Extraction of Landmine Signature from Ground Penetrating Radar Signal

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Abstract—With its principle of detection based upon electromagnetic (EM) wave propagation parameters inhomogeneities within the medium under consideration, ground penetrating radar (GPR) is poised to be a very valuable tool in the field of humanitarian demining, especially for the detection of plastic landmines. In this regard, however, its performances strongly depend upon the EM properties of the medium surrounding the target, and upon the dielectric contrast between the target and the surrounding medium.

After a short introduction to the world landmine problem, this article presents the extraction and modeling of buried targets signatures from a stepped-frequency continuous wave GPR signal. The signal is decomposed in its soil and target-in-soil contributions. The mine signature extraction process is detailed, and the outline of the GPR model used to simulate these signatures is also presented. More importantly, the reasons for mine signature extraction and simulation are discussed. This development is completed by the validation of the numerical model, which shows encouraging results for the path of research.

I. Mine facts and figures

The following figures can be found at the following addresses: www.state.gov/t/pm/wra/ and www.cirnetwork.org/info/fact_sheet.cfm.

A. Mines by the numbers

Landmines
- are estimated to be 45-50 million infesting at least 12 million km$^2$ of land
- affect more than 100 countries
- heavily affect 20 countries: Angola, Afghanistan, Croatia, Egypt, Cambodia, ...
- kill or maim a reported 10,000 people annually (UNICEF: 30–40% of victims are children of 15 or less)
- cost US$3–30 the unit.

B. Heavy economical impact

Landmines
- create millions of refugees
- prevent hundreds of thousands of km$^2$ of agricultural land from being used
- deny thousands of km of roads for travel
- costs US$300–1,000 the unit
- is slow: ~100,000 mines/year cleared.

So there is a real need for a faster, cheaper and more secure demining process. It includes, but is not limited to:

- improve currently used detectors
- increase research on new technologies

The list of currently available detectors and prototypes is presented at table I.

II. Radar system description

We use a stepped-frequency continuous wave (SFCW) radar because it possesses several advantages over the time domain technology [1], among which:

- possible to control the signal over a very large bandwidth (0.75–4 GHz)
- ease of characterization of the elements of the system (cables, antenna)

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• better signal-to-noise ratio (SNR) than for time-domain GPRs.

The antenna is used off-ground and has the following features:
• TEM horn (high directivity)
• used in monostatic mode (simpler modeling, shorter round-trip path).

The radar system is emulated by a vector-network analyzer (VNA). The measured signal is $S_{11}(\omega)$.

### III. Radar System Modeling

The signal measured by the radar is the sum of two contributions:

$$S_{11}^{\text{total}} = S_{11}^{\text{soil}} + S_{11}^{\text{target}}$$  \hspace{1cm} (1)

which can be rewritten using a transfer functions formalism as (Fig. (b); $H_m$ is neglected):

$$S_{11}^{\text{total}} = H_i + H (G_s + G_t)$$  \hspace{1cm} (2)

where

- $G_t$ is the “signature” of the target
- $G_s$ is the Green's function of the soil, and can be computed once $(\varepsilon_1, \mu_1), \ldots, (\varepsilon_N, \mu_N)$ are known
- $H_i, H$ are the transfer functions of the antenna.

$G_t$ depends upon many parameters, among others the depth of the target in the medium and the soil EM parameters. From (2) we have that

$$G_t = \frac{S_{11}^{\text{total}} - H_i - H G_s}{H}.$$  \hspace{1cm} (3)

$G_t$ can be computed thanks to a proper soil-target system modeling, for which we used the method of moments for objects embedded in stratified media [2] (not developed here).

### IV. Mine Signature Extraction and Simulation

#### A. Measured signature extraction process

The extraction of the mine signature is done in three steps:
1) determination the characteristics $H_i, H = H_i H_r$ of the antenna by measurements
2) extraction of the soil EM parameters $(\varepsilon_1, \mu_1), \ldots, (\varepsilon_N, \mu_N)$ (Fig. (a)) by inversion of the radar model for a soil without a target
3) subtraction of the soil contribution from the total radar signal and division of the difference by $H$ (see (3)).

The advantage of this method w.r.t. a classical extraction by moving average window is that once the soil EM parameters are known, the background can be subtracted from the total signal, for any height of the antenna, as $G_s$ can be computed once the soil EM parameters are known [3]–[6].

#### B. Example of measured signatures

Measurements for a soil at different moistures and containing different targets have been made (Fig. 2). Fig. 2(a) shows the time-domain $S_{11}(t)$ for a 4-layered propagation medium containing an AP PMN Russian mine, without filtering out the soil response; Fig. 2(b) shows the time-domain signature of the mine after extraction of the soil response in the frequency domain, which had been previously measured. The abscissa “configuration” refers to the water content of the layer containing the objects (1 is 0%, 9 is 25%). In configurations 1–6, the filtered signal shows much more clearly the presence of the mine, and the time position permits to accurately retrieve the depth of the target and correspond very well to the theoretical value. The reasons why configurations 7–9 led to less satisfactory results has still to be explained.

#### C. Signature simulation

Simulating mine signatures allows one to:
1) get an understanding of the physics of real experiments
2) set an upper limit for the performances of a GPR given a physical environment.

The first point is demonstrated at Fig. 3, where a virtual B scan in free space and in a layered medium are shown. The characteristic time domain hyperbola appears twice in the right figure, as the last layer is a PEC metal sheet. One can also see that the multiple reflections between the top and bottom of the cylinder are decaying faster in the layered medium, as the layer containing the target is lossy.

The second point can be inferred from the observation that in the simulations, no statistical imperfections such as soil roughness or clutter for example, are taken into account. So, if the modeling has been validated in quasi-ideal conditions, we can use it as an upper limit as follows: if, for a given soil and mine, the simulator gives a “not detected” answer, it is highly probable that in real field conditions the detector will also miss the target.

### V. Radar and Soil-Target Models Validation

In this scope experiments involving a conducting sphere embedded in a stratified medium have been led; the resulting extracted signatures are compared to simulations at Fig. 4.

The PEC sphere has a 5 cm radius and the 4-layers medium is constituted as follows: air, sand with 5% moisture and 15.4 cm thick, sand with 10% moisture and 13.5 cm thick, metal plane.

The reason why the computed signature is smaller in amplitude than its measured counterpart (see left figure) may be due to:

- directive radiation pattern of the TEM antenna not accounted for in the radar model
- remove-and-replace process necessary to introduce the mine in the soil which introduces air in the sand and lowers the value of its EM parameters.

The right figure shows these computed and measured signatures of the sphere in the time-domain. The time dependence
Fig. 1. Left: physical modeling of the reality; right: conceptual transfer function model.

Fig. 2. Left: measured raw GPR signal; right: measurement extracted mine signature.
is correctly predicted; only the amplitude of the first reflection seems underestimated, probably for the reasons exposed above. There are two reflections: the first one is due to the sphere, while the second one is due to the lowest layer, a PEC plane. This validation process is very important, as the modeling will serve to establish an upper limit of detection capabilities for a given soil and mine.

VI. Summary

Landmines cause heavy problems in affected countries, and demining is costful and slow. It is necessary to improve the existing demining tools and methods w.r.t. speed, security, effectiveness and cost. Research has been focused on the GPR, in measurement information retrieval—that is, target signature extraction—as well as in modeling.

From the measurement point of view, mine signature extraction appears promising for GPR signal SNR enhancement (noise = soil reflections) and is important in view of target classification. It is based upon the knowledge of the soil EM parameters, which we can extract from soil GPR signal.

From the modeling point of view, mine signature simulation could be used for establishing an upper limit of the GPR detection capabilities for a given soil and mine. Furthermore it can be used to make “virtual” experiments, which yield a good “feeling” of what would happen in reality. A simulated signature simulation has been compared to its measured counterpart and have shown good agreement.

VII. Future Work

It includes, but is not limited to:
better modeling of the antenna radiation properties
wider testing of the model
study of the degradation of the signature extraction w.r.t.
soil roughness.

ACKNOWLEDGEMENT

This work has been partially funded by the Belgian Ministry of Defence (HuDem project) and is partially funded by the FRIA as well as by the Royal Military Academy of Brussels. The authors are grateful to Ir. Pascal Druyts for the many discussions involving this subject.

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