Thermographic imaging or applications in cultural heritage

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Introduction – In the investigation of cultural heritage items, most of the valuable information often lies below the surface and, therefore, it is not accessible by means of ordinary visual inspection. On the other hand, such information is of the highest importance for scholars and conservators and highly fascinating to the general public. Due to this reason, over the recent years, non-destructive techniques for the analysis of artworks have been developed and, among others, infrared thermography is nowadays established as one of the most effective tool [1-5].

Although most of the thermographic studies have initially been carried out on mainly a qualitative way by the mere analysis of the recorded images, more recently a number of artefacts have been also quantitatively characterized by means of infrared thermography. Such characterizations require different thermographic approaches, both in terms of experimental configuration and of signal modelling, depending on both the optical and thermal properties of the artefact constituent materials.

In this work, after briefly reviewing the main aspects underlying the employ of the active thermography to the study of the cultural heritage, we report on some relevant results obtained by the application of the above mentioned thermographic approaches to the study of different kind artefacts characterized by semi-transparent external layers like paintings [6], illuminations and book-bindings [5].

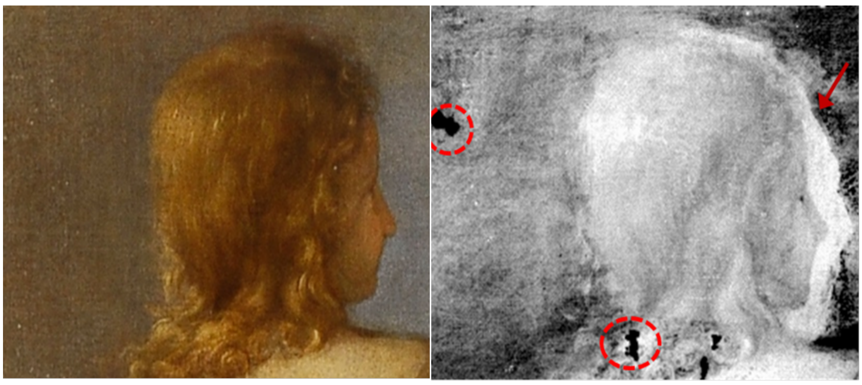

Fig. 1. Photo (left) and thermogram (right) of a painting revealing some *pentimenti* (arrow) and restorations (circles) beneath the surface [6].

In the case of book-bindings, we performed a quantitative analysis of those effects affecting the image quality of the features lying beneath paper and parchment layers, shown by means of the pulsed thermography. This can be particularly useful in the study of the historical book-bindings often made by using waste library materials of earlier periods consisting of written or printed scraps which are now buried beneath the cover or the counterguard and no longer visible.

Experimental and samples – The investigations have been carried out by means of the Pulsed Thermography (PT). The samples were heated by flash lamps delivering 3ms long pulses. The stimulated Mid Wave Infrared (MWIR) radiation emitted from the sample have been recorded by a MWIR camera in the 3.6–5.1μm wavelength range. Thermograms have been recorded over an acquisition time of up to 2 s after the pulsed heating with frame rates in the range between 150 and 500 Hz.

In order to explore the PT capability to detect and characterize graphic elements hidden beneath paper and parchment, some laboratory test samples consisting in ink layers laying beneath paper leaves of different thickness, have been prepared. They have been exploited to study the contrast of the buried ink features shown by the thermogram, as a function of time and depth. The quantitative analysis of the contrast *C*, assumed as the difference between the PT signal values taken on the inked and non-inked areas of the sample, respectively, was performed by adopting a simple theoretical 3D heat diffusion model implemented by a Finite Element Method (FEM) which accounts for the thermographic signal evolution.

Results and discussion – In the following, some results of a study carried out on the readability of hidden text are reported [7]. In this kind of investigation, the lateral diffusion of heat, which blurs the edges of buried writing, plays a crucial role, and the need to adopt a 3D analysis for the interpretation of PT thermograms is therefore essential. In particular, it is shown how the adopted 3D model proved effective in determining the PT signal profile across the edge of buried ink elements, and how it depends on the physical-geometric characteristics of the ink-paper structure. Finally, the soundness of the theoretical results was evaluated by comparing them with the experimental ones obtained by measuring the test sample described above.

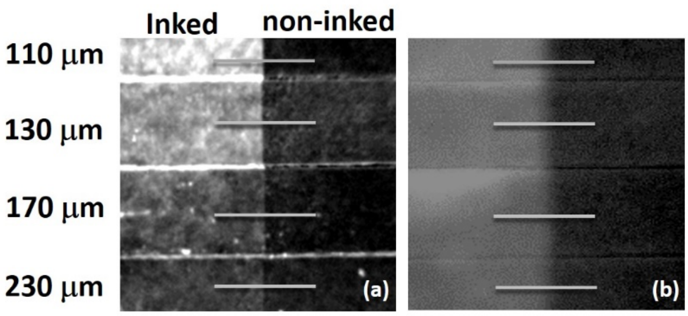

Fig. 2. Thermograms of the edge of the inked areas buried at different depths, recorded at (a) t=0.06s and (b) t=0.93s delays.

Fig. 2 shows two thermograms of the test sample, taken from the front side of the paper sheets of different thickness lying on top of the buried inked feature edge. They have been recorded at delay times of t=0.06s and t=0.93s from the heating light pulse. In the thermogram taken at later time the edge of the inked region appears broadened because of the lateral heat diffusion having occurred for a longer time and therefore being of a greater extent. In order to quantify such edge smearing effect, the following distortion parameter

$$\Delta(t) = x_{max}(t) - x_{min}(t) \qquad \text{Eqn. 1}$$

has been introduced. It accounts for the distance between the maximum and minimum contrast that occurs in the thermogram across the ink edge and defines how differently from an ideal step like profile ($\Delta = 0$) the signal contrast appears.

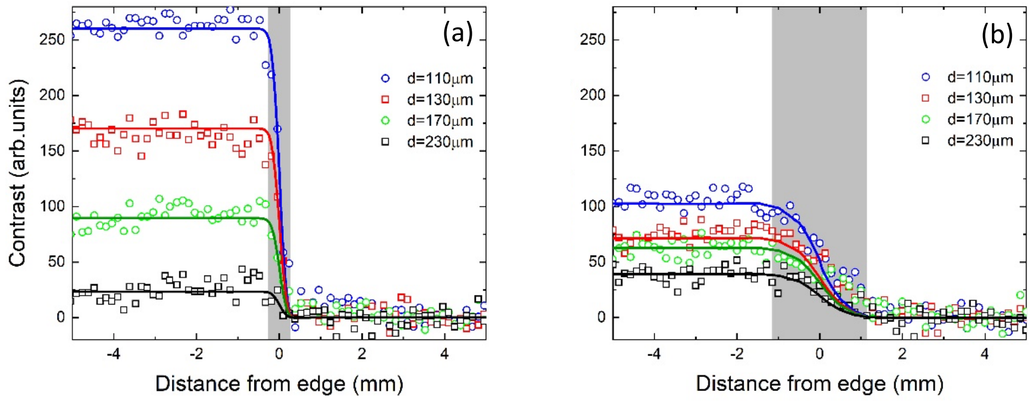

Fig. 3. Experimental (symbols) and theoretical (lines) contrast profiles across the inked edge areas recorded at two different delays: t=0.06s **(a)** and t=0.93s (**b**). The corresponding distortion indexes are Δ=0.56 mm (a) and Δ=2.30 mm (b), respectively.

In Fig. 3 shows the contrast curves obtained with the experimental data extracted from the thermograms of Fig. 2 along the highlighted lines crossing the edge of inked areas, lying at different depths. The curves obtained by the theoretical model for the corresponding depths have been also reported. The experimental data clearly show that the contrast decreases, as expected, with increasing ink layer depth, while the range where the distortion is relevant (highlighted in the figures) becomes broader for increasing delay times because of the increasing lateral heat diffusion. Moreover, at equal delay times, the distortion index Δ of the different contrast profiles, turns out to be the same for all the ink depth values. Finally, it is worth mentioning that the theoretical curves, if properly rescaled, superimposes very well the corresponding experimental data, witnessing the effectiveness of the adopted model.

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