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Some tests of 3D ultrasonic traveltime tomography on the Eleonora d'Aragona statue (F. Laurana, 1468)

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ABSTRACT

The use of a non-destructive technique in situ can be a valuable diagnostic tool to support verification of restoration, as well as a monitoring technique in works of art or historical monuments.

We present a high resolution 3D ultrasonic tomography to one of the most important statues of the Regional Gallery of Palazzo Abatellis of Palermo, the bust of Eleonora d'Aragona by F. Laurana (1430–1502). This technique allowed to study the structural continuity of the material of the marble.

Some tests have been carried out to optimize inversion parameters, such as voxel size and to choose between straight and curved rays.

We propose to calculate a minimum lateral resolution using the sampling frequency instead of that of the probes. Consequently it was chosen to use a voxel size of 2 cm, lower than the expected resolution, 0.07 m (calculated considering the median ray length), and also to use curved rays instead of straight rays approximation.

The resulting model showed velocity values corresponding to a sufficiently homogeneous and well-preserved marble, but in the lower front portion of the trunk at the breasts, that bears the entire weight of the artwork, low velocity values are present.

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1. Introduction

Many techniques are generally used for investigations of historical monuments and artworks. Ground penetrating radar (GPR) method is regularly used for non-destructive imaging (Conyers, 2004; Daniels, 2004). Numerous studies have shown that the GPR method can give good results to detect and locate fractures and discontinuities within the investigated medium (Bavusi et al., 2010; Grandjean and Goury, 1996; Pérez-Gracia et al., 2009; Rashed et al., 2003; Sambuelli et al., 2011). However this method does not allow to obtain an estimate of mechanical parameters of the material and it is difficult to apply it on small artworks characterized by irregular sculpted exterior surfaces.

Also the electrical resistivity tomography (ERT) method is generally used for the study of cultural heritage (Capizzi et al., 2012; Cardarelli, 2002; Leucci et al., 2007; Nuzzo and Quarta, 2010; Tsokas et al., 2008). However, the potential field distribution within a volume delimited by a very irregular surface, such as that of a statue, is difficult to model.

Surely a technique that can be used on small objects with irregular surfaces is ultrasonic one. Ultrasonic survey for non-destructive test and for characterization of artefacts is a rather established methodology (Blitz and Simpson, 1996; Dynes and Lytle, 1979; Gambardella et

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Fig. 1. Eleonora d'Aragona by Francesco Laurana (1430–1502).

al., 2008; Phillips and Fehler, 1991). 3D Ultrasonic Tomography is among the diagnostic methods for studying the structural continuity of the material, a fairly well-established technique in the diagnostic study of works of art (Capizzi et al., 2009; Cardarelli and De Nardis, 2001). This technique can be performed to evaluate either the velocity (or slowness) parameter and/or the amplitude attenuation, but the first is almost always preferred for its easiness of implementation. In any case, essential for the proper use of this diagnostic technique for the study of works of art is the careful choice of parameters used to invert experimental data. The optimization of these parameters allows locating within the studied volume possible structural unhomogeneous areas, fractures or damages.

Some tests are here presented to optimize data analysis and inversion parameters in order to better fit the shape and type of the investigated anomalies. In particular, we present the application of 3D ultrasonic tomographic technique on one of the most important statues of the Regional Gallery of Palazzo Abatellis of Palermo, the bust of Eleonora d'Aragona by F. Laurana (Fig. 1). Furthermore, the results obtained using different inversion parameters are also presented.

2. The problem of the Eleonora d'Aragona (by F. Laurana)

During the restoration and the expansion of the Regional Gallery of Palazzo Abatellis (Palermo, Sicily) most of the marble works of museum has been subjected to an intense analytical restoration.

The bust of Eleonora d'Aragona is a beautiful bust, shown on the original support designed by the architect Carlo Scarpa in the 60s.

The sculpture (thickness 22 cm, width 40 cm and height 43 cm) is finely carved from a block of white and microcrystalline marble, result of metamorphism of a limestone or dolomite. Veins are usually due to various mineral impurities such as clay, silt, sand or iron oxides which were present in the original limestone. The quarry where the block was caved is not known.

The cleanup of the sculpture has revealed the sign of a possible veining (or fracture that probably originated on a natural veining of the marble block) in the central portion of the neck, involving the whole face of the lady.

For these reasons the curators started a diagnostic study aimed not only to monitor the structural continuity of the veining or lesion, but also to detect the internal marble conditions and the precautions to be taken in view of the mobility of the bust.

3. Ultrasonic data acquisition and analysis

To answer to the above given questions, we decided to survey the statue using the high resolution 3D ultrasonic tomography.

Berryman (1990) suggests that it is better to use full waveform information (damping of the waves) instead of first arrival traveltimes (velocity) as input data for inversion, especially when the wavelengths are comparable in size to the anomaly dimension. In our case, considering a marble velocity of about 4600 m/s and the central frequency of probes (55 kHz), we obtain a wavelength of about 0.07 meter, considering the median ray length. However, in spite of the Berryman suggestion, we chose to use the acquired data sets only to implement traveltimes tomography, because in our opinion it is a very rough approximation to consider every amplitude variation due to absorption effects, especially when the coupling between transductors and marble are not fixed but changing for every ray according to the stress applied by the operator to the probes. Therefore, although amplitude information could be a valid support to interpretation of velocity analysis, the absorption (or damping) data are often affected by problems in source and receiver acoustic coupling with rough and irregular surface, like in our case.

We used the TDAS 16 instrument produced by the Italian Boviar. This multi-channel equipment acquires 16 channels using en electronic switch on four channels at a time with a maximum sampling rate of 1.25 MHz. The equipment is supplied with both receiver and transmitter probes with a central frequency of 55 kHz. Probes were equipped with special aluminium cone (0.5 cm of diameter for contact area) to allow accurate positioning of the sensor on the surface.

Fig. 2. Measurement points were placed on a transparent film used to avoid damages on the surface.