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DIGITAL IMAGE CORRELATION for THE ESTIMATION of STRESS DISTRIBUTION at SURFACE of LOAD MEMBERS

A Thesis Submitted to the Council of the College of Engineering, University of Diyala in Partial Fulfillment of the Requirements of the Degree of Master of Science in Mechanical Engineering

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Chapter One

Introduction

1.1 Introduction

In recent years, the full-field displacement and strain measurements have been the main research areas in terms of improvement of experimental techniques. [1].

Numerous strategies have been proposed within full-field displacement. Particularly with strain measurements, such as speckle pattern, holographic interferometry, geometric moire, speckle photography and Digital Image Correlation (DIC). [2].

Each technique of these DIC methods has been used in mechanical tests. However, it is not easy to determine the best procedure considering the ways as mentioned above. Therefore, this research takes into consideration the cost and accuracy of every single method.

The DIC method is intended to track of Region of Interest (ROI) of pixels at different stages of image. Image deformation is considered to measure the full-field strain. In this research, the DIC developed program has been used to be compatible with solid mechanics applications.

DIC is a non-contact optical method that is used to measure full-field displacements, strain, and stress. The captured images of the tested specimen have been considered input to the developed program. The specimen could be in different forms such as too small, big, compliant, soft, cold, or hot objects. Thus, this technique could be used inside or outside the laboratory [3]. DIC technique uses one of the mathematical algorithms explained later in this chapter to perform the correlation. This could be conducted by scanning and tracking the shift in ROI between a reference image and deformed configurations. The field of displacement, strain, and stress could be found by using multiple parameters in subset shape functions [1]. In this thesis, the developed program determines 2D-DIC full-field strain measurements by using x-y displacements. Furthermore, the developed program is used to investigate whether there is an angle of the specimen or not. The DIC program uses a cross-correlation coefficient as a tool to perform the correlation between the reference image and deformed images [1].

DIC program usually uses one of these measurements in the mechanical testing as they require only low testing costs and little amount of required image-processing to test recorded data. DIC technique is based on founding the spatial similarity or correlation between two images that are captured for the tested surface of a specimen of two-deformation image states. The main requirement to work on this technique is the existence of a surface pattern by which the deformation effect can be tracked. The surface pattern is either provided by an application of the speckle patterns on the specimen surface or by painting the tested surface with [illegible] percent white paints and [illegible] percent black paints.

Strain measurement is one of the essential aspects of mechanical studies. A strain is defined as the rate of change in length to the original length of any material. Strain, as well as other properties, are involved in many mechanical parameters (i.e. Stress-Strain Curve, Young's Modulus equation, Poisson's Ratio, etc.). Recently, most of the complex calculations and/or investigations require deformation, strain, and stress measurements at any point inside ROI to study the specification and behaviour of materials and structural components to make the best material selection in design. For this reason, designers and researchers are interested in having the full-field strain map for the specimen surface. Many instruments are capable of finding strains (i.e. strain gauge and

□inear □ariable Differential Transformer (□□DT)). □ ainly, these instruments are not used to create strain maps. To find the strain map, new technology was developed for that purpose which is the DIC. It provides a full-field map of displacements, strains, and stress of a sample surface that is under mechanical tests [□].

□nother aspect is handled of this thesis that deals with Digital Image Processing (DIP) techniques. That aspect discusses the way that the DIP detects crack, notch, and□or groove. This research works on the two above mentioned aspects, which are essential subjects in this research area.

The detection of cracks is not by itself an indication or prediction of the end of the structure's working life. However, investigations of cracks are essential for the assessment of structural integrity. □ccurate modelling of crack is a crucial issue for studying material behaviour.

1.2 Digital Image Correlation (DIC) Technique

DIC is an optical technique that uses the mathematical context to correlate images, examine data, and evaluate rustles of the samples used in the mechanical tests. This technique includes capturing as many pictures for a sample during the incremental load to examine the changes and behaviour of the sample surface. To apply this technique, the samples need to be painted by a random dot pattern (speckle pattern) to the surface which needs to be tested.

This technique works by capturing the first image with □ero loads or at any stage, which is called (reference image). □fter load increments, the different captured images with varying stages of load are called (deformed images).

Due to the deformation random dot pattern paints (speckle pattern), locations changes and these changes are detected by the developed program and□or Ncorr. These changes of patterns can be calculated after and before each load step by using the correlation process with one of the selected algorithms. □ strain full-field map can be created, as shown in figure (1-1) [□].

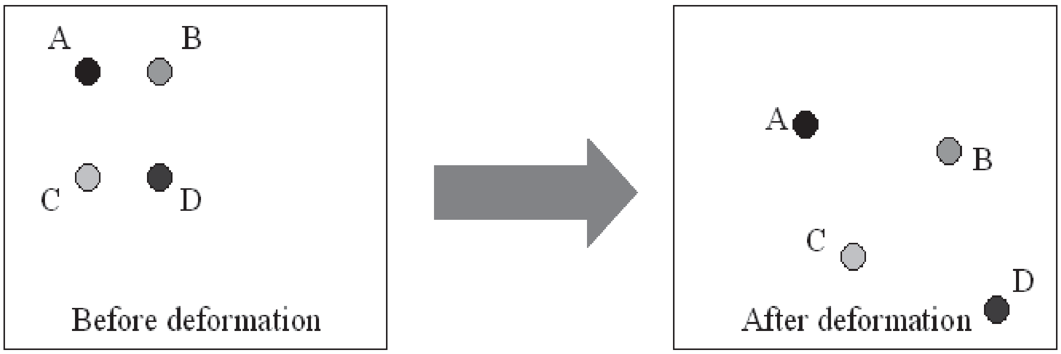

Figure (1- 1) Example of the pixels before and after deformation *[4]*.

□igure (1-1) the left side shows four different dots with different colours which gives an example of four pixels before the load. In contrast, the right side of figure (1-1) shows the image that offers the same dots (pixels) after deformation. This is performed by using the computer software that tracks and detects images to calculate hori□ontal and vertical displacements for each one.

DIC technique requires a digital image camera and computer software program to perform the correlation and the experimental work. The test results depend on digital image resolution (pixels columns (c) □pixels rows (r)), the width (w) and the height (h) of the sample, the distance between the camera and the sample (d) as shown in figure (1-2) [□].

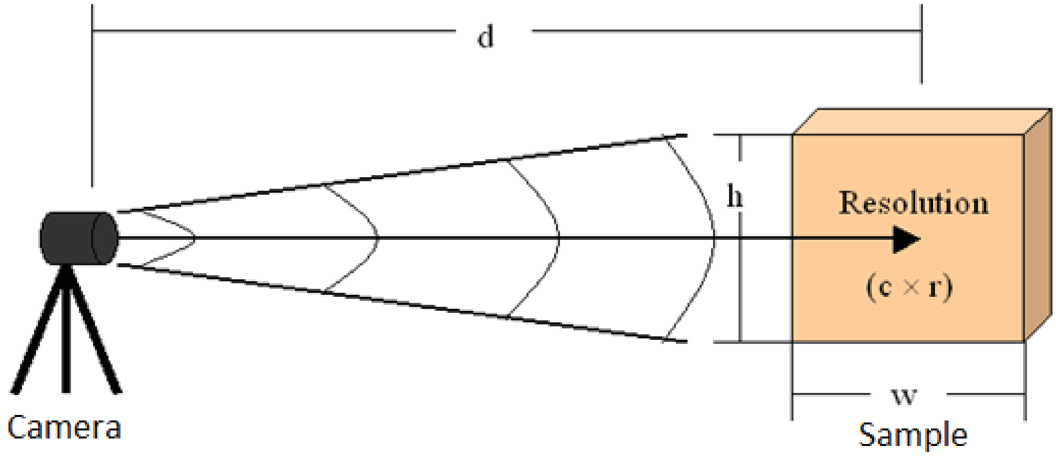

Figure (1- 2) Some variables involved in the digital image correlation technique. *[4]*

1.3 Algorithms of the DIC

There are various algorithms used in DIC techniques. □lmost all of them depend mainly on finding a square subset positioned at the midpoint of a concerned point (x^0, y^0) that is designated as an origin subset f (x, y), and this subset has a si□e of N □N pixels (N has to be an odd number) in origin and□or reference image [□].

Then, DIC algorithms work and focus mainly on finding the matching subset□ g (x, y) in the deformed image.

DIC familiar algorithms are listed below□

i. □tandard ID□ algorithm.
ii. □daptive ID□ (□-ID□) algorithms.
iii. Inverse Compositional □auss-Newton □lgorithm.
iv. Newton-Raphson iteration method.
v. Iterative spatial gradient method.
vi. □patial gradient method.
vii. The initial guess.

viii. Forward additive method.
ix. Inverse compositional method.
x. Computation of the gradient and hessian for the IC-GN method.

For more information about the methods mentioned above, the techniques from i-vi are explained in [□] . In contrast, the methods listed from vii-x are described in [□].

In this thesis, Pearson's linear correlation coefficient has been used to find the subset matching. Each four individual subsets matches, create a four-nodded element. Furthermore, from this element and by depending on Finite Element Analysis (FEA) principles, the advanced numerical calculations used to determine strain and stress, are explained in chapter three.

1.4 Crack/Defect Detection and Geometry Measurements Using Digital Image Processing (DIP).

There are many constructions exposed to fatigue loadings damage, because there are no early surface crack and/or defects detections. The essential reason for the damage is because of the random multi-initiations of short cracks on structures surface.

Manual structures surface check has many disadvantages. For instance, the invisibility of the cracks, the time cost, and it needs an expert's familiarity. For that reason, this can be replaced and conducted by using an automatic way, and the experimental necessity comes with image processing. This work develops a MATLAB program that automatically recognizes the defect/cracks, and this is performed by applying one of the image processing algorithms. In this thesis, survey papers and studies related to crack detection have been investigated. This thesis also includes the experimental work to validate and make proof of how this technique is important in crack detection and crack geometry measurement accuracy in terms of width, length, and angle. DIC algorithms also have been used to estimate displacements, strain, and stress fields around the crack tip.

1.5 Thesis Overview

This thesis consists of seven chapters, the following chapters are□

Chapter One	• Introduction
Chapter Two	• Reviews related literatures
Chapter three	• Theoretical consideration
Chapter □our	• The developed programs
Chapter □ive	• The experimental procedures
Chapter □ix	• The results of tensile tests for different two parts of the DIC and DIP image analysis with the discussion of these results
Chapter □even	• The conclusions and lists of recommendations for future work.

1.6 Objectives and Scope

This study mainly focused on building a DIC program, carrying out experiments, evaluation of image analysis to find full-field measurements in mechanical tests, which provide measurements of the resulting data, and validating these results concerning the numerical simulation software like □N□□□. The scope of this thesis is limited to the analysis of images recorded via D□□R camera.

The thesis concentrates on performing DIC code to study the functionality of this technique and carry out the measurements on image series taken from mechanical testing. In this context, only 2D problem has been considered. □lso, it is intended to perform the DIP program to detect crack location and measure its geometry in terms of width, length, angle and location detection.

The main objectives of this study are listed below□

- Develop DIC algorithm for handling and finding the in-plane full-field displacements, strains, and stresses.
- Develop DIP code to find crack□defect location within load increment and its geometry like length, width, and the angle of the crack□defect.
- Perform experimental studies on selected structural problems of the stress analysis.
- Compare DIC and experimental results with □E□ results.

□□□TR□CT

Digital Image Correlation (DIC) and digital image processing (DIP) are optical techniques appropriate to estimate displacement, strain, and stress map distribution without any contact with the tested surfaces.

This thesis examines the applicability and effectiveness of DIC and DIP techniques. □ program has been developed in this thesis using □□T□□□ programming language. DIC program has developed to obtain full-field displacements, strain, and stress measurements. In contrast, the DIP program has been used to perform crack□defect location detection as well as geometry in terms of angle, length, and width measurements.

In this thesis, a tensile test for four different flat specimens was carried out, which were painted by speckle pattern. The experimental rig was specially designed and manufactured to perform the tensile deformation test.

In order to guarantee the efficiency of the planned DIC and DIP systems, the comparison is considered between the results of these techniques with the results obtained by other methods (Ncorr, the finite element analysis (□N□□□), and both of the exact and analytical solutions).

In the case of aluminium without hole plate specimen, the minimum and maximum obtained accuracy values have reached (□□) □ in strain and (□3) □ in stress respectively, with the exact solution. In comparison, accuracy with Ncorr software has been obtained to be □□□. □or the copper plate with a central hole specimen when the analytical solution has been applied the minimum, and maximum obtained accuracy values were (□□.□) □ in stress and (□□) □ in displacements respectively, wherein with Ncorr software, the minimum and maximum obtained accuracies have been obtained (□1) □ and (□□) □ respectively. □ ith □N□□□, the accuracies have been obtained to be (□1) □ and (□□) □, respectively.

□urthermore, tensile tests have been carried out for two cracked□defected specimens. The experiments conducted for two flat □luminum and Copper plates. The DIP percentage of accuracy varies from (□□) □ to (□□) □ with the actual physical measurements. The obtained DIC percentage of accuracy as minimum and maximum were (□□) □ and (□□) □ with □N□□□ software.