Subsurface defect characterization in artworks by quantitative PPT

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Abstract

In this study, experimental thermographic data from a specimen fresco with fabricated inserts was acquired and processed by Pulsed Phase Thermography (PPT) to detect and characterize the subsurface defects. The well-known concept of Signal-to-Noise Ratio (SNR) is proposed for the selection of the proper phasegram frequency at which defect sizing is performed. Different filtering techniques are explored as a de-noising step prior to the application of the Canny edge detection algorithm. It is demonstrated with this investigation that PPT is a valuable tool for the qualitative and quantitative assessment of artworks. Holographic interferometry results are also included for comparison.

1. Introduction

Cultural heritage pieces such as frescoes and other artworks of historical interest are highly sensitive to environmental conditions such as temperature, humidity and air pollutants. Non-invasive inspection techniques are required to diagnose the state of an artwork piece. Optical inspection techniques such as holographic interferometry [1] have proven very effective in providing precise information about the size and location of defects. Nevertheless, holographic techniques are difficult to apply in situ principally because of the strict stability requirements and high costs. The technique of Electronic Speckle Pattern Interferometry (ESPI) constitutes an interesting alternative [1]. Another possibility is to use infrared thermography, which is a non-contact, non-invasive and Nondestructive Evaluation (NDE) technique [2]. However, problems such as non-uniform heating, emissivity variations, environmental reflections and surface geometry have a great impact on raw thermal data [2]. The phase delay data obtained by Pulsed Phase Thermography (PPT) [3] is of great interest in Nondestructive Evaluation (NDE) given that it is less affected than raw thermal data by all these problems [4], making of PPT a very attractive diagnosis technique not only for qualitative inspections but also for quantitative characterization of materials. The use of the phase from PPT in combination with the signal-to-noise ratio is investigated for the determination of the size and depth of fabricated subsurface defects in a fresco sample.

2. Experimental setup and data acquisition

Figure 1 shows the data acquisition configuration. The specimen was heated during 13 minutes using 3 lamps (250 W / lamp), and the surface cooling down was recorded with an IR camera. One thermogram was acquired every 30 s and the acquisition lasted for 3060 s (*i.e.* 1 hour and 30 s), providing 121 thermograms. The fresco specimen was manufactured with non-homogeneous materials to simulate the background irregularities typical of ancient walls. Four defects were inserted with the characteristics described in Table 1.

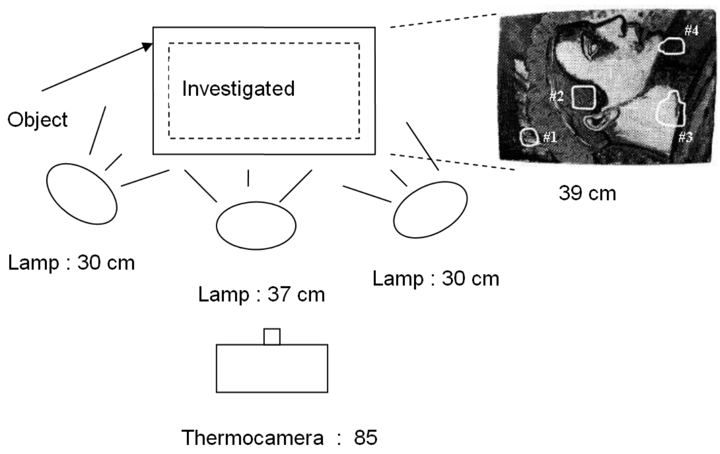


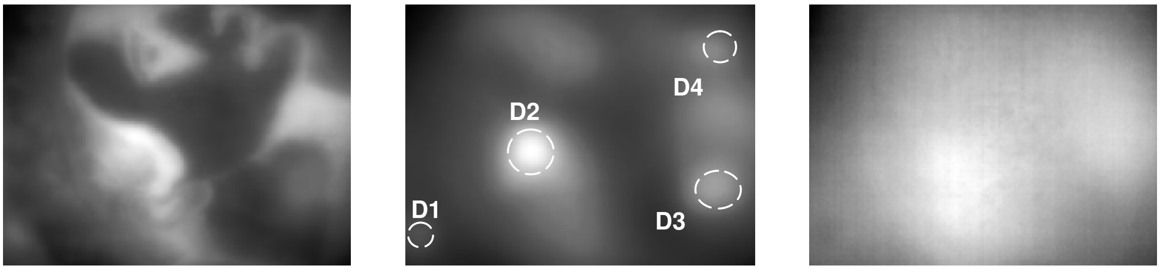
Figure 1. Experimental setup for data acquisition by pulsed thermography.

Table 1. Characteristics of the simulated defects in the fresco specimen (data adapted from reference [6]).

Defect	Type	Dimensions [mm]	Depth [mm]	Thickness [mm]	Reported area [mm^2]	Estimated area [mm^2]	% error
D1	sponge insert	35x35	3	3	1225	307	-74.9
D2	air void	45x30	10	10	1350	1146	-15.1
D3	air void	45x30	7	5	1350	1339	-0.8
D4	sponge insert	45x45	10	15	2025	658	-67.5

3. Results

Figure 2 shows three raw thermograms at different times. At early times (60 s in Figure 2a), the thermal signatures are related to the emissivity variations from the painting variations. Even though the impact of emissivity variations can still be seen at later times in the thermogram sequence (300 s in Figure 2b), it is possible at this point to have an indication of some of the defects (this image is in fact the one providing the best overall defect visibility). Dotted circles were added in Figure 2b to indicate the approximate locations of the four defects.

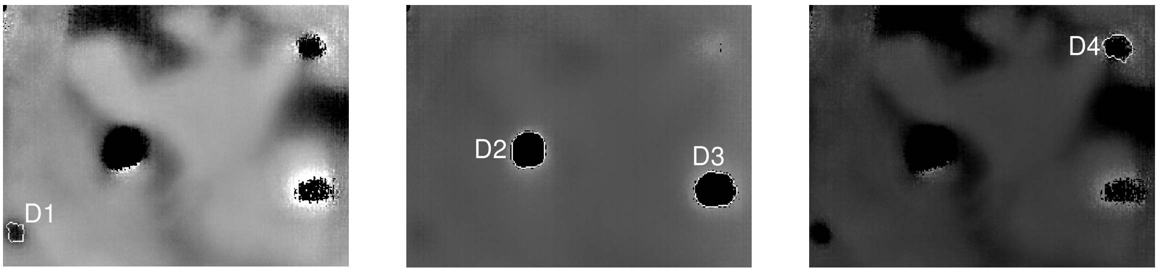


(a) **(b)** **(c)**

Figure 2. Raw thermograms at t=(a) 30 s, (b) 300 s, and (c) 1920 s. The approximate locations for the defects are shown in (b).

PPT was chosen to provide phase images or *phasegrams*, which are less affected by undesirable optical and thermal artifacts. However, noise content in phasegrams is considerable [5], especially at high frequencies. Hence, data was first filtered in order to de-noise the signal and then processed by PPT providing phase delay data. The resulting phasegrams were then used to detect the defects. For every defect, the signal-to-noise ratio (SNR) was estimated as[6]: $SNR=(S_{def}-S_{Sa})/\sigma_{Sa}$; where S is the signal, the phase in this case, evaluated in a defective area $_{def}$ or a sound area $_{Sa}$, and σ_{Sa} is the standard deviation in the sound area.

For a particular defect, the sound area was selected right next to it, calculated as the average value over the surface covered by the rectangular areas. Applying this operation to the whole sequence allowed to determine the frequency of maximum SNR for every defect and to use this frequency for the segmentation and size estimation. Once the frequency of maximum SNR was determined for every defect, the Canny edge detection algorithm [6] was used to find the defects edges in the phasegram matrix. Figure 3 presents the results. The defect size was estimated by calculating the area inside the segmented regions.



(a) **(b)** **(c)**

Figure 3. Phasegrams at f=(a) 1 mHz, (b) 0.34 mHz and (c) 1.3 mHz.

Preliminary results of the estimated area and %error are presented in the last two columns of Table 1. Space being limited, results from holographic interferometry as well as more thermography results will be presented and a thoroughly discussed in the final version of the paper.

REFERENCES

[1] LASer & Electro-optical Research in engineering metrology: http://dau.ing.univaq.it/~laser/, December 13th 2007.

[2] Maldague X. P. V. *Theory and practice of infrared technology for nondestructive testing*, John Wiley & Sons, N. Y., 2001.

[3] Maldague X. and Marinetti S. “Pulse Phase Infrared Thermography,” *J. Appl. Phys,* **79**:2694-2698, 1996.

[4] Ibarra-Castanedo C., González D. A., Klein M. Pilla M., Vallerand S. and Maldague X. “Infrared image processing and data analysis,” *Infrared Physics and Technology*, **46**(1-2):75-83, 2004.

[5] Ibarra-Castanedo C., Avdelidis N. P., Grinzato E. G., Bison P. G., Marinetti S., Liu C. Genest M. and Maldague X. P. “Quantitative inspection of non-planar composite specimens by pulsed phase thermography,” *Qirt Journal*, **3**(1):25-40, 2006.

[6] Grinzato E. G., Bison P. G., Marinetti S., Liu C. Genest M. and Vavivlov V. “Thermal NDE enhanced by 3D numerical modeling applied to works of art,” *15th WCNDT - World Conference on Nondestructive Testing*, [available online: http://www.ndt.net/article/wcndt00/papers/idn909/idn909.htm], Roma (Italy) 15-21 October 2000.

[7] Jain R., Kasturi R and Schunck B. G. *Machine Vision*, McGraw Hill, USA, 549 p., 1995.