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Frequency Resolved Acoustic Imaging in the Audio Frequency Interval: Panel Paintings

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Abstract **– In panel paintings the peculiarity of the substrate, due to the hygroscopicity of the wood, and the great variety of configurations determine their high sensitivity to the environmental conditions. An accurate evaluation of the structural damage may highly benefit their preventive conservation.**
We investigate the new application of a non-destructive and low-cost technique, a frequency resolved acoustic imaging method in the audio frequency interval, in the panel paintings' diagnostics of the structural damage. Three case studies are here proposed, showing very different features in terms of substrate configuration and conservation state of the painted film. A selection of acoustic images are presented, showing the potential of this method to reveal the effects of different causes of deterioration.
Keywords: Non-Destructive Testing; Acoustic Imaging; Structural Damage; Panel Paintings.

I. INTRODUCTION

The development of innovative non-destructive techniques for a cost-effective and accurate evaluation of the structural damage may highly benefit the preventive conservation of the panel paintings. Among the most advanced methods employed for this kind of artworks [1] we find for example the Holographic Interferometry, the Pulsed Thermography, also an integration of the two [2], and the Air-Coupled Ultrasonic Imaging [3]. But often cost barriers limit the use of these advanced techniques.

The present work examines the information obtained by means of a relatively low-cost acoustic technique in the new application to panel paintings diagnostics. The instrument, named Acoustic Energy Absorption Diagnostic Device (ACEADD), was conceived and patented to perform the measurement of the acoustic absorption coefficient on extended surfaces [4]. After the initial validation for demonstrating the correct localization of artificial detachments on laboratory models, the method was successfully employed in a number of studies on frescoes [5] and glazed ceramic tiles [6, 7]. In recent years the experimentation was extended to panel paintings, after the integration of an innovative highly directional acoustic source, useful for improving the spatial resolution and enhancing the sensitivity of the device to small defects [8, 9].

The first acoustic images of three panel paintings obtained in the audio frequency range, in the interval 1 kHz – 16 kHz, will be illustrated. The aim of the investigation is to explore the potential of the diagnostic method to: i) give helpful indications about the conservation state of this type of paintings; ii) to discriminate different damages, analyzing the features of a set of acoustic images displaying the data in different frequency bands.

II. THE ACOUSTIC IMAGES OF PANEL PAINTIGS

A. The diagnostic method and the device

The ACEADD device is composed of a non-contact transceiver unit (an acoustic source and a microphone in co-axial configuration) and its electronic chain, delivering sound waves towards the painting's surface and measuring in a back reflection geometry the amount of reflected acoustic energy, Σ. The instrument, depicted in Fig. 1, automatically scans the surface under test analyzing the acoustic response of a number of points.

The system equipped with the highly directive acoustic source (Audio Spotlight by Holosonics) shows a great potential in on site non-destructive applications thanks to the small size of the acoustic source, and to the great flexibility of the instrumentation which can be easily used where the artefact is placed. Fragile paintings can be analyzed in their standard location, thus taking into account the specific environmental conditions and also

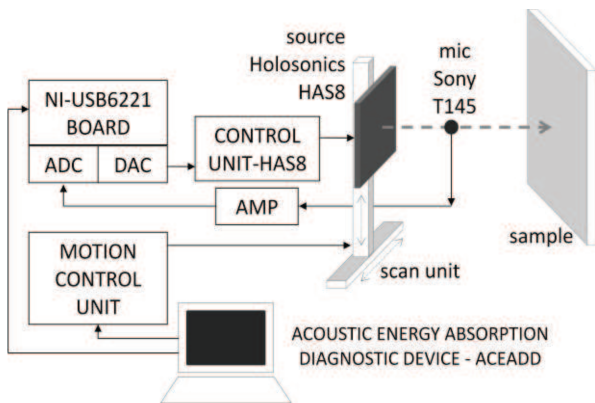

Fig. 1. Scheme of the ACEADD system.

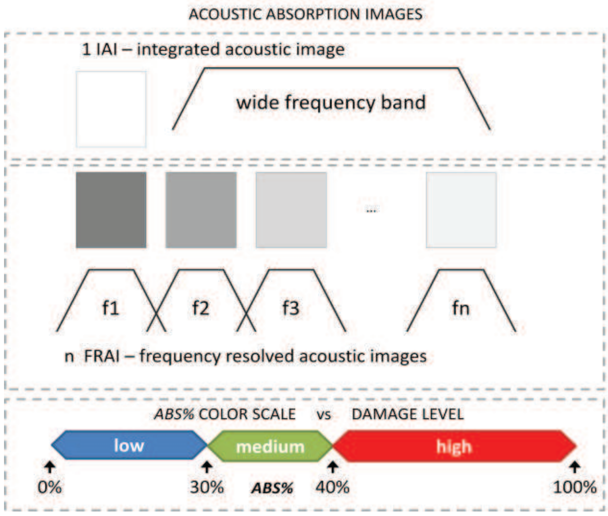

Fig. 2. Set of acoustic absorption images, and interpretation of the color scale used to display data.

avoiding the risks due to additional move.

In the post-processing procedure the most reflecting point (R) is usually assumed as reference, and for each analyzed point (i) the percentage of acoustic energy absorption, *ABS%*, is calculated with respect to the reference as follows

$$ABS\%_i = (\Sigma_R - \Sigma_i)/\Sigma_R. \quad (1)$$

Since the measurement is carried out employing a wide frequency band signal, the results are configured as a *set of images* displaying the quantity *ABS%*, as schematically shown in Fig. 2. In particular the method provides: i) one *integrated acoustic image* (IAI) displaying the data over the entire frequency interval, and ii) a number of *frequency resolved acoustic images* (FRAI) displaying the data in different narrow frequency bands (specifically 1/3 octave bands). The first image (IAI) sums up the information from many elements concurring to the overall state of conservation of the painting. The second ones (FRAI) provide these same information separated, as much as possible, and found in different frequency bands. Using a simple metaphor, it can be said that the integrated image is similar to listening to an opera performed by an orchestra, while the frequency resolved images are similar to individually listening to the same opera performed by a number of instruments playing solo. Since the parts showing a non perfect adherence vibrate at resonance frequencies that are inversely proportional to their size, different causes of deterioration can be evidenced in different images. Hence thick detachments or critical parts of the substrate are expected to appear in the images related to the low frequency bands; while thin flaws and superficial detachments are expected to become more visible in the images related to the high frequency bands.

Fig. 3. St. Bartholomew, IAI over the range (1 – 16) kHz.

Finally, the scheme at the bottom of Fig. 2 guides to the interpretation of the acoustic images: on the base of previous experience, the color scale used to display the experimental data features two significant thresholds (approximately at 30% and 40%) to indicate the limits between the low, medium, and high damage levels.

B. The case studies

The first case study is one of the major oil paintings of the remarkable collection Brignole-Sale, hosted in Palazzo Bianco (Strada Nuova Museums) in Genoa: *Venus and Mars* by P. P. Rubens (1632-1635). The oak wood substrate (1.42 m × 1.33 m, and mean thickness 3.5 mm) presents four horizontal boards and a vertical one, on the right, having grain running normal to the first ones. Presently, a heavy cradle in pitch pine is mounted on the back. Both the preparatory layer and the painted

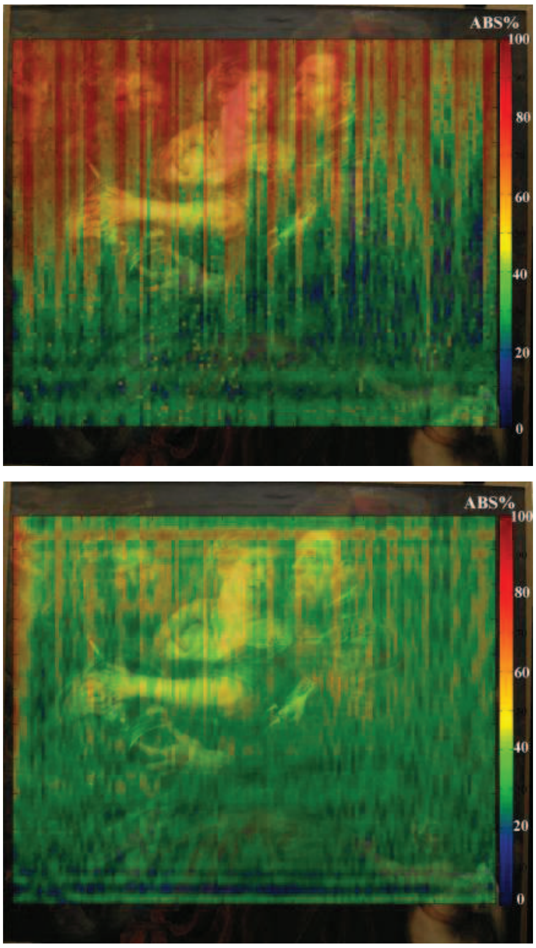

Fig. 4. Venus and Mars, FRAI at 4.0 kHz (top), and at 12.5 kHz (bottom) [8].

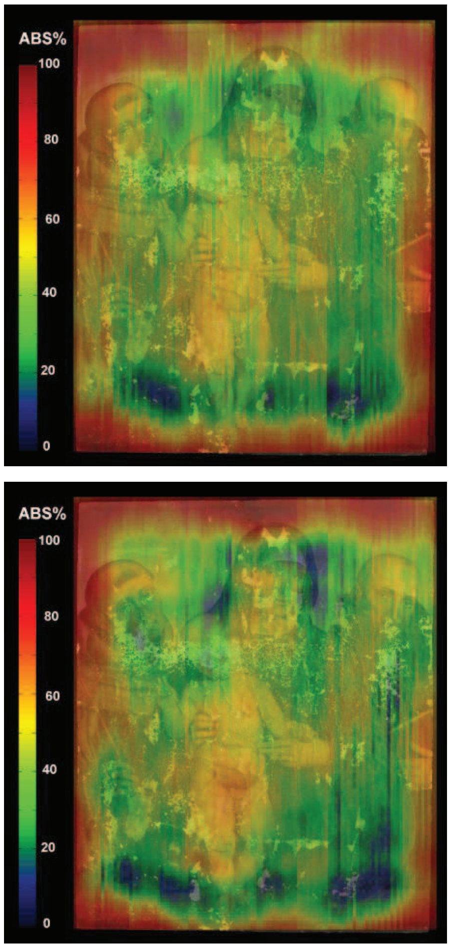

Fig. 5. Madonna with Child and two Saints, FRAI at 4.0 kHz (top), and at 10 kHz (bottom).

film are very thin [9].

The second case study is *St Bartholomew*, by an anonymous painter of the XV cent., preserved in the deposit of Palazzo Pitti in Florence, presently under restoration at the Istituto Superiore per la Conservazione ed il Restauro (ISCR) in Rome. The substrate in poplar wood, composed of four boards assembled in the long side direction, measures 2.2 m × 1.0 m, and thickness 1.0 cm. Two lateral narrow columns and a predella at the bottom compose the frame of the figure.

Also the *Madonna and Child with Two Saints*, probably XVI cent. after Francesco Francia, is preserved in the deposit of Palazzo Pitti in Florence, and is presently the subject of a thesis at ISCR in Rome. The substrate is a single poplar wood panel measuring 0.7 m × 0.56 m, 2.5 cm thick. No particular damage was present related to the substrate, while many detached areas of the preparatory and painted layers were distributed over the surface.

C. Results

The same measuring procedure was followed, and a similar data post-processing procedure was applied to obtain the acoustic images: for each image it included the normalization with respect to the reference point (R) and the reduction, where possible, of the effects due to the proximity of the panel's border, cutting the acoustic beam of finite size. In the present paper few representative examples, among the variety of acoustic images obtained during the investigation of the three case studies, are proposed in Fig. 3, Fig. 4 and Fig. 5.

Observing the areas highlighted by the color levels shading from yellow to red, a variety of elements seem to combine in the *integrated acoustic image*, clearly visible in Fig. 3. Few yellow vertical lines on the left, or the horizontal line in the central part on the predella, are present together with a number of red spots, among which those on the halo are particularly evident. The *frequency resolved acoustic images*, Fig. 4 and Fig. 5, suggest that in a certain measure it can be possible to separate the effects of different causes of deterioration. For example, in Fig. 4 (top) the image at the lower frequency band unveils a noticeable weakness in the upper half of the panel, also disclosing a sort of periodic structure, found to be compatible with the periodicity of the cradle structure, and progressively disappearing in the higher frequency band, Fig. 4 (bottom). In Fig. 5, slightly different areas appear in the two images: a red sector on the front of the saint on the left and a long horizontal area running below the knees of the child appear only in the high frequency image (bottom); furthermore the red area on the hand of the other saint on the right is particularly visible at the low frequency image (top).

Besides, more structured features such as straight lines or grids come out in the images of the two paintings (*St. Bartholomew* and *Venus and Mars*) characterized by a more composite substrate (multiple axes, junctions, cradle). On the contrary, for the third case in Fig. 5, only critical areas related to specific portions of the painted surface seem to emerge. In any case, as expected, finer details and more defined contours appear as frequency reaches higher values: for example in Fig. 4 (bottom) the critical part restricts to a narrow horizontal line, seemingly corresponding to a flaw in the upper board.

These results constitute an important knowledge base for orienting the next steps of the experimentation on panel paintings, encompassing the validation of the method on properly designed laboratory models.

III. CONCLUSIONS

The proposed analysis correlates acoustic energy absorption values to deterioration processes in paintings due to the failure of adhesion between adjacent elements, i.e. detachments of the painted film, flaws in the support or at the junction of adjacent wood axes. The instrumentation, composed of standard electronic components and a custom acquisition software, represents a new low-cost solution for effective diagnostics of the potential structural damage. The study indicates that the acoustic imaging technique in the audio frequency range provides very distant images depending on the analyzed painting, while following the same measuring procedure. Particularly structured elements are highlighted when the painting under test is characterized by a complex wood substrate. Furthermore, elements showing less defined patterns appear compatible with other characteristics of the specific painting. For these reasons, the method seems to be helpful for performing non-destructive diagnostics on panel paintings, for assisting preventive conservation actions or for periodical monitoring, that can be easily carried out on site. Beyond the correct localization of different damages, more accurate evaluation of the conservation state of an artwork can be accomplished by integrating the results of the acoustic investigation with other techniques. The knowledge of the thickness and the density of the different layers, derived for instance from stratigraphic analyses, can benefit to a more quantitative evaluation of the damage. The validation of the acoustic imaging method with laboratory models is presently under study.

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