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Noninvasive Low-cost Monitoring of Moisture in Monumental Buildings

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***Abstract* – In this work, a noninvasive low-cost TDR-based system for monitoring moisture content in Cultural Heritage structures is presented.**

The proposed system relies on an adhesive (removable) tape, constituted by two copper strips which run parallel to each other and act as sensing element. Experimental tests were carried out by intentionally moistening a portion of a wall, and monitoring the TDR response as the moistened area naturally dried up.

Preliminary results showed that, thanks to the non-invasiveness features, the proposed system is a good candidate for noninvasive monitoring of moisture in monumental buildings.

I. INTRODUCTION

In the last few decades, the interest of the Scientific Community in characterizing, monitoring and preserving Cultural Heritage objects has increased considerably [1], also thanks to the widespread awareness (both the Governments' and the Public's) of the importance of preserving the invaluable cultural treasures. Indeed, the deterioration processes of ancient structures and buildings is intrinsically related to the occurrence of particular microclimatic conditions inside monumental buildings/structures [2]; in particular, the presence of moisture is one of the major causes of decay of ancient building materials. As a result, a wide range of measurement techniques is presently applied for detecting its presence in structures [3]. Because of the inestimable value of the Cultural Heritage, it is crucial to employ moisture content investigation techniques that could guarantee non-invasiveness (or, at least, non-destructivity) of the investigated structure. Among these techniques, ground penetrating radar (GPR) [4, 5] and Electrical Resistivity Tomography (ERT) have been used extensively for non-invasive moisture characterization of subsurface.

Another possible strategy is to infer the moisture content of the structure from dielectric permittivity measurements. For example, in [6], time domain reflectometry (TDR) was employed in conjunction with a planar antenna (used as a sensing element) for non-invasive estimation of water content of materials, as shown in Fig. 1. In particular, the variation of the resonance frequency of the antenna was related to the variation of the water content of the structure. In this way, it was possible to obtain specific calibration curves that could be used for successive investigations on the same materials.

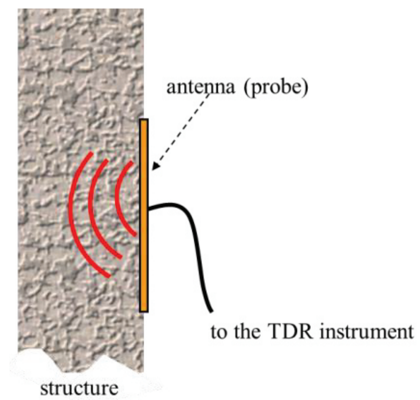

Fig. 1. Schematic configuration of a noninvasive, TDR-based investigation of monumental structures, using a planar antenna as probe.

On the other hand, in [7], wire-like sensing elements were used for monitoring moisture content in building structures. Each sensing element is a biwire (i.e., two copper wires parallel to each other and separated by a dielectric insulator). The wire-like sensing elements of [7] were installed under the wall plaster, and remained accessible through a junction box. For the sake of example, Fig. 2a shows two independent, wire-like sensing elements installed vertically in a house under renovation. Fig. 2b shows the final appearance of another wire-like sensing element installed in the same house.

(a)

(b)

Fig. 2. (a) Two independent wire-like sensing elements installed vertically, under the plaster, in a house under renovation as in [7], (b) appearance of one SE after the installation as in [7].

Starting from the positive results, in this work, a noninvasive TDR-based system for monitoring moisture content in Cultural Heritage structures is presented. In particular, in order to extend the adoption of the elongated sensing elements to Cultural Heritage structures (which, clearly, do not allow the installation under the plaster), a different configuration of the sensing elements was considered. More specifically, the proposed system relies on an adhesive (removable) tape, constituted by two copper strips which run parallel to each other and act as sensing element (SE). The removable tape can be several meters long and can follow the desired path on the structure. The major feature of the used tape is that it can be removed without damaging the structure: this is crucial when dealing with invaluable structures, such as monuments and Cultural Heritage in general.

Through an appropriate processing of the TDR measurements, it is possible to retrieve the moisture content profile all along the length of the SE.

Preliminary results showed that, thanks to the non-invasiveness features, the proposed system is a good candidate for noninvasive monitoring of moisture in monumental buildings.

II. MATERIALS AND METHODS

An adhesive tape manufactured by Next Tape s.r.l. [8] constituted of two parallel, 5.35-m long copper strips, was positioned horizontally on the surface of a wall (as shown in Fig. 3). The thickness of the copper tape was 0.25 mm. A portion of the wall (close to the end of the SE) was moistened by intentionally infiltrating 5 L of water in a limited portion of the wall. Then the wall was left to dry up naturally. TDR reflectograms were acquired at different time intervals. Fig. 3 shows a schematization of the disposition of the sensing element. Also the moistened area is indicated. The point of access (*p.o.a.*) indicates the connection point to the TDR instrument.

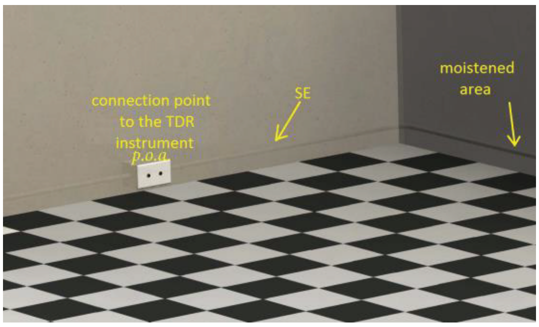

Fig. 3. Schematization of the disposition of the SE. The moistened area of the wall is also indicated.

TDR measurements were carried out through the HL1500, a portable reflectometer that generates a step-like voltage signal with a rise time of approximately

200~ps. The HL1500 has a BNC-type output connector with a 50 Ω electric impedance.

It is worth mentioning that different configurations of adhesive copper tape are available and commercialized by the company Next Tape s.r.l. In particular, two-, three- and four-strip tapes are available, with various width of the strips and with various mutual distance between the parallel strips. If necessary, a tape with tailored dimensions can also be designed and manufactured. For the sake of example, Fig. 4 shows an example of disposition of the adhesive tape as installed by the Next Tape s.r.l. in Palazzo della Ragione (Padova, Italy) [8]: it can be seen that the tape can follow the desired path; it can even bend several times (it should be mentioned that, in this case, the company had installed the tape for different purposes).

Fig. 4. Example of the possible disposition of a three-strip NEXT tape [8].

III. EXPERIMENTAL RESULTS

Fig. 5 shows the TDR reflectograms acquired from the SE. The reflectograms show the reflection coefficient (ρ) as a function of the apparent distance (d^{app}). It can be seen that, starting from the "moistened" condition, the overall apparent length of the SE decreases as the wall dries up. More specifically, as expected, as a result of the evaporation of water, the effective dielectric permittivity sensed by the SE lowers. Hence, as water content of the wall decreases, the ρ value in correspondence of the portion of the wall slightly increases.

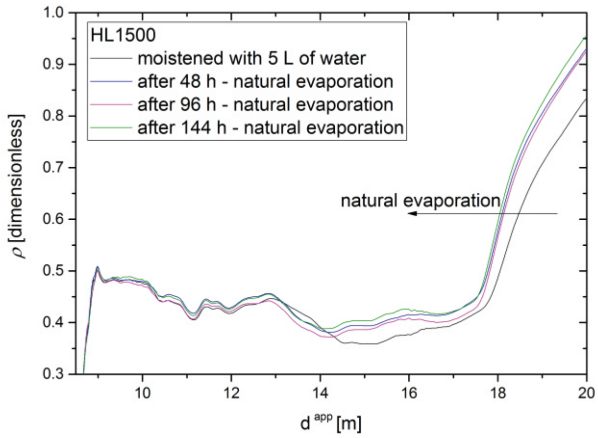

Fig. 5. Reflectograms acquired during natural evaporation and drying of the moistened wall.

In practical applications (for example for continuous monitoring of Cultural Heritage structures), it would be possible to install the tape and to employ low-cost TDR instrumentation, such as TDR-307usb manufactured by Ersted Zao or the TrueSTDR100, which could be left on site for the permanent monitoring of the structure.

These lower-cost, but reliable pieces of equipment could be controlled remotely, and could provide an alert if certain conditions/thresholds (indicative of the presence of excessive water content) are exceeded. This alert could be used by the Decision Makers to plan and intervene with more sophisticated pieces of equipment or specific technologies (such as ground penetrating radar) for in-depth analyses of the structure.

IV. CONCLUSION

In this work, the preliminary results related to the use of an innovative adhesive copper tape used as sensing element were presented. The used copper tape can be as thin as 0.25 mm, and can follow any desired path on the structure. Most importantly, it can be removed without damaging the structure.

Further work will be dedicated to carry out comparative TDR measurements through TDR instruments with different specifications and cost, so as to assess the feasibility of a low-cost permanent system for monitoring moisture content in Cultural Heritage structures.

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