GPR - ELECTROMAGNETIC SENSOR ARRAY DATA FUSION

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Abstract. A major risk during the construction of highways, railways, civil and industrial buildings is represented by the existence in the soil of ammunition and unexploded mines. Supplementary, in localities, during the excavation, pipes, electrical cables, archaeological sites, the voids might be found. The modern method for their detection is Ground Penetrating Radar (GPR) which gives necessary information at the scanning of the surface to be examined. Due to the high frequency, the maximum depth at which the objects can be detected is limited to 4 - 4.5 m. In the same time, the radar-grams interpretation is quite complicate, requiring rich experience and a corresponding database. To increase the probability of detection and evaluation of buried objects and voids, in this paper we propose the using of data fusion between those delivered by GPR and those provided by the equipments based on electromagnetic induction (EMI).

Introduction

Soil is a natural composite, most times multiphase. The soil components are characterized, among others, by their electromagnetic properties as relative magnetic permeability (μ_r), relative dielectric permittivity (ε_r) and electrical conductivity (σ). These properties are significantly influenced by the environment conditions as humidity, pollution with different pollutants etc. When in soil are buried objects with electromagnetic properties different from those of the host soil, these can be detected using electromagnetic techniques [1], [2], [3].

The electromagnetic techniques are based on the scattering of electromagnetic field generated by an emission loop on the soil component and its detection with an adequate reception loop.

The used electromagnetic field can have relative low frequencies of few kilohertz to hundreds of kilohertz and then the method is named electromagnetic induction or relative high frequencies from hundreds of megahertz to few gigahertz, named ground penetrating radar [4].

The electromagnetic methods for soil condition evaluation are used in present for

- Archaeological investigations
- Borehole inspection
- Bridge deck analysis
- Building condition assessment
- Contaminated land investigation
- Detection of buried mines (anti-personnel, anti-tank) an unexploded ordnance
- Evaluation of reinforced concrete
- Forensic investigations
- Geophysical investigations
- Pipe and cable detection
- Soil track and bad inspection
- Road condition survey
- Security applications

An actually special domain of applications of the electromagnetic methods for soil investigation and detection and characterization of buried object is represented by the detection of buried mines and munitions. Abandoned anti-tank and anti-personnel land mines and unexploded ordnance are a major hindrance to the recovery of many countries from the war. Their effect on the civilian population is disastrous and major efforts are being made by the international community to clear the problem. Most detection is done with metal detectors, which respond to the large amount of metallic debris in abandoned battlefield areas and hence have difficulty in detecting the minimum metal or plastic mines. Electromagnetic technology is being applied to this problem as a means of reducing the false alarm rate and providing improved detection of low metal content mines.

The electromagnetic induction methods, due their relatively low frequencies, present the advantage of electromagnetic wave penetration at high depths in soil and the obtaining of information of scattering from objects buried at high depths. The method presents the disadvantage of a small operation speed and low spatial resolution (defined as minimum distance between two scattering bodies which deliver distinct information of the scattered electromagnetic field). Ground penetrating radar, due to the high frequency has a lower depth penetration, can operate at speeds big enough and has a good separation power.

This paper presents the results obtained at the survey of an experimental polygon in which different types and calibers of artillery munitions and plastic anti-tank and anti-personnel mines have been buried in different positions, using the two above mentioned methods, namely the electromagnetic induction (EMI) and the ground penetrating radar (GPR). To increase the probability of detection, reduction of false alarms as well as for improving the spatial resolution, we propose a data fusion method [5] using the theory of evidence [6].

Physical principle of utilized electromagnetic methods

The principle scheme of the electromagnetic induction (EMI) method is presented in Figure 1.

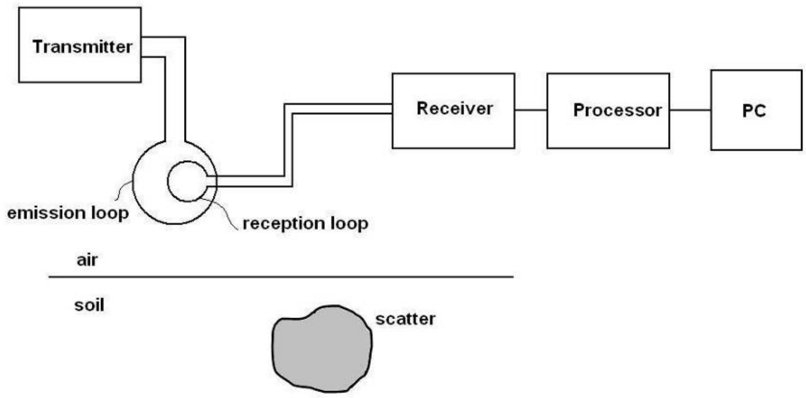

Figure 1. Block diagram of a generic EMI system

A transmitter delivers an alternative current with adjustable frequency in the range of tens of kilohertz to hundreds of kilohertz which circulates through a loop with prescribed geometric shape and one or multiple turns. Thus, around the emission loop, a sinusoidal electromagnetic field is created, which is partially reflected on the air-soil interface and is scattered by the scatter object having other electromagnetic properties than the host soil. The scattered field is detected by the reception loop, electronic processed, the information being processed and stored into a PC.

Due to the utilized low frequencies, the penetration depth is relatively large [7].

The ground penetrating radar (GPR) method has the principle scheme presented in Figure 2.

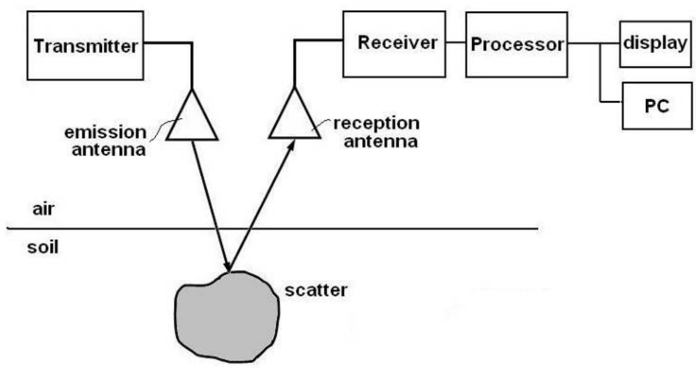

Figure 2. Block diagram of a generic GPR system

The electromagnetic wave created by the emission antenna partial penetrates the soil being reflected by the scatter. The reflected wave is picked up by the reception antenna and transformed in electrical signals which are appropriate processed. In this method, the time interval between the moment of electromagnetic impulse emission and the moment of reception of the signal reflected by the scatter from the soil, and the amplitude of reflected signal are measured [4].

Studied samples

Different types of artillery projectiles have been taken into study, being presented in Figure 3-6, as well as anti0tank mines, presented in Figure 7.

Figure 3. Ammunition with explosive projectiles, cal.76mm

Figure 4. 120mm HE mortar shell fitted with proximity fuze

Figure 5. 100mm artillery shells

Figure 6. 122mm CARGO

Figure 7. Anti-tank mine MAT 62B

The projectiles and the mines were buried into a soil having ε_r=4.2 and σ=0.1S/m, value determined with a Network/Spectrum/Impedance Analyzer, type 4395A Agilent – USA coupled with dielectric material test fixture type 16453A – Agilent USA.
The burial depth in all the cases was 60cm, the maximum burial depth of plastic anti-tank mines.

Experimental set-up

The equipment utilized for the electromagnetic induction method contains a programmable function generator type TABOR 1074 which fed a power amplifier type AG1012, delivering an alternative current with 1A amplitude on a plain rectangular spiral coil with 10 turns, 1m width and 25mm step.
It is detecting the E_x components of the electric field scattered by the buried object, using a sensor array made from 5x5 reception coils [8].
The coils from array are periodically interrogated, the induced signal being measured with a Lock-in Amplifier type SR 850 Stanford Research –USA. The commands of the components of the equipment as well as the acquisition of data are made by PC, the assembly being presented in Figure 8.

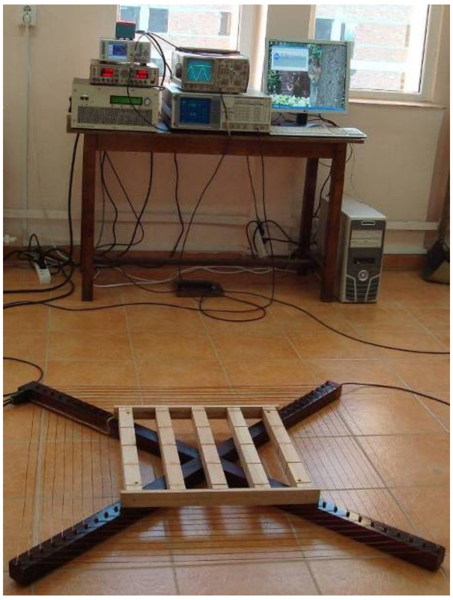

Figure 8. Experimental set-up for electromagnetic induction method

The ground penetrating radar utilized for the measurement is UtilityScan Standard System - GSSI – USA, with 400MHz antenna and an encoder mounted on the front survey cart wheel for an exact evaluation of the distances. The equipment measure the time intervals with 0.1ns precision and is presented in Figure 9.

Figure 9. Ground penetrating radar

Experimental results

In Figure 10 is presented the GPR indication for the survey of 3m distance over the zone where is buried an ammunition with explosive projectiles, cal.76mm, presented above in Figure 3, at depth of 0.6m.

Due to the fact that the body of ammunition with explosive projectiles is made from metal, with $\sigma=10^8$S/m, the reflection of electromagnetic wave is made with change sign ($\pm\pi/2$) of the phase. Thus, the indication will have light hue in gray scale. The shape of the indication is an hyperbola according to [4]. The same situations are observed in the Figures 11, 12 and 13.

It is difficult to make a correlation between the parameters of hyperbola and the caliber of the ammunition.

In Figure 14 is presented the GPR indication for the Anti-tank mine MAT 62B. As we were mentioned above, the mine is made from plastic, the quantity of metal is about few grams, thus the mine is difficult to be detected, the probability of false alarm being increased.
The plastic material will reflects the incident electromagnetic wave without changing of sign, thus the indication of GPR is the case of mine will have dark hue in gray scale, situation noted in the Figure 14.

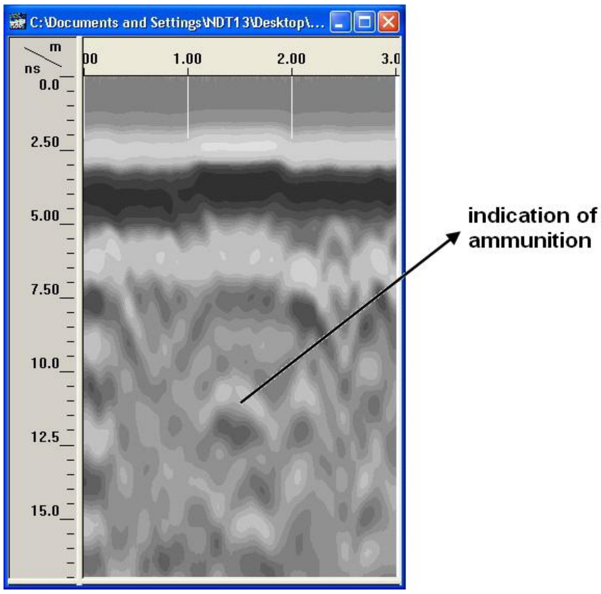

Figure 10. The GPR indication for ammunition with explosive projectiles, cal.76mm

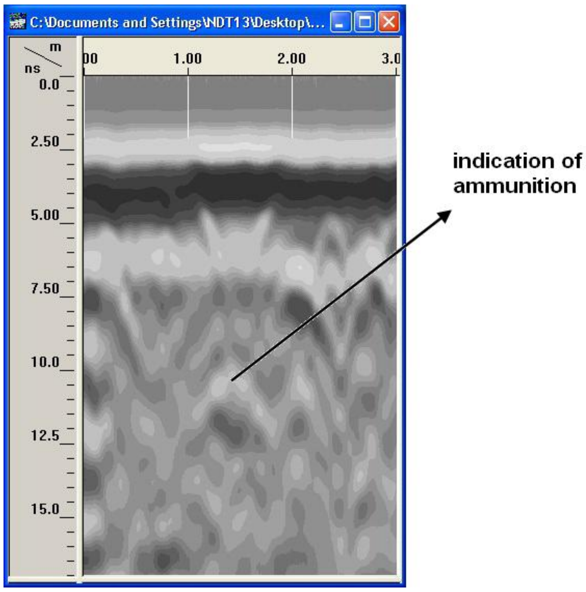

Figure 11. The GPR indication for 120mm HE mortar shell fitted with proximity fuze

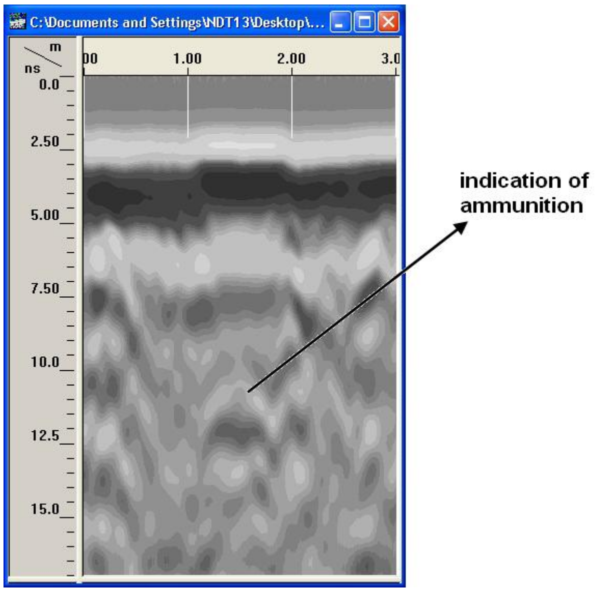

Figure 12. The GPR indication for 100mm artillery shells

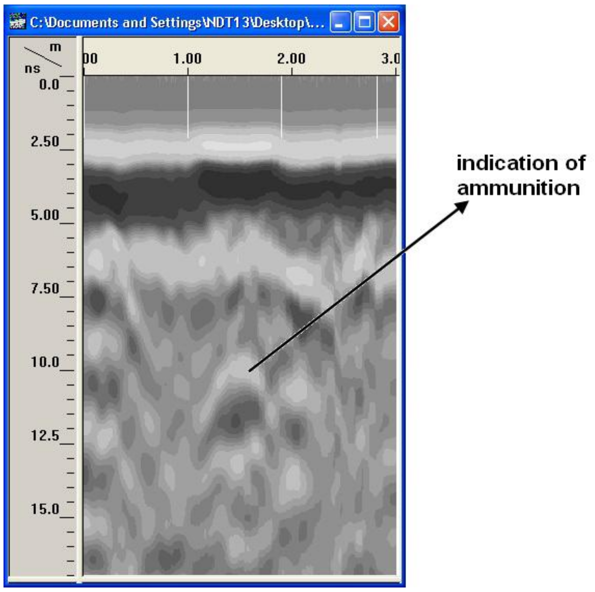

Figure 13. The GPR indication for 122mm CARGO

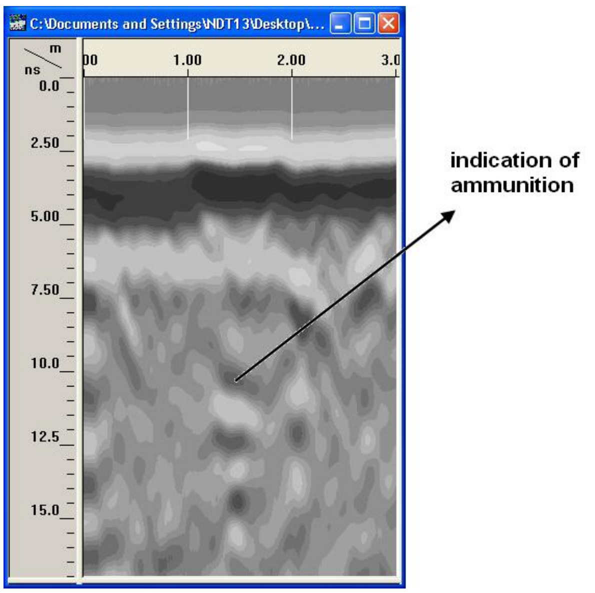

Figure 14. The GPR indication for Anti-tank mine MAT 62B

The electromagnetic induction method has the disadvantage of slow operation speed. In the case in which with the GPR, it is an indication difficult to interpretate, it is recommended the supplementary using of EMI and the realization of data fusion [5]. Using this procedure, we can obtain a C-Scan image of ammunition.
In Figure 15 is presented the result of data fusion between EMI and GPR obtained in the case of 122mm CARGO detection. In this case, the shape of the projectile is perfectly reconstructed, the procedure assuring a substantial increasing of the probability of detection and a substantial reduction of the probability of false alarm.

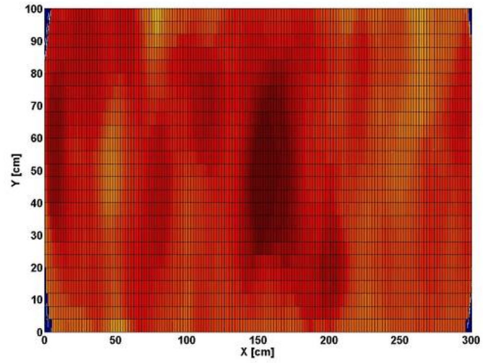

Figure 15. Data fusion results.

By the presented data fusion technique, the C-Scan image of the antitank mine MAT 62B can be obtained, buried at 60cm depth. This image is presented in Figure 16 and it is observed that the shape of mine is perfectly visible. The light color is due to the reflection without change of sign on the surface of mine.

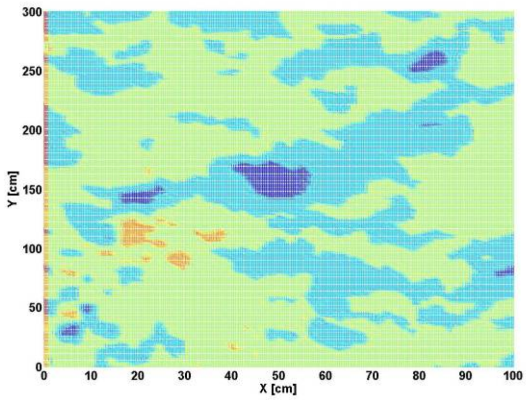

Figure 16. C-Scan of antitank mine

The proposed method also allows the increasing of spatial resolution of both methods, situation presented in Figure 17, for the case of two artillery shells, cal100mm.

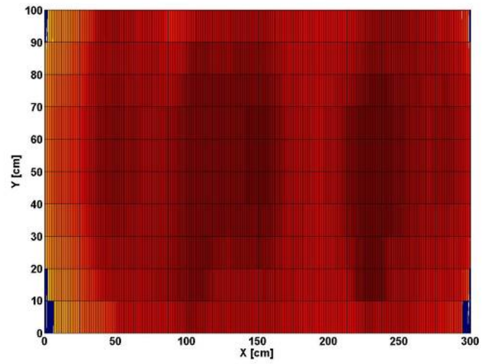

Figure 17. Results for 4 ammunitions

Analyzing the above figure, it is clearly shown the shape of the two projectiles that are tangent between them and another two projectiles placed in the lateral of the scanned zone.

Conclusions

The electromagnetic methods developed allow the detection with certitude of ammunition buried in soil. Even if in the case of plastic mines which by classical methods with metal detectors can not be practically detected, information with high level of confidence can be obtained. Using procedure of data fusion based by the theory of evidence, images C-scan with high level of confidence are obtained.

With these images, evaluation of the type of ammunition can be made.

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