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Utility detection and positioning on the urban site Sense-City using Ground-Penetrating Radar systems

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ABSTRACT

This paper presents the design of a novel Ground-Penetrating Radar (GPR) test site that has been integrated into the mini-city demonstrator Sense-City located at University Paris-Est (France). This test site provides several sources of measurement interest expressed by the presence of a multilayered soil with significant dielectric contrasts, and various dielectric pipes and blades buried at various depths in trenches filled with a backfill soil different from the natural soil. This paper presents experimental Bscans associated with the pipe zone acquired by three different GPR systems at frequencies ranging from 300 MHz to 1.5 GHz. The interpretation and comparison of the raw Bscans have allowed to characterize the dielectric properties of the soil layers, and to detect the hyperbola signatures of the buried pipes. The results of this study will help to guide future developments on polarization, operating frequency and signal processing to extract parameters (orientation, dielectric characteristics, position and size) associated with pipes.

1. Introduction

The growing demand for utility services in the urban landscape leads to bury an increasing number of utility pipelines (fiber optics, telecommunication lines, electrical cables, water and gas pipes, district heating network), most of them buried within 1.5 m of the ground surface. The already dense subsurface is getting close to saturation. Mapping the underground with a non-destructive technique is needed to retrieve the location of underground pipelines, in order to update urban cadastral databases and to contribute to space saving and to a wise use of land resources when planning for new networks [1,2]. Moreover, such an inspection is an opportunity to identify buried pipes and check their operating status [3,4]. The GPR (Ground Penetrating Radar) is one of the most significant and mature geophysical techniques that detects changes in electromagnetic properties and provides high resolution data [5,6]. Thus, a target below the ground surface, metallic or dielectric, can be detected. The central frequency and the bandwidth of the electromagnetic signal determine the system resolution, namely the minimum physical size of any material change that can be detected; the resolution is estimated to about half of the wavelength in the propagation medium. The difficulties encountered while using GPR for utility mapping are the variations within the area of a radar survey of the ground conditions (particularly water content) and of the soil type, which may have significant impact on both the absorption and the velocity of propagation of electromagnetic waves. Moreover, the buried pipes feature wide variations in dimension, may be metallic or non-metallic, and may be in close proximity to each other. A few international

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organizations promote some guides or recommendations in using GPR in utility engineering, such as the ASCE (CI/ASCE 38-02) and the ASTM (ASTM D6432-99) international (2011) in North America [7,8], EuroGPR in Europe, and the CEI (306-08) in Italy [9]. Moreover, a European action in a COST program (COST Action TU1208), promotes applied researches and recommendations on GPR applied in civil engineering, and the fourth working group is devoted to utilities detection and mapping by GPR [2].

In this context, it appears essential to develop and use benchmarking facilities enabling to calibrate, to evaluate GPR techniques for 2D and 3D utility mapping and to develop in parallel pre-processing and processing algorithms to extract quantitative information on the subsurface contents. Actually, there exists few test sites oriented to the characterization of urban underground [10–16]. In this paper, we present a novel utility test site built within the project Sense-City, a mini-city demonstrator in Marne-La-Vallée, France [17]. Sense-City test-bed consists of a 250 m^2 (25 m $\times$ 10 m) real size model of a city district focused on smart houses, roads and city furniture. It includes two distinct areas dedicated to the validation of utility mapping tools, one with buried pipes, and the other with buried blades; the objects have relative small lateral dimension (less than 15 cm). This site has been recently incorporated in the activities of COST TU1208 [2], and is opened to academic and commercial contributors who want to test their equipments or post-treatments. The present paper is focused on the sounding of the buried pipe area: the acquisition of radargrams has been made using several GPR systems operating in the time domain (GSSI SIR 3000, UtilityScan DF) and in the frequency domain (a SFCW made of a pair of bowtie slot antennas conceived in our laboratory) both operating at frequencies ranging from 300 MHz to 1.5 GHz. Thus, this work is a first step in the analysis and information retrieval (soil dielectric characteristics, pipe material and size, orientation) of experimental radargrams containing pipe signatures. The measurements controlled by several parameters such as the central frequency, the dielectric contrast of the objects (conductor, PVC air-filled or water-filled) with the soil, and the polarization provide a set of data that will be further analyzed in a second step by dedicated and improved signal processing algorithms that will be developed. The measurements are likely to provide additional information in a controlled environment to data previously mentioned in the literature. Firstly, the radargrams have been analyzed by classical techniques to learn about the soil under study.

2. Sense-City urban test bed for utility detection

Sense-City facility is a modeled urban test-bed dedicated to the validation of measurement technologies in the field of urban sustainability. This project is funded since 2011 within the Equipment of Excellence strand of the Investment for the Future Program in the period 2011–2019 [17]. Presently, the project is at its first stage: it consists in an outdoor 250 m^2 scale one demonstrator of a small city district built over a preexisting soil. The layout is built to tackle issues with regard to smart habitat and roads (see Fig. 1). In a second stage starting early 2017, it will encompass 400 m^2, include 2.5 m of soil structure to be tuned according to experimental requirements, and be deployed in a 3200 m^3 climatic chamber that will control temperature, hygrometry, sun exposure, rain events as well as air pollution.

The currently available test-bed falls within the purview of Sense-City smart road topic, as networks usually lie below road structures. Figs. 1 and 2a display the facility and pinpoint the location dedicated to utility mapping, namely a 10 m wide traffic circle with lawn at the center. The underlying soil results from a backfilling operation after construction of the nearby building. During preparation of the test bed (trench excavation), the soil structure in three layers, before the addition of asphalt on the surface, has been observed: the top layer is a 80 mm thick layer of aggregate cement, the second and third layers appear to be both the same type of soil whose composition is unknown. They have been separated by a geotextile (causing a discontinuity) at a rough 30 cm depth (see Fig. 3a and c). We have remarked that the second and third layers appear particularly wet, that may explain the presence of the geotextile aiming at reducing the ascent of water. Eight pipes and eight blades have been buried at depths ranging from 14.5 to 64.5 cm from the asphalt surface (see Figs. 2 and 3c). They have been positioned in two symmetric areas including each five rectangular, parallel, trenches with size 0.3m $\times$ 4 m and separated each by an offset of 40 cm. Each target is positioned in the middle of its trench and at a predefined depth according to the scheme of Fig. 3c. The trenches were filled with a soil made of fine elements (without gravels) commonly used for urban utilities. Its composition is different from the preexisting soil. The soil was compacted after filling and a 4.5 cm thick asphalt pavement was placed. Afterwards, a circular stretch of road was designed on the surface. The pipes are either made of PVC (diameter 6.3 cm) or of a conductor (diameter 6 cm), and the blades are either made of a polyurethane foam (thickness 2 cm or 3 cm, height 10 cm) or of a conductor (thickness 1 cm, height 5 cm), as it is displayed in Fig. 3b. The PVC pipes can be filled with a liquid to bring an additional dielectric parameter in the site. The detailed geometry of the pipe area is provided in Fig. 7.

Fig. 1. General view of the mini-city test bed Sense-City.