A METHOD FOR COMBINING FOCUSED MONOSTATIC AND BISTATIC GPR TO REDUCE MULTIPATH EFFECTS

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ABSTRACT

Imaging of buried objects using subsurface microwave technology can result in images with numerous undesirable artifacts due in part to noise and multipath scattering. In order to alleviate the problem of multipath scattering, the authors propose the combined use of monostatic and bistatic systems. Focusing both images and compensating the bistatic system enables us to place the direct path scatterers at the same position as in the monostatic case. A multiplication of the final images will attenuate the scatterers that are formed by multiple reflections and will therefore reduce artifacts. Results are shown using simulations in which the signatures of several point scatterers overlap for the direct reflections and where the multipath signatures do not; thus allowing the multiplication to enhance the final image.

1. INTRODUCTION

Ground Penetrating Radar (GPR) has become a common tool for the detection of buried objects due to its efficacy to obtain subsurface images [1]. GPR radiates pulses into the ground and records the echoes received from the different objects present in the scan area. However, target signatures are usually obscured by the high intensity ground surface signature and clutter, making target identification a difficult task. As discussed in [2], there are several factors that contribute to the formation of clutter such as inhomogeneities in the scan area and multipath reflections.

In order to enhance target visualization, background subtraction is usually performed to reduce clutter. This process consists of subtracting each of the received signals from a clutter scan reference [1]. The reference is taken from an area where no objects of interest are present, limiting its use in eliminating the clutter produced by multiple reflections between targets. This paper proposes the use of a multisensor approach to effectively reduce clutter produced by multiple reflections.

Data acquired using both monostatic and bistatic scan modes is jointly processed in order to enhance target reflections. As discussed in [3], a multisensor approach via the use of more than one bistatic system can be used to visually determine multipath reflections that often result in false target detection in airport surface radar scenarios.
The assumption, as indicated in [3], is that false multipath targets detected by the monostatic system are located at different positions from the bistatic case. Our approach is based on this assumption as well. The results of both imaging systems (mono and bistatic) are combined in order to obtain a final enhanced image. Our reason for using a monostatic and a bistatic system together is to keep the number of antennas to a minimum and to have a compact system suitable for future GPR field applications.

2. METHODOLOGY

The general block diagram of the method is shown in Fig. 1. Both monostatic and bistatic scans go through a wavefront reconstruction algorithm to produce focused images. Then, the focused bistatic image is shifted in both range and cross range directions and finally, the shifted focused bistatic and focused monostatic images are multiplied to produce the final image. More detail of the algorithm is given below.

The geometry of the monostatic system is shown in Fig. 2. In the monostatic configuration one antenna works both as the transmitter and receiver while in the bistatic case (Fig. 3) one antenna works as a transmitter and the other one as the receiver. The antennas move in the x (cross range) direction. At several equidistant positions a signal is transmitted and the received signal is recorded.

In the following discussion, environmental clutter is assumed to be removed. This can be achieved by using various techniques such as the ones proposed in [1], [4] and [5].

Consider a scan area containing T point scatterers. To form a monostatic GPR image, a single transmitter-receiver antenna is moved across the x-direction. The distance between the nth antenna position and target p is, \( R = \sqrt{(x_p - x_n)^2 + y_p^2} \), where \((x_n,0)\) and \((x_p,y_p)\) are the nth antenna and the pth target coordinates respectively. As a pulse signal \( f(t) \) is irradiated at each location, a response of the form:

\[
s_m(t,x_n) = \sum_{j=1}^{T} a_{jn} f(t - \frac{2\sqrt{(x_j - x_n)^2 + y_j^2}}{\nu}) \quad (1)
\]

is recorded, where \( \nu \) is the propagation speed of the medium and \( a_{jn} \) is the attenuation factor due to the distance between the target and antenna and is equal to:

\[
a_{jn} = \delta_j \frac{1}{4\pi((x_j - x_n)^2 + y_j^2)} \quad (2)
\]

where \( \delta_j \) is the radar cross section of the target and in our simulation is always equal to 1.

In the bistatic case, a transmitter antenna illuminates the region and a receiver antenna records the reflections from the media. The recorded signal has the form:

\[
s_b(t,x_m,x_n) = \sum_{j=1}^{T} a_{jn} f(t - \frac{2\sqrt{(x_j - x_m)^2 + y_j^2}}{\nu}) \quad (3)
\]

where \( x_m \) and \( x_n \) are the nth antenna positions for the receiver and transmitter respectively.

In Eq. 1. and Eq. 3, the multipath effect artifact is neglected. In the presence of this effect, Equations 1 and 3 become:

\[
s_m(t,x_n) = \sum_{j=1}^{T} a_{jn} g_j(t - \frac{2\sqrt{(x_j - x_n)^2 + y_j^2}}{\nu}) \quad (4)
\]

\[
s_b(t,x_m,x_n) = \sum_{j=1}^{T} a_{jn} g_j(t - \frac{2\sqrt{(x_j - x_m)^2 + y_j^2}}{\nu}) \quad (5)
\]

where:

\[
g_j(t) = \sum_{k=1}^{T} a_{kj} f(t - \frac{\sqrt{(x_k - x_n)^2 + y_k^2}}{\nu})
\]

\[
+ \frac{\sqrt{(x_k - x_m)^2 + (y_k - y_m)^2)}}{\nu})
\]

where \( a_{kj} \) is the attenuation factor due to the distance between the two point scatterers and is equal to:

\[
a_{jn} = \delta_j \frac{1}{4\pi((x_j - x_n)^2 + (y_j - y_n)^2)} \quad (7)
\]

No simple relationship can be observed between the monostatic and bistatic reflections from the same target in the time domain. However, as discussed in [6], such a relationship can be clearly seen between Eq. 1. and Eq. 3, in the frequency domain for the far field approximation case. Although there is no straightforward approach to calculate the 2-D spectrum of (1) and (3), the stationary phase method can be used to evaluate the resulting Fourier integrals [7].

The spectra of \( s_m(t,x_m) \) and \( s_b(t,x_m) \) are given by:

\[
S_{sp}(\omega,k_x) = \sigma_p F(\omega,k_x) \cdot \exp[-j(\sqrt{4k_x^2 - k_p^2} R_p^2] \quad (8)
\]

and

\[
S_{bp}(\omega,k_x) = \sigma_p F(\omega,k_x) \cdot \exp[-j(\sqrt{4k_x^2 - k_p^2} R_p^2] \quad (9)
\]

where \( F(\omega,k_x) \) is the Fourier transform of the emitted pulse, \( k \) is the wavenumber, \( k_x \) denotes the spatial frequency on the cross range direction, \( R_p \) is the separation between the transmitter and the receiver antennas, and \( R_f \) is the depth of the region of interest within the scan area.
It can be seen that the bistatic spectrum is the same as the monostatic one except for the term \( \exp[-j\left(4k^2 - k_r^2 \frac{R^2}{8R_i} + k_r \frac{R_k}{2}\right)] \) which introduces shifts in the range and cross range directions in the reconstructed image.

Thus, after compensating for the aforementioned shifting, target reflections from both monostatic and bistatic reconstructed images are at the same spatial locations for the direct path trajectories. However, the same is not true for the location of the artifacts due to multipath effects. Therefore, in order to enhance the target responses, the two responses are multiplied and the product image is displayed.

3. RESULTS

In order to assess the validity of the proposed method, simulated data was produced. The radar simulator is based on the signal models shown in section 2. In order to focus the hyperbolic signatures, the simulated data was compensated using wavefront reconstruction techniques based on [6, 8]. The target region was composed of three point scatterers at (1, -0.4), (1.2, 0) and (0.7, 0.2) meters. The irradiation was performed at equidistant increments of 1 cm. The length of the scan trajectory was 2m. At each scan location, a stepped frequency continuous wave signal was used. This signal had a bandwidth of 10 GHz and a center frequency of 6 GHz. In the bistatic case, the separation between antennas was 0.5m. The depth of interest within the scan area was 1.2 m. The efficiency of the method decreases when the targets are closer to the antennas. For example, Fig. 9 shows a target region composed of three point scatterers at (0.5, -0.4), (0.6, 0) and (0.35, 0.2) meters. In this case the range locations of the targets are halved compared to the previous example. As illustrated in the figure, the multipath artifacts are not effectively canceled under these conditions. The reason for this is that the approximation in this method is based on a far field assumption.

4. CONCLUSIONS

In this paper, the use of a multisensor approach to eliminate multipath clutter on GPR imagery was addressed. The relationship between monostatic and bistatic data was used to enhance direct target reflections and to eliminate multipath reflections. The proposed algorithm yielded good results when applied to simulated data under far field conditions. Future research will concentrate on taking advantage of additional antennas which can potentially increase the efficiency of the method in near field.

5. REFERENCES