Contouring reflective plates through image resizing and Iterative Intensity Integration Technique (IIIT)

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Abstract. Iterative Intensity Integration Technique (IIIT) is an intensity based correlation technique used to obtain the slope and curvature of loaded reflecting plates. Energy conservation principle forms the basis for this technique. The total quantity of light reflected by specimen before and after loading is assumed to be identical. It is best suited for contouring reflective plates that produce constant image size in load and unload state. But the corner and simply supported plates having the free edges to rotate while loading make reflected image enlarge/shrinks. Hence, preprocessing one of the images is mandatory to make it equal to size of other. In this present study, reflecting plates of corner supported rhombus and rectangular plate with holes are chosen and the experiments are conducted for central loading. One of images is resized and those images are subjected to IIIT. A suitable correction procedure is applied to results obtained from IIIT to get the final result. The same plates are modelled using ANSYS for known displacement and the partial slope and curvature values are determined. The obtained ANSYS results are exported to MATLAB for comparison of results with experiments and the least square errors are presented.

1. Introduction

The study of behaviour of the engineering structures under different kinds of loading conditions are important to analyse. Various experimental techniques play a vital role in determining the deformation field of loaded structures. There are several optical techniques, like Moire methods[1], [2], reflecting grid methods[3] photo elasticity[4], [5], speckle methods[6]–[8], coherent gradient sensing[9], [10] Digital Image correlation[11]–[13] and Intensity Integration Technique (IIT)[14] to determine the slope and displacement fields of loaded specimen. One has to select the appropriate method for depending on the range, sensitivity and based on reflective nature of specimen. The technological development in the field of laser, image acquisition devices and computer make optical methods to move towards correlation based measurement techniques. Few examples are Digital image correlation (DIC), Digital speckle displacement measurement (DSDM). These techniques work based on correlating speckle patterns on the series of images that are captured while loading the specimen. The algorithm used for correlating images in DIC is based on maximum correlation coefficient computed by locating the position of subsets within images to determine the displacement of speckle pattern.
Intensity Integration Technique (IIIT) is also one of intensity based image correlation technique which works on energy conservation principle. It utilises the cumulative (integrated) intensity, as correlation parameter to find the deformation field of reflective specimen. Subramanian and Radhakrishnan [15] propose this technique to find slope and curvature of reflective cantilever under collimated beam using IIIT. Subramanian and Jagannath verified the working of IIIT on large reflective specimen, using the diverging laser beam [14]. The cumulative intensity being unidirectional, IIIT had the limitation of applying it for two dimensional plates and this is overcome by dividing the reflective clamped circular plates into several strips optically [16] and applying IIIT between the corresponding strips in the load and unload images. By using virtual lines concept, the slope field for entire specimen is found out. By the same way, projecting curved strip on the specimen and applying IIIT along the strip is another way to contour the reflective surfaces only on line of interest. Vijaya et.al [17] determines the partial slope along the ‘S’ strip on centrally clamped circular plate by applying IIIT on curved strip. Projecting grid lines and speckle patterns is cumbersome process and it must eliminated to make experimentation simpler. Subramanian and Vijaya [18] proposed an iterative intensity integration technique for contouring two dimensional reflective plates without projecting grid on specimen. Just two experimental images captured during loading and unloading process are sufficient for determining deformation field. This method limits its usage to equal sized images captured in load/unload states. The clamped plates are examples for above situation as it restricts the edges from rotation while loading. The simply supported reflective plates and corner supported plates allow the edges to rotate while loading and hence the reflected rays from the edges of specimen diverge and the size of loaded image changes. IIIT must be modified to accommodate images of two different size. Instead of changing algorithm, a pre-processing procedures are suggested to resize one of images to other, subjecting those two images to IIIT and post processing procedure for accommodating the correction factor for deformation field. In this present work, corner supported rhombus plate as well as rectangular plates with holes are chosen. The experiments are conducted and the loaded images are resized to unload size. Deformation fields are determined and correction factors are incorporated to get final results. The results are compared with results obtained from ANSYS and errors are within limits.

2. Iterative Intensity Integration Technique (IIIT)
IIIT is one of latest algorithms in experimental mechanics for contouring reflective specimens. It works on energy conservation principle. The total quantity of light reflected by the specimen before and after loading is assumed to be same and IIIT extends that for every virtual pixel lines and columns. The algorithm and working principle of IIIT are elaborately given in Ref [18]. Every pixel position in an unloaded image is considered as virtual points and pixel lines along rows and columns are called as virtual horizontal guide lines and virtual vertical guide lines. Applying IIIT simultaneously along the all the horizontal virtual guide lines load and unload images (as in figure 1A and 1B) are called horizontal sweep IIIT. The horizontal sweep IIIT determines the change in position of virtual points by equating cumulative intensity along horizontal guide lines. These pixel shifts are added to indices of vertical virtual guide lines and thus changes the virtual guide lines (dotted lines in figure 1C) are noted. The intensities along new pixel lines are picked up for vertical sweep IIIT. The vertical sweep IIIT changes horizontal guide lines (dotted line in figure 1D) and these sweeps are done alternatively unless the difference between the guidelines in previous and current iterations becomes negligible. The final guide lines are indicated in figure 1E. The schematic representation of IIIT algorithm as shown in figure.1.The difference between the initial and final guidelines gives rise to pixel shift along x and y axis. The partial slope along x and y are computed as in following (1) and (2).

The horizontal and vertical sweeps IIIT are applicable only when both load and unload images are of same size. The corner supported rhombus and rectangular plate with holes undergo change in its size while loading the specimens. The loaded image size increases as the edges of plates are allowed to rotate. Hence a pre-processing procedure is suggested to resize the loaded image, followed by the IIIT. The resulting deformation field are incorporated with correction factors in x and y axis as post
processing procedure to get the final results. The schematic representation of image size is represented as in figure 2.

\[
\frac{\partial w}{\partial x} \approx \frac{\Delta x}{2D}
\]

\[
\frac{\partial w}{\partial y} \approx \frac{\Delta y}{2D}
\]

Figure 1. Schematic representation of IIIT.
2.1. Pre-processing of Images
The loaded reflected images are resized using default function in MATLAB and the intensities are interpolated using cubic interpolation [19]. The total quantity of light (sum of intensities over the image) reflected before and after loading assumed to be same. The total quantity difference between the load and unload images are less than 4% before resizing and 22% after resizing. Hence intensity normalisation is done to make both quantity of intensity remains same.

2.2. IIIT for determining deformation field
After intensity normalisation, both unload and resized loaded images are subjected to IIIT. The changes in the virtual guidelines are computed for every horizontal and vertical sweep IIIT. The difference between initial and final position of guidelines are used as shift in the pixels ($\Delta x_1$, $\Delta y_1$) with respect to unload size ($m$, $n$).

2.3. Correction factor as post processing
The linear difference ($\Delta m$ and $\Delta n$) between the loaded and unloaded image sizes are computed and added as correction factors in with respect to shifts obtained from IIIT ($\Delta x_1$, $\Delta y_1$). The total shifts are determined as per (3) and (4) and partial slopes are computed using equation (1) and (2).

$$\Delta x = \Delta x_1 \pm \Delta m$$
$$\Delta y = \Delta y_1 \pm \Delta n$$

3. Experimental verification
The experimental setup consists of a spatial filter, collimating lens, through which the laser light is passed and made to fall on corner supported rhombus plate made up of black Perspex of size 29x29x2mm and specimen reflects light back on a matte finished screen which is kept at distance of $D$ from the specimen as in figure 3. The experimental images are captured using a CMOS camera, and fed into computer for further processing. From the captured images it is found that the size of loaded image is higher in x and y axis as compared to size of unloaded image. The same way, the experiment is repeated for the rectangular specimen of 38x20x2 mm with two holes of $\phi 10$ mm located at equi-distant from the centre. The captured experimental images are shown in figure 4
Figure 3. Schematic experimental setup.

Figure 4. Experimental images for Rhombus and Rectangular plate with holes.

The figure 4 shows the experimental images obtained along with its sizes. The images are cropped in such a way that the shape is completely enclosed in rectangle. The unload image with resized loaded images are subjected to IIIT. The Region of Interest is masked and shift in pixels are considered only in region of interest (ROI) and respective initial virtual lines are considered in horizontal and vertical sweep in background. The schematic representation of it are shown in figure 5.
4. Numerical Analysis for Rhombus and rectangular plate with holes
The corner supported rhombus plate(29x29x2mm) and a rectangular plate(38x20x2mm) with two holes are modelled in ANSYS using 4node SHELL 181 element, a known displacement is given at centre of the plate and clamped at all corners. A four-noded SHELL 181 is the only element that provides the curvature values using SMISC sequence number 12, 13, 14 to get kxx, kyy, kzz respectively. Also the slope contours are developed using post processor commands (DOF solutions) directly. These values obtained from ANSYS are scattered and hence these values are imported into MATLAB and a smooth mathematical surface is fitted and results are interpolated equivalent to the size of unloaded image. The partial slope contours along x and y axis are as shown in the figure 6.
5. Experimental results and comparison with theoretical solution

The experimental results are compared with solution obtained in ANSYS for both cases and shown in figure 7 and figure 8. The partial curvature values are computed by numerically differentiating the partial slope obtained in ANSYS as well as experimental slope. The comparison plot shows the closer trend between theory and experiments.
Figure 7. Centrally loaded Corner supported Rhombus plate: (a) and (b) partial slope along x and y axis (c) and (d) partial slope along x and y.

Figure 8. Centrally loaded Corner supported Rectangular plate with holes: (a) and (b) partial slope along x and y axis (c) and (d) partial slope along x and y.

6. Conclusion
Iterative Intensity Integration Technique is one of image correlation algorithms, which works on basis of energy conservation principle, used here to correlates load and unload images of different sizes. The loaded image is resized simply to size of unloaded image using the functions available in MATLAB and modified loaded with unloaded image, are subject to IIIT. The deformation field obtained is
subjected to linear correction equals to difference in size along x and y axis in terms of pixel. This intuitive method, produce the result with least square error less than 10 percent. IIIT works successfully works on reflective plates with holes. The holes in plate do not reflect and hence those regions are considered as background and masked appropriately. Instead of resizing the unloaded image, one can recast new loaded image by interpolating intensity equivalent to virtual points in unloaded image and modifying intensity based on scaling factor [19].

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