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Integrated use of GPR and TDR for wood permittivity evaluation

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***Abstract* – In this paper we propose an experimental case of the joint use of ground penetrating radar (GPR) and time domain reflectometry (TDR) for the estimation of the dielectric permittivity of several type of wood. In particular, the well known method of the diffraction curves is compared with the results of an "auto-focussing" strategy based on a linear microwave tomographic approach and with a TDR measurement. The effect of the actual offset between the antennas is accounted for too.**

I. INTRODUCTION

The electromagnetic characteristics of the wood, where a ground penetrating radar (GPR) signal propagates, are of great interest within GPR prospecting related to the study of conservation state of the wooden structures. In particular, these characteristics, if correctly retrieved, allow not only a correct time depth conversion [1] but also a correct focusing of the buried targets (such as voids, knots, etc.) through a migration or, more in general, an inversion algorithm [2].

Moreover, depending on the applications, the characteristics of the medium can be important in themselves and not only in relationships to the reconstruction and interpretation of the targets. This can happen e.g. when the "final" quantity of interest is the moisture content of the wood [3]. In general, the dielectric permittivity, as well as the electrical conductivity of the embedding medium, depends in a meaningful way, but also in a complicated and often unknown way, on the chemical, physical and mineralogical properties mixture composing the wood at hand. This makes quite hard to get a reliable a-priori knowledge of them. In particular, some experimental values or semi-empirical laws are available [1,4]; nevertheless, they should be considered as reference-average quantities, which are useful in order to test the likelihood of a measure in the field but should not replace it.

In particular, the measure of the dielectric permittivity of the wood can be performed from the same GPR data [5], classically by means of the shape of the diffraction curves or by means of CMP data. More recently, an "auto-focussing" method based on the linear inversion under the Born Approximation of GPR data has been introduced [5-6]; however, until now, it had never been experimentally validated. Alternatively, the dielectric permittivity can be evaluated through the time domain reflectometry (TDR) technique [7].

In this paper, a comparative experimental evaluation of the dielectric permittivity of some samples of wood is proposed. Results show an excellent agreement between the diffraction curve method and the TDR measurements.

II. TEST SETUP

The test has been performed using the samples of fir, maple, chestnut, cherry, beech, ash and pine. The samples has been dehydrated at 105º Celsius for 24 hours. In particular, drying wood prevents from inhomogeneity due to possible gradients of moisture content. Moreover, the dehydration also reduces the dependence of the permittivity on possible gradients of density. Successively the samples were immersed in water and saturated. More specifically, the TDR and GPR measures were performed at different steps with several degree of saturation.

The measurements have been performed with an IDS Ris Hi-mode system equipped with an antenna at nominal central frequency of 2 GHz. Each B-scan has a time window of 32 ns, discretised by means of 2048 samples. When moving the antenna on the wood, extreme care was taken in order to pull the antenna at a constant velocity. The repetition of the scan along the same line three times has allowed a test about the uniformity of the antenna movement velocity. Just after the GPR measurement, a TDR measurement has been performed. The experimental setup for TDR measurements included a TDR unit (Campbell Scientific TDR100); a non invasive three-rod probe and a 3.5 m-long 50 Ω-matched coaxial cable that connected the probe to the TDR unit. The TDR100 generates a step-pulse signal with a rise-time of 200 ps, which corresponds to a frequency bandwidth of approximately 1.7 GHz. Fig. 1 shows the experimental setup.

Fig. 1. Experimental test setup

III. RESULTS FROM THE TDR METOD

As aforementioned, the relative dielectric permittivity of the prepared sample was determined through the well-known TDR method [8].

In TDR measurement, the step-pulse signal generated by the TDR unit propagates along the probe inserted in the material under test; the reflected signal is acquired by the same TDR unit and is displayed in terms of reflection coefficient, as a function of the apparent distance in air.

As detailed in ref. [9], for low-loss and low-dispersive materials, the relative dielectric permittivity can be evaluated through the following equation:

$$\varepsilon \cong \left(\frac{L_{app}}{L_{phys}} \right)^2 \qquad (1)$$

where L_{app} is the apparent distance of the probe inserted in the sample under test (L_{app} is calculated directly from the TDR waveform), and L_{phys} is the physical (actual) length of the probe.

According to ref. [10], the accurate value of L_{phys} was evaluated through preliminary TDR measurements performed in air and distilled water (this was necessary because a tiny portion of the sensing element is contained in a Teflon cap, and this portion must be correctly subtracted to obtain the actual value of L_{phys}).

For the case considered herein, reference TDR measurements were performed using the non-invasive three-rod probe (Fig. 1). For each acquisition the instrumental averaging number was 128. The number of sample points for each waveform was 2,048.

As an example, fig. 2 shows one of the acquired TDR waveforms and the corresponding first derivative curve. The derivative facilitates the evaluation of L_{app}; in fact, the first peak of the derivative (occurring approximately at 6.2 cm) corresponds to the beginning of the probe, whereas the second one (occurring approximately at 5.5 cm), corresponds to the open-ended probe termination.

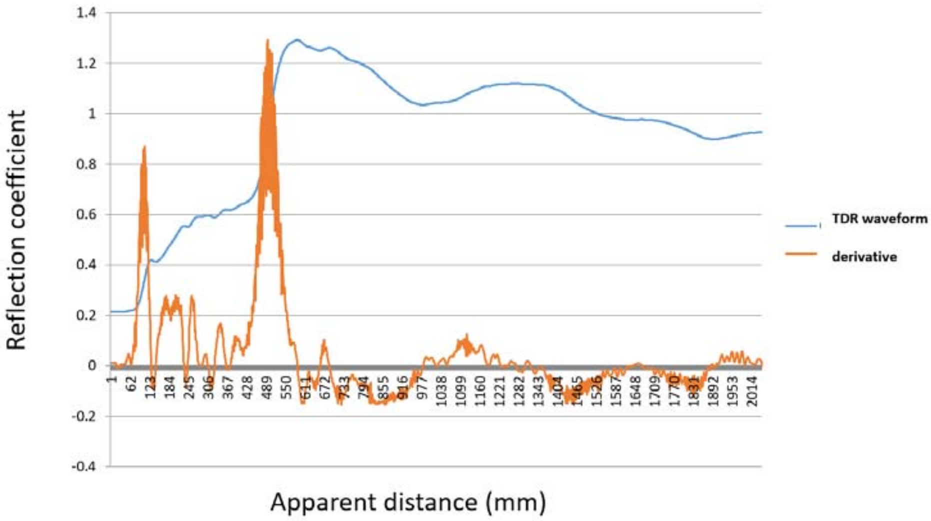

Fig. 2. TDR waveform (blue curve) and corresponding first derivative (orange curve) obtained for the wet maple

The relative dielectric permittivity of the sand, calculated through equation (1) and averaged over the four measurement points in the tank is 4.01 (evaluated with a corresponding expanded uncertainty of 3%).

IV. RESULTS FROM GPR MEASUREMENTS

For GPR measurements the experimental setup was a wooden sample on a metal rod (Fig. 3). This allow to analyze the data using the diffraction curve method.

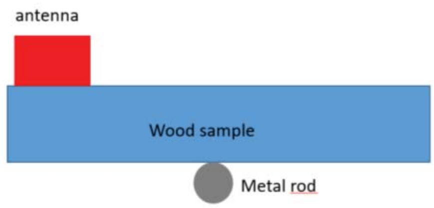

Fig. 3. GPR experimental setup

The diffraction curve method is based on the matching between the data and a model describing the two-way time of the GPR signal. This model provides a curve while considering the movement of the antenna over the target. In particular, given an electrically small target (in our case the bar with the small cross section in terms of the probing wavelength) at the abscissa x_o, if the offset between the transmitting and receiving antennas is neglected, with reference to fig. 2, the model for the diffraction curve is given by

$$t = \frac{2}{c}\sqrt{(x-x_o)^2 + \left(\frac{ct_o}{2}\right)^2} \qquad (2)$$

where c is the propagation velocity in the soil, linked to the relative permittivity ε_{sr} by the well-known relationship $c = \frac{c_o}{\sqrt{\varepsilon_{sr}}}$, and t_o is the minimum recorded time, gathered when the source-observation point flies just over the target, so that $x = x_o$.

As well known, we can recognise that the diffraction curve is in this case a branch of hyperbola. Conversely, if the offset Δ between the antennas is accounted for, after some manipulation, eq. 1 can be re-written as follows:

$$t = \frac{1}{c}\sqrt{\left(x-x_o-\frac{\Delta}{2}\right)^2 + \left(\frac{ct_o}{2}\right)^2 - \left(\frac{\Delta}{2}\right)^2} + \\ + \frac{1}{c}\sqrt{\left(x-x_o+\frac{\Delta}{2}\right)^2 + \left(\frac{ct_o}{2}\right)^2 - \left(\frac{\Delta}{2}\right)^2} \qquad (3)$$

where Δ is specifically the offset between source and observation point, and x indicates the midpoint between source and observation locations. In this work, eq. 3 was considered, accounting for the offset between the actual gaps of the 2 GHz antennas, equal to 5 cm. Although the effect of this offset is not strong, it rigorously makes the diffraction curve not to be a hyperbola any longer. In particular, a range of diffraction curves ranging from the trial value ε=3 (top curve in fig. 4) to the trial value ε=5 (lowest curve in fig. 4) was considered. The curves have been ranged with a stepΔε=0.2; however, for graphical reasons in fig. 4, only the extreme curves and the best matching curve (which has been heuristically seen to correspond to ε=4), are reported. As aforementioned, the best matching has been heuristic, i.e. worked out from the visual correspondence between the field scattered by the metallic bar and the superposed diffraction curve.

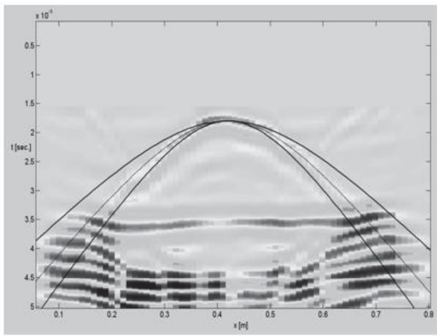

Fig. 4. Diffraction curves for ε=3 (upper solid line), ε=4 (central dashed line) and ε=5 (lower solid line).

V. CONCLUSIONS

In this paper, an experimental comparison between GPR and TDR measurements for the determination of the dielectric permittivity of a series of wood samples was proposed. A good correspondence, especially because (as it is easily calculable) was found between GPR and TDR measurements. On the basis of the obtained results and considering that the comparison between TDR and GPR measurements is a topic that has not been fully investigated yet, more research effort will be dedicated to further explore the discussed topic.

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