Forensic Science International 204 (2011) 134–138

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

3D GPR in forensics: Finding a clandestine grave in a mountainous environment

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ARTICLE INFO

Article history:
Received 29 September 2009
Received in revised form 20 May 2010
Accepted 21 May 2010
Available online 16 June 2010

Keywords:
Ground penetrating radar
Forensic investigation
Clandestine burial

ABSTRACT

In the present work we show a forensic case study carried out in a mountainous environment. Main objective was to locate a clandestine grave which is around 10–20 years old and contains human remains of one individual and a metallic tool, probably a pick. Survey design started with an experimental burial of a pick at the expected depth (1 m) as well as the calculation of synthetic radargrams in order to know if the 250 MHz antenna was suitable for its detection and to have a record of the reflection of the pick. Conclusions extracted from the experiments together with rough terrain conditions suggested the use of the 250 MHz antenna which allowed a good compromise between target detection and dense grid acquisition of an extensive survey area.

1. Introduction

Ground penetration radar (GPR) is a well accepted technique for the detection of clandestine graves since it was first successfully utilized in 1986 by Vaughn [1]. Despite the fact that GPR can help as part of a forensic investigation sequence [2], it has not been standardized by Spanish law enforcement because specialized training is necessary for acquiring, processing and interpreting the data. On the other hand, the advantages of using non-intrusive methods, such as GPR, are preservation of the crime scene, little destruction of forensic evidence and, therefore, the possibility of reconstructing events at the scene [3].

Although some authors have recently achieved successful results under controlled conditions, such as in a cemetery test area [4] and over a simulated urban clandestine grave [5], ultra-dense grid strategies for 3D GPR [6] are rarely applied in real forensic cases because they require special training for both data acquisition and 3D data processing. In addition, rough surfaces and time are often strong limitations in homicide investigations, and therefore most surveys are still carried out in only two dimensions.

The following case study presents the collaboration with Spanish law enforcement in locating a clandestine grave of a homicide victim. Police suspicions suggested the search for a clandestine grave, which allegedly contains skeletal remains of one individual and a pick buried at 1 m depth. The investigation site is located on a steep sloping area with mountainous vegetation. The soil of this area consists mainly on massive limestone, and therefore provides a good dielectric medium for GPR. The surface was covered by trees, bushes, stones and tree stumps. The area was divided into four zones called bands. A portion of each band was marked based on police instructions. Previous police investigations of the four bands had consisted of visual searches, use of metal detectors and 'trial and error excavations' (digging with shovels). Other details, such as the situation surrounding the event, dates, etc., will not be fully described because the homicide case is still active.

The use of GPR for detecting the skeletal remains of an individual buried in a clandestine grave many years ago (10–20) presents a considerable challenge due to the small size of the remains in relation to the scale of the survey area (circa 3890 m^2), the low geophysical contrast of the body and the strong dependence on the soil effects on skeletonisation [1]. The efforts of this study focused on detecting the ferrous part of the pick, which turned into finding a needle in a haystack.

The main goal of this study was to assist police investigations by discriminating areas into four bands and selecting the bands that might be of interest. Other goals involved testing of GPR technology for forensic investigation under extreme conditions, the use of 3D ultra-dense data acquisition strategies, the design of an in situ experiment for understanding the type and geometry of the GPR response expected in this specific environment and the combination of GPR and fluxgate magnetometer data.

2. Methodology

2.1. Planning

Due to the large size of the survey area and the small size of the pick, the data acquisition strategy was a critical decision taken in order for success.

Additionally, topography and surface conditions were strong limitations for designing the survey methodology. For example, antenna stability is always needed for good data recording and positioning. In this case, the antenna needed to be

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doi:10.1016/j.forsciint.2010.05.019

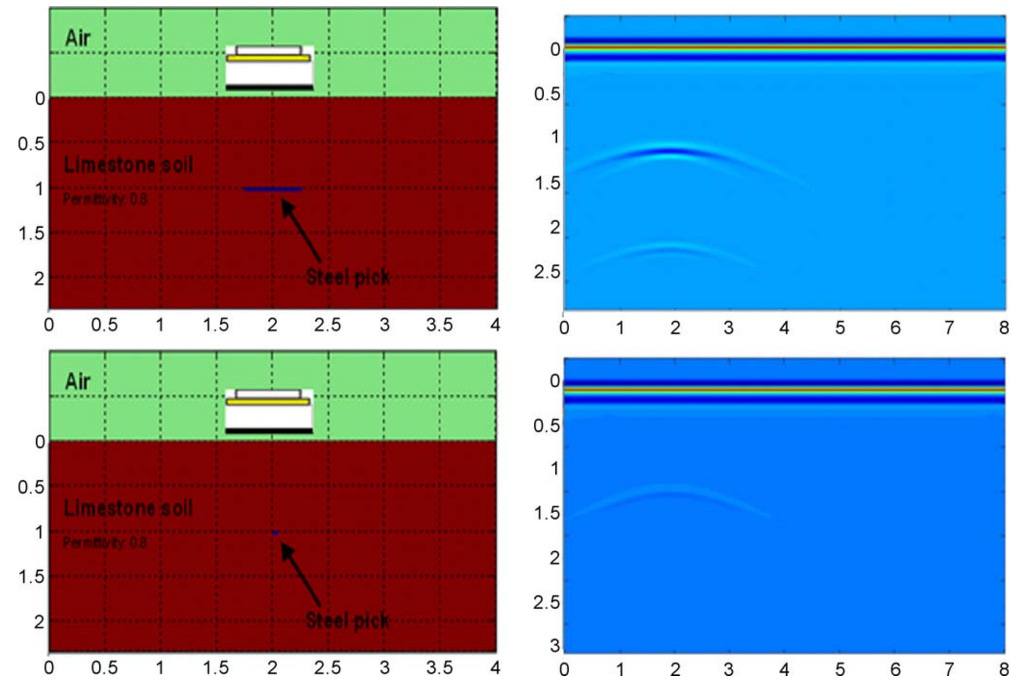

Fig. 1. FDTD models showing the effect produced by the existence of a steel pick buried at 1 m depth in the positions described in Fig. 2. Left: models; right: synthetic radargrams.

heavy enough to avoid slipping and rolling because of the pronounced slope. Therefore, a robust configuration of the GPR equipment became a strong requirement. A 250 MHz antenna was chosen for this reason, and smaller antennas with higher frequencies (although desirable) had to be avoided. However, a 500 MHz antenna might be used (prior to excavations) in future campaigns, but this smaller antenna would only be considered for areas which show interesting results with the more robust 250 MHz antenna.

Another difficulty in this study was the size of the target and its unknown position in the grave. Apart from the two possibilities considered, a worst-case scenario, which was excluded due to its improbability, is that the metallic part of the pick was buried perfectly orthogonal to the surface.

An in situ experiment was designed to help characterize the expected GPR response. A pick was buried (including the worst scenario) to a depth of 1 m in band number 1, and the day after two ultra-dense datasets were recorded with 250 and 500 MHz antennas (using a profile spacing of 15 and 5 cm respectively) over a small grid of 4.5 m × 4 m.

In the worst scenario, the pick could be detected in only one profile. Taking into account this possibility, ultra-dense 3D GPR strategies and the possibility to relax the most restrictive grid spacing (a footprint of the antenna at 1m depth and expected strong response of a metal target), a space between profiles of 15 cm was considered as optimum.

2.2. Simulation

In order to simulate the potential response of the 250 MHz antenna from a pick buried at 1 m depth in both scenarios, synthetic radargrams were created using GprMax software v.2.0 [7]; this software is an electromagnetic wave simulator for ground penetrating radar, developed using the Finite Difference Time Domain method (FDTD).

The synthetic radargrams (Fig. 1) reveal the capability of the 250 MHz antenna to detect the target, although they also point out how subtle the reflection may be. In reality, other potential reflectors such as stones or metal rubbish items could generate a similar response.

2.3. Data acquisition

First, to facilitate the geophysical work, the four bands were cleaned up by cutting off branches of invader bush species and taking out the biggest stones. However, a lot of obstacles must remain, as the crime scene is located in an environmentally protected area.

The whole area was surveyed in 10 days by being divided into two consecutive campaigns. Workdays comprised 7–8 h of fieldwork, depending on meteorology and light conditions, and 2–3 h of data pre-processing, which included signal processing, situation of profiles and obstacles, at the hotel.

Ultra-dense data acquisition with the 250 MHz antenna resulted in a total of 1368 parallel profiles spaced by 15 cm and trace recordings every 5 cm. In order to avoid the very steep slope, GPR lines were recorded along contour lines, orthogonal to the slope. Site conditions and police clues constrained the GPR survey to be completed with irregular grids. Thus, careful field notes were taken of the precise position of every profile and the obstacles presented (trees, bushes and tree stumps).

Topography and corner points of every grid were surveyed with a differential real-time kinematic (RTK) GPS model Settop AL-102 of Trimble. Unfortunately trees impeded good coverage for continuous RTK precision, so GPS connection to GPR was avoided.

3. Results

Although the GPR data showed good signal penetration, careful 2D and 3D processing permitted obtaining best results. The migration velocity of 0.08 m/ns was determined through diffraction hyperbola analysis.

3.1. Experiment

As Scan 3D module of Reflexw [8] software allows for a rapid and complete 2D–3D data processing (see Table 1), it was selected for data processing of the study's small rectangular grid. Due to the particular preferences of 3D visualization functionalities, individual processed radargrams were imported to GPR-SLICE [9], and two

Table 1
Sequence processing applied to the GPR data collected for the experiment.

GPR processing sequence	
Scan 3D (Reflexw)/GPR-SLICE	
1	Dewow
2	Flip every 2 scan
3	Static correction based on the automatically determined first onset
4	Background removal based on all traces
5	Band pass Butterworth: lower cutoff (165 MHz) and upper cutoff (710 MHz)
6	3D-FK migration based on velocity = 0.08 m/ns
7	Gain function: linear (0.5) and exponential (0.2)
8	Export to GPR-SLICE
9	Generation of two 3D data cubes following pseudo 3D and full-resolution processing schemes