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Combined use of GPR/TDR for Geophysical Prospection in Cultural Heritage Investigation

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Abstract – **In this paper, an overview of the use of ground penetrating radar (GPR) and time domain reflectometry (TDR) to be used for noninvasive inspections of Cultural Heritage monuments is presented. In particular, after a brief description of the theoretical aspects behind each measurement technique, some experimental results analysis related to three columns at the Regio VIII in Pompeii are presented.**

I. INTRODUCTION

Non-destructiveness is a mandatory requirement for the inspection of ‘structures’ which must not be destroyed or altered. In this regard, ground penetrating radar (GPR) is a well-established technique for the investigation of buried or inaccessible monuments. The deep interest in the geophysical methodologies is due to the technological innovations involving lightweight equipment, relatively easy to use. At the same time, their flexibility and versatility allow the investigation of large areas with a reduced acquisition time. The development of dedicated and efficient codes also ensures a quick data processing; nevertheless, the correct application of geophysical devices and the subsequent data interpretation require a qualified expert. GPR is one of the best developed techniques in Geophysics [1, 2]. The concept of using radio waves to penetrate the surface/ground and detect sub-surface objects dates back to the the beginning of the twentieth century. Since then, GPR has increasingly become a popular method for archaeological research and for Cultural Heritage studies where the use of non-destructive approach is essential.

Another well-established EM investigation technique is time domain reflectometry (TDR). Also this technique, in fact, can be used with antennas to guarantee noninvasiveness of the measurement system [3]. In practical applications, TDR can be used to carry out preliminary survey on the structure under test; then, if necessary, more in-depth GPR inspections could be carried out.

Based on these considerations, in this work, an overview of the use of GPR and TDR for measurements on cultural heritage is presented.

II. GPR THEORETICAL BACKGROUND

GPR is an EM geophysical method for high-resolution detection, imaging and mapping of subsurface structures. In principle, GPR can be considered as composed by a central unity, a transmitting and a receiving antenna, and a computer. The central unit generates EM pulses that are radiated into the target by the transmitting antenna. The pulses are radiated in all the directions, but most of the energy is radiated within a conic volume under the antenna. When the EM waves meet any discontinuity (a buried object, or also the interface between two geological layers, a cavity, a zone with different humidity etc.), they are scattered in all the directions (the intensity of the scattered power is not spatially uniform, but depends on the scattering target) and so partly also toward the receiving antenna [4].

Typically, the transmitting and the receiving antenna are incorporated in a rigid structure and move together. In modern systems, the gathered signal is represented in real time on the screen of the computer, and is stored in the computer. The GPR system is usually powered through rechargeable, portable batteries in the form of a zero frequency electrical voltage, and the central unit transforms this energy into a signal in the microwave frequency range. Most of the returned signals in radar profile are reflections from subsurface discontinuities, although other types of waves may also be present. Wave types such as a direct airwave, a critically refracted airwave and a direct ground wave generally appear as well, as predicted by the Ray Theory and simple geometrical relations.

It should be mentioned that many examples of detection of ancient tombs, crypts and cavities are present in the literature. With respect to other geophysical methods, the advantages of the GPR surveys includes

- enhancement the information quantity and quality, being a high resolution diagnostics technique;
- achievement of a detailed physical and geometrical characterization of the subsurface structures;
- achievement of both historical and structural information about the monumental buildings investigated; and
- identification the damage status, classification and map-

ping within some architectural elements such as walls, masonry, columns and pillars and even statues.

III. TDR THEORETICAL BACKGROUND

In addition to the GPR technique, another EM technology that can be used for Cultural Heritage investigation is TDR. Clearly, TDR does not allow a 3D reconstruction of the subsurface; however, it allows the determination of the materials physical properties and in particular the measurement of the dielectric permittivity of the investigated structure [5]. Through a specific processing, these data can be used to infer, for example, the presence of other materials beneath the surface.

In TDR measurements, a step-like EM signal propagates along a probe or sensing element (SE) inserted in (or in contact with) the system to be monitored. The variations of the electric impedance that are encountered by the EM signal provoke partial back-reflections of it. The raw output of a TDR measurement is a reflectogram, which displays the reflection coefficient (ρ) as a function of the apparent distance (d^{app}) travelled by the EM signal [6]. The quantity ρ is called time-domain reflection coefficient ($-1 \leq \rho \leq +1$) .The analysis of the reflectogram, performed through a specific data-processing, allows retrieving the desired information on the system under test [7].

One of the clear advantages of TDR with respect, for example, to transmission measurements (such as free space measurements) is that reflectometry relies on single-port measurements, thus simplifying considerably the measurement setup.
For preserving a noninvasive approach, antennas can be adopted as sensing elements. Fig. 1 shows the schematization of the use of a planar antenna connected to a TDR instrument, and placed in contact with a wall structure. The variations of the resonant frequency of the antenna can be associated to the dielectric characteristicsof the structure that is being investigated [3]. In turn, the dielectric characteristics can be used to retrieve other characteristics of the structure (e.g., moisture content) [8] or to sense the presence of different materials beneath the surface.

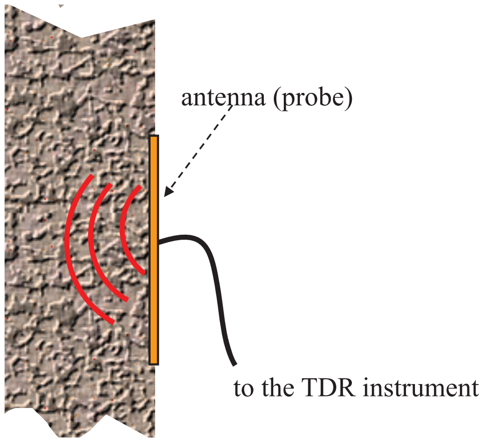

Fig. 1. Schematic configuration of a noninvasive, TDR-based investigation of monumental structures, using a planar antenna as probe.

Fig. 2. Picture of the investigated columns in Pompeii.

IV. EXPERIMENTAL RESULTS

This section reports the GPR data acquisition and analysis on three columns at the Regio VIII in Pompeii (Italy). In particular, as shown in Fig. 2, three columns were investigated using GPR Ris Hi-Mod manufactured by IDS instruments.

Vertical and horizontal lines were marked on the surface in order to acquire GPR data along each one. A 2 GHz center frequency antenna was used. The position on the column was determined with a survey-wheel odometer. During the radar acquisition, the sampling interval was 512 samples per trace. The spatial sampling was 0.002 m, and the temporal window was 12 ns. Knowing the diameter of the column (1.3 m) and obtaining the reflection from its end on the opposite side of the antenna, an average EM wave velocity of 0.11 m/ns was estimated. Radar profiles were processed with Reflex software (Sandmeier) in order to obtain 2D slices [9]. The processing applied to each radargram was the following: search for time 0 ns; subtract DC-shift; and, finally, migration. After this processing, horizontal radargrams were transformed into cylindrical coordinates, by using a Matlab routine. Fig. 3 shows the position of the vertical radar line data on the specimen and radar data obtained from circular profiles related to column number 1.
The main features observed in these image correspond to some strong reflections and the irregular anomalies between them. The strong anomaly (labelled D in Fig. 4) could be due to the small fractures. Other low amplitude irregular reflection events are most likely as a consequence

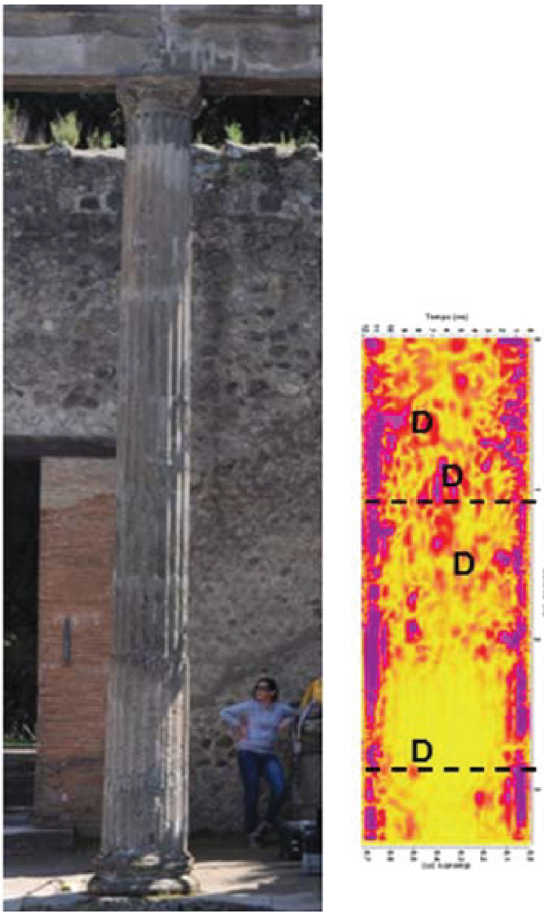

Fig. 3. Vertical radar data image on Column #1.

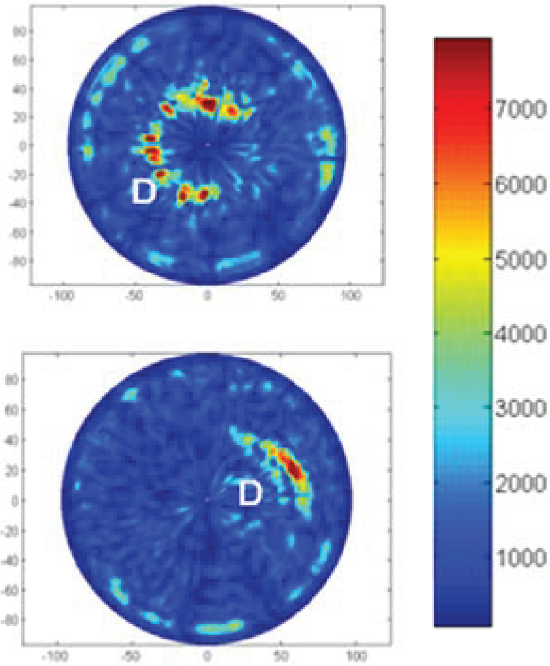

Fig. 4. Radar data images obtained from circular profiles on Column #1. Major anomalies are marked with the letter D.

of the internal desegregation of the material due to the humidity and water actions. The strong reflection events at the sides (Fig. 4) probably indicates the contact between the antenna and the column surface.

V. CONCLUSION

In this work, an overview of the use of GPR and TDR techniques for the investigation of Cultural Heritage structures was presented. Both the considered techniques can be considered as optimal tools for noninvasive monitoring of buried/hidden ancient structures. In practical applications, thanks to its quickness of use, TDR could be used for the preliminary inspection of structure under investigation. Successively, if (for instance) the TDR results indicate variations of the dielectric characteristics of the structure, then the GPR system could be employed for a more accurate and in-depth investigation of the monumental structure.

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