}(ds, f) = A.\, e^{-i2\pi 2df/C} \,.\, e^{-i2\pi 2d\Delta fk/C} \quad (26)$$

Where f = fo + KΔf, fo is the initial frequency, Δf is the frequency step, and K is the number of steps.

$$\mathrm{scorr} = A.\, e^{-i2\pi 2df/C} \sum .\, e^{-i2\pi 2d\Delta fk/C} \,.\, e^{i2\pi kn/N} \quad (27)$$

If A is assumed to be 1,

$$\mathrm{scorr} = e^{-i2\pi 2df/C} \sum .\, e^{-i2\pi 2d\Delta fk/C} \,.\, e^{i2\pi kn/N} \quad (28)$$

Hence, the obtained vector Scorr is a function of the distance ds and the response of A reflecting object will have a sinc shape. A range Profile is obtained by taking the absolute value of Scorr as shown in figure (4).

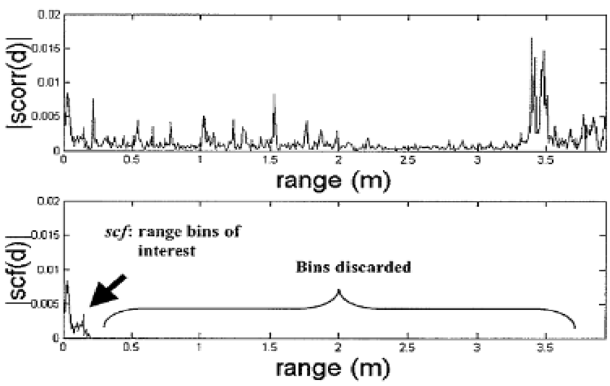

Fig.4. plot of the corrected signal above and the complex range function obtained by applying IFFT.

Theoretically, these responses are the responses of reflecting objects that are located beyond the range of interest. Since these Peaks obscure the weak reflections contained in the range of interest dint, they are simply discarded. The vector containing the remaining range bins of interest is named scf.

D. First difference in range direction

Once a range complex Profile Scf is available that contains the Responses of the reflecting objects located within the range of interest, the first difference is applied in the range domain [8]. The purpose is to detect transitions in the responses in order to emphasize the presence of the weak reflections from the plastic landmine. The first difference is applied as follows and results will be as shown in figure (5).

$$\mathrm{Sdern} = \mathrm{Scfn} - \mathrm{Sdfn}\text{-}1 \quad (29)$$

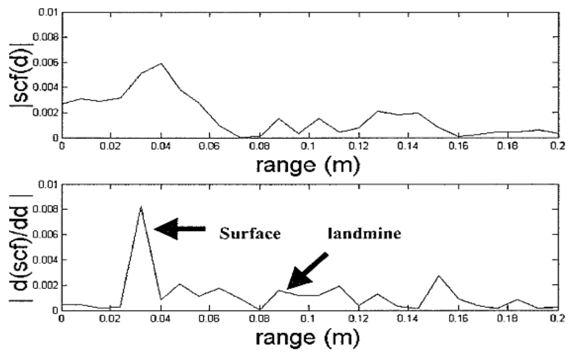

Fig. 5. scf range profile(top), sder range profile (button)

IV. SAR PROCESSING AND SIMULATION RESULS

A signal burst (i.e. A set of continuous wave signals) with N frequencies is transmitted, received and stored at the current GPR location and the (IFFT) is applied to it in order to obtain a complex range profile as it has been explained in [4],[9]. Then the GPR moves to the next position over the ground by advancing one cross-range step Δdc and the process is repeated until a set of L complex range profiles is collected and a SAR complex data array with dimensions N×L is stored, as shown in Figure [6].The set of L data vectors can be viewed As the equivalent of the received signal of a single antenna with a length dc = L * Δdc This Process is known as synthetic aperture radar. The SAR response is the integration of the signal received from a point target at each of the L antenna positions.

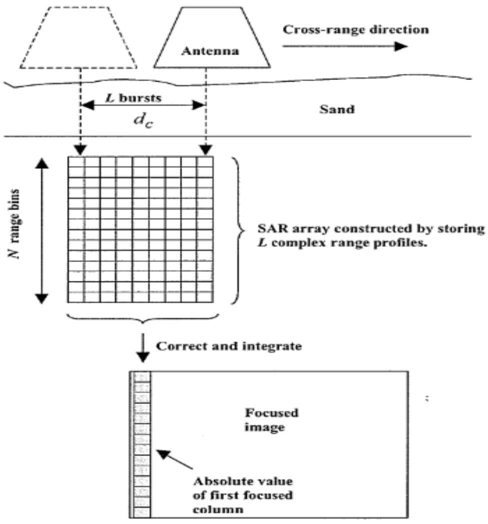

Fig. 6. SAR image being formed

A. SAR range curvature correction

If the absolute value Of the SAR array were displayed at this Point, the image would be unfocused. This occurs due to the distance differences between the center of the synthetic antenna and the reflecting object at each cross-range location as shown in figure(7).

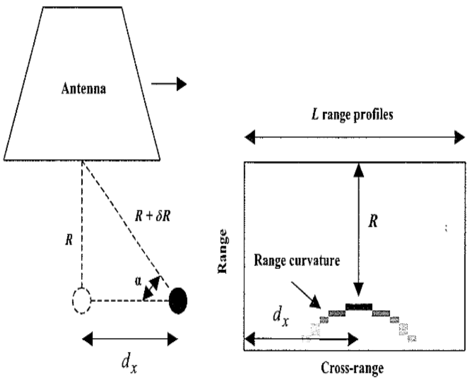

Fig. 7. GPR moving and an example of unfocused image obtained by displaying the absolute value of the SAR array.

The Quadratic distance БR from the top center cell in the SAR array to each of the other cells that causes the range curvature (hyperbolic response) is pre-computed using(3.18).

$$\delta R = \sqrt{R^2 + dx^2} - R \qquad (30)$$

Each δRis used to construct a two-dimensional correction exponential matrix as

$$Esar = e^{-i2\pi\delta Rf/C} \qquad (31)$$

This exponential is point by point multiplied by the SAR array in the frequency domain as

$$SARk, l= Esark,l \,.\, \zeta\,\{sarn,1\} \qquad (32)$$

Where ζ { } denotes the Fourier transform. Then SARk,l is transformed back producing the corrected array sarfn,1.

B. SAR Integration

As mentioned before, the received signal is the sum of the reflections from all the objects illuminated by the antenna beam. Because in the corrected array sarfn,1 the range responses from each reflecting cell are aligned, the columns in the array arc summed horizontally in order to synthesize a single complex range profile scmpn.

$$scmpn = \sum_{l=-L/2}^{L/2} sarfn, 1 \qquad (33)$$

Where, L is the number of columns in the SAR array, and the subscript m denotes the column number in the final image F. At this point, the first column of the sarn,1 array is discarded. Because at the next antenna position a new column will be appended, the dimensions of the array are kept constant.

C. Adaptive reference subtraction

The first difference is applied to the incoming data vector scmpn,m in order to attempt to detect transitions in the cross-range direction within the depth of interest. It is applied as

$$scdern,m = scmpn,m - scmpn,m \qquad (34)$$

In order to illustrate the purpose of this process, figure (8) shows a two-dimensional image in which the absolute value of scder n is displayed. The image contains the response of a plastic landmine buried in sand. In this simulation, the range of interest dint is 20cm, the cross-range step Δdc is 1cm, L is 20cm and the GPR traveled distance is 1m. The absolute value of scmpn,m , in which the first difference was not applied is shown in figure(9).

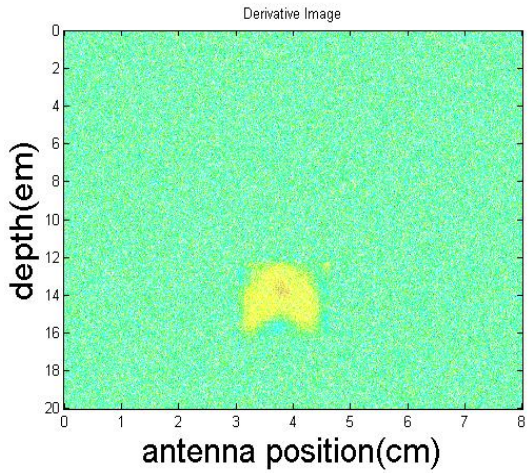

Fig. 8. Image of the absolute value of scder n,m . The reflections of a plastic mine buried in sand are noticeable.

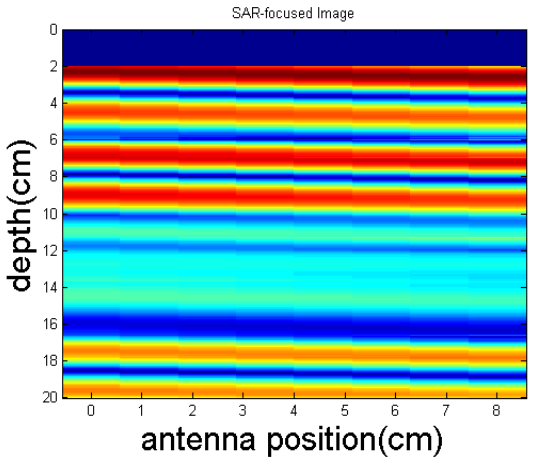

Fig. 9. Absolute value of scmpn,m in which no derivative is applied.

By comparing these two images it is evident that the first difference works effectively in enhancing the weak responses of the plastic mine.

V. CONCLUSION

In this paper, a digital signal processing algorithm has been introduced that used to detect responses of weak reflecting objects buried in sand. Although a low contrast exists between the plastic landmine and the sand responses, the algorithm was able to enhance the weak responses of the landmine in the obtained images. The main advantages of the proposed system are that images of buried weak reflectors are obtained without the need of a pre-scanned complex matrix. The future work concerns the implementation of this algorithm and enhancing it by applying the Multiple Signal Classification (MUSIC) algorithm.

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