Bistatic Radar Signature of Buried Landmines

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Abstract

With the proliferation of low-intensity conflict, landmines have proven to be one of the weapons of choice for both government and guerrilla forces around the world. Recent improvements to mine technology pose increasingly significant problems for demining operations, requiring the constant upgrading of countermine technologies. Ground Penetrating Radar (GPR) is one of the most exhaustively researched topics in the detection of buried mines as it can be used to detect non-metallic and plastic mines. However, identification and recognition are still unsolved problems, due to the scattering similarity between mines and clutter objects. This study provides an experimental evaluation of the improvements that a bistatic approach could yield and what can be gained from investigating the angular dependencies of the radar signature.

1 Introduction

Amongst the other geophysical investigation methods, Ground Penetrating Radar (GPR) appears to be a promising candidate, as it allows non-invasive and cost-effective surveys to be undertaken, and has the advantage of a high resolution imaging capability ([1] [2]). GPR operates by transmitting an electromagnetic signal into the subsurface and detecting a target reflected signal at a receiver antenna, reflection due to the dielectric discontinuity between the target and the surrounding medium. GPR has a wide range of applications in archaeology ([3] [4]), engineering ([5] [6]), and geological applications ([7] [8]).

One of the problems with GPR for landmine detection is that dielectric discontinuities occur at places other than the mine, such as roots, rocks and hollows, as well as other battlefield debris. These reflections can hide the existence of a mine by cluttering the return signal and provide false alarms [9].

Typical GPR surveys are collected in common offset mode, where one transmitting and one receiving antenna move together along the surface keeping a constant offset. Generally, such configuration is also reposted as monostatic or quasi-monostatic because the two antennas are almost co-located. Although the majority of experimental trials have been performed following this approach, a bistatic geometries, in which the transmitter and the receiver are

independently managed, may offer several key benefits, especially for low-observable targets or low SNR scenarios ([10] [11]). For example, targets designed to minimise backscatter might be easily detected by a bistatic configuration. Objects with irregular or rough shape could reflect the incident wave in a particular direction far from the monostatic receiver, thus multiple looks at a target from a variety of antenna spacing could make it easier to distinguish target of interest from clutter features ([12]). Finally, changing the transmitter and receiver distance can better highlight targets with composite structure and internal assemblies.

As most of antipersonnel landmines are made in plastic, with a metal content limited to a couple of grams, their detection and discrimination from objects causing false alarms can be improved by exploiting their bistatic signature. In opposition to metallic targets, a variation of the separation between antennas will illuminate a progressively different internal section of the target, generating a signature clearly affected by the characteristics of that particular area.

Employing a number of representative inert landmines buried in a sharp sand environment, the paper presents the results of a preliminary characterisation of the bistatic signature of buried landmine to demonstrate that such approach can effectively enhance the knowledge of the features of the detected target and highlight the eventual presence of internal structures.

2 Target and acquisition description

A set of bistatic signatures from three different inert landmines has been acquired in a test sand pit located at the Defence Academy of the United Kingdom in Shrivenham (Figure 1a). The sharp sandy material of the pit is characterised by a very low clay content and a gritty texture for a better drainage and to avoid trench effects during digging operations (Figure 1b).

Figure 1: Experimental environment. (a) Test pit. (b) Host material.

The GPR equipment employed for the measurements consisted of an IDS Aladdin radar and an IDS THRHF radar, both provided by IDS Georadar srl. The two impulsed devices carry dipole antennas with a central frequency and a bandwidth of 2 GHz and 3 GHz, respectively. A soft pad, the PSG (Pad System for Georadar, U.S. Patent no. US 7,199,748 B2 of Politecnico di Milano, Italy, [13]), was placed between the radar equipment and the soil to ensure a better coupling and fixed antenna orientation from trace to trace REF. Measurement set-up is pictured in Figure 2.

Figure 2: Measurement details. (a) Data acquisition. (b) Employed GPR devices.

The ensemble of bistatic signatures has been collected by progressively shifting both the transmitter and the receiver away from the target location, known as *Common Mid Point* (CMP) acquisition. The CMP sounding is completed by progressively increasing the transmitter/receiver separation (offset) of the antennas in steps relative to the selected mid-point location along the original profile. The process is sketched in Figure 3. An accurate positioning has been achieved by jointly employing an odometric wheel (visible in Figure 2b).
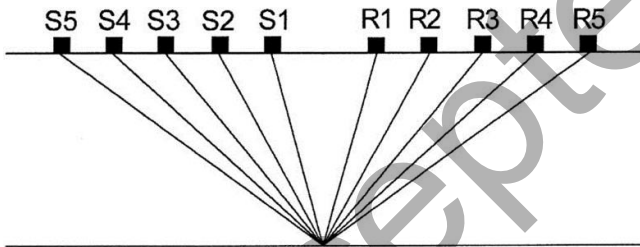

Figure 3: CMP acquisition scheme. S_i represents the source location, while R_i stands for the receiver position.

The higher frequency equipment acted as the receiver module to take advantage of the finer sensitivity of its components. Acquisition details are provided in Table 1.

Parameter	Value
Separation range	6 – 33 cm
Offset increment	1 cm
Time window	30 ns
Time sampling	0.0587 ns

Table 1: acquisition details.

No processing steps have been computed on the data to preserve their original features and to avoid eventual artefacts ([14]).

It is essential that properly constructed inert landmines are used for research and development, otherwise the results could be significantly affected or misleading. For the purpose of this research, a number of representative landmine models, provided by the Defence Academy of the United Kingdom, were used and their bistatic signature was acquired.

These were complete with all their external and internal components and were filled with a high explosive simulant commonly used to train the UK Ammunition Technical Officers; the substance has the same electrical and chemical properties of commonly employed explosive materials.

In particular, the Italians VS-50 and SB-33, and a Soviet PFM-1 devices were investigated. Targets are pictured in Figure 4, and their geometrical features are described in Table 2 ([15]).

Figure 4: Investigated targets. From left to right: SB-33, VS-50 and PFM-1 model.

Model	Length/Width/Height [mm]
SB-33	85 / 85 / 30
VS-50	90 / 90 / 45
PFM-1	120 / 20 / 61

Table 2: Targets descriptions.

Targets were buried at approximately 10 cm, with their activator plate pointing toward the surface, as shown in Figure 4.

Special reference needs to be made to the scatterable PFM-1 landmine, which is in reality filled with a liquid explosive and not with a solid mixture. However, this limitation is negligible for the scope of this study.

Moreover, as the main purpose was to evaluate the efficacy of this approach for detecting internal scattering mechanisms, the choice of these particular targets answers the need of having a group of devices with different design and structure (Figure 5).

Figure 5: Details of the target design. (a) SB-33 and (b) VS-50 device. *Courtesy of Cranfield University.*

3 Results

Bistatic signatures of landmines are presented in the commonly employed range versus offset display, in which the

bistatic angle is computed from the distance between the transmitter/receiver antenna and the target depth.

Results of the PFM-1 landmine are displayed in Figure 6. A single reflection is visible, with a spatial extension directly linked to the physical dimension of the target, and no further events are detectable. Given the nature of the target, a solid dielectric component, this was expectable.
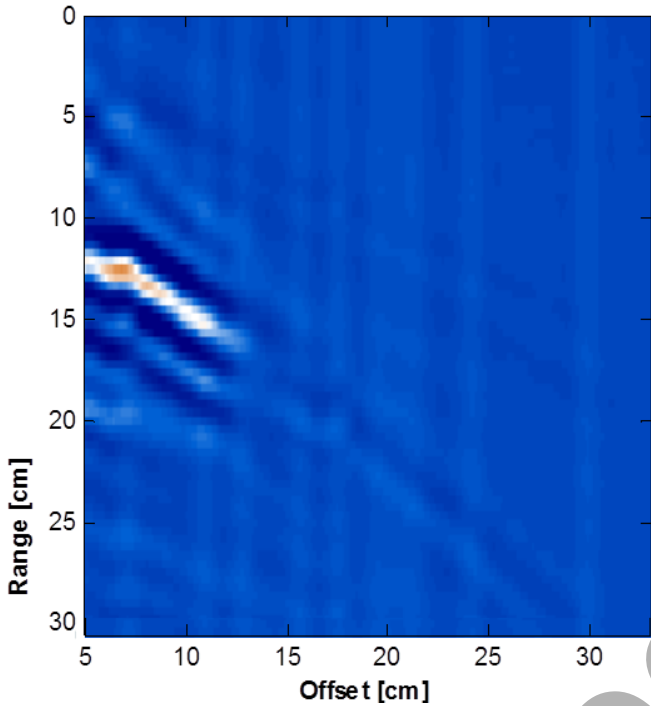

Figure 6: Bistatic signature of the PFM-1 landmine.

Situation changes when the illuminated target includes internal assemblies, which is the case for the following devices. Because the antenna separation controls the vertical position of the reflection plane, as described before, the presence of a structure beneath the top layer of the mine will generate an additional scattering feature which hopefully would be stronger under particular incident angles.

The bistatic signatures of the VS-50, shown in Figure 7, support these hypotheses. In this case, three events are detectable, events that have almost the same spatial extension. While the upper and lower reflections are due to the top and the bottom of the landmine, the middle one is due to an internal structure. Its constant trend over the separation range assumes an internal layer covering the whole landmine extension. Considering the design of the target, Figure 5b, the detected multiple reflections is due to the presence, below the activator plate, of a sunburst of air gaps, which allow the detonation to take place.

In opposition to the previously described targets, the SB-33 landmine presents a highly heterogeneous internal design, as can be hinted from Figure 5a. Their ranges versus offset results are provided in Figure 8.

Also in this case, more than one reflection is evident, depicting a target with a composite structure. However, the middle reflection is spatially longer than the top and bottom one, demonstrating that the scattering event is not homogeneous over the target space. The responsible of this reflection is the void located aside the detonator which is located in a particular section of the target. In this case the advantage of a bistatic approach is clearly visible, as this reflection is stronger under a particular angular range, differently from the other reflections. Finally, as the extension of the upper and lower reflections is a marker of the target physical dimension, in this case a smaller object is identified, in agreement with the characteristics detailed in Table 2.
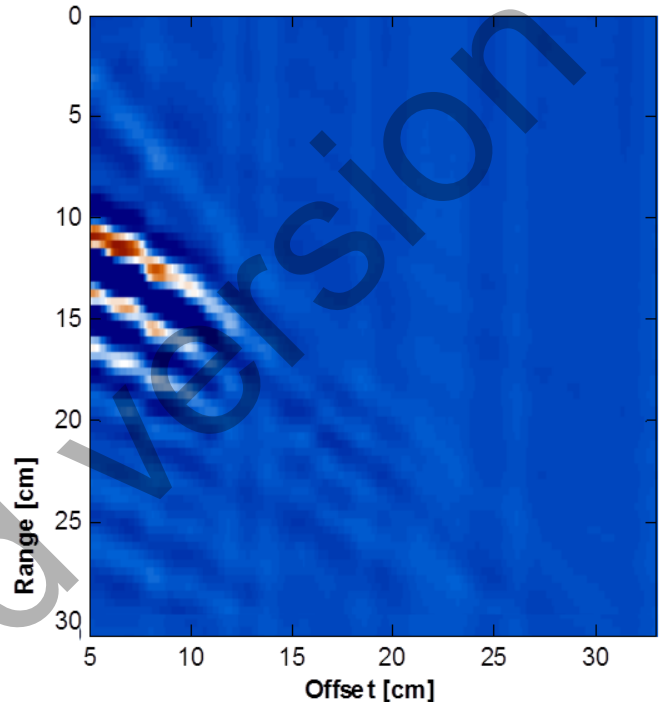

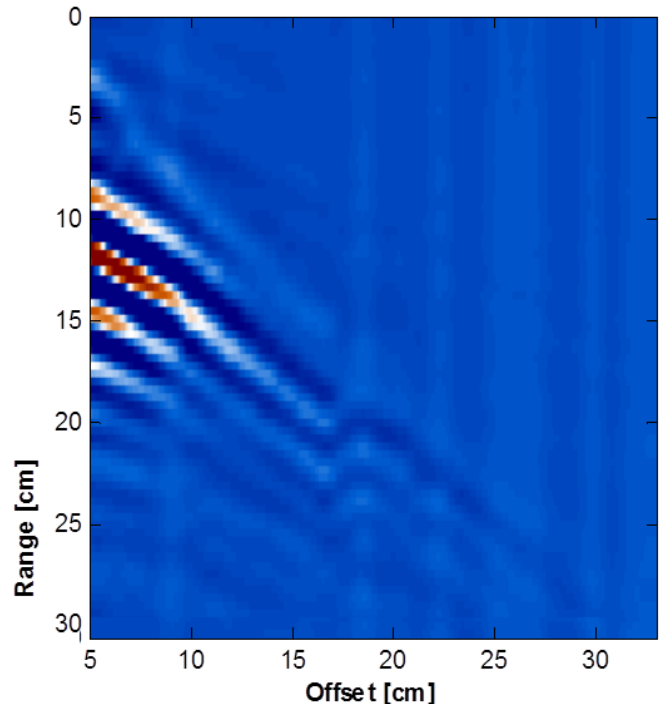Figure 7: Bistatic signature of the VS-50 landmine.

Figure 8: Bistatic signature of the VS-50 landmine.

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4 Conclusions

The presented research has investigated the capabilities and advantage of a bistatic approach for landmine recognition. In particular, three different representative landmines have been investigated, each of them with a different external and internal design. The outcomes demonstrated that acquiring the signature changing the transmitter and receiver separation could yield additional information on the eventual presence of internal components, feature which is unlikely to be present in commonly encountered clutter objects. Hence, the possibility of detecting this feature, which can be considered as a discriminant characteristic, could significantly improve the performance of GPR and enhance its deployment as a landmine detection sensor. These results should be compared to the equivalent signatures of clutter targets, to further demonstrate the efficacy of this acquisition approach.

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