Structured-Light Based 3D-DIC Measurement

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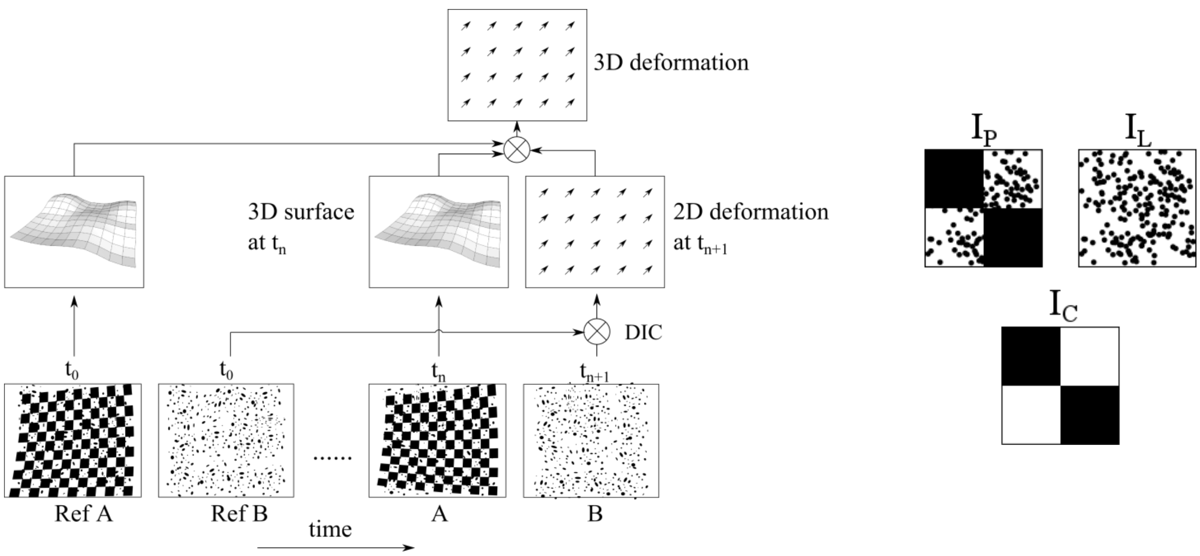
Abstract. In this work, a novel approach for three-dimensional deformation measurement is proposed. In contrast to conventional dual camera 3D digital image correlation (DIC) systems the information about the out-of-plane displacement is determined by the projection of structured light. A fixed pattern LED projector illuminates the surface of the observed object with structured light, alternating with a full-field illumination. By detection and triangulation of the projected structure in the images, it is possible to reconstruct the surface shape of the object. The camera recording with the intrinsic surface speckle pattern is used as input for a conventional 2D-DIC algorithm, which provides information about the 2D displacement. The combination of 3D-shape and 2D-displacement determines the 3D deformation field as in standard dual-camera 3D-DIC. Out-of-plane rigid body translations are recorded to compare the accuracy of standard stereo imaging, checkerboard pattern, and stripe projection.

Introduction

Conventional 3D DIC systems typically use two or more cameras to obtain the out-of-plane displacement via stereo triangulation. Alternatively, one camera can be used in conjunction with a geometric pattern projection to measure 3D deformation. The camera-projector approach may help to reduce overall system costs, especially for high-speed DIC applications. Another benefit of such a system is the ability to measure surface shape without the need for surface speckle pattern. Previously proposed approaches utilize the projection of sinusoidal [1-2] or colour coded [3] fringes. We recently introduced an integrated system consisting of a single camera, a LED projector and a white LED for full illumination. The projector has a fixed pattern, which is either a regular 81 x 81 checkerboard structure or an irregular set of vertical stripes (Fig. 2).

Implementation

The procedure to measure 3D deformation of a specimen is shown in Figure 1a). First, two reference images are acquired at the beginning of the experiment (t_0). One image (Ref *A*) shows the specimen with the checkerboard pattern projected onto the surface, while the other image (Ref *B*) displays the sample uniformly illuminated and serves as reference input for a standard 2D DIC algorithm. By detecting the positions of the corners of the checkerboard projection in Ref *A* with sub-pixel accuracy, the 3D coordinates of the sample surface are triangulated.



a) b)

Fig. 1 a) Recording with alternating illumination; b) Sketch for the correction of pattern and speckle shift between A and B images.

During the experiment the camera takes images with alternating illumination: images with pattern projection (*A*) and images with full illumination (*B*). The *A* images are used to calculate the surface shape at the time t_n. The *B* images are processed by a standard 2D DIC algorithm and provide the in-plane deformation at time t_{n+1}. To accurately correct these deformations with the out-of-plane displacements given by the surface acquired in (*A*), the shifts between t_n and t_{n+1} must be determined. This is done by comparing the pattern image I_P, shown in Figure 1b), with the product of the full illumination speckle image I_L and an artificial projection pattern I_C.

$$0 = \left| I_P(x_P - dx_P, y_P - dy_P) - \left(I_C \cdot I_L(x_L - dx_L, y_L - dy_L) \right) \right| \quad (1)$$

Solving Equation 1 allows determination of pattern position as well as the shift between I_P and I_L with sub-pixel accuracy, thus enabling correction of the 2D DIC result with the surface out-of-plane displacements at time t_n. For a checkerboard projection, it has been demonstrated that the so obtained 3D surface deformation agrees reasonably well with results from the standard stereoscopic approach. However, due to the regularity of the checkerboard pattern, detection of a special marker is required for unique indexing. If this marker is distorted beyond recognition by strong surface curvature, or falls onto a hole in the sample, a unique relation between world coordinates and the checkerboard pattern cannot be established. Therefore, we have recently implemented an irregular pattern of horizontal stripes with different thickness. Six stripes form a unique code-word, thus allowing a more robust indexing of the projected pattern.

Results and Conclusion

Results are presented, comparing the accuracy of the projector-camera system to standard dual camera 3D-DIC. The experiment conducted was an out-of-plane rigid body translation of a speckled plate by 1 mm. Figure 2 shows the E_{xx} strain map obtained by dual camera (d), checkerboard projection (e), and stripe projection (f). The standard deviations are 130 µS for the classic dual camera setup, 184 µS for checkerboard projection, and 235 µS for the stripes.

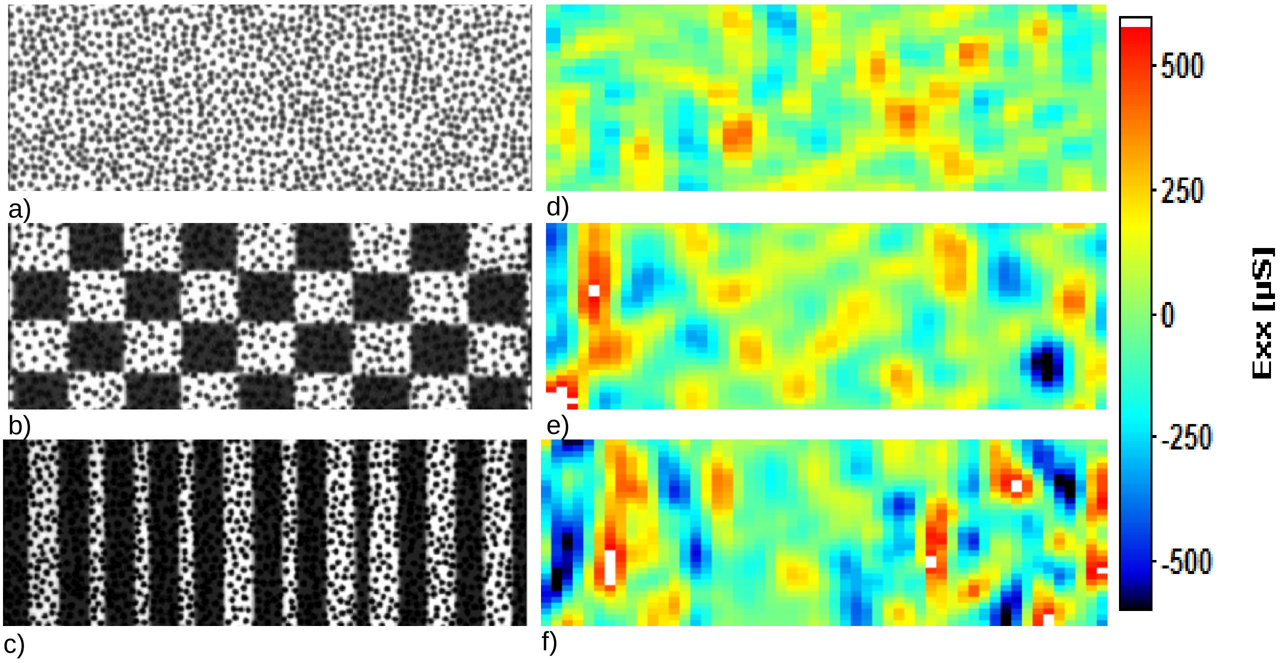


Fig. 2 a) Pure speckle image; b) Speckle with checkerboard projection; c) Speckle with irregular vertical stripes; E_{xx} strain maps for d) dual camera, e) checkerboard projection, and f) stripes.

Overall, the projector-camera system shows good agreement with standard dual-camera DIC. The new approach offers a good alternative, in particular for high-speed DIC applications requiring expensive high-speed cameras, thereby making the test method more accessible. Further validations will be presented in the talk.

References

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