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Adaptation of DIC technique for simplified applications in experimental mechanics

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Abstract.
The literature and practical application of Digital Image Correlation (DIC) present sophisticated methodologies and algorithms that through a correlation between image data, capture complex strains and deformation fields. However, its application requires extensive surface preparations, careful calibrations, high computational capabilities, and in some cases is still susceptible to errors. Through two experimental campaigns, this paper presents an adaptation of the 2D Digital Image Correlation (2D-DIC) technique, where instead of a speckle pattern to derive full-field deformation data, markers with high contrast features are adopted to extract point-wise strains. The primary goal of this adaptation is to define an approachable methodology for researchers without any background in DIC or image analysis and offer an additional tool set for experimental campaigns.

1 Introduction

Digital Image Correlation (DIC) is considered a powerful tool for non-contact strain measurements and deformation analysis across various fields. It offers a non-invasive and highly sensitive mode for data recording, making it crucial for understanding complex material behaviours in solid mechanics and material sciences. Unlike traditional techniques like strain gauges or extensometers, DIC offers full-field, contactless data, enabling comprehensive insights into deformations and strains exhibited [1]. The application of DIC finds limitations due to the need for elaborate test setups, high-quality image capturing, and meticulous calibration, all of which demand specialized knowledge and equipment [2, 3]. The processing and correlation algorithms further complicate the implementation of DIC, requiring expertise in both image processing and experimental mechanics [2].

Consequently, DIC is often not applied to address simpler problems where traditional measuring systems, such as transducers and strain gauges, despite several limitations are often considered adequate and reliable with significantly less complexity. Measuring systems such as transducers, string potentiometers, LVDT and other mechanical extensometers, are externally introduced onto the specimen, allowing single-point-wise measurements. However, they are susceptible to damages resulting from sudden specimen failure, detachment during experimentation, or need to be dismounted before failure. Further, these systems are limited to anticipated strains presented and fail to account for any local phenomena.

The literature on 2D-DIC also presents research on full-field strain mapping alongside a system of virtual extensometers that allowed the measurement of both direct [4, 5] and indirect [6] deformations. However,

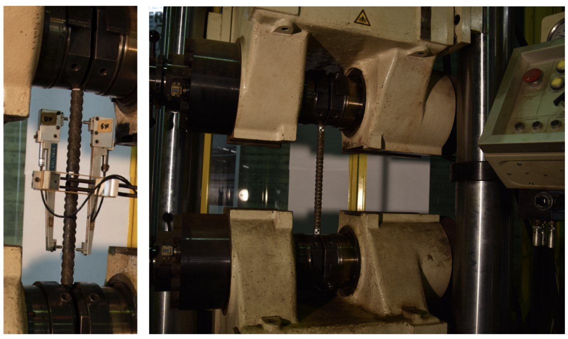
Journal of Physics: Conference Series **2802** (2024) 012008 doi:10.1088/1742-6596/2802/1/012008

speckle pattern tracking proved to be both extensive in terms of surface preparation and errors due to problematic meshes in the interpolation algorithms, especially when large deformations occurred [7, 8].

The current paper aims to simplify the implementation of the adapted DIC technique by reducing technical considerations and by adopting a single-step calibration. This objective is addressed through two test cases: a uniaxial tensile test on a steel rebar and a three-point flexure test on a laminated wooden beam. In the first test, while the primary aim is straightforward, ie., to collect the strain along the applied strain, the additional data collected through DIC offers valuable insights into strain localization and quantification. In the second case, the adapted DIC is used to measure the sliding between the laminate layers of the wooden beam in response to the cyclic loading applied. Previously applied for the measurement of indirect and coincidental strains for periodic masonry media [9], the current study through these two test cases, demonstrates how the adapted DIC technique enables both straightforward data capturing and indirect strain measurements by creating a system of virtual extensometers, while also reducing aspects such as extensive surface preparation, processing times, or interpolation errors.

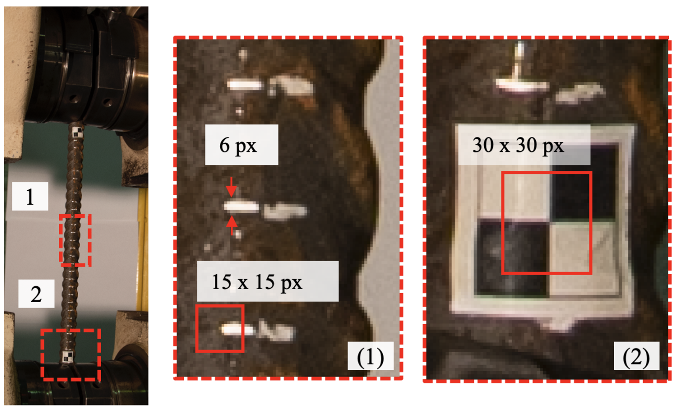
2 Test on Rebar

The first test case considers a 16mm diameter steel rebar with a length of 0.3m subjected to uniaxial tension and tested according to the setup outlined in EN ISO 15630-1:2010 [10]. The primary objectives of the experiment were to characterize the elastic behaviour, the plastic deformations, and the post-peak response. Figure 1a shows the LVDT that would traditionally be used to measure the strain between the central section of the rebar, which is either dismounted after the elastic deformation phase or susceptible to damage due to fracture after the plastic deformation phase. In addition to this, the actuator records the applied force and the displacements presented.



(a) (b)

Figure 1: (a) Conventional test setup with LVDT used to record the strains presented, (b) Proposed adapted DIC setup with high contrast features



(a) (b)

Figure 2: (a) High contrast features, targets and incisions installed on the surface of the rebar, (b) subset size derived for incisions (c) subset size derived for the targets

To facilitate accurate image capturing, the experimental setup included a DSLR camera with a high resolution of 6000 x 4000 and a floodlight source emitting white light with an intensity of 5500 lumens. Additionally, a white background was strategically applied to enhance visibility and contrast during image capture, shown in figure 1b.

Two distinct surface preparation methods were implemented during the test. The first method involved placing high-contrast targets directly onto the surface of the rebar, facilitating precise tracking of deformations and behaviours. Meanwhile, the second method consisted of creating incisions or marks at regular intervals of 10mm along the length of the rebar, enabling detailed observation of localized changes and deformations. Through the experiment, the images were captured at a 1-second interval.

The captured images were processed by adopting two correlation sizes relative to the two typologies of high-contrast features adopted. For the targets a correlation subset size of 30x30 pixels was utilized whereas for the incisions made along the rebar, a subset size of 15x15 pixels was used, as seen in figure 2. Two main outcomes were derived from the analysis: firstly, the global strain determined, which was compared with the data recorded by the actuator to establish the reliability of the results; and secondly, the characterization of post-peak behaviour, which involved accurately tracking the progression of deformation and identifying failure points along the length of the rebar, see figures 3 and 4.

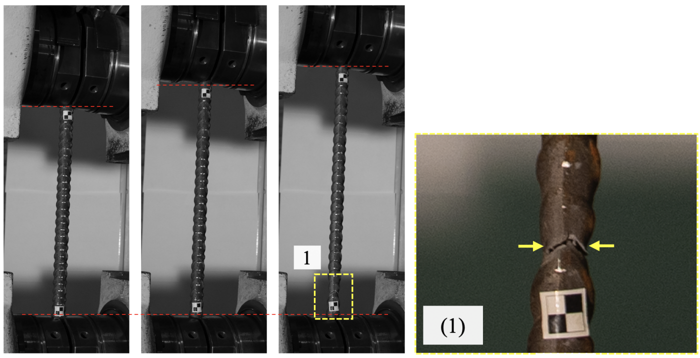


Figure 3: (a,b,c) Elongation of the rebar subjected to the tensile force, (d) fracture zone highlighted

While the elastic deformation of the rebar showed an elongation distributed along its length, the plastic strain and failure were localized to the lower portion of the rebar, see figure 3d. The rebar specimen tested exhibited failure close to the lower wedge grip of the loading machine. The DIC technique allowed for tracking the overall global strain exhibited in the rebar, and the localized strain captured around the plastic elongation and fracture. A comparison of these strains with the actuator data recorded is presented in figure 4.

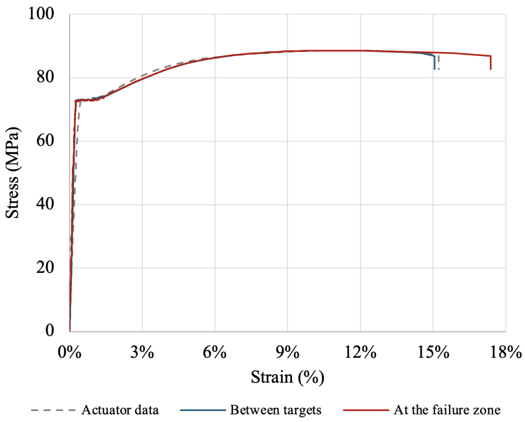
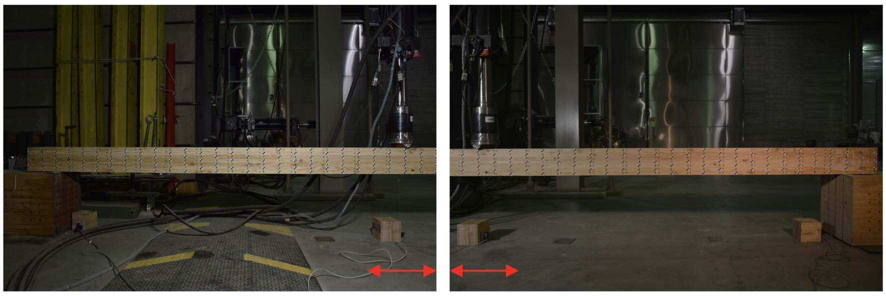


Figure 4: Stress-strain plot of the tensile test on the rebar, comparing the actuator outcomes to the strains recorded through DIC

Journal of Physics: Conference Series **2802** (2024) 012008 doi:10.1088/1742-6596/2802/1/012008

3 Test on Laminated wooden beam

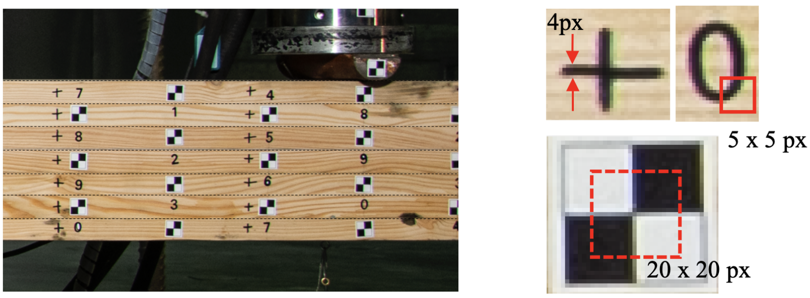
For the second test case, a laminated wooden beam subjected to three-point bending stress and cyclic loading was considered. The test aimed at characterizing the global deformation response to the applied bending stress as well as the sliding behaviour exhibited by the laminate layers, shown in figure 5. The wooden beam specimen was 5 meters long with a cross-section of 0.175m x 0.150m. The beam was composed of 7 laminate layers, reinforced with 18mm bars at regular intervals, see figure 6a.



(a) (b)

Figure 5: Left half (a) and right half (b) of the beam captured by the two DSLR cameras set up, with overlap highlighted.

Considering the specimen geometry, the DIC setup adopted two DSLR cameras, with overlapping fields of view to capture the deformations. Lens distortions were corrected by positioning both cameras at an equal height so that the specimen occupies the centre grid of the field of view, see figure 5a and b. Different surface preparation techniques were employed, such as high contrast targets and graphic features marked on the wooden surface, each offering varying levels of accuracy in data recording 6b. Despite the influence of lighting conditions, a subset of grey intensity distribution remained consistent across images, minimizing potential errors in correlation.

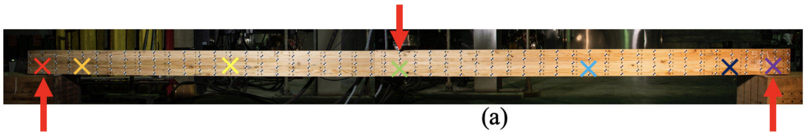


(a) (b)

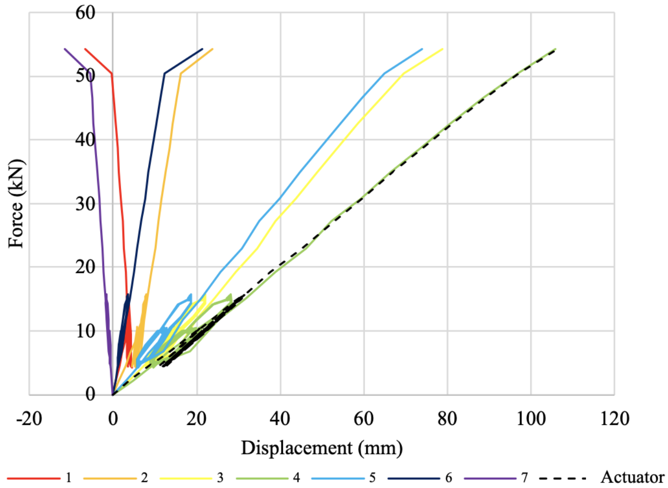
Figure 6: (a) Laminate layers of the wooden beam, with the high contrast features introduced (b) subset size derived for incisions

For processing the images captured, two correlation subset sizes were chosen; 20x20 pixels for the targets and 5x5 pixels for the graphics, while also considering high contrast zones to minimize correlation errors. The images were processed individually, with the extracted results correlated with the applied force. Two primary outcomes were targeted: the global displacement along the beam's length, see figure 7 and the local shear component between laminate layers, see figure 8. The global displacement evaluated demonstrated a symmetric response during cyclic loading until failure on either side of the beam, consistent with data recorded by the actuator, as seen in figure 7b.

Further, the shear or traction between the laminate layers was quantified as a relative displacement between two points, each belonging to a laminate layer. The adapted DIC was able to track the movement of the high contrast features introduced and allow precise measurement of these indirect strains. The traction between the upper and lower laminate layers are presented in figures 8b and c, respectively.

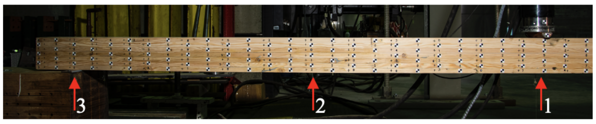


(a)

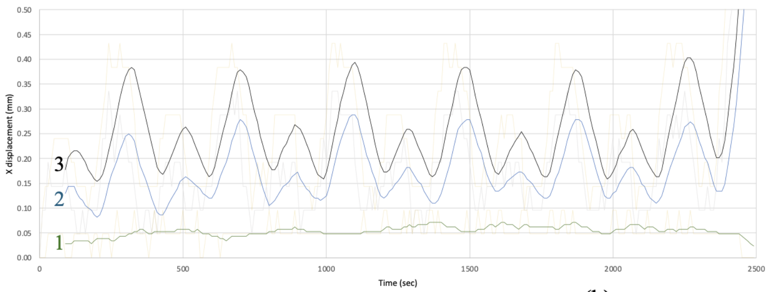


(b)

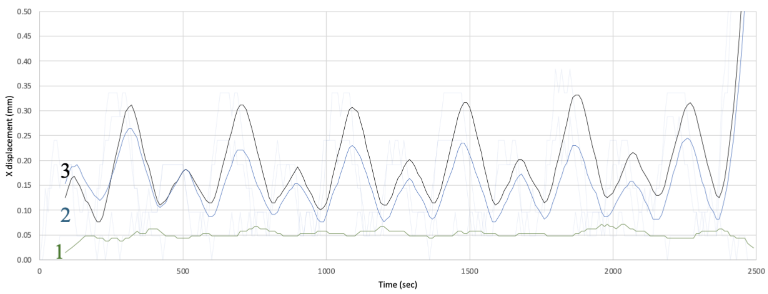
Figure 7: Force-vertical displacement plots of captured about the length of the beam (a) and comparison with the actuator results (b)



(a)



(b)



(c)

Figure 8: Traction between laminate layers captured at centre, quarter and end of the beam (a), between layers 3 and 4 (b) and layers 5 and 6 (c)

Journal of Physics: Conference Series **2802** (2024) 012008 doi:10.1088/1742-6596/2802/1/012008

4 Conclusion

The paper presents an adaptation of the Digital Image Correlation (DIC) utilising high contrast features as opposed to that of a discrete speckle pattern while minimizing the need for extensive surface preparations and calibrations. This was demonstrated through two test cases, capturing direct and indirect strains across different media, testing conditions and scales. Using high-contrast markers enables the extraction of point-wise strains, effectively creating a system of virtual extensometers. This approach allows the extraction of a wide range of displacement and strain data, while also capturing local behaviours. The use of minimal high contrast features reduces the correlation processing time and provides accurate and reliable strain measurements, offering researchers a practical and accessible methodology.

5 Acknowledgments

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