



From apparent to real moisture index in masonry through inversion of microwave data: a first attempt

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Nowadays, the preservation of cultural heritage has become a matter of debate, as numerous factors contribute to its deterioration. In this case, water plays a key role, as it can cause significant damage to construction materials over time. Direct measurements of water content (WC) are not feasible in cultural heritage buildings because they are destructive. Therefore, it is essential to apply methods which are non-destructive and also highly sensitive to the presence of water.

Microwave-based moisture instruments utilize the transmission or reflection microwaves (i.e., electromagnetic waves in the frequency range: 0.3-300 GHz) to evaluate WC within materials. However, a major limitation of WC microwave measurements is that they provide cumulative moisture values that integrate the contribution of all material layers from the surface up to the probe's penetration depth. As a result, previous studies have only relied on displaying cumulative moisture maps instead of the true ones.

This work addresses this limitation by a simple least squares (LS) inversion approach based on an average weighted function, since no information about the actual weighting function implemented in the device is available. The forward model was assumed that the cumulative measurement at each penetration depth is of a weighted linear combination of moisture contributions from successive layers. Then, the LS solution was computed through the Moore-Penrose pseudoinverse to lead to the real WC at discrete depths without physical sampling.

The method was applied to a real dataset acquired at the Certosa del Galluzzo (Florence, Italy), a 14th-century historical complex affected by moisture deterioration. The instrument used in this study was the Moist 350B sensor, designed by HF sensor GmbH (Leipzig, Germany). The device utilizes the transmission and reflection of electromagnetic waves in the range of microwave (approximately 2.45 GHz) to evaluate the WC within materials by measuring their dielectric permittivity. It is equipped with five interchangeable probes, which are used for detecting WC at different penetration depths: 3 cm, 7 cm, 11 cm, 30 cm, and 80 cm.

First, the interest zones were identified by infrared thermography (IRT). Subsequently, the microwave sensor with all probes was applied to acquire cumulative data in these areas. Finally, synthetic Gaussian noise with a standard deviation of 1.5% (on the basis of the manual) was added to the dataset to simulate realistic measurement uncertainty prior to the inversion.

The inverted data for the superficial layer (at 3 cm) reveal good agreement with the IRT results, whether the area is wet or dry. In addition, the results indicate that when a layer is highly saturated, the layer below will be significantly affected so that its moisture amount is lower compared to the acquired data. In fact, the presentation of raw data, especially in a highly saturated layer, causes the layer below to be considered overestimated compared to the real values. In summary, the proposed approach can effectively reconstruct the real distribution without any physical sampling.