Infrared Physics & Technology 67 (2014) 296–305

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

A novel algorithm for fast compression and reconstruction of infrared thermographic sequence based on image segmentation

Jin-Yu Zhang *, Wei Zhang, Zheng-Wei Yang, Gan Tian

Xi'an Research Institute of High-Tech, Hongqing Town, Xi'an 710025, PR China

HIGHLIGHTS

- A novel algorithm for compression and reconstruction of infrared thermal image sequence is proposed.
- Image segmentation is utilized to the compression of the thermal image sequence in space dimension.
- Thermal image sequences of two embedded defective specimens made of different materials are successfully tested.
- A high compression ratio is comfortably achieved, and the speed is remarkably improved.

ARTICLE INFO

Article history:
Received 12 March 2014
Available online 23 August 2014

Keywords:
Infrared thermographic sequence
Thermal image compressing and reconstruction
Image segmentation
Thermographic inspection

ABSTRACT

High resolution in space and time, which is associated with massive data processing and storage, is becoming the new trend of thermographic non-destructive inspection application. Therefore, it is demanding to develop a fast and precise data post-processing technique for high resolution thermal images. Through analyzing the attenuation of thermal wave temperature and the morphology feature of thermograph, the authors propose a novel algorithm, which provides an effective way to improve the precision and computing speed for post-processing of thermal image data, in this paper. Firstly, the algorithm will sort the thermographic sequence data in space by using image segmentation method. Secondly, the algorithm will employ classical fitting calculation to fit all the temperature decay curves. At last, the algorithm will use the fitting parameters of the curves as the parameters for compression and reconstruction of thermographic sequences. The proposed algorithm manages to compress thermographic sequences in time and space simultaneously. To validate the proposed algorithm, the authors used two defective specimens which were made of different materials to conduct the experiment. The experimental results showed that the proposed infrared thermographic sequence compression and reconstruction algorithm is an effective solution with high speed and high precision. Compared to the conventional method, this algorithm is not only noise resistant in time domain but also can increase the computing speed by hundreds of times.

1. Introduction

Infrared thermographic inspection is a new non-destructive inspection technique which have being applied in more and more engineering projects in recent years [1–8]. The compression and reconstruction processing of infrared thermographic sequence is the critical part since it is the fundamental and premise of all the prevailing thermal wave image processing methods. And fitting calculation in time domain is the basic thermographic sequence compression method [6–9]. By fitting the infrared thermographic sequence, it can reduce the noise of pixel points in time domain significantly. It also reduces the impact of uneven heating. Thus it will increase the contrast of defects. Only the fitting coefficients of sequence need to be stored after fitting. These coefficients can be easily applied to the fitting functions to reconstruct the original thermal wave images. This can greatly reduce the memory space needed to store the data [7–9]. For a regular set of infrared thermal images, they comprise of hundred of thousands or millions of thermographic sequences. To fit the huge number of thermographic sequences is a very tough task which needs to spend many hours and makes on site inspection in short time impossible. Therefore, how to compress the thermographic sequences without losing the thermal images' features becomes an engineering challenge to be solved urgently. It also has a high value in academic research.

* Corresponding author. Address: Xi'an Research Institute of High-Tech, 2 Tongxin Road, Xi'an, Shaanxi 710025, PR China.
E-mail address: mejyzhng@163.com (J.-Y. Zhang).

http://dx.doi.org/10.1016/j.infrared.2014.08.009
1350-4495/

Shepard et al. is one of the pioneers who were dedicated in researching the methods to compress and reconstruct thermographic. He initiated the groundbreaking work and proposed a unique method renowned as thermographic sequence reconstruction (TSR) [9]. Firstly, this method takes the logarithm of the original data both in time domain and frequency domain at the same time. Secondly, it performs fitting calculation by using polynomial fitting model. Thirdly, it uses parameters of the fitting model to achieve the compressing of thermographs. Shepard's method received good results in real application. Zhang et al. [10] proposed a non-linear LM fitting method based on thermal wave theory model to replace the polynomial fitting model after an in-depth study of the basis of transmission of thermal wave. This method achieved good results in some applications. Zhang et al. [11,12] also proposed GA and differential evolution (DE) based algorithm which gave global optimization performance and greatly improved the compression efficiency. Chen et al. [13] proposed a homotopy alternating iteration method which reduced the dependence on the initial condition like LM algorithm effectively and make convergence in a big range possible. Considering a highly coupled nature of global analysis often results in a significantly slower convergence of the data fitting algorithm, Pelet et al. [14] developed a global fitting algorithm, which was based on image segmentation. This algorithm provided all the images an appropriate initial estimated values. By making the feature of fluorescence lifetime images identical to fluorophore distribution, the converging speed can be greatly accelerated. Although these methods have gained better effect, they have disadvantages compared to TSR method. Since these methods employ iterative algorithms, they need large computation and long computing hours which impedes the application in real engineering practice. Especially the development of thermal imager in recent years makes the resolution increased from 320×240 to 640×480, even 1024×768. Thus the number of thermographic sequences to be processed has been increased 4–10 times, as well as time for data fitting and image compression. This makes it more difficult to perform on spot non-destructive inspection for engineering application.

To solve the problem, Zhang et al. [15] proposed a K-means based global compression algorithm. This method greatly improved the compression efficiency of thermographic sequences, thus remarkably increased the processing speed. Because the K-means method demands large computer RAM and the computation speed becomes slow when dealing with large number of sequences [16], the speed of compression and reconstruction of infrared thermographic sequences using K-means based algorithm could be restricted.

Therefore, this article proposed a simple efficient two-dimensional infrared thermal image sequence compression and reconstruction algorithm, which is using equidistant classification and thermal image segmentation methods, to improve the overall compression ratio, while greatly improving the thermal image processing speed of the system. By processing experimental data using proposed algorithm and other classical algorithms, it is found that the proposed algorithm has better processing results and faster processing speed.

The content is organized as following: Section 2 describes the characteristics and laws of thermographic sequences. Section 3 is the description of our proposed thermal wave image compression and reconstruction algorithm; Section 4 presents the experiment and result analysis. And conclusions are in Section 5.

2. Reconstruction basis of thermographic sequence

A lot of research and practical tests showed typical infrared thermographic sequences typically have the following three main features [9–15]:

(1) Since a number of thermographic sequences associated with a number of image frames, this large amount of data causes inconvenience in data storage and post-processing. The number of thermal image frames collected usually can be hundreds or thousands. Therefore, a large storage space is required. For example, in detection typical inspection (the frequency of thermal imager is 60 Hz, the acquisition time is 30 s, the resolution of pixels is 640×480), the collected original thermographic sequences require a storage space of 1.1 GB.
(2) The defect' thermographic feature tends to appear at different time according to its depth. The deeper the defect is, the later its appearing. Therefore, one frame or a few frames often does not fully capture all the defects on a specimen. In order to capture all the defects on the specimen, it may be necessary to set a longer acquisition time.
(3) Other factors (e.g. specimen' intrinsic defect, inconsistency of infrared imager components' response feature, external environmental disturbance, uneven heating, and etc) caused low contrast, big noise, unevenness in the collected thermal images. Image post-processing is required to eliminate these issues.

Since infrared thermography inspection is non-destructive inspection with a fixed visual field, i.e., the position of capturing thermal images during detecting process remain unchanged. Each thermographic sequence has one-to-one correspondence to specific pixel in all frames of thermal images. If we take a specific pixel in the image as the research object, we will get one complete time sequence and each value of the time sequence is corresponding to a temperature value or thermal radiation value of the pixel at the time when the thermal image was taken.

Infrared thermal image data sequence as a special kind of time series has its own characteristics. Fig. 1 shows a typical frame of pulse thermal image and three selected representative sequence sampling points. Fig. 2 shows the specimen surface temperature change curve of the selected sampling points. Three curves from top to bottom are the temperature decay curve of surface points in defect zone 1, defect zone 2, and no defect zone respectively. The surface temperatures of specimen rose rapidly after instantaneous pulse thermal wave excitation, then experienced rapid cooling stage and steady cooling stage, the temperature gradually became stable until it finally reached its thermal equilibrium. The temperature whole process can be roughly summarized into three stages: rapid cooling stage, steady cooling stage and temperature stabilization stage. It can be found that the difference of temperature change in defect zone and non defect zone occurred in the rapid cooling stage and steady cooling stage.

It also can be found that steady cooling stage is the most representative process. In this stage, the trend of temperature change in defect zone differed from that in no defect zone. The difference also

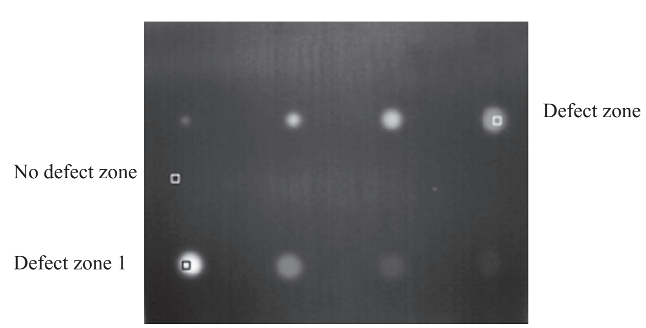

Fig. 1. A typical frame of thermal image and three selected sampling points.