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SVD Based Principal Component Thermography

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1.1 INTRODUCTION:

Undoubtedly, PPT is a useful defect detection technique; but it does raise a conceptual difficulty regarding the appropriateness of applying sinusoidal basis function to represent a transient response that comprises modes of exponential delay. Additionally this technique is sensitive to the hardware setup and calibration settings such as the frame rate, the experiment duration, due to its effect on the statistical sampling. This concern prompted a review of alternative basis functions that might provide a more appropriate means of decomposing thermal response data produced by pulsed thermographic inspection [9] [10

An alternative technique called Principal Component Thermography based on SVD is presented in this section. It uses orthogonal function for decomposition and operates on the subsequence frames by arranging its pixel values spatially and temporally to highlight its data variance.

1.2 PRINCIPAL COMPONENT THERMOGRAPHY (PCT):

Using Fourier transform, signal in the temperature-time space can be decomposed into phase-frequency space which uses sinusoidal basis function for transformation but the temperature profile in pulse thermography is typically a transient signal which cannot be represented efficiently in terms of sinusoidal basis functions. SVD is an alternative tool to extract spatial and temporal data from a matrix in a compact or simplified manner. Instead of relying on a basis function, SVD is an eigenvector-based transform that form an orthonormal space. As discussed in section 4.2, SVD is presented as [25] [26]

!* = ‡**x* ˆ2 (1.1)

WHERE ‡2‡ = _,ˆ2ˆ = _; THE COLUMNS OF ‡ ARE ORTHONORMAL EIGENVECTORS OF !!2 KNOWN AS

Empirical Orthogonal Functions!2(EOF)! describing spatial variations of data, the columns of ˆ are orthonormal eigenvectorsx of known as Principal Components (PCs) represent ‡the timeˆ variations and is a diagonal matrix containing the square roots of eigenvalues from or in descending order.

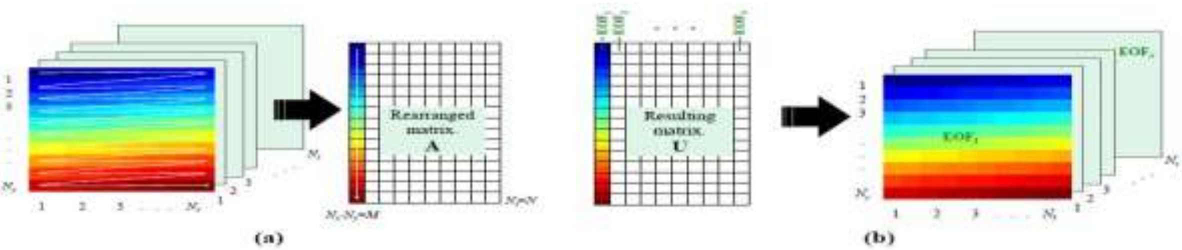

Figure 1.1 (a) Data rearrangement from a 3D sequence to a 2D **A** matrix in order to apply SVD (b)

Rearrangement of 2D **U** matrix into a 3D matrix containing the EOFs (courtesy by [21])

Data acquired from a thermogram matrix in the course of SVD based PCT is customarily organized in_the_manner_as depicted_ in **Figure_ 1.1**. The thermographic 3D matrix with dimensions 6 , ˜ and 8 , where 6 and ˜ describe the pixel dimensions of each frame and _8 describes the number of frames, needs to be rearranged as a 2D matrix with dimension• × _, where • = _6 . _˜ and _ = _8 as illustrated in **Figure 1.1** (a). To ensure uniform variance on a pixel by pixel basis, each of the • column vectors are subjected to a standardization process, which is achieved through

Â (%,   ) = ™(,*œ›)_š› (1.2)

where

•* = _⁻ ∑__⁻ !(%,) (1.3)

and

ž*⁻ = __⁻ ∑___ (!(%,) − •)_ (1.4)

After applying the SVD to the 2D matrix, the resulting **U** matrix, providing the spatial information, can be rearranged as a 3D sequence as illustrated in **Figure 1.1** (b) [27] [31].

1.3 SIGNAL TO NOISE RATIO (SNR):

SNR is calculated as approach proposed by Lee et al. [32] and reported in Eq. (1.5)

∑ B ∑£ Ÿ2„-†*(D,_) 5/(…}¦
†}¢) (1.5)

x__ = _/_.¤œM_(D,_)O¥^{5}

The numerator is the average power of the thermogram and the denominator represents average power of noise. The noise N(i , j) is calculated as the difference between two thermograms acquired for a single scene simultaneously. To utilize Lee et al. [32] approach in studying the noise from single thermal image Eq. (1.5) is modified into Eq. (1.6)

∑B¦¤Qƒ(D)5
¥/_ (1.6)
¤œM_(D)
x__ = O¥^{5}

where Pf(i) is the intensity profile along defective and N(i) is the difference between two profiles such as Pf(i) across the defective [33].

1.4 EXPERIMENTAL SETUP:

Experimental setup is same as discussed in section 1.3. CFRP material is used as a test sample for this experiment. The test sample is energized with halogen lamps and the temporal temperature map has been recorded for 100 seconds duration.

1.5 RESULTS AND DISCUSSION:

In PPT approach, FFT is applied over the temporal thermal profile of each pixel of the experimental video and amplitude sequences and phasegram sequences are obtained as shown in the **Figure 1.8**. Since phase information is more useful than the magnitude one, phasegram sequences are considered to extract the information. The way of extraction of temporal pixel is shown in the **Figure 1.3**. The best phase image is obtained at a frequency of 0.13 Hz, shown in

Figure 1.2.

In PCT approach, resulting matrix$_{EOF}$**U** is obtained by applying economy-sized SVD on the rearranged matrix **A** and the series of $_{EOF}$§ is reconstructed from matrix **U** as shown in **Figure 1.1**. The best PCT image is obtained at __, shown in **Figure 1.3**.

SNR of best PCT image and best PPT image is listed in **Table 1.1** for defect no 1 to 10. SNR of defects of PCT image is higher than PPT image, which leads to the better resolution of PCT image.

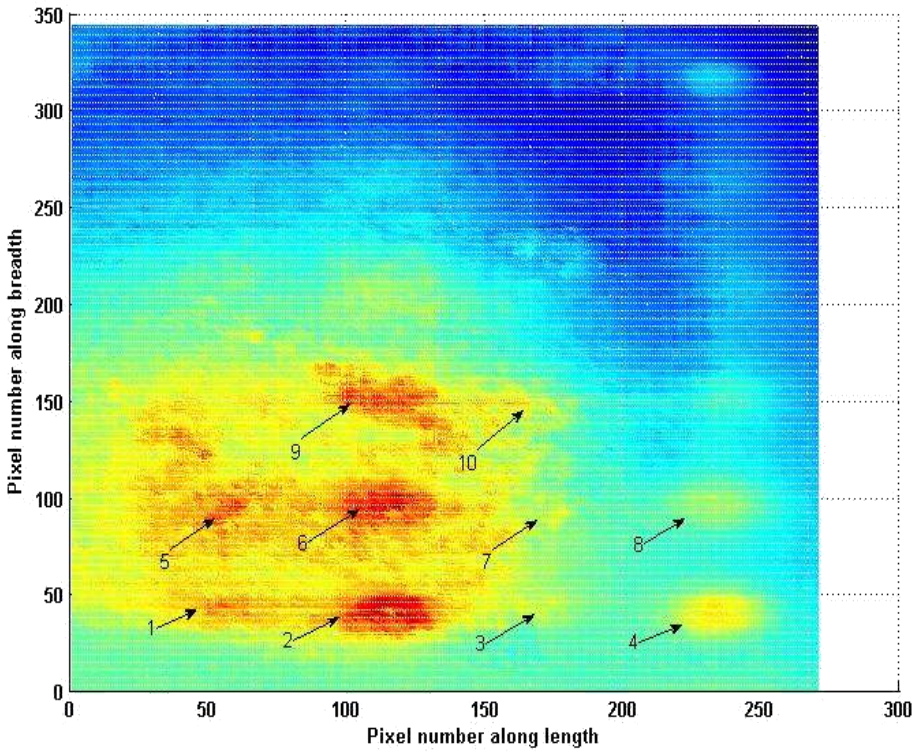

Figure 1.2 Phase image at0.13 Hz

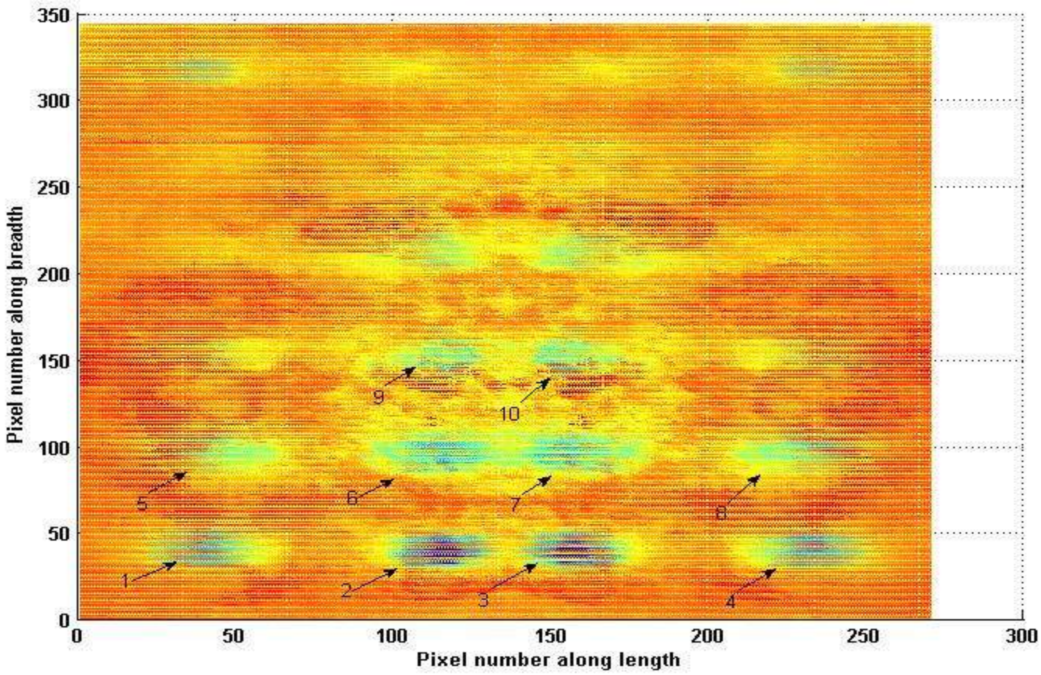

Figure 1.3 PCT image at EOF_

Table 1.1 SNR of best PCT and best PPT image

Defect no	SNR of PCT image (dB)	SNR of PPT image (dB)
1.	0.0612	
2.	0.1057	
3.	0.1108	
4.	0.0601	
5.	0.0315	
6.	0.1007	
7.	0.0988	
8.	0.0277	
9.	0.2909	
10.	0.5602	

1.6 SUMMARY:

1. The validity of the defect detection capability of PCT technique has been carried out on a CFRP sample.
2. SVD based PCT uses orthogonal function to represent the temperature profile which is a transient signal and overcomes the drawbacks of using sinusoidal basis function.
3. It has also been observed that resolution of PCT image is better than PPT image.

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