A Review on Deformation Measurement from Speckle Patterns using Digital Image Correlation

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Abstract - *The deformation measurement of a structural element subjected to external loads at any point is vital in several engineering domains such as mechanical, civil, aerospace, etc. For example, in the fields of mechanical engineering and civil engineering, the deformation properties are evaluated by measuring the surface displacement under a given load and structural stability is assessed by measuring the whole deformation of concrete and steel structures under load respectively. The conventional instruments that measure strain such as strain gauges, extensometers, etc. cannot create strain maps. A full-field strain measurement is possible with digital image correlation (DIC), a non-contact optical deformation measurement technology. The DIC method's main premise is to collect speckle images that are naturally carried or purposefully created on an object's surface before and after deformation and convert them into a gray image. This measurement method is easy to use, belongs to the non-contact measurement category, and has a high level of accuracy.*

***Key Words*: Digital image correlation, speckle images, deformation measurement**

1. INTRODUCTION

The determination of mechanical characteristics in various materials necessitates the use of appropriate strain measuring techniques. This is particularly true when loading circumstances result in complex heterogeneous deformation fields. Full field measurement techniques, in particular the Digital Image Correlation (DIC) methodology, are well suited to this task. This technique, also known as the white light speckle technique, is an optical-numerical full-field measuring technique that uses a comparison of images taken with a digital Charge Coupled Device (CCD) camera at different load steps to determine in-plane displacement fields at the surface of objects under any kind of loading. The primary concept of the DIC method is to collect speckle images on an object's surface that are naturally transported or purposely formed before and after deformation and convert them into a grayscale image.

The DIC has been widely used in material testing where the specimen size is small and the experimental setup is well-known. Due to its benefit over point-wise measurement techniques it allow a vast area of structures to be measured efficiently from a distance and the DIC has gained increased favour in large-scale structural testing in recent years.

Three-dimensional (3D) DIC works by computing a correlation function between two gray-scale images taken at distinct time intervals before and after deformation. From the coordinates of captured images and the camera calibration process, the true spatial coordinates of locations before and after deformation are rebuilt. High spatial resolution charge-coupled device (CCD) or complementary metal oxide semiconductor (CMOS) cameras, camera tripod supports, optical lenses, lighting system, camera synchronization unit, speckle pattern, and computer with appropriate software for displaying post-processing and storing data are needed for 3D-DIC measurements.

2. REVIEW OF RELATED WORKS

The method of implementing digital image correlation was first described in 1983 by Sutton *et al.* [1]. The authors describe how digital images of an object are taken before and after being transformed and use generated light intensity levels to transform distinct data into a continuous form through a surface fit.

To increase the accuracy of the DIC method, Bruck *et al.* [2] introduced the Newton-Raphson method of partial differential corrections and it is used to increase the accuracy of displacement and gradient calculations. The Newton-Raphson method is based on the calculation of correction terms that improve the initial assumptions of the DIC algorithm. By using the displacement of a subset center calculated within a pixel, the algorithm is less likely to find a local minimum, and more likely to find an absolute minimum.

D. Lecompte *et al.* [3] compare three different speckle patterns that originate from the same reference speckle pattern and introduces a method for determining the speckle size distribution of speckle patterns using morphology. The results shows that the size of the speckle along with the size of the pixel subset used, clearly affects the accuracy of the measured displacements.

The optimized Newton-Raphson algorithm was used by Bing Pan *et al.* [4] to study the tensile test of thin aluminum plates with circular holes, and the full field strain information was effectively extracted from the actual displacement field data of the DIC method. The calculation results are consistent with the theoretical method.

Bing Pan *et al*. [5] proposed digital image correlation (DIC) method using iterative least squares algorithm (ILS) for displacement field measurement and point-wise least squares algorithm (PLS) for strain field measurement. In ILS, correlation function concept is not used. But algorithm is actually equal to the optimization of the sum of squared difference correlation function using improved Newton–Raphson method.

The mean gray intensity gradient also introduced by Bing Pan *et al.* [6] for quality evaluation of the speckle patterns used in DIC. To test this concept, five different speckle patterns were translated numerically, and the displacements measured using DIC were compared with the exact ones. The errors are evaluated based on mean bias error and standard deviation error and found that they are closely related to the mean gray intensity gradient of the speckle pattern used and a good speckle pattern has a large mean gray intensity gradient.

Xiang Guo *et al*. [7] used a three-dimensional (3D) digital image correlation using plasma spray for speckle preparation in which a bandpass filter, neutral density filters, and a linear polarizing filter are used to reduce intensity and noise in images to measure the full-field strain of the surface at 2600°C. The results show that the proposed model is easy to implement and has high accuracy in high-temperature deformation measurement.

To reduce the effect of electromagnetic waves radiated by high temperature on the image, H. Deng *et al.* [8] placed a bandpass filter in front of the camera lens. . Two cameras are needed to take images before and after deformation. 3D-DIC was used to get the deformation field.

Tianci Hu *et al.* [9] proposed multi-camera based full-field 3D displacement measurement using DIC. This method needs only a small overlap area between the cameras and doesn't require additional calibration steps. By subtracting the coordinates before and after translation the full-field displacement was attained.

Y. Ding *et al.* [10] compare different correlation function models and studies the performance and unimodality of the shape function and associated functions, and the best function model is determined. Also analyzed the three whole-pixel search algorithms such as point-by-point search method, hill-climbing method and differential evolution algorithm. It was found that the hill climbing method based on the zero mean normalized least square distance sum function has the best performance and accuracy.

3. SPECKLE PATTERN

A speckle pattern is a random granular pattern created by a coherent light beam, such as a laser, reflecting off a rough surface such as a metallic surface, a display screen, white paint, or a sheet of paper. An example of speckle pattern is shown in fig 1.

The interference of reflected incident light beams with the corresponding optical phases causes this pattern. Even when modest changes in the incident beam direction or the lighted spot occur, the shape of the speckle pattern tends to shift.

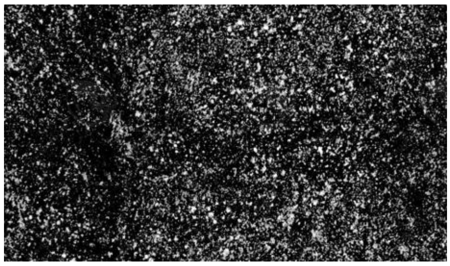

Fig 1: Speckle pattern

3.1 Speckle Patterns Types

The following are the two primary forms of speckle patterns:

Subjective speckle pattern – Subjective speckle pattern refers to speckle patterns created at the image plane of a lens. Interference of waves from various scattering regions of a resolution element of the lens causes subjective patterns. The response functions of the randomly de-phased waves are combined in this region, resulting in speckle patterns.

Objective speckle pattern - The formation of objective speckle patterns occurs when a diffuse object is irradiated by a coherent wave. The size of the speckle pattern is determined by the interference between waves from different scattering sites. With increasing distance between an observation plane and an item, the size grows linearly.

The surface speckle field of an object will alter in response to its deformation. The in-plane deformation information of the object surface can be retrieved indirectly by evaluating the change information of the speckle field before and after deformation. Surface polishing, artificial painting, and speckle transfer can be used to create artificial speckle if the object's surface lacks speckle or the quality of the speckle is inadequate.

4. DIGITAL IMAGE CORRELATION

The 2D DIC works on the idea of collecting the speckle images that are naturally carried or purposefully created on the object's surfaces before and after deformation then converting them to a gray image. Image taken before and after deformation is termed as the reference image and the target image respectively. To examine and quantify the correlation of the grayscale information in the speckle image, the correlation search technique is utilized. To get the object surface deformation information, complete the maximum gray field sub-region matching.

Image capture module (CCD camera, electron microscope, and other optical imaging equipment), light source (white light source), and DIC analysis processing module make up the 2D-DIC image acquisition technique (computer with built-in image processing and DIC algorithm program).Fig 2 reperesents the image acquisition module of 2D-DIC.

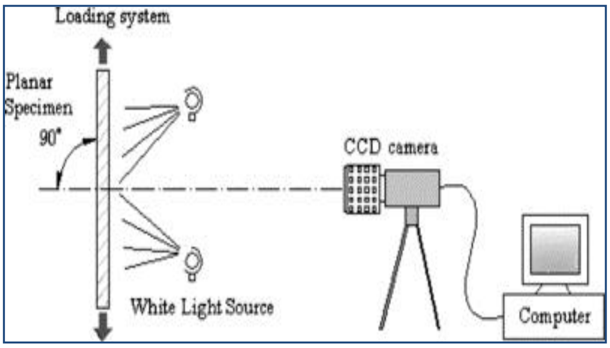

Fig 2: 2D-DIC Image acquisition module

During the DIC measurement procedure, the image acquisition device's location should be kept constant, and its optical axis should be perpendicular to the measured surface and aligned with the measured surface's centre area. Adjust the focal length of the lens at the same time to make the speckle field of the surface under test clear and occupy the majority of the image. The procedure described above can significantly increase the accuracy of DIC measurement findings

4.1 Mathematical Model

The random speckle pattern is used in the digital image correlation approach to perfectly match the corresponding locations on two images. The reference image is on the left, while the deformed image is on the right in Fig. 3.

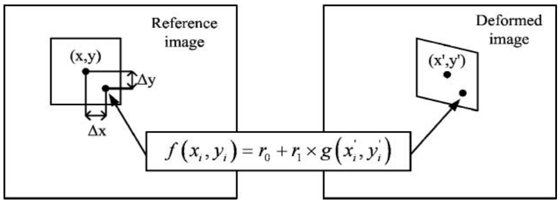

Fig 3: Basic principle of digital image correlation

A reference subset of (2M + 1)*(2M + 1) pixels centred at point (x, y) is selected in the reference image. The matching technique involves finding the appropriate subset in the deformed image centred at point (x', y') that has the greatest similarity to the reference subset. Clearly, the grey level relationship in the reference image remains the same in the deformed image.

5. CONCLUSIONS

Digital image correlation is an optical full-field deformation measurement technique and is widely utilized in civil engineering, aerospace, and other sectors due to its non-contact, high-precision, full-field characteristics. The DIC measurement system's basic principle is to use image acquisition equipment to collect natural textures or artificial speckles on the surface of the test piece before and after deformation, then use a computer design algorithm to solve the in-plane displacement value of each point on the surface using the relationship between the grey scale change of the speckle image and the surface displacement. This measurement method is easy to use and belongs to the non-contact measurement category, thus it may do full-field measurements and provide a wider measurement range and greater accuracy.

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BIOGRAPHIES

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