Digital Image Correlation

About DIC

DIGITAL — Use of Computer

IMAGE — Images captured by CCD Camera

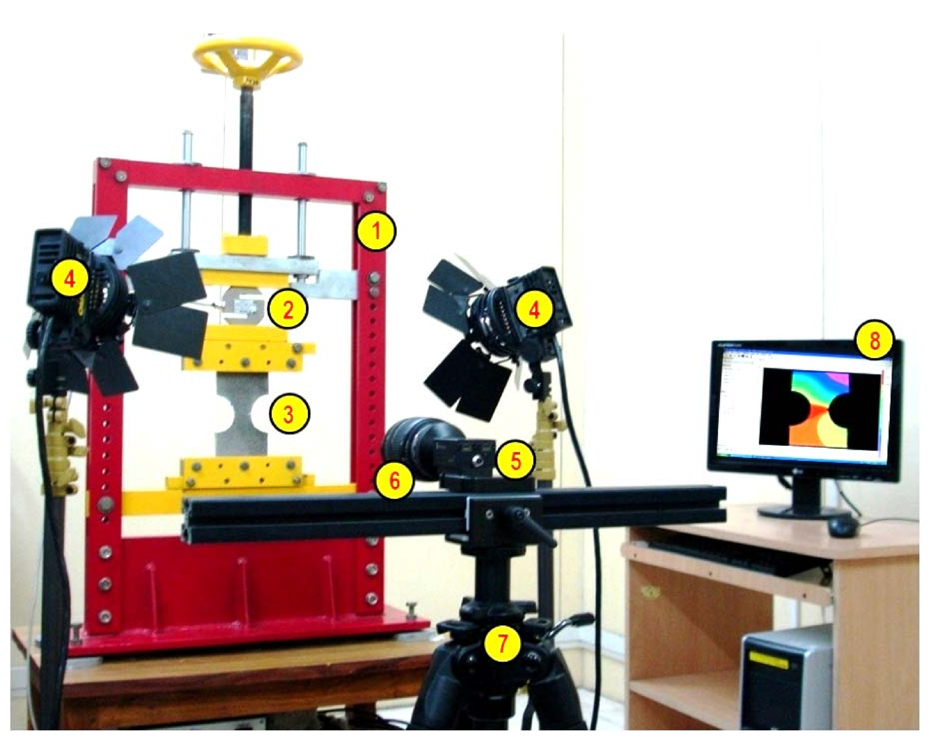
CORRELATION — Comparison of images at different state of deformation

- Optical, non-contact, full-field computer assisted experimental technique for displacement and strain measurement.
- It belongs to the class of non-interferometric optical techniques.
- It involves acquiring of two or more images, matching them based on statistical and continuum mechanics principles and extracting the displacement and strain fields.
- Artificially introduced speckles act as information carriers. Also known as "White light speckle correlation".
- It can handle large specimen size varies from 1 mm to 10,000 mm.
- This technique has been used successfully for large deformation measurements. In view of its simplicity, the technique has been extended to study the deformation at multiple length scales.
- At this stage of development, the accuracy of the method is not high, but a very useful technique to get some information where conventional techniques fails such as at very high temperature.

Reasons for growing interest in DIC

- If the natural texture of the specimen has a random gray intensity value then the specimen preparation for DIC is not required.
- Random texture can be created by spraying B/W paint.
- DIC does not require laser source. A white light source can be used for illumination during the measurement.
- Developments in HD analog and digital high-speed cameras provide pictures at 10^4 to 10^6 fps, which suits dynamic DIC analysis.
- The physical size of 1 pixel may vary from 1 nanometer (or less) to 1 cm (or more).
- Analysis can be performed on images provided by other imaging techniques like SEM/ AFM.
- Cost of CCD and CMOS sensor based cameras have decreased.

Experimental setup for DIC

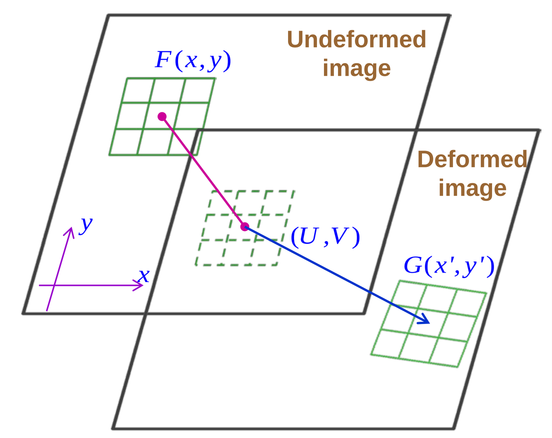


1 Loading frame
2 Load cell
3 Speckled specimen
4 Light source
5 CCD Camera
6 Lens
7 Tripod stand
8 DIC software

Figure Courtesy: Kishore Zingre, Use of digital image correlation to solve solid mechanics problems, M. Tech thesis, 2010.

Principle of DIC

- DIC measurement is based on tracking a group of pixels (called subsets) in the deformed and reference image through temporal matching and correlation functions.
- Initially, digital image is divided into smaller regions called subsets.
- Subset shape functions are imposed to the reference subset to account for the deformed shape of the subset in the deformed image.
- The deformed position of the subset may not be at the integer location. Therefore, interpolation functions are used to obtain the gray intensity value at non-integer location.



- Correlation function (C) is defined to match the similarity between the subset in the undeformed and deformed image.

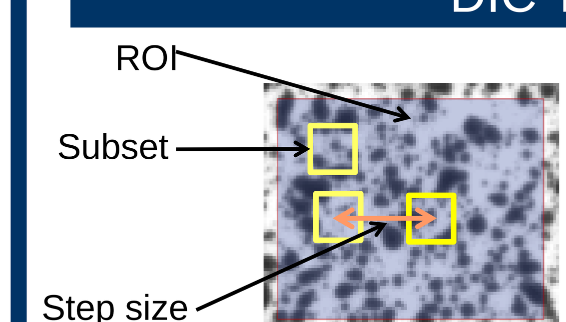
$$C=\frac{\int_{\Delta M^*}(F(x,y))\,(G(x_0+U,y_0+V))\,dA}{\left[\int_{\Delta M^*}[F(x,y)]^2dA\int_{\Delta M^*}[G(x_0+U,y_0+V)]^2dA\right]^{1/2}}$$

- The unknown parameters $\left(u,v,\frac{\partial u}{\partial x},\frac{\partial u}{\partial y},\frac{\partial v}{\partial x},\frac{\partial v}{\partial y}\right)$ are determined by minimizing the correlation function using Newton-Raphson method.

2D DIC Flow Chart

Selection of camera, lens and lighting
↓
Image data acquisition
↓
Undeformed image | Deformed image
↓
Temporal matching
↓
Displacement measurement
↓
Strain measurement

DIC Terminologies



- DIC is a subset based image correlation technique. Subset is a collection of group of pixels carrying a unique gray value information for deformation measurement.
- The distance between the subset centers are called step size.
- Subset shape functions are applied to the subsets of the reference image to approximate the deformation of the subset in the deformed image. It is essentially a transformation from pixel coordinates of the subset in the reference image to the coordinates of the deformed image. First order shape function is given by

$$\begin{bmatrix}U(x,y)\\V(x,y)\end{bmatrix}=\begin{bmatrix}u\\v\end{bmatrix}+\begin{bmatrix}\frac{\partial u}{\partial x}&\frac{\partial u}{\partial y}\\\frac{\partial v}{\partial x}&\frac{\partial v}{\partial y}\end{bmatrix}\begin{bmatrix}\Delta x\\\Delta y\end{bmatrix}$$

- Correlation function: is used for matching of the subset in the deformed and undeformed image. the correlation algorithm used are sum squared differences (SSD), Normalized sum square differences (NSSD), and Zero-normalized square differences (ZNSSD)

Correlation function	Characteristics
SSD	Sensitive to all deformed subset lighting changes
NSSD	Insensitive to scale changes of the subset intensity
ZNSSD	Insensitive to offset and scale subset intensity changes

Figure Courtesy: Shiva prasad B, Digital image correlation and its application to fracture mechanics, M. Tech thesis, 2010.

Parameters affecting DIC measurement

Loading → **Test Machine**: Misalignment, Out of plane displacement, Vibration, Calibration

Specimen → **Speckle Pattern**: Size, Shape, Density, Contrast, Illumination

Sensor → **Camera**: Resolution, Dynamic range, Noise, Lens

Analysis → **Software**: Interpolation, Correlation, Shape function, Subset size, Step size, Filter size

Courtesy: Pascal Lava: Practical considerations in DIC measurements, 15th ICEM Conference, Cardiff, 3rd September 2014.

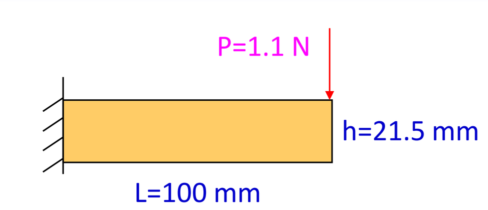
3D DIC

Steps involved in obtaining 3D displacement data using 3D DIC are

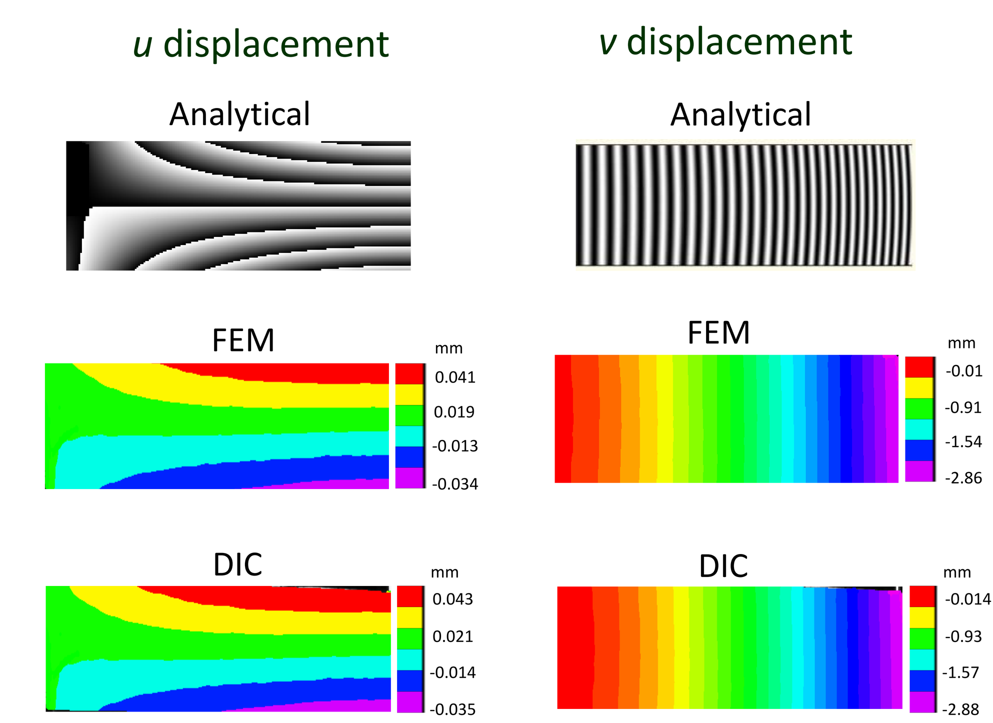
- The process starts with camera parameter calibration to identify the relative position and orientation of cameras in the stereo rig.
- Two or more cameras are positioned to view same object area and images are captured simultaneously by all cameras.
- 2D image correlation is performed to identify matching regions in different views.
- Mapping function generally projective to account for perspective distortion.
- Thereby, 3D displacement vector $(\bar{u},\bar{v},\bar{w})$ is obtained for all points.

Applications to solid mechanics problem

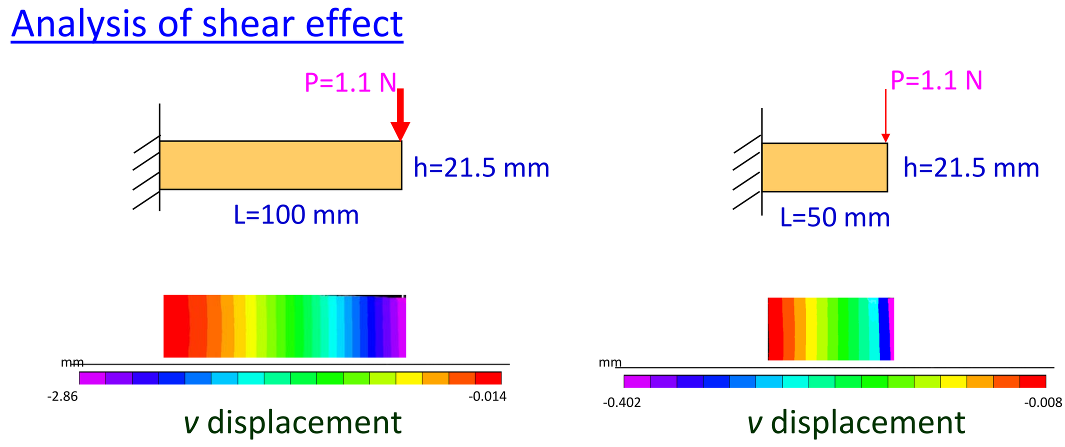
Cantilever Beam with an in-plane load



Material: Polyurethane
E = 25 MPa



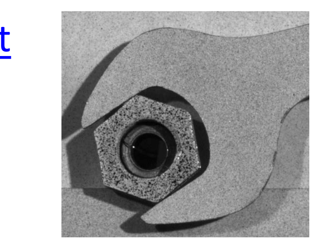
Analysis of shear effect

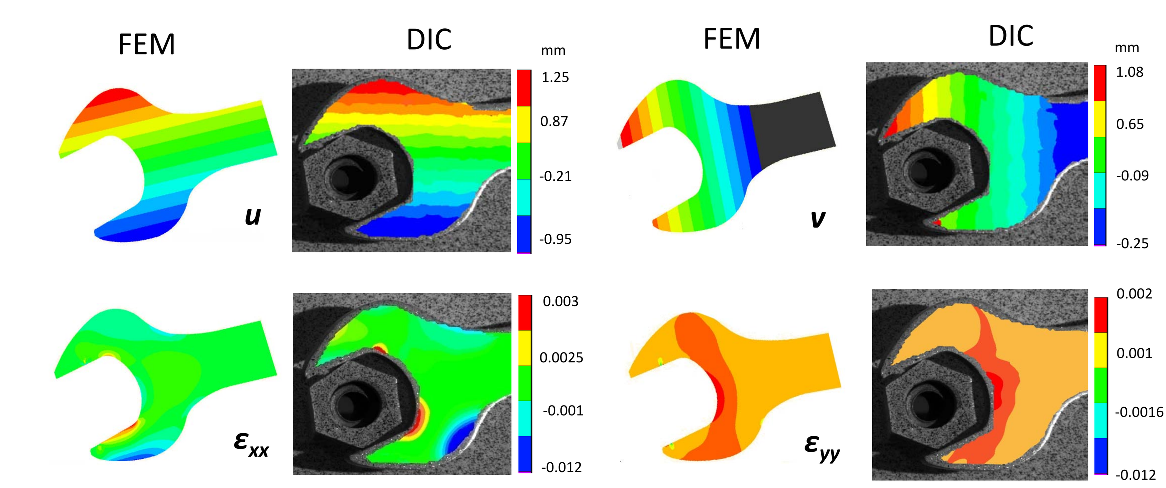


Shear effect				
Cantilever beam (mm)	Load (N)	Deflection		
		Without shear Effect (Analytical) (mm)	With shear Effect (Analytical) (mm)	DIC (Spraying) (mm)
L = 100, h = 21.5	1.1	2.75	2.85	2.86
L = 50, h = 21.5	1.1	0.344	0.392	0.402

Application to practical problems

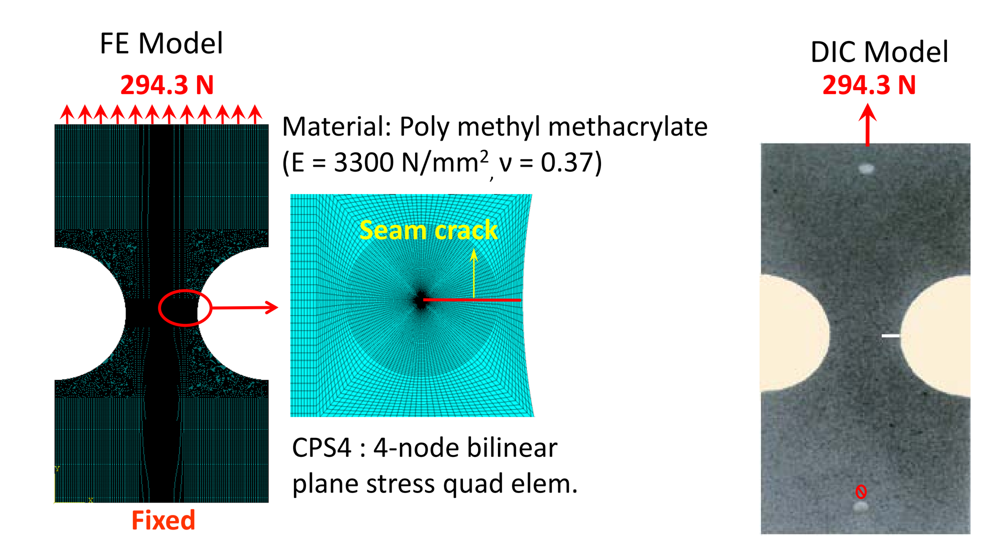
Spanner tightening nut

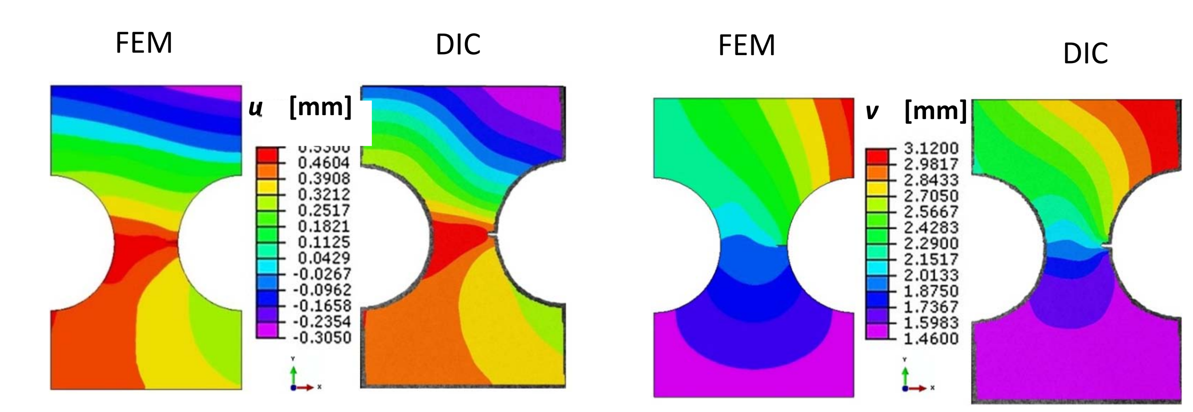


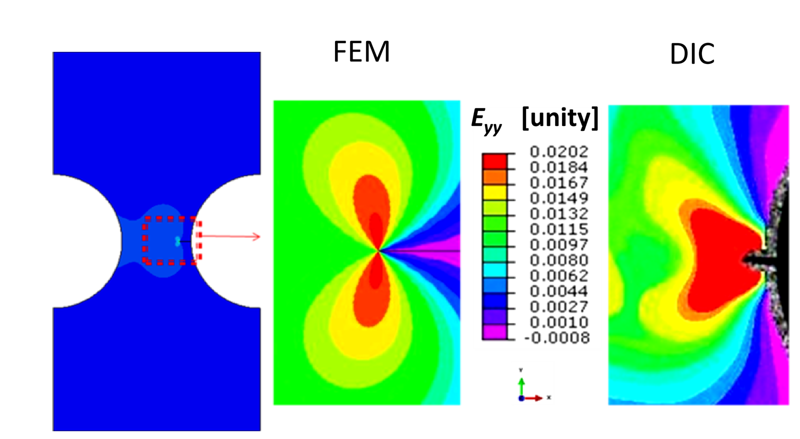


Applications to fracture mechanics problem

C groove specimen







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