Pulsed Infrared Thermography Application Documentary Materials

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Contributor: Vasiliki Dritsa , Noemi Orazi , Yuan Yao , Stefano Paoloni , Maria Koui , Stefano Sfarra

Pulsed Infrared Thermography (PT) is nowadays established as an effective tool thanks to its remote character allowing the in situ non-destructive investigation of the artworks by means of relatively simple experimental procedures.

pulsed infrared thermography ground penetrating radar cultural heritage investigation

1. Introduction

Scientific investigations of Cultural Heritage (CH) are of relevant importance since they allow for the gathering of valuable information, such as the ones concerning their manufacturing processes and/or preservation conditions. Among other techniques, Pulsed Infrared Thermography (PT) is nowadays established as an effective tool thanks to its remote character allowing the in situ non-destructive investigation of the artworks by means of relatively simple experimental procedures [1].

PT falls in the active modality. Contrary to passive thermography, active thermography requires an external heat source to stimulate the materials under test. Commonly, halogen lamps, high-power photographic flash, and laser beams are widely used, and other high-power cinematographic lamps and quartz line infrared (IR) lamps are used. In addition, active thermography is subdivided into lock-in thermography (LIT), PT, step-heated thermography (SHT), and vibrothermography (VT) according to external heating methods, and PT and LIT are the most utilized. Parker and other researchers integrated the PT idea into various non-destructive testing (NDT) applications. The concept of a PT system for defect detection consists of applying a short time and powerful energy pulse to an object and then recording the temperature rise, decay, or both curves in transient mode.

PT is one of the active infrared techniques, which uses an optical device as an external heat source. Among the active thermography techniques described above, it is the easiest to apply and widely used [2][3][4][5][6][7][8][9]. From the physics point of view, PT relies on the spatially resolved detection of the transient IR emission from the sample surface (in both the mid-wave (MW) and the long-wave (LW) IR spectral ranges), typically induced by the absorption of short light pulses.

2. Documentary Materials of PT and/or Passive IRT Applications

Among different applications, PT has been successfully adopted for the non-destructive detection of subsurface features in documentary materials. In the study of ancient books, PT has been applied to the analysis of bookbinding and, more specifically, to the investigation of the adhesion state among their different parts [10] and/or to the detection of the presence of possible damage [11]. Such experiments have often been carried out by means of integrated approaches combining the use of PT with other techniques able to provide complementary results, such as near-infrared reflectography (NIR) [12], and two-dimensional proton nuclear magnetic resonance relaxometry [13][14].

In addition to the analysis of the inhomogeneities in the book structure, PT enables the detection of the presence of buried graphical features, such as hidden texts or underdrawings on illuminations, even if their influence on the heat diffusion and, hence, on the resulting temperature distribution at the sample surface, is negligible. Such a possibility relies on the fact that library and archive items are made of optically semi-transparent materials and, unlike in the optically opaque ones, both the VIS light heating and the subsequent IR emissions take place over a specific sample depth depending on the sample optical properties. Therefore, the contrast in the recorded PT images may also originate from buried features characterized by different visible (VIS) absorption or IR emission properties with respect to that of the surrounding medium.

In this respect, it is worth pointing out that the detection of subsurface inhomogeneities is granted by the following mechanisms. When the position depth of the buried feature is smaller than the penetration depth of the VIS light, then PT contrast is mainly due to different temperature rises induced at the feature as compared to that at the surrounding parts because of the feature VIS absorption properties. On the contrary, deeply buried features may be possibly reached by the diffusing thermal wave, and owing to their different emissivity, a contrasted IR emission may take place.

Thanks to the latter mechanism, PT has proven to be more effective than IR reflectography [12] for the detection of in-depth buried elements, mainly when they are located beneath optically diffusing layers, such as the ones made of paper [15]. The presence of such layers can significantly prevent the IR radiation from traveling undisturbed back and forth from the surface to the subsurface feature and, consequently, the recording of readable reflectographic images.

On the basis of the considerations reported above, it is clear that the PT signal originating from optically semi-transparent materials is not merely proportional to the temperature variation at the sample surface as in the case of optically opaque ones. Therefore, quantitative evaluation in this kind of specimen is less straightforward than the ones carried out in other CH items, such as ancient bronze statues, due to the large number of sample properties involved in the PT signal description. Nonetheless, numerical models for the PT signal originating from features buried in semi-transparent materials have recently been proposed [16], and their development is still underway. In addition, image processing tools such as wavelet transform thermography (WTT) [17] and higher-order statistics thermography (HOST) [18] have effectively been employed even in the investigation of books to improve the visibility of the detected features in the acquired PT images.

As specifically regards the field dealing with investigations on ancient books, PT has been adopted for the detection of both the earlier scraps that had been reused to reinforce structural parts of the book-bindings and of the written fragments that had been inserted beneath the endpaper to keep the turn-ins well-attached to the board [11][19]. In this respect, it is worth pointing out that, in some cases, the contents of such written scraps can be of great interest to scholars and conservators, being able to provide information on the conservative history of books. For instance, **Figure 1** shows the results obtained on the back-end paper of a 17th-century book hosted at the *Biblioteca Angelica* in Rome (Italy) by means of the experimental setup described in Ref. [19]. The thermogram reported in **Figure 1**b has been recorded right after the VIS heating pulse over the area highlighted by the red rectangle in **Figure 1**a. As seen, such a thermogram allows the readability of the text on a fragment lying in contact with the back surface of the end leaf. As mentioned before, such a possibility is granted from the localized absorption of the visible heating light at the text ink, which, in turn, produces a more significant local IR emission with respect to the surroundings. Moreover, the IR radiation over the mid-wave infrared (MWIR) has been specifically detected since it is not substantially scattered when propagating through the end leaf on its way to the IR camera, thus allowing a more precise visualization of the text content in the recorded thermogram.

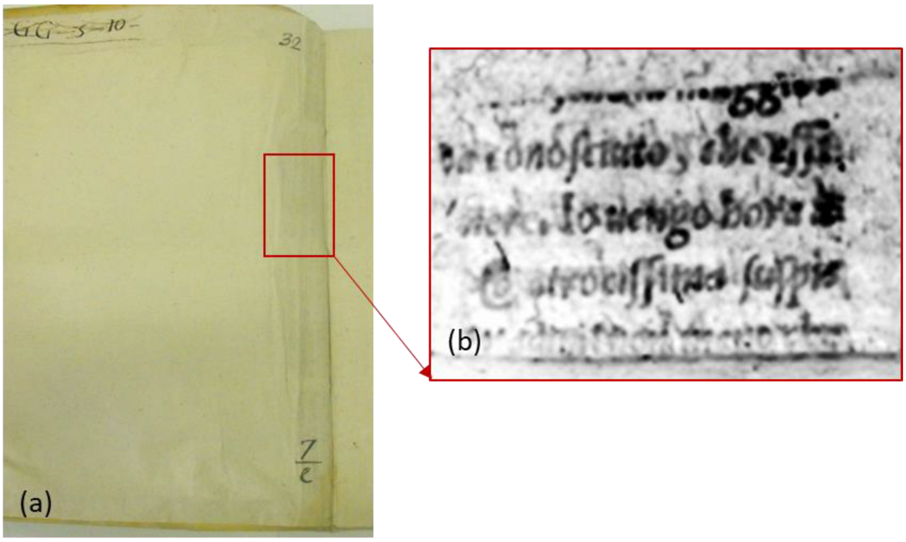

Figure 1. A 17th-century book, *Biblioteca Angelica* (Rome); (**a**) photo of the front end-leaf and (**b**) thermogram corresponding to the area marked by the rectangle in (**a**).

In this regard, it is worth mentioning that similar kinds of subsurface features have been investigated by the mobile macro-*X*-ray fluorescence (XRF) scanner technique that also enabled the mapping of the elemental composition of even the fragments located deeper in the bookbinding. However, the application of this technique is strongly limited to texts made of iron-based inks, thus excluding all carbon-based ones [20].

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