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Spectral analysis of ground penetrating radar signals in concrete, metallic and plastic targets

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ABSTRACT

The accuracy of detecting buried targets using ground penetrating radar (GPR) depends mainly on features that are extracted from the data. The objective of this study is to test three spectral features and evaluate the quality to provide a good discrimination among three types of materials (concrete, metallic and plastic) using the 200 MHz GPR system. The spectral features which were selected to check the interaction of the electromagnetic wave with the type of material are: the power spectral density (PSD), short-time Fourier transform (STFT) and the Wigner–Ville distribution (WVD). The analyses were performed with simulated data varying the sizes of the targets and the electrical properties (relative dielectric permittivity and electrical conductivity) of the soil. To check if the simulated data are in accordance with the real data, the same approach was applied on the data obtained in the IAG/USP test site. A noticeable difference was found in the amplitude of the studies' features in the frequency domain and these results show the strength of the signal processing to try to differentiate buried materials using GPR, and so can be used in urban planning and geotechnical studies.

1. Introduction

In this paper, the geophysical method GPR was employed along with signal processing techniques in order to improve the detection of buried targets and therefore minimize the ambiguities in the interpretation of geophysical results. The methodology was applied on two important families of targets: resistive targets, such as concrete tubes, plastic drums or pipes, and on conductive targets, such as metallic drums or pipes. Both targets simulate real situations in the field of urban planning, infrastructure studies and environmental contamination.

To achieve the goal of differentiating the material of the targets with GPR was necessary the frequency domain analysis. This domain was possible to determine small variations in the spectrum, which can not be determined in the time domain. These tools measure the average frequency distribution in time or spectral density at a given time interval.

The signal processing techniques that were used are: power spectral density (PSD), providing a significant measure of the distribution of average power in a time series (Agnew and Parker, 2011; Welch, 1967), short-time Fourier transform (STFT), determining the variation with time of the frequency content of the signal, corresponding to a spectral decomposition technique or time–frequency decomposition (Allen and Rabiner, 1977; Owens and Murphy, 1988; Tomazic, 1996) and Wigner–Ville distribution (WVD) that can be defined as an instantaneous spectral density (Cohen, 1995; Sejdic et al., 2009; Waldo and Chitrapu, 1991). These tools that use the time–frequency analysis of signals are widely used in geophysics, such as seismic processing (Chakraborty and Okaya, 1995; Wu and Liu, 2009), analysis of the geomagnetic field (Constable, 2005) and others.

The PSD, STFT and WVD are applied in GPR method to improve the target detection or signal analysis, for example in van Genderen and Nicolaescu (2005) that applied the PSD to improve the detection of the small objects in a complex background. This method is based on the Yule-Walker auto regression using an estimator of power spectral density on time domain signals and the results provided a significantly improved detectability and range-resolution. Lai et al. (2010) used the GPR and STFT to characterize the frequency-dependent dielectric relaxation phenomena in concrete targets, with good results varying from fresh to hardened state. Lopera et al. (2007) analyzed the time–frequency signature of the GPR data in landmine identification comparing the WVD and wavelet transform (WT) and the results showed that Wigner–Ville distribution contain more valuable information than the features extracted using WT improving landmine and false alarm classification.

Thus, these spectral features were used to verify the difference between the three types of materials using the GPR and according to the literature these characteristics produce good results in determining specific properties of each material. These approaches were applied in

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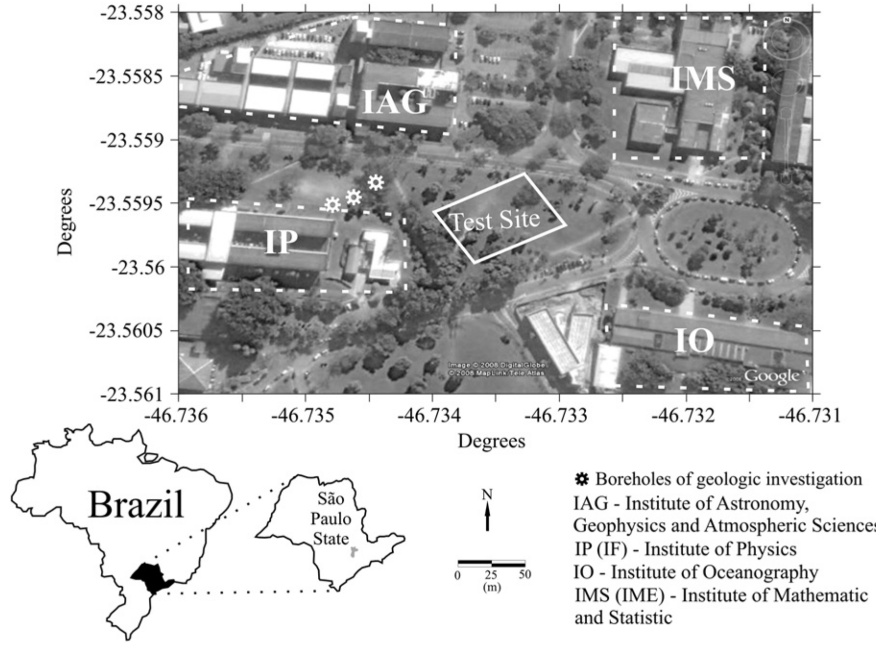

Fig. 1. Location of IAG/USP test site.

GPR data obtained by numerical simulation and real data acquired on the IAG/USP test site. The simulated data were used to make the analysis more consistent, where the spectral features were applied in different sizes of target and electrical properties. These techniques were used to distinguish between concrete, metallic and plastic targets for the GPR profiles acquired in the test site.

On the campus of University of São Paulo (USP) the first area for controlled tests of shallow geophysics in Brazil was installed (Porsani et al., 2006). The IAG/USP (Institute of Astronomy, Geophysics and Atmospheric Science of University of São Paulo) test site aims to emulate geotechnical, environmental and archeological sites through the installation of seven lines consisted of different buried materials as electrical cables, optical fiber, metal, PVC and concrete pipes and plastic and metal drums, as these targets normally are found in large urban centers.

2. Study area: IAG/USP test site

IAG/USP test site is located on the campus of the University of São Paulo in São Paulo, Brazil. It is characterized by sand-clayey sediments of Resende and São Paulo formations that underlie the local area, overlapping onto granite–gneissic basement (Porsani et al., 2004). The area has a relative dielectric permittivity of 20 and an electrical conductivity of 10 mS/m (Borges, 2007), corresponding to conductive sand-clayey soil. It has a dimension of 30 m × 50 m, and the depths of target tops range from 0.5 to 2 m. At the mid-field (NS) position a steel guide pipe with 3.8 cm of diameter was buried, which serves as a reference for geophysical surveys.

Seven lines were installed in the test site, with different materials: archeology, PVC pipes, concrete tubes, metallic drums, plastic drums,

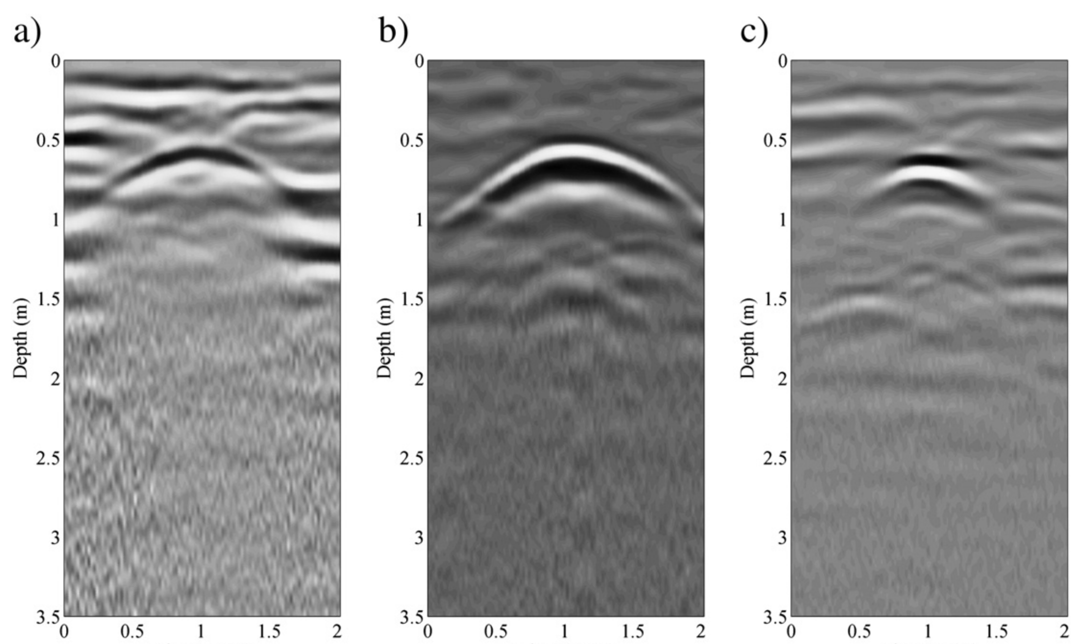

Fig. 2. Examples of GPR data obtained with 200 MHz in the IAG/USP test site. a) Concrete target. b) Metallic target. c) Plastic target.