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PRACTICAL IMPLEMENTATION OF DIFFUSED SENSING ELEMENTS FOR TDR-BASED MONITORING OF RISING DAMP IN BUILDING STRUCTURES

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Abstract - This paper describes the operating and technical details of the practical implementation of an innovative time domain reflectometry (TDR)-system for monitoring rising damp in building structures. The proposed system employs wire-like, passive, diffused sensing elements (SE's) that are embedded, at the time of construction or renovation, inside the walls of the building to be monitored. The SE's remain permanently inside the wall, ready to be interrogated when necessary.

Keywords: moisture monitoring, smart building, structural health monitoring, rising damp, time domain reflectometry

1. INTRODUCTION

Smart monitoring and diagnostics have become essential, and monitoring systems are now expected to be reliable, effective, accurate, and possibly maintenance-free. Another desired requirement is non-destructiveness, which becomes mandatory when dealing with building structures. Some of the state-of-the-art solutions for nondestructive monitoring rely on electromagnetic methods, such as ground penetrating radar [1–3] and microwave transmission/reflection measurements [4]. One of the possible technological solutions to guarantee, simultaneously, all of the aforementioned requirements is to endow the system to be monitored (STBM) with built-in sensors, which remain permanently within the system and which can be interrogated non-invasively whenever necessary. However, most of the available embeddable sensors are local or point sensors [5, 6]. An addition downside is that most embeddable sensors often work on battery; hence, they require periodic maintenance. Finally, the sophisticated electronics of these sensors may not last long inside construction materials.
Starting from these considerations, the Authors have developed a time domain reflectometry (TDR)-based system, to be used in conjunction with low-cost, passive, flexible, wire-like sensing elements (SE's) for monitoring moisture content, and in particular the rising damp phenomenon, in building structures [7, 8]. Similarly to the sensing elements employed in [9] for the localization of water leaks in underground pipes, the basic idea is to extend the principles of punctual TDR-based monitoring to networks of diffused SEs, embedded permanently within the STBM's. One of the major advantages of the proposed sensing system is that the considered SE may be even tens of meters long and can follow any desired path inside the STBM, thus allowing to obtain a diffused profiling with a single SE. Furthermore, these SE's are passive; hence, they do not require maintenance. In addition to this, the considered SE's have no electronics on board, and the wires of the SE are protected from the environment by a plastic jacket, thus ensuring a lasting service life.
On such bases, after having validated the system in [7], the present work describes all the steps for the practical implementation of the proposed TDR-based monitoring system in a real house for the permanent monitoring of the rising damp. In the following, after a brief description of the background, all the technical and operating aspects are described in detail, and the preliminary results for the functional tests of the system are also reported.

2. MATERIAL AND METHODS

TDR had been originally developed mainly for the localization of faults in electric wires; however, thanks to its adaptability, TDR has progressively established itself as an appealing solution in the most diverse application contexts, such as moisture content measurements in porous materials [10], soil moisture measurements [11, 12], liquid level and permittivity measurements [13, 14], etc.
Generally, in TDR measurements, a step-like electromagnetic signal propagates along a SE inserted in the system to be monitored. The response of the system, in terms of reflected signal, is used to retrieve the desired information on the system under test. The direct output of the measurement is a reflectogram, which displays the reflection coefficient (ρ) as a function of the apparent distance (d^{app}) traveled by the EM signal along the SE [15]. The SE's used for the present practical implementation are flexible two-wire sensing elements, similar to the ones used in [7]. Each SE consists of two parallel copper wires (each with cross-section area of 1 mm^2), insulated from each other by a semi-rigid PVC jacket, as shown in Fig. 1. Fig. 2 shows a schematization of the envisaged practical implementation of the proposed sensing system. The basic idea is to permanently embed the SE's inside the walls of the building. The connection of the TDR instrument to the

Fig. 1. Picture of the biwire used as sensing element.

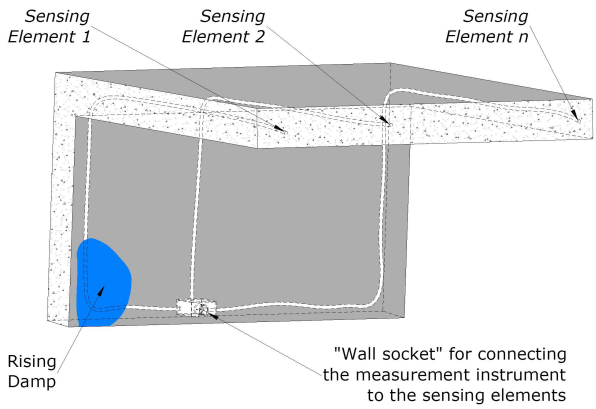

Fig. 2. Schematization of the possible implementation of SEs for monitoring building structures.

SE's could be obtained by creating a 'point of access to the SE', through a wall socket/plastic box on the wall.

The TDR measurements reported in this paper were performed through the Hyperlabs HL1500; a low-cost, portable unit, particularly suitable for on-the-field applications. This instrument guarantees an optimal trade-off of cost minimization and achievable measurement accuracy. The HL1500 generates a step-like signal with a rise time of 200 ps and with amplitude equal to 250 mV. The output port has a BNC connector, and the output impedance is 50 Ω.

3. INSTALLATION OF THE SENSING ELEMENTS

For the installation of the proposed system, a house under renovation was identified and chosen as case-study. This house had had severe problems with the rising damp in the past; therefore, it was deemed functional for the purpose of the work.

For an effective practical implementation of the embedded monitoring system, the first step was to analyze the planimetry of the building, so as to identify the places in which it was more strategic to install the SE's. Fig. 3 shows the planimetry of the building chosen for this implementation. The black circles indicates the points in which the SE's were installed, whereas the white squares indicate the positions of the plastic boxes (to be installed inside the walls) where the connectors to the SE's are housed. The positioning of the SE's was decided so as to cover the rooms of interest, still minimizing the presence of plastic boxes in the walls. As a result, in total, 22 SE's and 11 boxes were installed. Because the rising damp is a phenomenon of moisture rising from underground, the SE's were positioned perpendicularly to the floor. Each sensing element had a length of 1.6 m. Fig. 4 shows the installation of a SE: it can be seen that the SE is inserted a few millimiters under the surface of the wall. It can also be seen that the sensing element is connected to a coaxial cable (RG58 type): this cable is introduced only to facilitate the subsequent connection of the TDR instrument and is not a 'sensitive' part of the system. For each SE, the length of the coaxial cable was 2.4 m. As shown in in the inset of Fig. 5, when the SE is not being used, the coaxial cable is rolled up and placed inside the wall box. When it is necessary to check for the presence of rising damp, the coaxial cable is rolled out of the box and connected to the TDR instrument.

4. EXPERIMENTAL RESULTS

Once the SE's were installed, for each of the SE, a TDR reflectogram was acquired. These reflectograms represent the 'signature' of the normal operating condition of the wall (i.e. with no rising damp). Subsequently, when checking for the possible presence of moisture, the comparison of the 'new' reflectograms with the stored 'signatures' will help assessing the presence of water infiltration. Fig. 6 shows the acquisition of the 'signature' TDR reflectogram. The case depicted in Fig. 6 is one of the cases in which a single wall box houses the connectors to more than one SE. Clearly, each SE is independent of the other, and each connector must be connected separately to the TDR instrument.

For the sake of example, Fig. 7 shows the reflectogram acquired for three of the 22 SE's. As expected, it can be seen that, in dry condition of the wall, the reflectograms are practically horizontal in the portion between 5.3 m and 7.7 m, which corresponds to the apparent length of the SE's. In presence of rising damp, it is expected that the reflectogram will show significant dip and a lengthening of the overall apparent length of the SE: this would be due to the presence of water, whose high relative dielectric permittivity value (approximately 78) increases the typical relative dielectric permittivity of the building materials (in the order of 4-5), thus provoking specific changes in the TDR reflectograms.

On a final note, it is worth pointing out that, similarly to monitoring in civil buildings, viaducts, bridges and a lot of other infrastructures could benefit from the embedding of these SEs. Additionally, the application of this system is not limited to moisture content profiling; on the contrary, it would also allow to periodically monitor the health status of the structures. The embedded SEs, in fact, could also be used

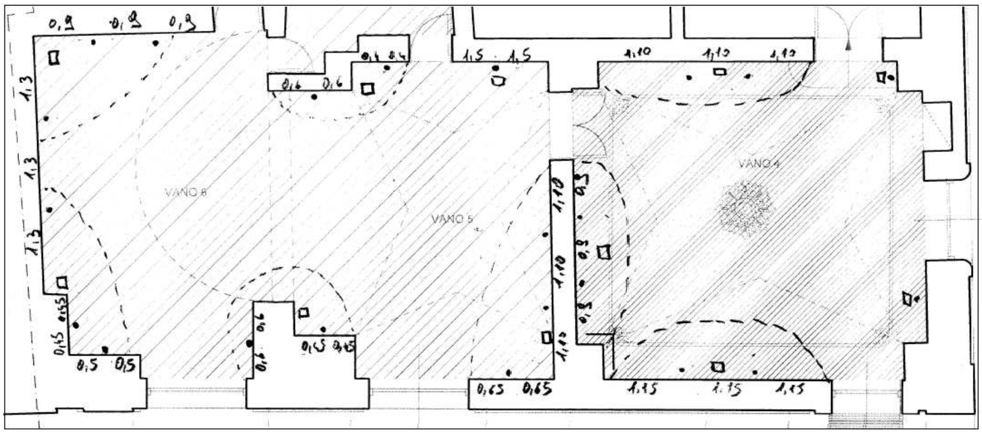

Fig. 3. Planimetry of the building in which the SE's were installed. The black circles indicates the position of the SE's, whereas the white squares indicate the position of the 'point of access to the SE' on the wall.

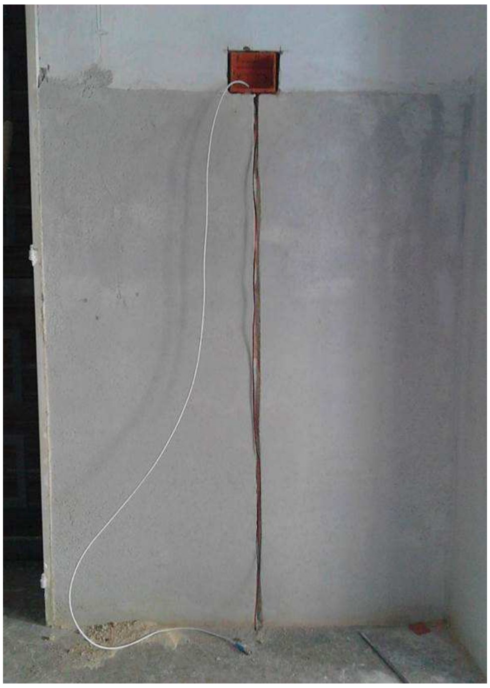

Fig. 4. Installation of the SE and installation of the wall box.

Fig. 5. Picture after the installation of the SE is completed. The inset shows how the coaxial cable is rolled up ad placed inside the wall box.

to detect the incipient growth of cracks. For example, by acquiring the TDR response right after a structure has been completed, it would be possible to store it in a data-base and to use it for subsequent comparative purposes when checking for the health status of the structure (ex-post monitoring): any change in the TDR response could be related to possible degradation/aging of the structure.

5. CONCLUSIONS

In this work, the practical implementation of diffused, flexible, wire-like SEs in conjunction with TDR for diagnostic and monitoring of rising damp in building structures was addressed. The experiments carried out for each of these applications confirmed the potential for practical application of the proposed system.

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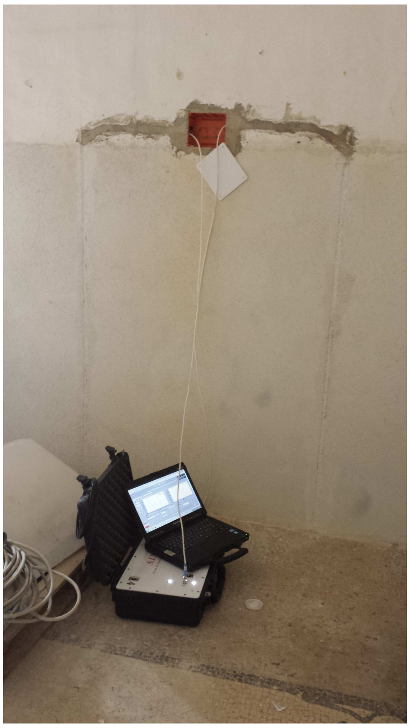

Fig. 6. Reflectograms acquired for three of the SE's installed.

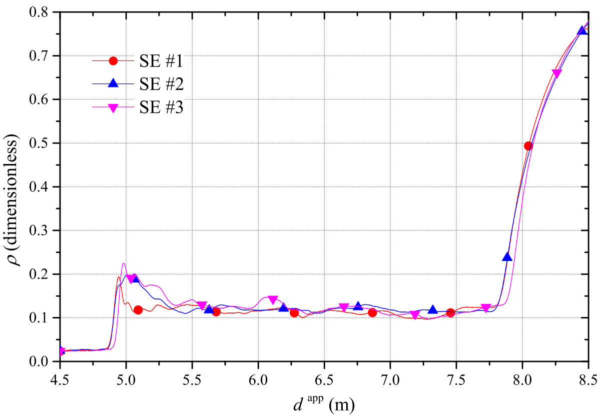

Fig. 7. Reflectograms acquired for three of the SE's installed.

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