Research on Digital Image Correlation Method used for Strain Detection

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Abstract. Strain measurement is an important means to study structural strength. Strain gauge measurement method is widely used in different industry area. The strain gauge should be stuck on the surface of the measured object to detect displacement or strain. As the measurement mode is contact measurement, strain gauge can have a certain impact on the measured object itself. So research of strain detection is increasingly moving from contact method to non-contact method. In this paper, we design a digital image correlation non-contact method used for strain detection. The basic principle of image correlation method is introduced. And the image process algorithm is detailed described. A set of laser lighting hardware is especially used for object illumination to get a random distribution light spot instead of sticking target bar on object. The measurement results show that this method can detect strain with good effect and can be applied to non-contact strain detection test.

1. Introduction
Strain is an important physical parameter of material. The measurement and state evaluation of stress is an indispensable part of industrial production. At present, strain gauge method is a widely used and mature strain measurement method. It has the advantages of wide measurement range, high precision, good output characteristics, stable performance, high reliability and working in harsh environment\cite{1}. As this measurement mode is contact measurement, strain gauge should be stuck on the surface of the measured object to detect displacement or strain. This can have a certain impact on the measured object itself.

With the development of image sensing technology and image process algorithm, measurement based on image process has been more and more widely used. Computer vision, phototypography, stripe projection measurement are different application area based on image process to measure objet dimension size or displacement\cite{2-4}. Digital image correlation method is the technology by using computer to process digital image and with the help of digital image correlation processing to get the characteristics as we need.

In this paper, we present a kind of digital image correlation method used for strain detection. The structure is organized as follows: Section 2 introduces the basic principle of digital image correlation. Section 3 presents strain detection method by using digital image correlation. Section 4 introduces measurement test. Finally, Section 5 concludes the paper.
2. The basic principle of digital image correlation

The digital image correlation method uses camera to acquire two speckle images before and after the surface deformation of the measured object. And then correlation operation is carried on to the two speckle images. According to the extreme value condition of the correlation coefficient, the extreme point position of the correlation coefficient can be obtained by calculation and analysis, and then the corresponding strain information can be detected[5]. The basic principle of digital image correlation is shown as Figure 1.

![Figure 1: The basic principle of digital image correlation](image)

Image before deformation is also called reference image and image after deformation is also called target image. As the surface speckle distribution of the measured object is random, the speckle distribution of each sub-region is different from that of other sub-regions. Through calculation, analysis and search for the movement and variation of the sub-region, the displacement of the point can be obtained. Select point \( P(x,y) \) as the center of a square reference image subarea in the reference image. Use image correlation search method to search \( P'(x',y') \) in the target image where \( C_{f,g}(p) \) is a minimum or maximum value shown as formula(1). \( P'(x',y') \) is the position of \( P(x,y) \) after deformation.

\[
C_{f,g}(p) = \text{Correction}\{f(x, y), g(x', y')\} \tag{1}
\]

In formula (1), \( f(x, y) \) is the gray vale of point \( P(x,y) \) in the reference image. \( g(x', y') \) is the gray vale of point \( P'(x',y') \) in the target image. Correction is a function to describe the similarity between \( f(x, y) \) and \( g(x', y') \). \( p \) is the deformation vector between \( P'(x',y') \) and \( P(x,y) \).

The most common forms of definition of correction functions include standardize correlation function, standardized covariance correlation function and least square distance correlation function. In this paper, we choose least square distance correlation function shown as formula(2).

\[
C = \sum_{x=-M}^{M} \sum_{y=-M}^{M} [f(x, y) - g(x + u, y + v)]^2 \tag{2}
\]

The value range of \( C \) is \([0, +\infty)\). And if \( C \) is closer to 0, the similarity is higher. Numerical distribution diagram of correlation function is shown as Figure 2.
3. Strain detection method by using digital image correlation

For most of the measured objects not only the rigid body displacement but also the nonlinear deformation will occur on the surface of the object after force loaded shown as figure 3. Therefore, it is necessary to consider the influence of displacement gradient on the correlation coefficient.

Supposing there is inhomogeneous deformation between reference image and target image. Any point \( Q(x+dx, y+dy) \) near sub-area center point \( P(x, y) \) has a mapping relation with the point \( Q'(\tilde{x}, \tilde{y}) \) in the target image and the first order displacement deformation function is shown as formula (3).

\[
\begin{align*}
    x &= x + dx + u(x, y) + \frac{\partial u}{\partial x} dx + \frac{\partial u}{\partial y} dy \\
    y &= y + dy + v(x, y) + \frac{\partial v}{\partial x} dx + \frac{\partial v}{\partial y} dy
\end{align*}
\]

In formula (3), \( \frac{\partial u}{\partial x}, \frac{\partial u}{\partial y}, \frac{\partial v}{\partial x}, \frac{\partial v}{\partial y} \) are the displacement gradient of the sub-area. \( dx \) and \( dy \) are the \( x \) and \( y \) distance between \( Q \) and \( P \). Therefore, the displacement and its displacement gradient in the center of the sub-region can be used to describe the displacement and deformation of the sub-region. As to in-plane two-dimensional strain theory, \( Exx, Exy \) and \( Eyy \) are description of strain components shown as formula (4). \( Exx \) is the charge rate of \( x \) direction displacement and \( x \) direction coordinate. \( Eyy \) is the charge rate of \( y \) direction displacement and \( y \) direction coordinate. \( Exy \) is the charge rate of \( y \) direction displacement and \( x \) direction coordinate.
\[ \begin{align*}
    E_{xx} &= \frac{\partial u}{\partial x} \\
    E_{yy} &= \frac{\partial v}{\partial y} \\
    E_{xy} &= E_{yx} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}
\end{align*} \] (4)

4. Strain Detection test

In order to produce a high-quality random speckle pattern on the surface of the measured object, we set up a set of laser lighting hardware shown as Figure 4. The laser light goes through two reflectors and beam expander projected on the measured object. CCD camera acquires images of the object before and after deformation. Compare with traditional spray painting method, this laser lighting method is convenient and do not affect the object surface.

Figure 4. Optical path diagram of laser lighting

The strain detection test equipment is shown as Figure 5, including He-Ne laser, CCD camera and optical lens, reflector, beam expander, computer and software. The images acquired by CCD camera are shown as Figure 6. Uniform and comparable random spots can be seen on the surface of the measured object.

Figure 5. Photo of strain detection test equipment
The in-plane displacement of the surface of the object to be measured can be obtained by using digital image correlation method to process the image before and after deformation. The software measurement result is shown as Figure 7. In Figure 7 (a), x direction displacement is shown in the left part and y direction displacement is shown in the right part. In Figure 7 (b), strain parameters $E_{xx}$, $E_{xy}$ and $E_{yy}$ are in turn shown in the left part, middle part and the right part.
5. Conclusions
In this paper, we present a strain detection method based on digital image correlation. First, the basic principle of digital image correlation is introduced. And then, strain detection method by using digital image correlation is introduced. In order to get a high-quality random speckle pattern, a set of laser lighting hardware is used. Finally, $x$ and $y$ direction displacement, strain parameters $E_{xx}$, $E_{xy}$ and $E_{yy}$ are calculated out by software.

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