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Stationary Wavelet Transform denoising in Pulsed Thermography: influence of camera resolution on defect detection

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Denoising filters are widely used in image enhancement. However, they might induce severe blurring effects the lower is the resolution of the original image. When applied to a thermal image in Non-Destructive Testing (NDT), blurring could entail wrong estimation of defect boundaries and an overall reduction in defect detection performances. This contribution discusses the application of a wavelet-based denoising technique to a thermographic sequence obtained from a Pulsed Thermography testing, when using a high-resolution 1024x768 FPA infrared camera. Influence of denoising approach on data post-processed by Principal Component Analysis is discussed. Results indicate marked enhancement in defect detection, especially when compared to those obtained with a standard-resolution 320x240 FPA infrared camera.

Introduction

Pulsed Thermography (PT) has shown great potential in the field of Non-Destructive Testing (NDT), mainly because of its capability in inspecting wide surfaces in relatively short testing-time. This represents an advantage when compared to other NDT techniques as ultrasonic testing.

However, detection of thermal waves reflected by internal defects might become a difficult task. Indeed some difficulties in performing test might arise, mainly because of non-uniform heating, environmental reflections and low Contrast to Noise Ratio (CNR) for defects that are deep in the sample: all these aspects contribute in limiting both the maximum depth of inspection and the size of the minimum detectable defect. Different studies [1, 2] have shown how a denoising processing directly performed on the raw thermal images increases the defect detection probability. However, if on the one hand denoising surely decreases noise level, on the other hand it could generate blurring effects that might reduce defect's contrast, besides worsening the estimation of defect boundaries.

This paper discusses how a wavelet-based denoising pre-processing can influence Principal Component Analysis (PCA) when used on two sets of thermal sequences acquired with thermal cameras having different resolutions. The paper is organized as follows: the experimental set-up is presented at first in Section 1; Section 2 presents the wavelet-based denoising strategy used; impact of the denoising pre-processing and benefits achievable in terms of CNR in high and low-resolution thermal sequences are highlighted in Section 3, while Section 4 reports the main conclusions.

Experimental setup

Pulsed Thermography tests were performed on a 280x280x4 mm carbon fiber reinforced polymer specimen with Teflon® insertions of different sizes (from 5 to 15 mm - x direction in Fig. 1a) and depths (from 0.3 to 2.0 mm - y direction of Fig. 1a). An ultrasonic C-scan was also performed on the same panel, in order to get reference data in terms of defects size and position (Fig. 1a).

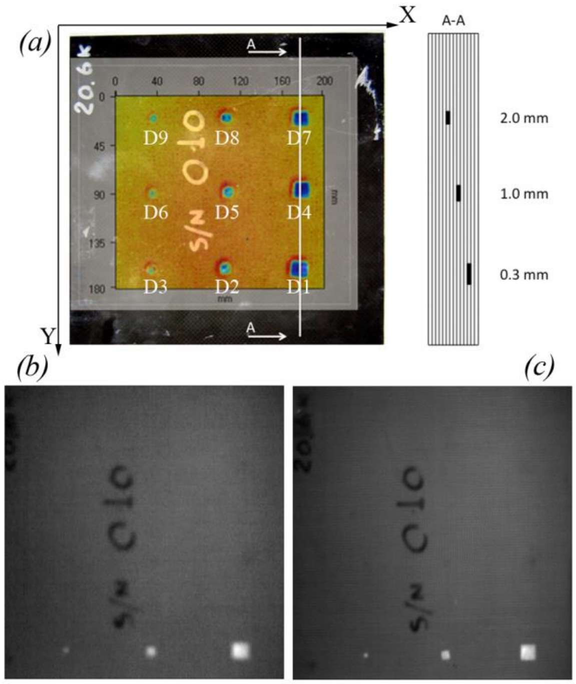


Fig. 26. Ultrasonic C-scan (a); thermal image acquired by 320x240 FPA at t=0.1 s after heat pulse (b); thermal image acquired by 1024x768 FPA at t=0.1 s after heat pulse (c).

The panel was placed 500 mm far from two flash lamps. Flash lamps provided a total load of 6 kJ in a 700 μs time interval. Two uncooled microbolometric infrared cameras with different resolutions were used for monitoring temperature evolution of the panel's surface. The first camera is equipped with a 320x240 FPA sensor, which is a quite common resolution for infrared cameras, whilst the second, an Infratec Variocam® HD, disposes of a 1024x768 FPA. Apart from different resolutions, the two infrared cameras show same specifications as it concerns thermal sensitivity (better than 0.1 K) and measurement accuracy (better than ± 2 K). Acquisition rate and truncation time were set to 30 Hz and 20 s respectively for both infrared cameras.

Fig. 1b and 1c show thermal images (cold frame subtracted) respectively from the 320x240 FPA and the 1024x768 FPA.

Proposed approach for enhancing defect identification

Interest of the scientific community in denoising techniques as pre-processing tools for enhancing PT results has gained relevance during the last years [1, 2]. It is widely accepted that the use of denoising filters on raw thermal images enhances the performances of well-known post-processing algorithms as Pulsed Phase Thermography, PCA, Signal Reconstruction, etc., making it possible to improve the defect detection task.

Among all denoising strategies, those based on wavelet processing do show interesting performances in terms of CNR improvement. Indeed, a trade-off between the removed noise and the blurring in an image always exists. However, wavelets capability to give detailed spatial-frequency information implies better discrimination between the noise and the real data, respect to what achievable with other filters like median or Gaussian ones, and such property might lessen the blurring effect or even overcome it completely.

The denoising approach used in this paper is based on the Stationary Wavelet Transform (SWT). Such transform has resulted in better performances respect to the Discrete Wavelet Transform (DWT), because more details can be preserved in approximation coefficients (see [3] for an application in image denoising). No further image enhancement methods are performed on the raw thermal sequences, even though some recent algorithms are available [4].

SWT has been applied to both high-resolution (HR) and low-resolution (LR) thermal sequences, using a *bior3.1* wavelet at decomposition level 2. PCA has been used in the subsequent post-processing.

Results and comparison between HR and LR sequences

Fig. 2 and Fig. 3 show the first Principal Component (PC) (only small-depth defects area) calculated respectively on the LR and on the HR thermal sequences. A comparison of PCs calculated when the sequences are/are not denoised is shown.

Denoising worsens PCA results when it is performed on the LR sequence (Fig. 2 a, b). Even though the pedestal of the PC profile (Fig. 2c) results smoother for the denoised sequence, the blurring effect leads to an evident lowering of the peaks corresponding to defects, thus resulting in a reduction of the CNRs. This happens especially on the smallest defect, as highlighted in Table 1.

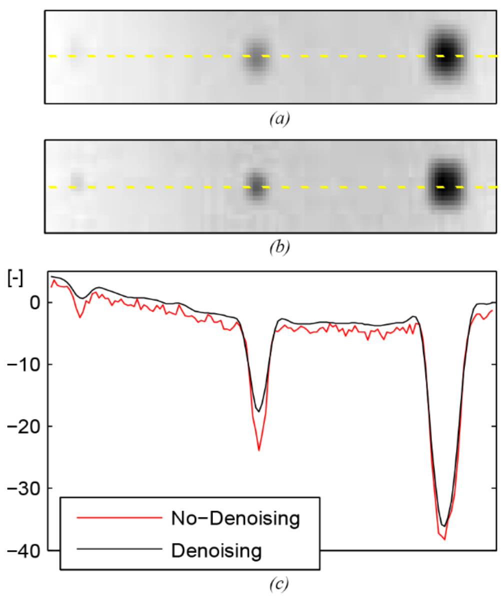


Fig. 2. First PC of thermal sequences from 320x240 FPA: with denoising (a); without denoising (b); profiles over defects line (c).

	CNR		
	No-Denoising	Denoising	% Difference
D1	4.4	4.2	-4 %
D2	7.0	5.7	-19 %
D3	3.8	2.4	-37 %

Table 1. CNRs for LR sequences. First PC.

Percentage difference is calculated according to Eq.1:

$$\% \, Diff = 100 \cdot \frac{CNR_{den} - CNR_{no\_den}}{CNR_{no\_den}} \qquad [1]$$

On the other hand, the use of the same denoising approach on the HR sequence is effective in reducing the noise content while keeping defect information, thus resulting in CNRs enhancement especially for the small defect (see Table 2).

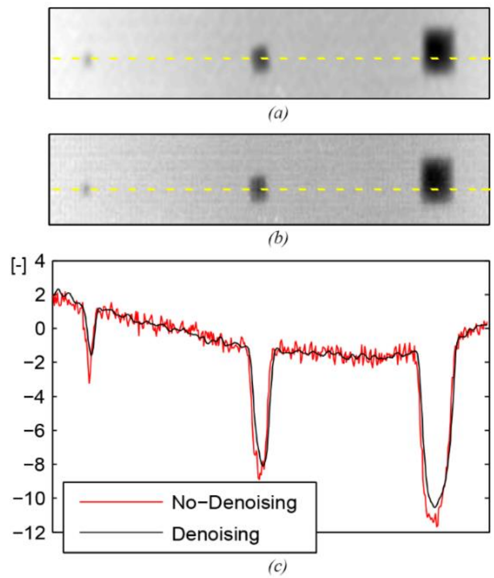


Fig. 3. First PC of thermal sequences from 1024x768 FPA: with denoising (a); without denoising (b); profiles over defects line (c).

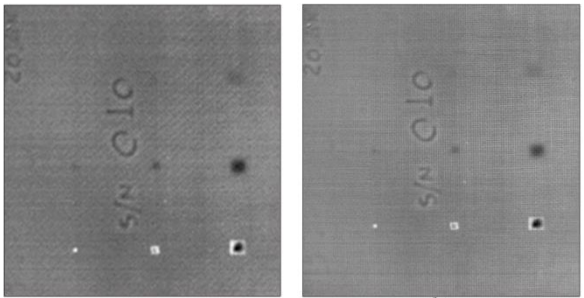
	CNR		
	No-Denoising	Denoising	% Difference
D1	3.7	3.7	0 %
D2	3.5	3.9	+11 %
D3	3.4	4.4	+29 %

Table 2. CNRs for HR sequences. First PC.

Deeper defects, which are not enhanced in the first PC, can be detected at higher components: indeed, in both LR and HR thermal sequences, they show the maximum contrast on the fourth PC, which is analysed hereafter. Fig.4 shows the fourth PC for both denoised and non-denoised HR thermal sequences. The CNRs associated with defects D4-D7 (i.e. the ones that can be well appreciated) are reported in Table 3.

	CNR		
	No-Denoising	Denoising	% Difference
D4	2.4	3.2	+33 %
D5	1.3	2.8	+115 %
D6	1.4	2.5	+ 79 %
D7	0.8	1.9	+ 137 %

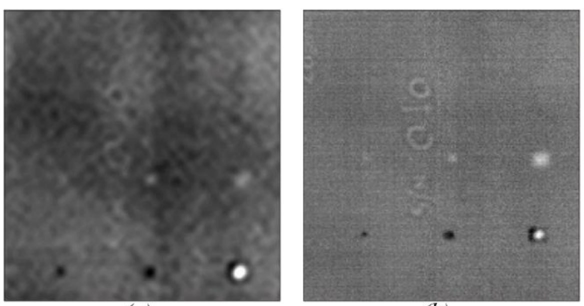
Table 3. CNRs for HR sequences. IV PC.



(a) (b)

Fig. 4. Fourth PC of thermal sequences from 1024x768 FPA: with denoising (a); without denoising (b).

Again, when denoising is applied to the HR sequence it demonstrates its effectiveness in providing image enhancement. As a consequence, all the CNRs show a marked increase respect to the non-denoised case; percentage differences are more relevant respect to values obtained with small-depth defects on the first PC, where noise content is clearly less incident. Fig. 5 shows the fourth PC for both denoised and non-denoised LR sequences. CNRs associated with defects D4-D5 (i.e. those visible in Fig. 5) are reported in table 4.



(a) (b)

Fig. 5. Fourth PC of thermal sequences from 320x240 FPA: with denoising (a); without denoising (b).

	CNR		
	No-Denoising	Denoising	% Difference
D4	3.0	2.8	- 7 %
D5	3.4	2.1	- 38 %

Table 4. CNRs for LR sequences. IV PC.

As for small-depth defects, denoising applied to the LR sequence worsens PCA processing. Denoising makes the image more flattened, thus decreasing the defect's contrast with respect to the image background (i.e. the area of the image not containing any defect) and therefore reducing the CNRs.

Conclusions

The paper has discussed the influence of camera resolution on a wavelet-based denoising, in Pulsed Thermography. Influence of denoising on PCA results has been shown.

Impact of blurring effects on the LR sequence is strong: blurring, which inherently happens when performing denoising pre-processing, produces distortions and defocusing that might become so important to lessen defect detection capability, especially with the smallest defects.

Nevertheless, wavelet-based denoising has demonstrated to be a powerful tool if performed on a HR thermal sequence. When used in conjunction to PCA, CNRs increase and make it possible to highlight defects that are less evident if no denoising is performed.

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