Digital Image Correlation in 2D with NCORR (MATLAB): Working with High-Speed Digital Images

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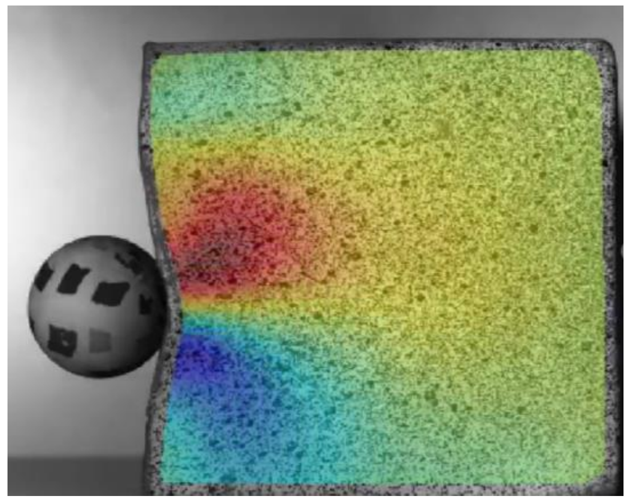
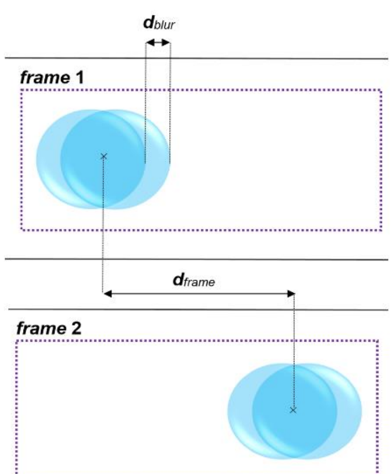


Abstract. Digital image correlation (DIC) is a non-contact characterization technique capable of quantifying full-field deformation and strain. This process generally involves the careful placement and aim of one or more digital cameras relative to an object undergoing physical change. Recorded images are then imported into a DIC software that utilizes cross-correlation algorithms to compute small local changes on the surface of the material undergoing deformation. These small changes are generally represented as delta-pixel and/or strain values (i.e., U, V, ε_{xy}). To date, there exist a handful of powerful third-party commercial softwares, and a few open source packages. In many cases, especially in academic and budget-sensitive settings, the utilization of open source packages, built in environments such as MATLAB or Python, are deployed. In this brief note, discussed are some key design criteria one should consider when working with high-speed imagers in these settings, together with a short walkthrough on how to use NCORR (by Justin Blaber)[1], which is MATLAB GUI capable of ingesting high-speed digital images to perform a 2D DIC analysis to compute deformation and strain.

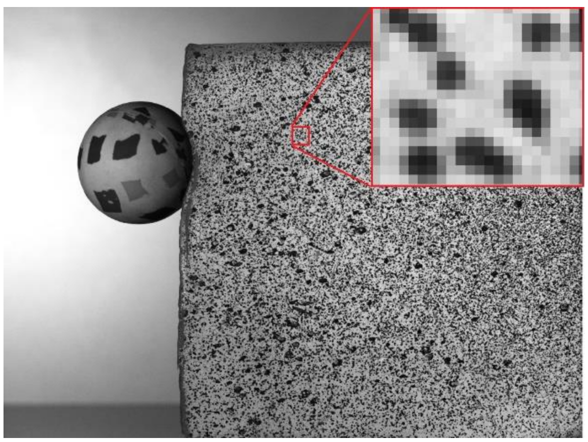
Experimental Design. When designing a high speed DIC experiment (whether in 2D or 3D) it is crucial that groups consider the guidelines put forth by the *International Digital Image Correlation Society*, or iDICs.[2] These guidelines define: measurement requirements, equipment and hardware needed, specifics about the DIC pattern (speckling), preparation procedures for the measurement, calibration and verification, experimental cautions, and some information about DIC software and reporting requirements. A few key guidelines are re-produced below:



Temporal Sampling & Motion Artifacts. During dynamic events that surpass the characterization capability of consumer cameras (i.e., 30-60 fps), high-speed cameras are required. In general, good practice is to take the fastest temporal feature in the event (if known) and ensure you have a minimum of three frames to span it, and then increase to improve temporal clarity. In the case of a ball impacting a block of ballistics gelatin, if it takes 1 ms from initial impact until ricochet, a viable guess on minimum interframe time ($\mathbf{d_{frame}}$) and frame rate would be ~333 µs and ~3 kfps, respectively.

Another critical setting is the exposure time, or shutter speed. This defines how long each frame collects light for. The longer the exposure period, the more photons the pixels can collect per frame, but at the cost of a higher propensity of displaying motion blur artifacts. Note that DIC is based on sub-pixel routines, and thus sub-pixel motions must be carefully considered. Therefore, as recommended by iDICS, the maximum allowable test piece motion (over the course of the exposure time) should be at least equal to the noise-floor. To give you an idea, this threshold could be ~0.01 pixels, and for machine vision systems 0.1 – 0.3 pixels, and some dynamic modal tests have accepted up to 3 pixels of motion during an exposure period.[2] The observed motion blur (d_{blur}) is directly related to the object speed, the length of the exposure time, the field of view (FOV), and the sensor resolution (SR). Motion blur can be calculated using the following equation: Motion blur = Object speed x Exposure time

Patterning/Speckling. The pattern requirements:[2] It is recommended that a pattern feature size (i.e., speckle size) spans 3-5 pixels, as features with less than 3 pixels risk being aliased, and areas with speckles larger than 5 pixels require larger processing subsets (or facets) that in turn decreases the spatial resolution of displacements and strains. The speckle, or feature, density should be around 50%, or 25-40% if round speckles are used. The patterning should be sufficiently randomized, and if local periodicity is intrinsic to the patterning, the algorithm may fail to produce accurate correlation information. The contrast ideally should be as high as possible: black on white, or white on black. A helpful tool to verify that you are in the ballpark of 'speckle quality' is to digitally zoom into the image and count how many pixels traverse an average sized speckle, see image to the left.

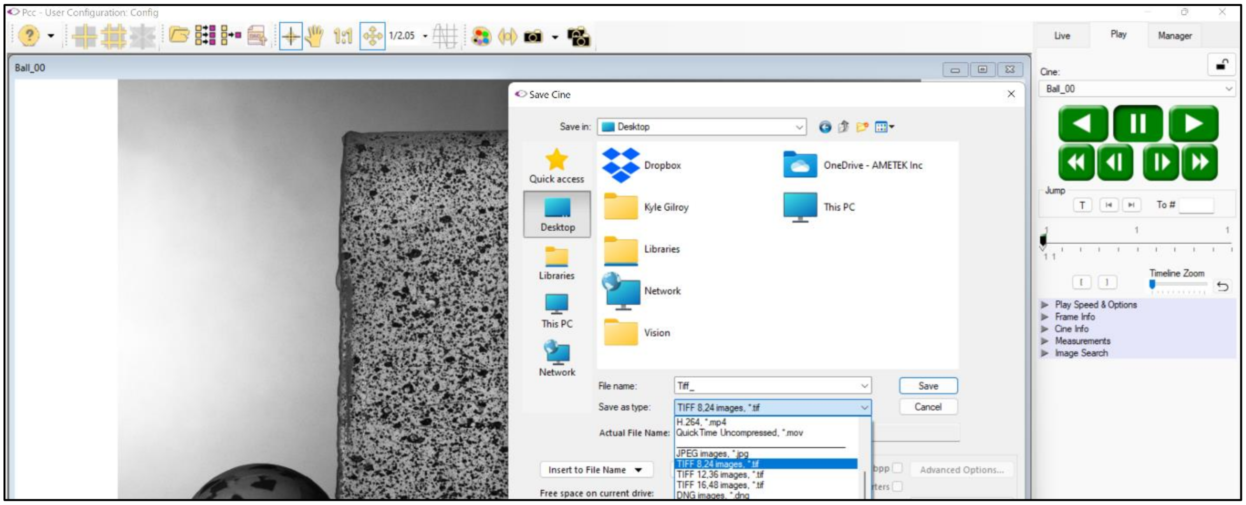


Experimental cautions. When designing your experimental setup, you want to be careful to avoid all sources of vibration and this includes things like cables dangling, camera fans being on during the measurement, tripod instability, local air conditioner units or fans, computer being located on the same table as the camera and/or test specimen, and/or any sort of externally induced vibrations like walking during the recording. In terms of lighting, avoid hotspots from a specular reflection which could result in inaccurate or null data. This can be avoided by using the proper diffused lighting and using non-reflective paint such as matte or chalk.

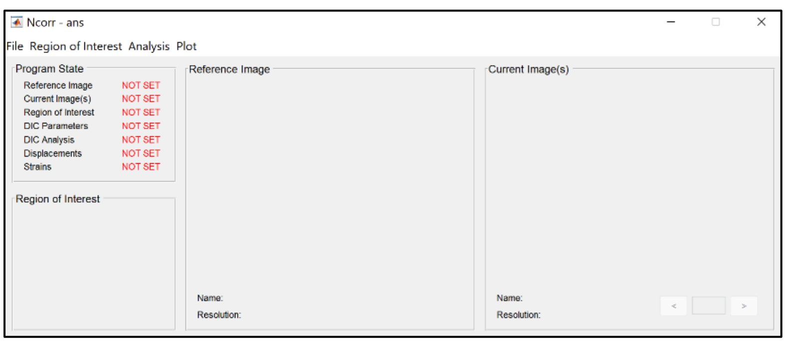
2D vs 3D Tests. In general, the use of one camera is for performing 2D measurements, and deformations ideally within the test specimen should only primarily occur coplanar with the imaging sensor, or within the focal plane. If there is any degree of out-of-plane motion during deformation, it may contribute significantly to computed 2D deformation, and thus will produce inaccuracies. Imagine simply moving the specimen toward or away from the single camera that has standard lensing/optics, in turn, the subject's pattern will expand or retract, respectively, and thus trick the algorithm. To counter this, a bilateral telecentric lens is recommended to mitigate errors.[2] If a telecentric lens is not used, it is recommended to use a long focal-length lens to maximize the working distance and minimize errors caused by out-of-plane motion.[2] In the example used herein, where the ball impacts ballistics gelatin, there is inevitably some small degree of out-of-plane motion. To counter these challenges, ultimately two or more cameras are required to generate a 3D data set. This process formally is referred to as stereophotogrammetry.

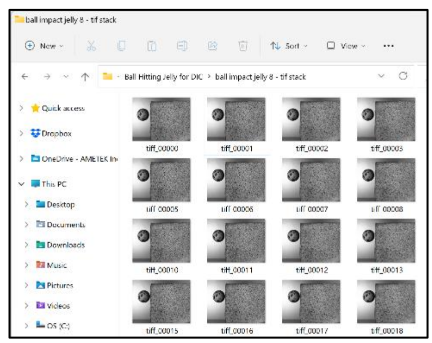
Processing High-Speed Digital Images via NCORR:

Step 1. Save the recorded video from PCC to a folder as a stack of Tiff-8s (Recommended naming: Img_)

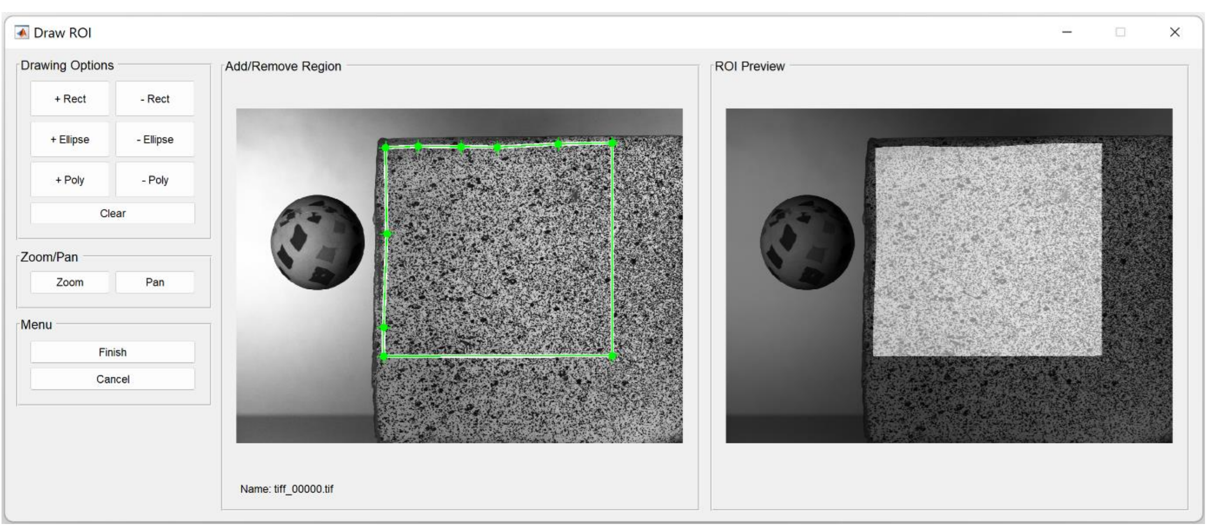


Step 2. Select *File*, and then *Load* a Tiff-8 Reference Frame into NCORR, then load the analysis frames.

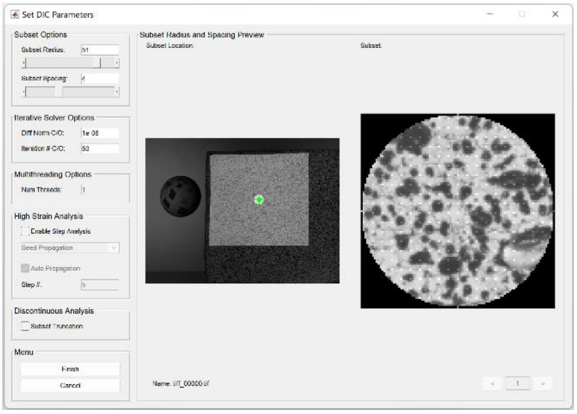


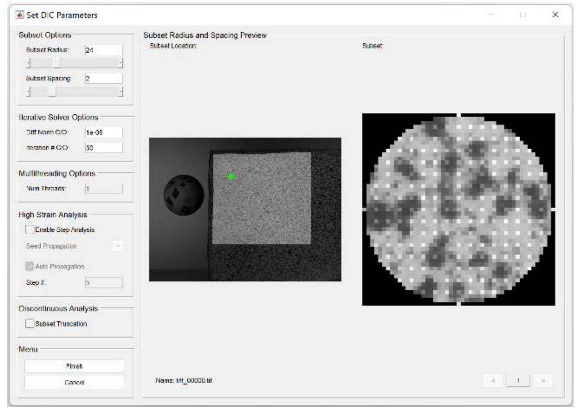


Step 3. Draw a Region of Interest (ROI) – the area over which the analysis will be performed

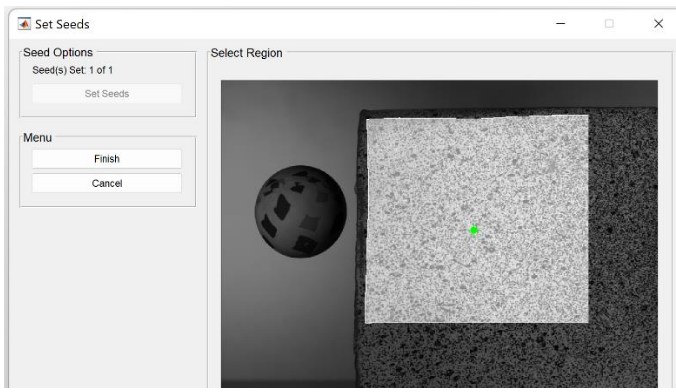


Step 4. Define the Subset radius, Subset spacing, and other DIC parameters

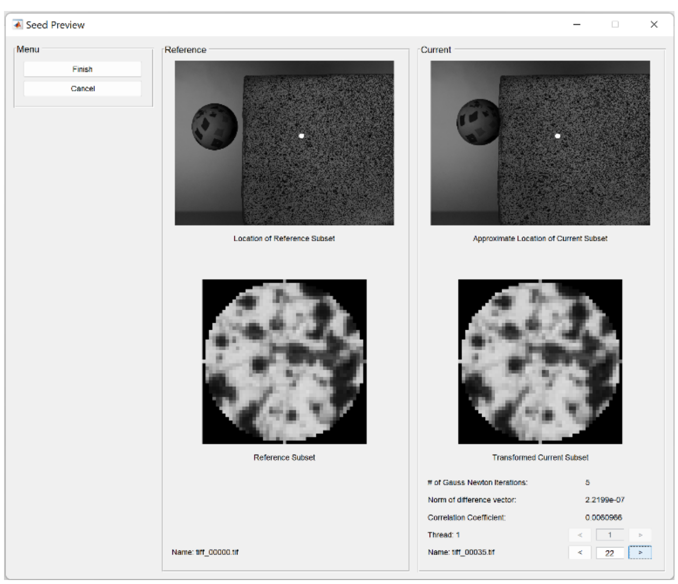




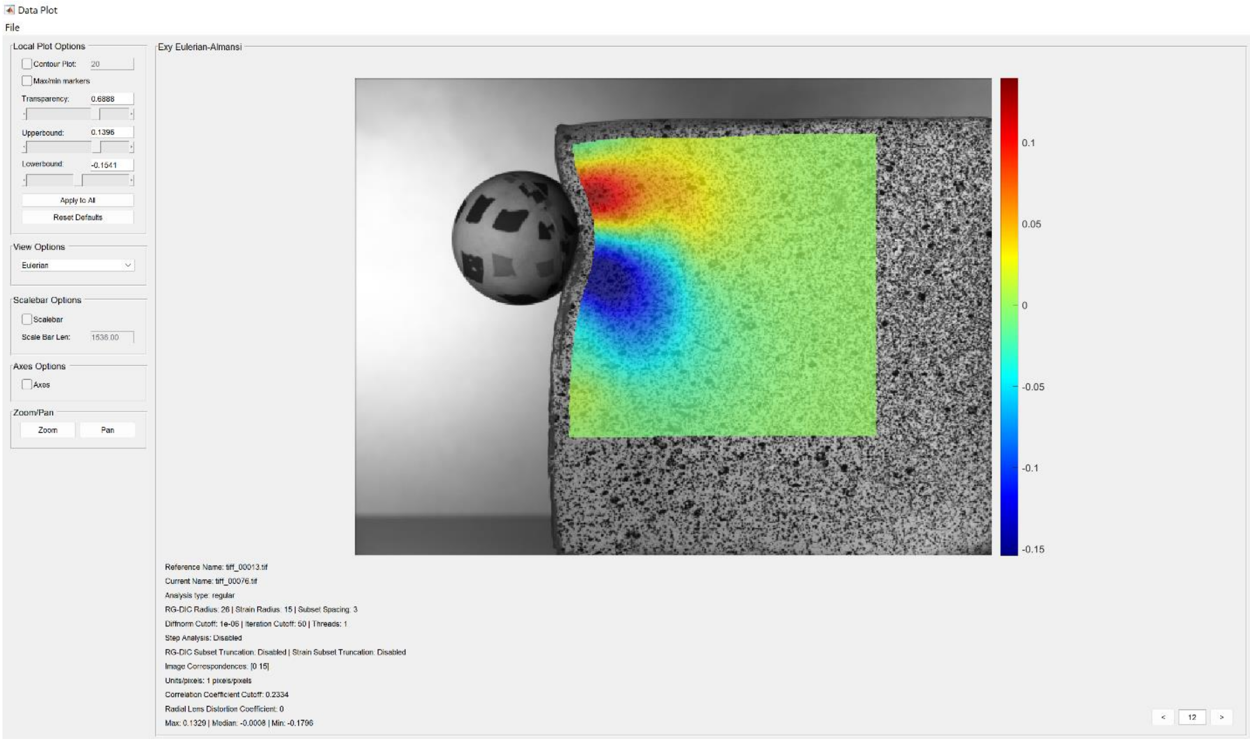
Step 5. Set the 'Seeds' by clicking the ROI. Since this is one analysis region, number of Seeds = 1.



Step 6. Cycle through Frames to Review the Reference Subset and Transformed Current Subsets



Step 7. Review the outputted data (deformation and/or strain). Displayed here is Eulerian-Almansi (ε_{xy}):



Conclusion. This short technique note serves as an overview on how to carry out 2D DIC on high-speed images. As one can see from this sample data set and walk through, it is straightforward to carry out digital image correlation in 2D on high-speed images in MATLAB using NCORR. This provides a quick way to compute deformation occurring in the x-y plane of the sample specimen. If one plans on making informed decisions from extracted analysis data, it is highly encouraged to carry out rigid control experiments to validate these measurements and consider out-of-plane motion errors. If you are interested in learning more about the NCORR code, the code authors have a very detailed overview in reference 1 under the dropdown called "DIC Algorithm".

References

1. Ncorr: Open-Source 2D Digital Image Correlation MATLAB Software. Experimental Mechanics. J Blaber, B Adair, A Antoniou (2015). NCORR v1.2. https://www.ncorr.com/index.php
2. International Digital Image Correlation Society, E.M.C. Jones, and M.A. Iadicola, (2018). A Good Practices Guide for Digital Image Correlation. https://doi.org/10.32720/idics/gpg.ed1.Cc