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An improved feature extraction algorithm for automatic defect identification based on eddy current pulsed thermography ☆

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ABSTRACT

In this paper, an improved feature extraction algorithm in Eddy Current Pulsed Thermography (ECPT) is developed to realize automatic defect identification. The proposed feature extraction algorithm includes a data block segmentation, a variable interval search, a correlation value classification and a between-class distance decision function. The data block segmentation and variable interval search are firstly combined to reduce the repetitive calculation in automatic defect identification. The classification and between-class distance are used to select the typical features of thermographic sequence. The method is not only able to extract the main image information, but also can reduce the time of thermographic sequence processing to improve the detection efficiency. Experiments and comparisons are provided to demonstrate the capabilities and benefits (i.e. reducing the processing time) of the proposed algorithm in automatic defect identification.

1. Introduction

Non-destructive testing and evaluation (NDT&E) [1,2] is important to ensure the safety of industrial manufacture and equipment operation, such as car industry, shipbuilding industry, petrochemical engineering and aerospace fields [3]. Electromagnetic nondestructive testing based on electromagnetic phenomenon can detect damages in ferromagnetic materials [4,5], carbon fibre reinforced materials [6–8] and so on. ECPT attracts much growing attention focus in (NDT&E) since that it can realize accurate non-contact inspection of a large area with a short time and large standoff distances [9,10]. It is also an available method to build a mathematic model of the data acquisition and self-adapting to analyze instability and nonlinearity [11–19]. Specially, this method contains Pulsed Eddy Current (PEC) and thermographic NDT techniques to reveal the information of the transient thermal responses of the defects [20,21]. The existence of defects will influence the distribution of the Joule heat. The Joule heat will produce the high temperature area and low temperature area [22]. The thermography technique records the different feature of the surface heat distribution. The information captured by thermography

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technique is displayed by the form of infrared image. The acquired infrared image sequences contain abundant and valuable information about the measured material in both spatial and time domains. The information about the defects of the conductor material can be extracted through infrared image sequence processing. In order to highlight the information about defects, many image processing algorithms have been used to process the image in the area of ECPT [23–25]. Principal components analysis (PCA) [26,27] has been applied to extract patterns of transient thermal distribution [24] and characterize the flaw depth in composite structures [25].

However, since the physical meaning of PCA is indefinite, it is difficult to further analyze information. Furthermore, PCA is also lack of the criterion to judge the existence of defects [20]. In order to solve these problems, independent components analysis (ICA) has been used to process the infrared image sequence to extract the abnormal features of surface defects [28–30]. ICA is a kind of Blind Source Separation analysis method [31–34]. ICA thinks that the initial acquired information is the interactional result of several independent components (ICs). The purpose of ICA is to compute all the ICs which have contained the main features of initial data. The ICA can be used to reduce the data volume and improve the efficiency of further data processing. In one IC, the characteristic of the area which has been influenced by this IC is highlighted. The other areas' characteristics which have been influenced by other ICs is restrained. In ECPT, the large image sequence can be represented by several ICs. And one IC displays one feature of the image sequence. The statistical independent ICs are estimated by the matrix transformation. The major procedure of ICA is the whitening method to pre-process the initial data and the iterative computation of the matrix transformation. However, without any prior information, the iterative calculation has to search in the whole data domain. The whitening procedure and the calculation are time-consuming. It should be mentioned that the efficiency of thermal image sequence processing is very important in the actual detection. It will influence the testing cost, the availability of detection, and so on. When ICA deals with large amounts of image data, their processing efficiency cannot meet the demands of the reality [35]. Hence, it is important to investigate how to build new image processing algorithms to improve the processing efficiency in ECPT.

With this motivation, a new characteristic pick-up algorithm is proposed by using the similarity of the typical transient thermal responses (TTRs) with the mixing vectors (the vectors of the pseudo-inverse matrix of the de-mixing matrix) in ICA. It can solve the efficiency problem of ICA by utilizing the selection of known information.

Specifically, the details of the algorithm are given as: firstly, the proposed algorithm divides the TTRs included in image sequence into several parts by the thresholds and finds the low-correlation TTRs by variable interval search. The specific determination criterion of variable interval is to compute the length of the area with largest temperature variation. The variable interval search in infrared image sequence can reduce the repetitive computation without missing the typical TTRs. Secondly, the normalized covariance matrix is calculated to classify the acquired TTRs. Order the covariance value of the covariance matrix and put the TTRs with low covariance value into one classification. Thirdly, the criterion of the largest between-class distance is used to pick up the typical TTRs. The mean value of each classification should be separately calculated. Then compute the non-correlation value of the TTRs with the mean value of other classifications. For one TTR, the sum of non-correlation value with other classifications is its between-class distance value. The TTRs with the largest between-class distance can be regarded as the typical ones. Finally, the typical TTRs can compose one matrix to linearly transform the initial image sequence. The main features of infrared image sequence can be extracted by the typical TTRs. Experimental results show that it can select the typical TTRs which are similar with the mixing vectors in ICA, in order to show the information about defect detection in NDT&E. Furthermore, they show that the processing time of defect detection under the proposed algorithm is shorter than ones under the ICA. That is, it can extract the main image information about defects efficiently by comparing the ICA.

The rest of the paper is organized as follows: Section 2 introduces the theoretical considerations. Section 3 introduces the experiment schematic diagram. Section 4 introduces the experiment results. Section 5 presents the conclusions and future work.

2. Theoretical considerations

2.1. The description of ICA in ECPT

The infrared image sequence records the whole transient thermal responses for the sample. ICA is used to process the image sequence to extract the main heat distribution information about defects. Only several images (independent components (ICs)) can represent the whole image sequence. It can decrease the time of defects detection. ICA processes these pictures by Eq. (1).

$$X^T(t) = \overline{W}Y'(t), \tag{1}$$

where $Y'(t)$ denotes the preprocessed initial data. $X^T(t)$ describes several ICs. $\overline{W}$ represents the de-mixing matrix. The mixing matrix M is written by the pseudo-inverse matrix of $\overline{W}$. From the results of ICA in [30], Fig. 1 shows that one thermal image can be divided to L typical feature areas, which are named by ICs. To derive the typical feature areas, the whitening algorithm is utilized to pre-process the initial data, and $\overline{W}$ is iteratively computed [36]. However, the two procedures need much time to run, which will increase the whole time of defect detection and restrict the improvement of detection efficiency at the actual testing.

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