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A new method to deal with the effect of subset size for digital image correlation

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ABSTRACT

A novel 2D digital image correlation technique is developed to deal with the effect of subset size and to improve the calculation accuracy. In this paper, a new method for efficient using pixels is discussed and the relations between pixels and the central pixel are investigated. A relatively large subset size is chosen in the method and all the pixels in a subset are not treated equally. Coefficients are set to each pixel rely on the importance of them to identify a subset from target images which are calculated by the normal distribution based on the distances between them and the central pixel. Compared with traditional digital image correlation, the method is a tradeoff between using a large subset size and a small one. Selection of subset size for traditional digital image correlation is replaced by selection of parameters for the equation in this method. The effect of subset size to correlation calculation is somewhat alleviated and the calculation accuracy is improved. Computer simulated, random speckle images are used to test the proposed technique and good results are reported.

1. Introduction

Deformation measurement of specimen surface is an important task of experimental mechanics. Various non-contact full-field optical methods have been applied for this purpose [1,2]. Digital image correlation (DIC) [3,4] has been widely used as a powerful and flexible tool for the surface deformation measurement which is an optical metrology based on digital image processing. DIC allows full-field deformations of a specimen surface to be calculated from digital images captured before and after deformation. A significant advantage of DIC is that it is robust and has fewer requirements in experimental environment. The measurement accuracy is affected by many factors such as the speckle pattern, the image capturing system and the correlation criterion. During the past few years, many factors have been extensively investigated by many researchers [5–7] and significantly improved. However, in traditional DIC, the subset size is usually selected by users and all pixels in a subset are treated equally no matter the importance of them to identify the deformed subset.

Traditionally, subset size selection is a necessary step of using DIC and has a large effect on the calculation accuracy. In this paper, a new method is developed to deal with the effect of subset size for DIC. We refined DIC techniques to effectively use pixels in subsets. The basic principle of DIC is tracking the same points between the reference and deformed images. The pixels surrounding the central pixel in a subset are used to identify it from the deformed image. Generally, the subsets selected from reference images are not only transferred of the positions but also transformed the shapes during the deformation of the specimen. The neighboring pixels in a reference image remain as neighboring in the deformed images for the deformation continuity of the specimen surface. Thus, the displacements of the nearby pixels are similar to the central pixel while which of the pixels at the edge or corner are much different. The importance of each pixel in a subset is not equal according to the distances between them and the central pixel. Traditionally, all the pixels are treated equally in correlation criterions no matter the importance of them. In this paper, the relations of the pixels and the central pixel are discussed and coefficients calculated by the normal distribution are set to each pixel so as to use the pixels more efficiently. A relatively large subset size is always used in the method and the importance of pixels is adjusted by changing parameters of the distribution. Subset size selection is replaced by selection of the parameters for the normal distribution. Since the

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effects to calculation results of the pixels far from the central pixel are smaller than others, the calculation accuracy is also improved by the method.

The paper is organized as follows. Section 2 describes DIC and the problem of treating all pixels equally. Section 3 details the importance of each pixel in a subset and the method of 2D DIC with coefficients. Section 4 presents experiments which use computer simulated random speckle images to test the proposed technique.

2. Outline of the digital image correlation

2.1. Basic principle of digital image correlation

DIC uses random speckle patterns on a specimen surface to obtain the full-field surface displacements by matching the subsets of images captured before and after deformation [8–10]. For DIC to work effectively, the specimen surface must have a random gray intensity distribution as a carrier of deformation information which deforms together with the specimen surface. Generally, a natural or white light source is sufficient for illuminating the specimen since DIC does not require laser sources, which are commonly needed for other optical techniques.

In the processing of recorded images, the same pixel between two images recorded before and after deformation are tracked. Typically, a subset of $(2M+1)\times(2M+1)$ pixels from the reference image is chosen, and its corresponding location in the deformed image is determined. The matching procedure works through searching the peak or valley position of the distribution of correlation coefficient. The position of the deformed subset is determined when the extremum of the correlation coefficient is detected. The differences in the positions of the reference and deformed subset center yield the in-plane displacement vector.

A correlation criterion is critical for DIC which is predefined to evaluate the similarity degree between the reference and deformed subsets. Different definitions of correlation criterion have been proposed by researchers such as cross-correlation, normalized cross-correlation, sum of squared differences and etc. [11]. Zero-normalized sum of squared differences correlation criterion (ZNCC) is widely applied in the DIC method for it offers robust noise-proof performance and is insensitive to the offset of the illumination lighting:

$$C_{ZNCC} = \sum_{i=-M}^{M}\sum_{j=-M}^{M}\left\{\frac{\left[f\left(x_i,y_j\right)-f_m\right]\times\left[g\left(x'_j,y'_j\right)-g_m\right]}{\Delta f\Delta g}\right\}, \quad (1)$$

where $f(x_i,y_j)$ and $g(x'_i,y'_j)$ are the gray levels of the points in the reference and deformed subset.

$$f_m = \frac{1}{(2M+1)^2}\sum_{i=-M}^{M}\sum_{j=-M}^{M} f(x_i,y_j), \quad g_m = \frac{1}{(2M+1)^2}\sum_{i=-M}^{M}\sum_{j=-M}^{M} g(x'_i,y'_j),$$
$$\Delta f = \sqrt{\sum_{i=-M}^{M}\sum_{j=-M}^{M}\left[f(x_i,y_j)-f_m\right]^2}, \quad \Delta f = \sqrt{\sum_{i=-M}^{M}\sum_{j=-M}^{M}\left[f(x_i,y_j)-f_m\right]^2} \quad (2)$$

Traditionally, all the pixels in a subset are treated equally no matter the importance of them to identify the deformed subset from deformed images. The calculation accuracy is sensitive to subset size selected by users of DIC. However, the relations of the pixels and the central pixel are not equal due to the complexity of deformation. The correlation calculation may be influenced by the pixels which are little relevant to the central pixel. What's more, the searching speed is also influenced by these pixels. It is necessary to study the importance of pixels and use them efficiently in correlation criterions.

2.2. Tread-off between a large subset size and a small one

In traditional DIC, before displacement calculation, an essential step is to select a subset size which has significant effects on the calculation accuracy. Usually, the subset size is selected manually by users according to the image pattern and deformation of specimen surface. All the pixels in a subset are treated equally in the correlation criterions no matter the importance of them to identify the deformed subset from deformed images. Subset size selection is a trade-off between using a large size and a small one so that sufficient pixels are included in a subset to distinguish itself and the calculation errors are relatively small. More pixels will be included in a subset if a larger subset size is selected. For example, if the subset size is changed from 30×30 to 40×40, the number of pixels in a subset is roughly doubled. As the added pixels are far from the central pixel and the deformation of them may be very different to it, the reliability of them to identify the deformed subset is lower than others. The calculation accuracy may be affected by these pixels. Then, it is necessary to investigate the importance of each pixel in a subset and use them more efficiently to improve the calculation accuracy.

If a small subset size is selected such as 31×31. Compared to a relatively larger one such as 61×61, it can be considered that coefficients of all the pixels in a smaller subset size are one while which of the others are zero. The pixels near the central pixel is important and the coefficients of them are always set to one no matter which subset size is selected. On the contrary, the importance of other pixels is relatively lower which need to be considered whether included in a subset or not. It is obvious that the coefficient curves are not smooth which can be replaced by more smoother curves. In our method, the coefficients of each pixel in a subset are calculated from smooth curves rather than selection between one and zero. The coefficients can be adjusted by changing the curves based on the image pattern and specimen deformation. Thus, subset size selection for DIC is replaced by selection of parameters to equations which are used to calculate coefficients of pixels. The advantage of this method is that the coefficients of each pixel can be adjusted accurately since more complicated curves can be selected according to the situation of the experiments. What's more, the coefficients of pixels near the central pixel are larger than others and the calculation accuracy can be improved.

3. Digital image correlation with coefficients

3.1. The importance of pixels in a subset

It is necessary to study the importance of pixels in order to efficiently use them to identify a subset from deformed images. As shown in Fig. 1, several pixels in a reference subset are selected. P is the central pixel of the subset, R is a pixel near the central pixel and Q is a pixel at the corner of the subset. The positions of the three pixels are changing during the deformation of the specimen surface. P', Q' and R' are the corresponding pixels of them in the deformed subset. S' and T' are the points of same relative coordinates to pixels R and Q, respectively. The gray levels of S' and T' are used in correlation criterions to compare with which of R and Q. As the gray levels of each pixel are assumed not change during the deformation, the gray levels of the pixels P', Q' and R' in the deformed subset are equal to which of pixels P, Q and R. The gray level of the point S' is similar to which of pixel R since the position of S' is almost same to R'. Nevertheless, the gray level of the point T' is much different to which of the pixel Q.