Stereo-measurements with optimal patterns processed by Localised Spectrum Analysis

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Abstract
Localized Spectrum Analysis is a full-field measurement technique developed in experimental mechanics to measure displacement fields by processing periodic patterns (e.g., checkerboard patterns). This method has already been used in many different applications and has shown better metrological performance than Digital Image Correlation (DIC) used with a random pattern. However, LSA was still limited to 2D cases. This work presents stereo-LSA, an extension of the method to a pair of stereo images, which permits the measurement of the 3D displacement field on a sample surface engraved with an optimal checkerboard pattern. The method will be presented and applied to different cases. A comparison with standard stereo DIC will be presented.

Introduction
The measurement of displacement and strain maps is usually performed using pattern tracking techniques, the most common being Digital Image Correlation (DIC). In such techniques, the measurement quality is closely tied to the texture on the sample surface. It can easily be demonstrated that the optimum pattern is the one that maximises the grey level gradient in the images, which leads to a periodic checkerboard pattern on the sample surface [1] (cf. Fig. 1).

Fig. 1 – Example of a checkerboard pattern (square size of 100 [µm]).

While DIC is not well suited to analysing periodic patterns, Localized Spectrum Analysis (LSA) takes advantage of the periodicity to minimise the optical residual in the frequency domain [2]. Thanks to this checkerboard pattern, LSA offers high metrological performance and enables controlled and reproducible patterns on the tested specimens. Although this technique was successfully used in 2D in different applications, no extension to 3D has been proposed so far. In this talk, the extension of 2D-LSA to stereo-LSA will be presented.

Methods & Results
Conducting stereo-measurements involves two more steps than standard in-plane measurements. The optical system first needs to be calibrated in order to reconstruct the observed surface in 3D [3]. Then, the matching between the images obtained from the different cameras must be performed. Even with a flawless optical system, the different observation angles of each camera make it difficult to achieve a good match using LSA. This challenge arises from the significant displacements (especially large rotations) between the two images, inducing different wave carriers in the images. In standard LSA, phase extraction is performed along the periodicity directions of the reference image (in its undeformed state), which assumes similar wave carriers in all the images. A specific procedure was, therefore, developed to address the mismatch caused by different wave carriers. The observed surface can finally be reconstructed in 3D using the calibration parameters and the pixel-wise matching of the images obtained from the different cameras.

Application and results. Different application cases will be presented during the talk. The method is first validated through a purely numerical case. In the second case, stereo-LSA and stereo-DIC are used to analyse a real buckling test on a metal sheet. In the third application, stereo-LSA is applied to study the phase transformation of a shape-memory alloy (SMA) under cooling. For this latter case, a Cu-Al-Ni single crystal specimen, which exhibits a martensite-austenite transformation in the temperature range [-20, +41] °C, was tested. Heating and cooling cycles were obtained by setting the sample on a Peltier cell. Fig. 2 shows the strain maps and the out-of-plane displacement map obtained using stereo-LSA. It can be seen that significant out-of-plane displacement is obtained where the martensite wedges are visible. An "Alicona-IF Portable" optical profilometer was finally used to validate these results obtained from stereo-LSA.

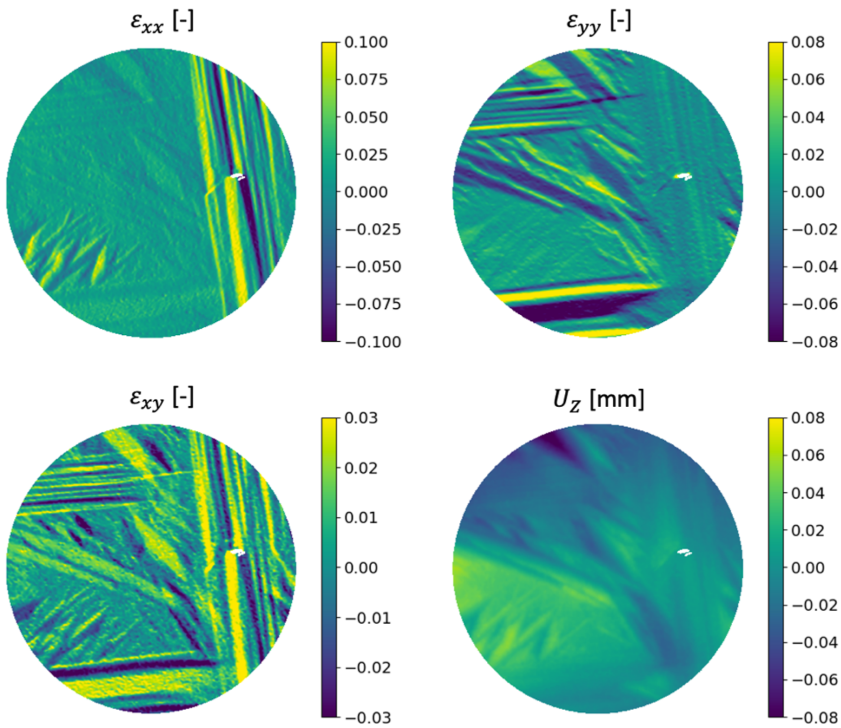

Fig. 2 – Strain maps and out-of-plane displacement map obtained on the SMA at the end of the test.

Conclusion

This work proposes an extension of LSA to 3D. It follows the same strategy as that routinely used for stereo-correlation: calibration grids are employed to calibrate the optical system, and the 3D reconstruction of the surface is derived from 2D-LSA analyses, using an image from one camera as the reference. To address the apparent rotations induced by the different observation angles of each camera, the equations of LSA were slightly modified. This new formulation accounts for global rotations between two images and permits LSA to be performed between images captured from different observation angles, though it does not handle highly localised rotations. Overcoming this limitation is one of the future objectives of this study.

The method was subsequently validated through three application cases. In the first case, it was assessed using a fully synthetic scenario. The second test compared standard stereo-DIC and stereo-LSA, evaluating the method for large out-of-plane displacements. Ultimately, both methods yielded similar results, with differences remaining on the order of the noise magnitude. The third test case focused on the phase transformation of an SMA, which displays higher strain gradients and lower out-of-plane displacements. The results from this latter case were validated using an optical profilometer. Finally, it is worth noting that an article on this work is currently under review [4].

References

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