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Prediction of the effects of soil and target properties on the antipersonnel landmine detection performance of ground-penetrating radar: A Colombian case study

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Abstract

The performance of ground-penetrating (GPR) radar is determined fundamentally by the soil electromagnetic (EM) properties and the target characteristics. In this paper, we predict the effects of such properties on the antipersonnel (AP) landmine detection performance of GPR in a Colombian scenario. Firstly, we use available soil geophysical information in existing pedotransfer models to calculate soil EM properties. The latter are included in a two-dimensional (2D), finite-difference time-domain (FDTD) modeling program in conjunction with the characteristics of AP landmines to calculate the buried target reflection. The approach is applied to two soils selected among Colombian mine-affected areas, and several local improvised explosive devices (IEDs) and AP landmines are modeled as targets. The signatures from such targets buried in the selected soils are predicted, considering different conditions. Finally, we show how the GPR can contribute in detecting low- and non-metallic targets in these Colombian soils. Such a system could be quite adequate for complementing humanitarian landmine detection by metal detectors.

Keywords: Ground-penetrating radar; Detection performance; Pedotransfer functions; FDTD modeling; Humanitarian demining

1. Introduction

In 2004, statistics of landmine victims ranked Colombia as the third most heavily mine-affected country in the world with 812 casualties. Nowadays, it is estimated that more than one hundred thousand antipersonnel (AP) landmines are buried across 422 municipalities, which constitutes 40% of the national territory (ICBL, 2005).[1] These are American and Belgian manufactured landmines, as well as landmines manufactured by the Colombian Military Industry (INDUMIL). However, a considerable number is made in an artisan way by the guerrillas (*e.g.*, FARC and ELN[2]). These low cost landmines are called *improvised explosive devices* (IEDs). Although the Colombian

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[1] International Campaign to Ban Landmines, ICBL.
[2] Fuerzas Armadas Revolucionarias de Colombia — FARC, Ejercito de Liberacion Nacional — ELN.

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government ratified the Ottawa Convention in 2001, the guerrillas still place IEDs across the country. The Explosive Devices Manipulation Unit (MARTE) of the National Military Forces is the most expert group in mine-clearing works in Colombia. They use classical demining procedures, namely, electromagnetic (EM) induction methods (metal detector, MD). However, MDs do not reliably detect plastic, low-metallic landmines[3] in a post-conflict area contaminated by grenade fragments, cartridges, and other metallic materials buried premeditatedly to confuse the deminers. Besides the fact that some Colombian mined areas contain ferruginous soils (*i.e.* with a high iron content) which adversely affects the sensibility of EM induction methods, a significant amount of IEDs contain only plastic and other non-metallic elements. When demining is performed using a MD, all these factors increase the probability of having an accident up to 40%.[4] Therefore, additional sensors for complementing the MD are required in mine-affected areas with difficult conditions such as those in Colombia.

Several sensors for landmine detection have been proposed and utilized worldwide (MacDonald et al., 2003). Among these, ground-penetrating radar (GPR) is considered as a promising technology, because of its ability to detect both metallic and non-metallic AP landmines by non-invasive subsurface sensing (Bruschini et al., 1998; Carin et al., 1999; Gao et al., 2000; Chen et al., 2001; Scheers, 2001; Roth, 2004; Daniels, 2004). It is well known that the performance of GPR is influenced by the EM properties of the soil, particularly with changes in moisture content (Das et al., 2001; Rhebergen et al., 2004; van Dam et al., 2004; Miller et al., 2004). Moreover, earlier researches have demonstrated how the detection uncertainty of GPR depends on the target features (van der Kruk et al., 2003; Daniels, 2004; Rhebergen and Ralston, 2005). Some studies have been carried out on the use of GPR for landmine detection in Colombia (Lopera et al., 2004, 2005). In these studies, measurements were taken using a 0.8 GHz time-domain GPR and it was concluded that an ultra-wide band (UWB) GPR would be more appropriate for landmine detection. Consequently, thorough studies are being performed with the aim of applying an UWB GPR for demining applications in Colombia (Lopera et al., 2007, 2007).

In this paper, we study the influences of soil and target characteristics in order to predict the detection performance of an UWB GPR for two representative mine-affected areas in Colombia. Accordingly, an EM model based on pedotransfer functions is coupled to a two-dimensional (2D), EM finite-difference time-domain (FDTD) GPR model so as to calculate target reflection responses for different environments. Firstly, typical AP landmines and IEDs and two types of soil from Colombian mine-affected areas are selected. Secondly, soil EM properties are derived using pedotransfer functions and available soil geophysical information. Finally, the GprMax FDTD model (Giannopoulos, 2002) is used for calculating the target signatures. The predicted performance shows how GPR could contribute to low- and non-metallic AP landmine detection in difficult soil conditions. Note that target detection is considered without taking into account target classification. To our knowledge, this paper constitutes a first contribution to a technological solution of demining issues in Colombia. The proposed methodology can be applied to other terrains and targets.

2. Materials and methods

2.1. Soil characteristics

Two ferruginous soils have been selected from two highly mine-affected departments of Colombia, located within The Andes mountain chain: Santander and Antioquia. The soils are classified as silt loam and loamy sand, respectively; their organic content is less than 1% and their reddish color is due to the presence of mixed oxides containing fine iron particles (their Fe percentage is 5.2% and 8.8%, respectively). These soils make the detection of low-metallic AP landmines using MDs more complicated (Toews and Sirovyak, 2003), due to their high magnetic susceptibility (MS, χ) and magnetic viscosity (or frequency-dependent MS, χ_{FD}) (Mullins, 1977). In order to determine the effect of the iron components on the EM properties, the magnetic susceptibility of the selected soils was measured using a Barington MS2 dual-frequency sensor (0.46/4.6 KHz) (Dearing, 1994). Several samples were taken from the upper 30 cm of the soil profile. Two measurements are obtained: the MS at low frequency (χ_{LF}) and the MS at high frequency (χ_{HF}). The frequency-dependent MS can therefore be expressed as a relative loss of susceptibility ($\chi_{FD} = \chi_{LF} - \chi_{HF}$) (Dearing et al., 1996). Results of these measurements and other available properties of both soils are summarized in Table 1.

[3] A low-metallic AP landmine is made with less than about 8 grams of iron or equivalent.

[4] Information source: http://www.derechoshumanos.gov.co/minas/.