SCANNING MICROWAVE MICROSCOPY TO CHARACTERIZE, MONITOR AND PRESERVE CULTURAL HERITAGE MONUMENTS

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INTRODUCTION

In the last decades, the interest of scientific community in characterizing, monitoring and preserving heritage monuments has increased in reaction to the acceleration of the degradation process due to the rising level of pollution.
The actual strategies adopted to contrast the degradation of the artefacts are corrective strategies. Preventive strategies capable of detecting early stages of the deterioration process and prompt an action to stop it before major damage happens, are deficient.

We present the ADRIANA project, in collaboration with the Autonomous Institute of Villa Adriana and Villa d'Este (VA-VE), UNESCO World Heritage Site since 1999 in Tivoli, Italy. The project aims to develop microwave probes to get local images and spectral properties of surfaces and sub-surfaces of the marble stones of Villa Adriana and, therefore, gather information on their conservative status by detecting physical and mechanical changes associated with the deterioration.

SITE

The site of Villa Adriana requires continuous restoration and conservation works that aim at the safeguarding and usability of its huge heritage. We have identified for the first investigations one of its most important buildings, the Maritime Theater (Fig. 1).
It is a circular islet, 25 m in diameter, surrounded by a canal underlined by an Ionic portico with architectural decoration inspired by marine motifs.
The islet was the apartment of Adriano originally reachable via two movable bridges.

Fig.1 – Villa Adriana "Maritime Theater".

Five main types of material alteration have been identified due to internal factors (summer/winter temperature changes, water infiltrations, presence of biodeteriogens, presence of soluble salts, erosion due to drafts).

1. Porous structure related to chemical-mineralogical composition of the stone
2. Water easily penetrated into the porous spaces, its transition from liquid to solid had destructive effects for the material, linked to the formation of ice crystals which produced breakage of the capillary walls and, at a macroscopic level, the appearance of fractures.
3. Presence of water-soluble salts. Water evaporation leaves the salts inside the stones which crystallize creating cracks.
4. Repetition of salts gel-thaw and crystallization-dissolution cycles led to the rapid destruction of the original porous structure, with micro and macro-fractures creations.
5. The presence of water also leads to deterioration phenomena by biological agents: algae and lichens. The formation of black films and crusts is evident, especially in humid substrates, which facilitate the presence of lichens that penetrated the porosity of the stone, corroding the surface with their dramatic mechanical effects.

METHOD

Near field scanning microscopy:

Set up developed at the CNR-IMM Rome laboratories (Fig. 2) works in reflection mode and the imaging consists of the maximum signal peak of amplitude (or phase) point-by-point measured at a chosen frequency. In this way a single image is obtained which provides a shot of the illuminated surface of the sample under examination. The scanning area is a 2,5 square cm suitable for local study of small samples.

Fig.2 – Scanning Near Field Microscopy setup: VNA Agilent E5071B (300 KHz to 8.5 GHz), SMA connector with etched tip and 3D printed chuck and sample holder.

Microwave Tomography:

A microwave tomography system has been designed with the following objectives:
1. To be used on a "in-field" environment;
2. To be completely non-invasive towards the object under test.

System prototype consists of a set of 20 antennas used both to illuminate the sample (transmission) and to receive the signal (reflection), positioned in contact with the external structure of the material to be inspected. The antennas have designed by CST Studio Suite 2018 and their layout by Altium Designer 20 (Fig. 3).

Fig.3 – Antenna and antennas holder.

A switching matrix connects the antenna set with a Vector Network Analyzer, which is used for multistatic and multi-frequency acquisition (Fig. 4). The measured data is processed by an inversion algorithm to obtain a reconstruction of the sample and the inclusions inside it. The algorithm is the opensource MATLAB framework MERIT Microwave Radar-based Imaging Toolbox.
The instruments management and acquisition software has been developed using Microsoft Visual Studio 2019 with Vb.NET language.

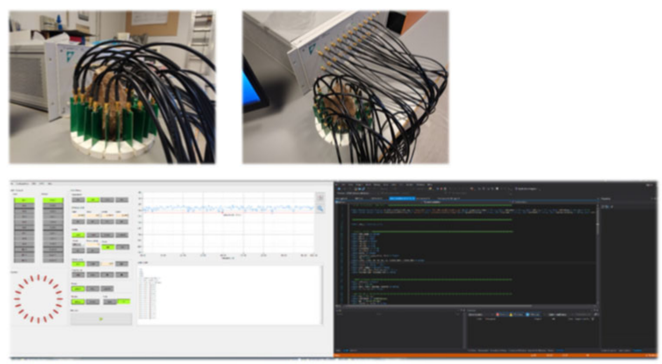

Fig.4 – Antenna matrix and acquisition software

ONGOING IMPROVEMENTS

We are setting up a portable instrument by building a new compact homemade switch matrix to be connected to Keysight P9375A (Fig. 5) and the new acquisition software.

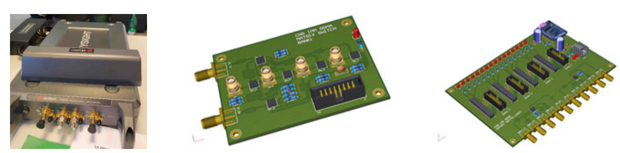

Fig.5 – Keysight P9375A, new homemade multiple switching matrix 4x2 and control unit.

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