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Equivalence of Intensity Integration Technique with Line Summation method for Contouring of 1D Reflective Surfaces

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Abstract

Digital image correlation and tracking (DIC) is an optical method that employs tracking and image registration techniques for accurate 2D and 3D measurements of changes in images. This is often used to measure deformation, displacement, strain. Intensity Integration Technique and Line summation method are one of DIC Techniques. The purpose of this research is to identify the similarities between the Intensity Integration Technique and Line Summation method for Cantilever beam under the given loading conditions where the slope and curvature is found out for mirror like reflective surfaces. In Intensity Integration Technique (IIT) for small deformation, it is assumed that total amount of light reflected by a designated area on the surface would be same before and after deformation when there is no change in illumination (conservation of the total quantity of reflected light). Line summation method is a grid method where the optical strain of grid lines is related to slope and curvature of the loaded beams (Theory of bending). The spacing between two grid lines is unaltered under no load condition and spacing changes when it is in loaded condition. Thus, the strain is related to slope and curvature. These findings may be useful in study of material deformation, nature of defect (inclusion and void) and crack propagation in real-world applications, as it has the potential to become a cheap, simple yet accurate solution.
Keyword- Correlation, IIT, optical strain, deformation, line, summation, slope, curvature, reflective

I. Introduction

Experimental mechanics can be defined as the investigation by experimental means of the mechanical behavior of engineering systems subjected to load. The system can be a structure, a material, soft matter such as human tissue, a fluid structure coupling; the list is practically endless. Implicit in the definition is that some kind of measurement system is used to capture a quantity that describes the system behavior.

The main attributes conventionally associated with experimental mechanics are the deformation and the mechanical strain. Many of these techniques have been available for decades but recently have been gaining popularity because of the advances in computing power and decreasing hardware costs. More importantly from the design perspective, the necessity for experimental data to validate numerical models of systems manufactured from complex nonlinear inhomogeneous materials, such as fiber reinforced polymer composites, is ever increasing. Experiment mechanics approaches have much to offer and it is the purpose of this module to provide an overview of the range of application and operation of the techniques.

A. *Digital Image Correlation Methods*

Digital Image Correlation (DIC) and tracking is an optical method that employs tracking and image registration techniques for accurate 2D and 3D measurements of changes in images. This is often used to measure deformation, displacement, strain it is widely applied in many areas of science and engineering. The digital image correlation method for experimental mechanics has been extended further to rigid body mechanics and to determine the centerline displacements of a cantilever beam by correlating the speckle intensity patterns. In the digital image correlation methods, IIT is one of the digital image correlation methods where integrated intensities obtained from loaded and unloaded specimen are used to find slope of the loaded specimen.

B. *Principle of Intensity Integration Technique*

When a polished, secularly reflecting mirror-like surface is illuminated by a light beam, the total amount of light reflected by any designated area of interest on it is unaltered even when its surface topology gets altered (say, due to some loading or disturbance) so long as this deviation is small. In this instance, the conservation of the total quantity of reflected light, expressed as the sum of intensity levels over small finite areas (pixels), serves as a means of correlation for comparing the unreformed and deformed images and estimating the slope and curvature at various points on the modified surface [1]. IIT in its basic form is a double exposure method and requires, for comparison, intensity distributions of images from two states of the object, one before deformation and another after. The apparent slope and curvature due to the divergent beam optics are inherent in both the intensity distributions and need to be subtracted from one another to yield absolute values of slope and curvature.

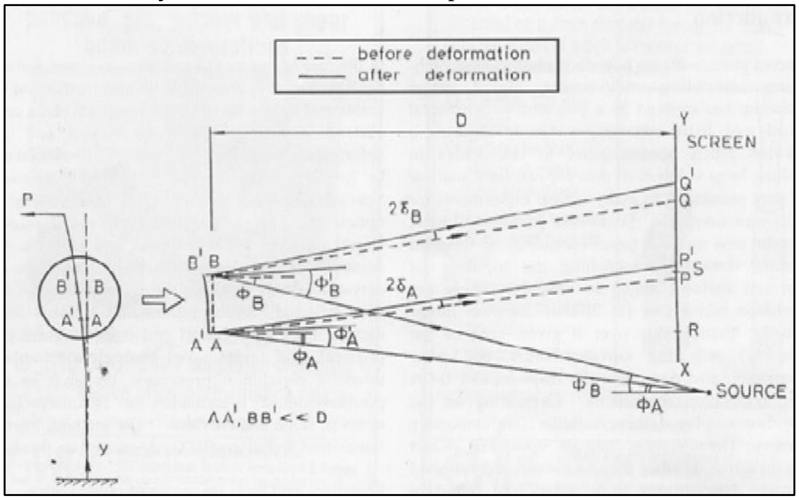

Fig. 1: Experiment Setup

From Figure 1, $PQ=AB+D(\varphi_B-\varphi_A)$. (1)

In the small deflection theory of thin beams if w denotes the lateral deflection, its first and second derivatives viz. (dw/dy) and (d^2w/d^2y) give respectively the slope and curvature.

$$P'Q' = PQ+2D\ (\delta_A-\delta_B) \quad (2)$$

$$I_1 / I_2 = 1 + [2D\ (d^2w/d^2y) / (1 + D\chi a)] \quad (3)$$

Here $D\chi a$ is apparent curvature, I_1 is Intensity of light before deformation and the distance D between the beam and screen is constant. So, the curvature is proportional to the deformed intensity of light I_2 [1].

C. Principle of Line Summation Method

Line summation method is another type of DIC Technique where a grid is employed for obtaining slope and curvature values. The optical strain of grid lines is related to slope and curvature of the loaded beams (Theory of bending). The spacing between two grid lines is unaltered under no load condition and spacing changes when it is in loaded condition [2]. Thus, the strain of those grid lines is related to slope and curvature according to the beam bending equation.

$$\sigma_b / y = M/I = E/R$$

Here, 1/R gives curvature where it is proportional to bending stress σ_b. Hence the strain proportional to stress for the given young's modulus E.

D. Mechanics of Cantilever Beam

Given a cantilever beam with a fixed end at the left and a load P applied at the free end of the beam. Bending moments are produced by transverse loads applied to beams. The simplest case is the cantilever beam, widely encountered in balconies, aircraft wings, diving boards etc. The bending moment acting on a section of the beam, due to an applied transverse force, is given by the product of the applied force and its distance from that section. It thus has units of N-m.

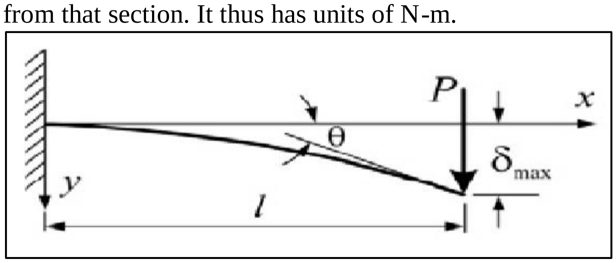

Fig. 2: Cantilever beam

When the load is applied at the free end the moment is created in the beam and according to the beam bending equation it is said that moment is proportional to curvature. So, that when the load is applied at the free end we get the moment maximum at the fixed end thus the curvature obtained will be maximum at the fixed end.

II. MODELING AND SIMULATION

A. Modeling of Cantilever Beam

A 40mm long cantilever beam, made of acrylic sheet which is subjected to a tip deflection given at the free end is modeled.
Beam Specifications:
Length (L) = 40 mm
Width (B) = 20 mm
Height (H) = 2 mm
Cross-Section Area = 40 mm^2 and
Young's Modulus (E) = 2.5Gpa, Poisson's ratio = 0.3

Selected Beam Element is BEAM 188 which is modeled as per the dimensions and the beam is divided into 100element divisions. Meshing and Boundary conditions has been applied where the left end is fixed and the right end is given a tip displacement of 1mm from that the Slope and Curvature values are obtained.

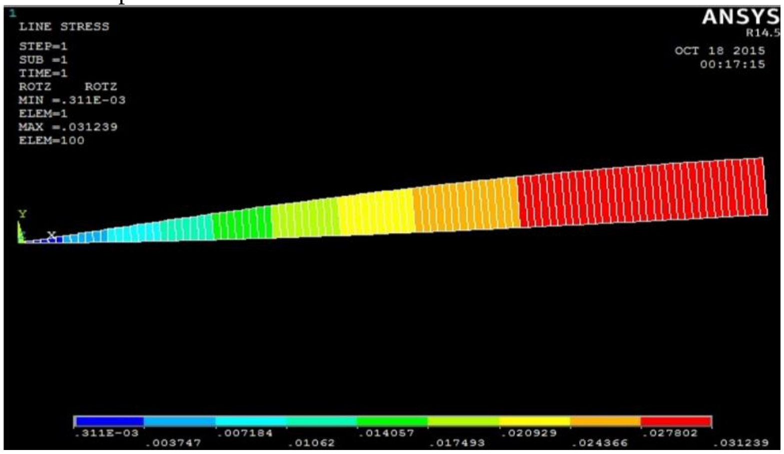

Fig. 3: Slope Plot

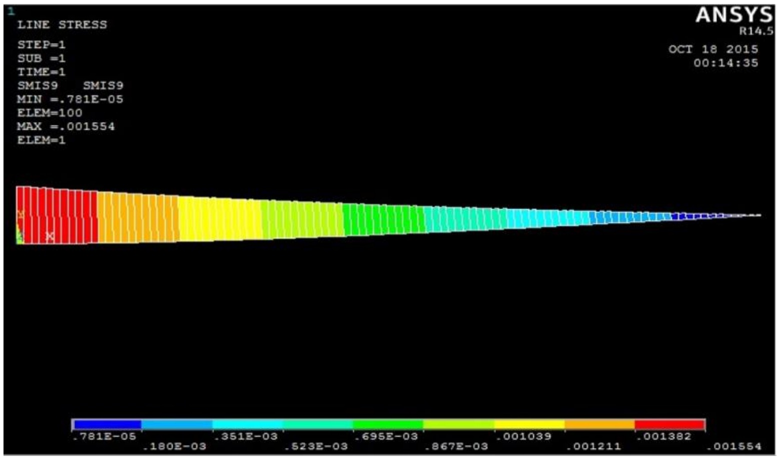

Fig. 4: Curvature Plot

B. Numerical Simulation

Relationship between Slope, Tip slope and Tip Deflection of Cantilever Beam

$$\text{Tip Slope } \theta_{tip} = PL^2/2EI \tag{4}$$

$$\text{Tip Deflection } \delta_{tip} = PL^3/3EI \tag{5}$$

$$\theta_{tip}/\delta_{tip} = 3/2L \tag{6}$$

Slope at any given length is given by

$$\theta_{eqn} = PLx/EI - Px^2/2EI \tag{7}$$

$$\theta_{eqn}/\theta_{tip} = 2\xi - \xi^2 \text{ , where } \xi = x/L \tag{8}$$

From the expression derived for the θ_{eqn} in terms of x, L and tip displacement δ_{tip}.

$$\theta_{eqn}/\theta_{tip} = 2\xi - \xi^2 \tag{9}$$

The length of the Cantilever beam is divided into 100 element divisions and the Slope and Curvature is determined at each division i.e. for each element length of 0.4mm along the cantilever beam.

III. EXPERIMENTAL VALIDATION

A. Optical Bench Setup

Specimen which is made up of acrylic material is placed in a fixture as a cantilever in between the screen and laser source. The laser light is focused through the lens and made it to fall on the specimen. After passing through condensing lens the reflection of the specimen is displayed in the screen, Charge-Coupled Device (CCD) camera is used to capture the image of the reflected specimen.

Total Length of bed	*170 cm*
Accuracy of Calibration	*0.01%*
Laser	*He -Ne, 2mW*

Table 1: Specifications

B. Image Capturing for Loading and Unloading Conditions

Charge Coupled Device Camera is used to take the reflected image on the screen. The image taken from CCD Camera setup for loaded and unloaded condition. Reflected image of the specimen will be made to fall on the screen when the tip deflection of 1 mm is given to the Cantilever beam at free end. The length of the reflected specimen in the screen increases when it is unloaded and the distance D between the object to screen is calculated by using the scale on length of bed.

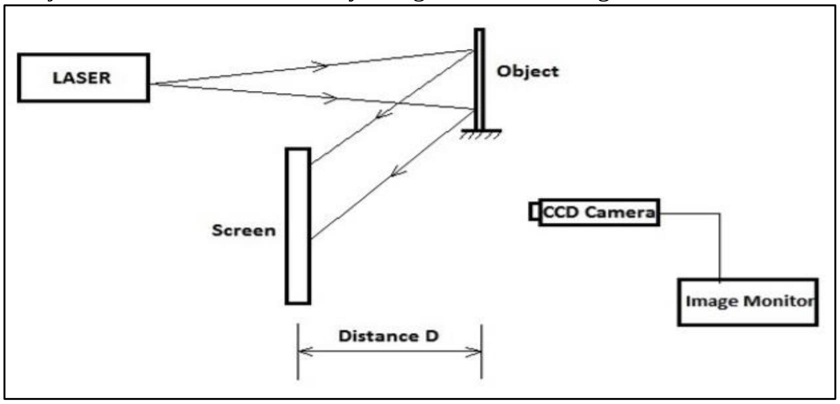

Fig. 5: Experiment Setup

C. Experiment Procedure

The optical bench is setup as per the specifications and the laser is switched on, the setup is aligned to reduce errors that might occur and the positions of the components are kept fixed as per the specifications. The camera is mounted at a near normal position to the optical bench where the images of the cantilever beam are captured for the following conditions.

1) Loaded without grid.
2) Loaded with grid.
3) Unloaded with grid.
4) Unloaded without grid.

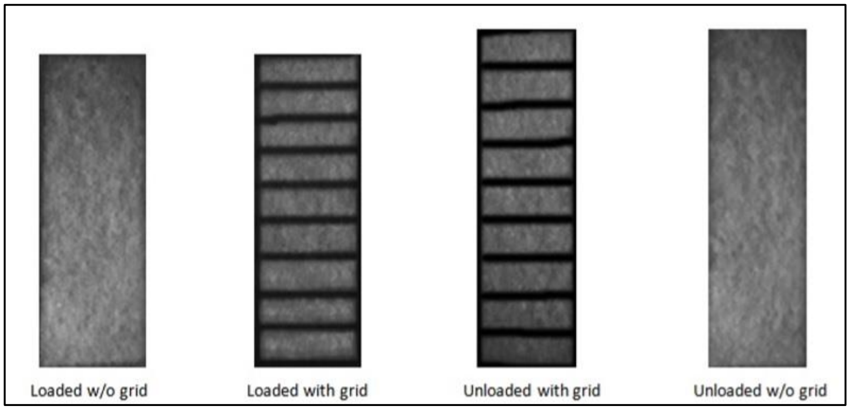

Fig. 6: Cantilever beam Images

For the above conditions, the image one with grid gives the data for Line summation method and the other gives the data for Intensity Integration Technique. The images are stored in the computers which are used as the inputs for the MATLAB programming. The image without grid provides the necessary information for the IIT method since the pixel is summed up to the next corresponding pixel along the length of the beam. For line summation method the images of Cantilever beam with grid are made into a skeleton structure using Matlab Image processing toolbox as shown in fig6.so as to count the lines and measure the line spacing for getting the slope and curvature values.

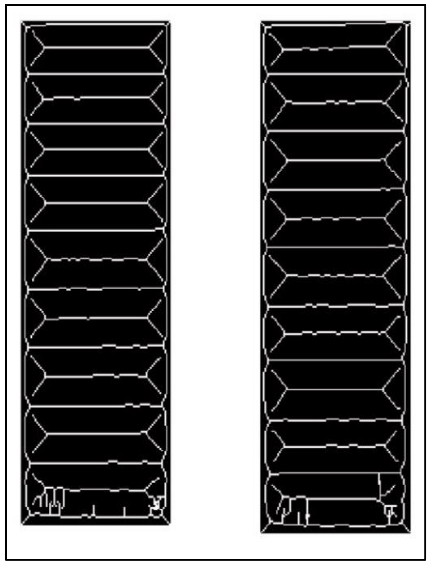

Fig. 7: Loaded specimen with grid   Unloaded specimen with grid

The skeleton images of Loading and unloading conditions of Cantilever beam with grid as shown in above figure where the line count is made and the difference in the line spacings gives the curvature and the shift in the line position gives the slope of the cantilever beam.

IV. RESULTS AND DISCUSSION

The Slope and Curvature values from Intensity Integration Technique and Line Summation method are compared with the theoretical values. The graph below shows the slope comparison between IIT, Line Summation and theoretical values after normalizing the pixel, slope and curvature values to value 1.

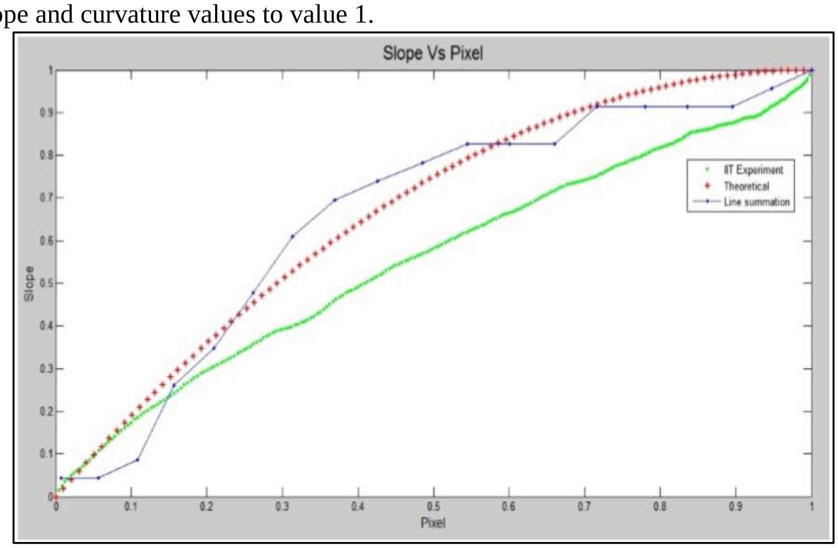

Fig. 8: Slope comparison

From the comparison of slope values which are shown above in the graph, the slope values from Line summation method is closer to the theoretical values as compared to the slope values from the method of Intensity Integration Technique.

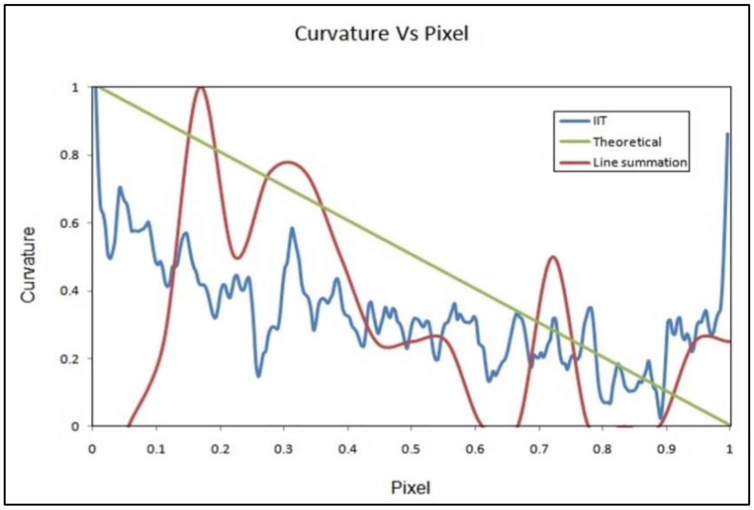

Fig. 9: Curvature comparison

In the case of curvature, the values obtained from the IIT gives more accurate solution as compared to the values of Line summation method since more intensity values are closer to the theoretical values of the curvature.

V. Conclusion

A new method for contouring of 1D reflective surfaces called Line summation method which is analogous to Intensity Integration Technique where the slope and curvature values are obtained for a tip loaded Cantilever beam and those values are compared with the Theoretical values. Since the values obtained from the Line summation method are not much closer to the true values. Further experiments have to be carried out to get the values closer to the true values by means of introducing more grid lines i.e. more the grid lines are more the accurate values of slope and curvature.

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