Experimental Evaluation Of Surface Strain Measurement By Digital Image Correlation Based Subpixel Registration Technique

S. Agnes Shifani, M.S. Godwin Premi

Abstract: The development of Digital Image Correlation (DIC) have created a popular, attractive factor for full-field displacement and measuring strain. Inspite of its improvement, it is sufficiently used as a post-processing factor because of its computational cost and accuracy. In recent years, many researchers proposed new algorithms to improve the accuracy and speed using DIC. The objective of this work focus on subset image size and selection of seed points using image registration process along with average gradient of corner feature. With the help of image correlation method in strain measurement is executed from its first step of setting reference image, deformed images with different loads, matching the sub pixel location, selection of seed point to obtain strain field on surface under this research. The procedure of DIC method in utilizing open source platform Ncorr. Finally, the experimental output validation is evaluated from strain measurement and the result compared with strain value from UTM via tensile test. The strain from both strain gauge and DIC shows that the deviation is not exceeding more than 0.05 pixels.

Index Terms: Sub pixel registration, strain, displacement, Ncorr, DIC

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1 INTRODUCTION

Strain is the change of length before and after deformation. Calculating the pixel movement from a set of digital images mostly used in computer vision and improved by many new methods. This to aid understanding the deformation of material through strain graph. In image processing, lots of technologies are available to measure local displacement and strain like strain gauge, speckle metrology[20], moiré interferemetry[19]. Those systems suffer about its characteristic limitation like gauge just say its discrete local area, moiré interfery gives complete displacement and strain mapping but technically demanding, limiting and time consuming. Speckle metrology with DIC, finding displacement in material under stress including biomechanical [21-22], so it requires contrast enhancement. The strain may depend on positive strain and negative strain like positive strain depend the length, displacement position and negative strain depends contracted. Using contact measurement devices like Linear Variable Differential Transformer, gauge in term of tensile or compression test under various input load is giving some drawbacks. For instance, using LVDT for mechanical properties of human brain tissue [16], extensometer was utilized to calculate strain using fatigue test of carbon fiber or epoxy plate [17]. However, these methods are simple and inexpensive, they meet some disadvantages about time consuming. To overcome this drawback, we go for alternative methods like Video extensometer, non-contact Digital Image Correlation. In recent decades, DIC is the top most technique to measure the strain in an accurate way in all engineering field. In automobile manufacture by decreasing the weight of the vehicle. In civil engineering in beam line components. In the field of structural health monitoring visualizing full 3D image of the heart.DIC is a new and popular technology for the measurement of strain and displacement, the main part is its very accuracy and fast. Correlation is the comparison of images at different state of deformation. The most popular method digital image correlation is a fast, most accurate, non-contact, full-field computer facilitated experimental method for displacement and strain calculation. Its under the class of non-interferometric optical technique. It matching two or more images based on their mechanics principles also speckles act as information carriers and extracting displacement and strain field. Digital Image Correlation (DIC) technique plays an important role in structural field operations to mean to the better matching method, commonly used in photogrammetric and computer vision. The concept of this trending method is comparing the reference and loaded image by tracking pixels relocation in region of interest (ROI) then calculating displacement and its gradient [1].

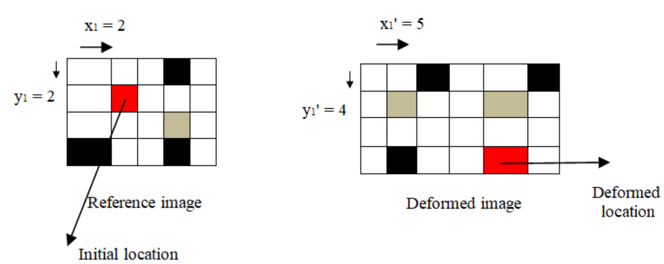

***Fig.1** Correlation procedure*

Pixel movement: $dx = x_1^{'} - x_1$= 3 pixel and $dy = y_1^{'} - y_1$= 2 pixel.Fig.1.shows the image correlation procedure. The first image represents the reference image and an initial pixel located in the position of (x_1,y_1)=(2,2) and the new location from deformed image is $(x_1^{'}, y_1^{'}) = (5,4)$ie. (3,2) pixel from its original position. The good advantage of DIC is record deformed images and then precedes those images for further process of specimen under various forces. Then the strain distribution can be calculated by using the derivatives in

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displacement section. This should be done by making various techniques like stripes, dot circles, grids etc on the surface of the specimen.[1,3] camera resolution and speckle pattern quality are the two main reasons of accurate result. The subset position from initial picture will be found in secondary picture by matching and calculated the gray levels and then find the nearest best match point of first and second image subsets. From this procedure, location of points in loaded images is found. From the above manner, applying normalized cross-correlation always gives the better displacement [8]. Even though; a sub pixel displacement registration method plays much important role to raise the exact measurement value in better resolution, even though every pixel is discrete in image correlation method. This study proposed the fast matching calculation that is one among the great resolution displacement estimation technique, to get better accuracy [13] [11] Reduce strain mean error less than 5με when comparing with conventional method. By using bicubic spline, strain error of 210με they used lower resolution camera. By using uniaxial test on aluminum plate and obtained mean strain error 5.8%.Reduced mean strain less than 5με using DIC to overcome this, use larger focal length, which reduce the field of view at larger distance. [12] Goal of this research is finding out the displacement through grid intersection from video sequence. They have improved the way uses accurate level video to calculate grid intersection as a analysis for surface strain calculation. The experimental result says that over 50 images frames in a video array average frame processing duration was 47.39ms (21.1fps) along with standard deviation of 2.05ms. Though GPU acceleration demonstrate at faster than 15fps i.e. 1500 sub pixel per sec. [14] proposed technique that the physics-based model along with finite-element (FE) based digital image correlation (DIC) which is noise sensitive, the model-based DIC is robust against the Gaussian noise effects. [15] Implemented 2D-DIC framework that includes CPU and GPU task for speedup the processor that much better than conventional. Nowadays, there are lots of economic software presents depends on two dimensional DIC to measure strain and displacement. Whatever, the drawbacks of using economic software's are their costs, and the constraints established to users because no customizations of the source code, to better fix its requirements, are permitted. Alternatively, an open source, user friendly software can terribly diminish costs and can be tailored to user purpose. All for this, a advanced, unique and open source 2D DIC software Ncorr which built on MATLAB platform [18]. Apart from this, few more free and open source software for DIC techniques are available, but in MATLAB program [2], for which a license is necessary

2 EXPERIMENTAL SETUP

The proper digital image correlation set up consists of a light source, Personal computer with MATLAB (NCorr), high resolution camera with lenses of 25mm focal length, Universal Testing Machine (UTM).The camera is fixed on a steady stand to ensure the proper position. The DIC set up shown in fig.2.The specification of rectangular aluminum specimen is 30 ×6×2.54 mm. In general, aluminum plate which has used for multipurpose field means in industry, buyers great, marine condition, indoor parts of auto outline and other squeezing. The prepared specimen must contain the sprayed surface before the speckles are installed [4]. Speckle pattern is the vital role to get the exact output when using digital image correlation. The specimen will then be loaded on lighting condition that expanded grey level distribution in the dynamic range [5]. Basically, DIC consists of at least a digital camera, zoom objective and PC software. This technique can be used to measure contour used for many tests like tensile, torsion, bending, combination of strain and dynamic.

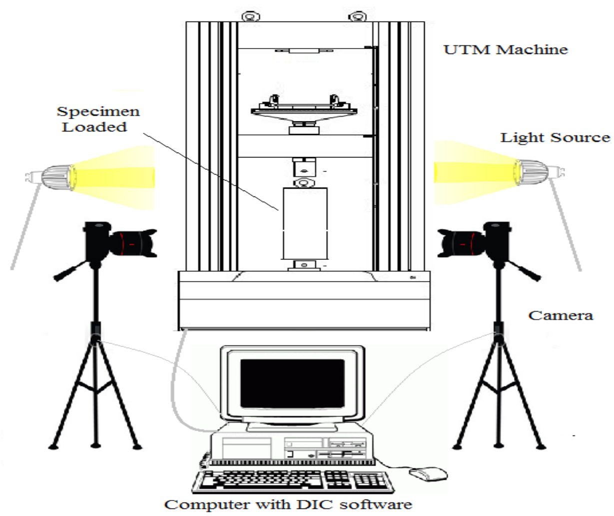

Fig.2.*Basic DIC setup*

2.1 Tensile Test by UTM Machine

The prepared specimen is ready for testing and is fixed in UTM. The initial load is started with zero and is slowly increased until the specimen breaks. Meanwhile, the digital images will be captured by the fixed camera at various load level with the interval of every 2 sec. Strain accuracy and spatial resolution is based on increasing the resolution of the images. The time required to break aluminum plate on utilization of load (kN) is around 15 min. In this time, we captured totally 260 images at the interval of 2 sec and these images were moved to further correlation programming. Fig.3 (a) and (b) means the prepared specimen of this work. The step by step image acquisition procedure for DIC analysis is given below.

- Fix the specimen in UTM
- Start to apply load
- Meanwhile start to capture the images with different load level
- Note the reading of time
- Vary the load until the specimen breaks

Fig.3(*a)Reference image (b) Deformed image*

Frame per Second (FPS) is the ratio of number of images to particular time duration in seconds

FPS = TOTAL IMAGE/DURATION

Calculating the number of images at every load is the product of frame per second (FPS) value with recorded time at the corresponding load [10].

FPS X TIME = NUMBER OF IMAGES

3 PROPOSED DIC ALGORITHM

The main focus of proposed algorithm is to find out full field displacement and strain measurement from reference and deformed specimen surface. Pixel intensities have been compared in the midst of numerous images. We need some mechanism for this situation. Fig.4 explains the theoretical overview idea of proposed algorithm. It explains, the first step is to perform reference, deformed images and ROI select. Then, Hessian matrix is applied to track the edge of corner feature. Enhancement process is used to obtain the proper sub pixel location. Using block matching method, find the corresponding region for further process. Next is comparing statistical unity of various subsets in different stages by selecting correlation criteria. Then the above criteria are diminished to estimate the displacement and strain values. All of the above reasons apply to only one subset but to all subset on specimen surface to find displacement and strain. At last, smoothing filter is applied to eliminate unnecessary noise from the specimen to get the better strain value.

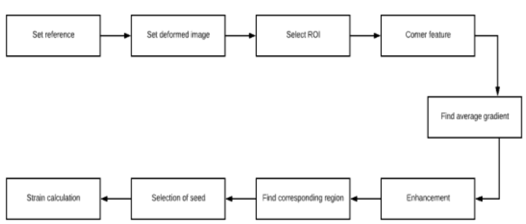

***Fig 4 :** Flow diagram of Proposed work*

4 IMPLEMENTATION USING NCORR

The next important step is determining and analyzing the strain which is obtained from correlation technique on images after settlement of camera along with other terms. As per the word of the software developer of Ncorr at least R2009a+ and needed proper toolboxes. The post processing and correlation procedure needs compiler to perform [6].

4.1 STRAIN COMPUTATION METHOD USING NCORR

At first, complete the entire installation and then execute the Ncorr program from MATLAB. Type "handles_ncorr = ncorr" in the MATLAB terminal window. At the first step, from the prepared specimen take some digital images before applying load. Consider these images as the reference images. Ensure about to obtain better images without any vibrations on specimen. Set the reference image at zero loads. Then, slowly vary the load and capture the image(s) with different load, called as current image(s).For example: first image-250kN, second image- 500kN) that is shown in fig.5 (a) and (b). To proceed this, all images should have the same format and it should be in 'tif' format

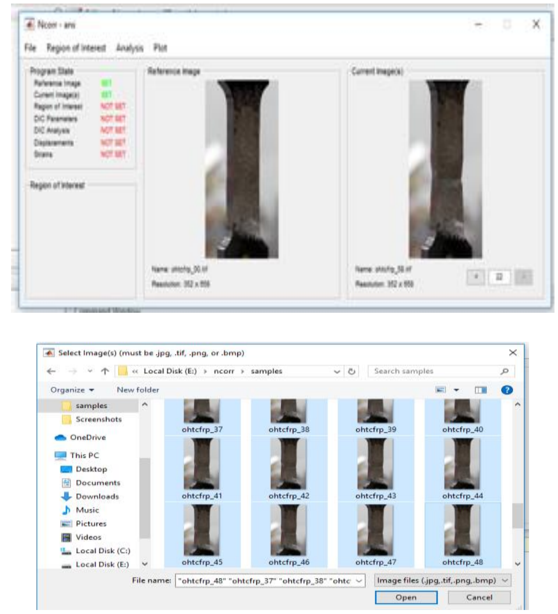

***FIG.5**. (A) (B) SETTING REFERENCE IMAGE AND DEFORMED IMAGE(S)*

Now, reference and current image(s) ready for further process as shown in fig.5 (a),(b).All images are moved to MATLAB function. The much important point is that ROI must be an array of similar size as the initial image. Selection of ROI is depending on gauge field and strain area to be estimated. The shape of ROI may be rectangular, circular or pyramidal. The rectangular white part in specimen is considered as the ROI as shown in fig.6.

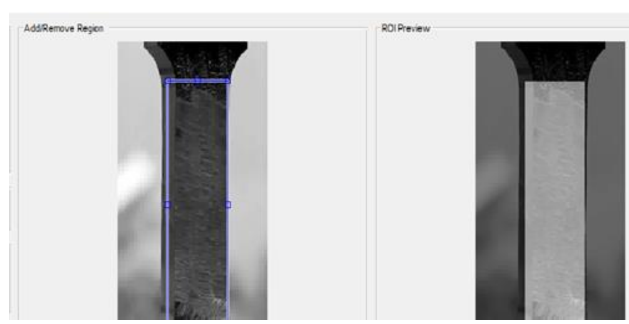

***Fig. 6**.Selection of ROI*

A green mark was located on the "Subset Location". The subset size is dependent on distance between the dots. The space between the points decreases proportionally to the computational essence.

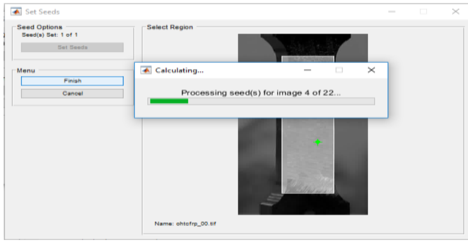

Fig. 7a*.Selection of seed points*

In common, mean and variance of picture noise are constant values, so the displacement calculation precision can be controlled by managing the SSSIG, that can be more or less by varying the subset size [7].

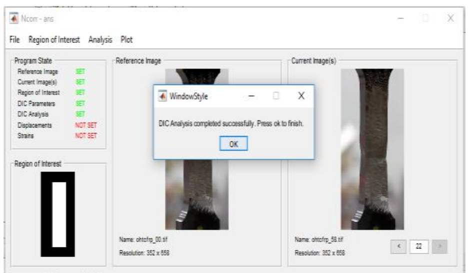

Fig. 7b*.Selection of seed points*

Subset radius is the important option to get accurate displacement. Selecting smallest subset which always gives the noiseless displacement data. To speed up the computation process, multithreading options is always the best way. When the size of the thread is increased, the result becomes much precise. The next phase is choosing region for further steps. There is possible to select more than one region when creating ROI. Here only one region is selected. Providing the initial guesses and separation of ROI is all about seed placements. Now, the seed selection is completed that is shown in fig.7 (a) (b). To avoid the error during process, seed point to be checked. In the final phase, during the process using the coordinates received for every picture analysis and numerical calculation of corresponding specimen will get the needed amount of displacement value. Output strain value depends the assigned value of strain radius. In this calculation we used the strain radius as 50. Strain radius value and subset radius is better to be similar even though the lowest radius value which is given noiseless strain value. The output value will have two arrays. The array represents x and y coordinate of the images. Now using this displacement array, we can obtain strain. It uses reference array, Displacement array to calculate optimal strain shown in fig.8.The final step represents strain distribution appeared inplane space in terms of $\mathcal{E}_{xy}$ and $\mathcal{E}_{yy}$ that shown in fig.9 (a), (b).

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \end{bmatrix} \qquad \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{11} & a_{12} & a_{13} \end{bmatrix}$$

Reference array **Deformed array**

Displacement Array= [Reference array]- [Deformed array]

Fig 8. *Calculation of displacement*

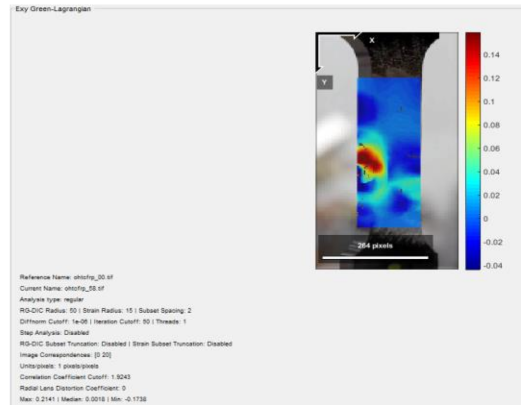

Fig. 9a*. Strain distribution in* $\mathcal{E}_{xx}$ *plot*

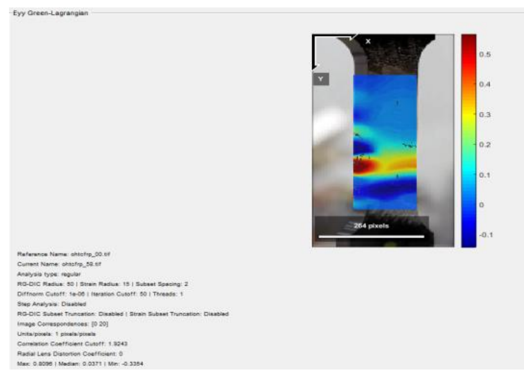

Fig.9b *Strain distribution in* $\mathcal{E}_{yy}$ *plot*

6 DISCUSSION

This set is composed of 22 images, size of 352 pixels by 658 pixels, of real tensile test on aluminum plate. Measurement of strain for contact and non-contact methods have similar objective but dissimilar in experimental arrangement, tools. This is clearly too cost than DIC method. In this calculation we used 21x21 pixels subsets and 2 pixels of spacing between subset centers. Linear interpolation is the big support to calculate better displacement. Fig.8. shows results of proposed algorithm for displacement and strain field evaluated which corresponds image 21 of Sample 22. In the plate area where u ≈ 0.7 pixel, error is around 0.006 pixels. On the other hand, in the plate area where u ≈ 1 pixels, error is around 0.03 pixels with the correlation coefficient is 1.9344 Suppose the specimen is plate with circular hole have large deformation and to reduced number of pixels in border subsets. As a consequence, this area gives high differences. The strain analysis shows that as loading increases the range of qualities increases also. However, it should be noted that errors in the displacement field results influences the accuracy of strain field as well. Although this limitation, this result is important because it shows that calculated strain accuracy depends on deformation level of object.

7 CONCLUSION

The proposed algorithm for DIC is improved by introducing image registration process into the existing DIC method. This research analysis concludes that the proposed algorithm can accomplish greater computational speed than existing method without losing its accuracy. With the help of image correlation, the number of iteration could be reduced in subset matching process also the estimated strain value from both strain gauge and DIC means that the variation is not more than 0.05 pixels. This work proposed technical procedure and methods of applying open source platform Ncorr that is depends on MATLAB for accurate strain estimation. Furthermore, calculated strain with the corresponding displacement coordinates shown in Fig. 9 (a),(b) and the value of median strain ε_{xy} using Ncorr is 0.0018. Also, in future, the interesting part is finding strain in image correlation using electromagnetic waves on deformed images to improve the result. Finally, it concludes that the combination of image registration with DIC can give in a more accurate, smarter measuring method for full field strain and deformation.

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