Contactless and Fullfield 3D-Deformation Measurement for Impact and Crash Tests

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1 Introduction

The demand for accurate, time-resolved full-field deformation measurements has led to the development of new techniques for optical deformation measurement technology. These techniques are ideally suited for FEM model verification and for the determination of material characteristics under quasi-static or dynamic loading conditions. In this article, we introduce an accurate non-contacting full-field measurement technology applicable to three-dimensional measurement problems. This measurement technique is based on digital image correlation with a stereoscopic camera setup. The usage of latest high speed cameras allows now measurements of impact and crash tests with an accuracy and resolution, that is comparable to static tests. These accurate measurements allow further improvement of passive safety through optimization of the deformations of components or the complete car body in the event of a crash. These cost-effective optimizations are becoming more and more important as new materials and joining methods are being introduced into the automotive manufacturing industry.

2 Digital Image Correlation

The digital image correlation technique was originally introduced in the early '80s by researchers from the University of South Carolina [1]. The idea behind the method is to infer the displacement of the material under test by tracking the deformation of a random speckle pattern applied to the component's surface in digital images acquired during the loading. Mathematically, this is accomplished by finding the region in a deformed image that maximizes the normalized cross-correlation score with regard to a small subset of the image taken while no load was applied. By repeating this process for a large number of subsets, full-field deformation data can be obtained.

More recently, the DIC method has been extended to use multiple cameras, permitting the measurement of three-dimensional shape as well as the measurement of the three-dimensional deformation [2]. The three-dimensional technique requires the use of at least two synchronized cameras acquiring images of the loaded specimen from different viewing angles. By determining corresponding image locations across views from the different cameras and tracking the movement throughout the loading cycle, the shape and deformation can be reconstructed based on a simple camera calibration.

2.1 Measurement Setup

The experimental setup for the DIC method is comparatively simple and illustrated in Figure 1. For test conditions where the specimen is either non-planar, or the deformation is not pre-dominantly in-plane, the specimen shape and deformation can be measured using a two-camera setup. The two cameras are mounted on a rigid bar to avoid relative motion of the cameras.

Figure 1: Setup for 2D and 3D-deformation measurement.

The DIC method does not require the use of lasers and the specimen can be illuminated by means of a white-light source. However, the specimen surface must have a fairly uniform random pattern, which can either be naturally occurring or applied to the specimen before the test. Among the many methods for pattern application are self-adhesive, pre-printed patterns, stamps and application of paint speckles with air-brushes, spray cans or brushes.

2.2 Image Analysis

Though a large variety of DIC algorithms have been developed over the years [1,3,4,5,6], one particular method has established itself as the preferred method for deformation analysis due to it's capability to measure arbitrarily large rotations and strains in excess of 500%, as well as it's superior accuracy and efficient implementation. This algorithm [3,4] is based on an iterative solution process for finding the maximum of the cross-correlation coefficient in an n-dimensional parameter space. The parameter space is spanned by the parameters of a mapping function that transforms coordinates from the original image frame to coordinates in the deformed image and typically includes the mean displacement in the horizontal and vertical directions as well as the four gradients of the displacements with respect to the coordinate axes. Using this parametrization, an originally square neighbourhood in the undeformed image can be mapped to a sheared, strained and rotated subset in a deformed image. This is illustrated in Figure 2. As the deformed coordinates will not fall onto the sampling grid of the image, accurate gray-value interpolation techniques are required to achieve optimal sub-pixel accuracy without bias [4].

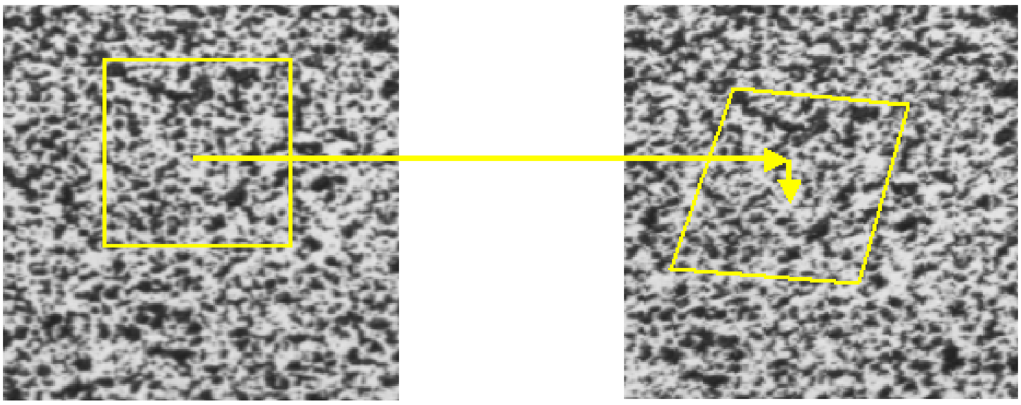


Figure 2: Undeformed and deformed image with subset. The mapping function permits the matching of square areas from the undeformed image to non-square areas in the deformed image.

For three-dimensional shape measurements, a similar algorithm is used. However, the mapping function is now based on the known calibration parameters of the cameras, and the sought parameters are the location and orientation of a segment of the surface assumed to be locally planar. For deformation measurements, additional parameters describing the orientation and position of the surface segment after deformation as well as parameters describing higher-order deformation terms are added to the mapping functions. This process can be interpreted as a projection/back projection approach, as illustrated in Figure 3.

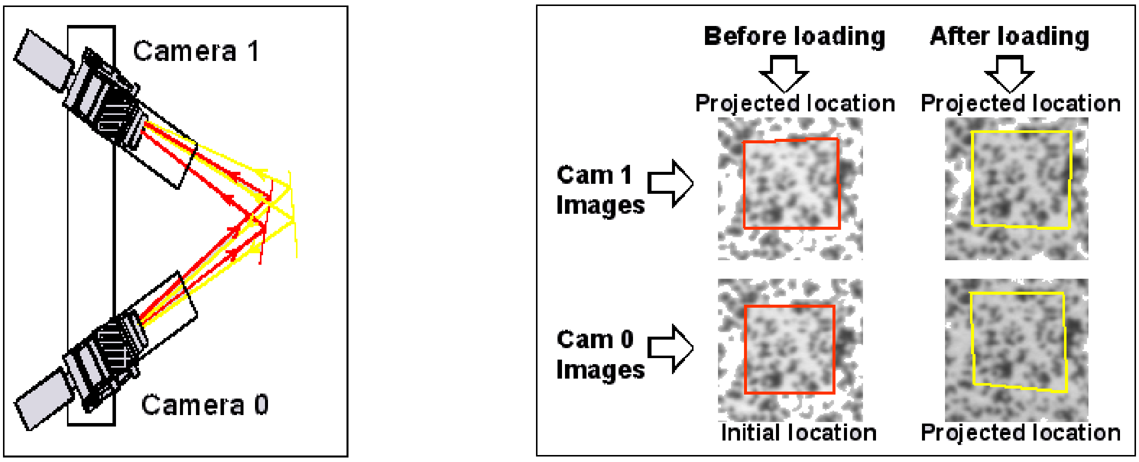
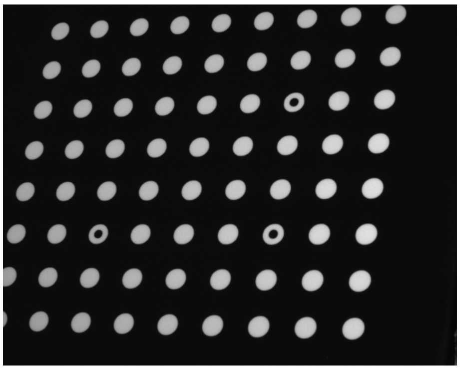


Figure 3: 3D measurement principle. Usage of projection and back projection method to determine the position and displacement of small segments of the surface.

2.3 Calibration

As opposed to two-dimensional systems, where camera calibration is simply the determination of a scale factor, three-dimensional systems have to be calibrated. Commonly, a pin-hole camera model with Seidel lens distortions is used. The calibration process involves the acquisition of a series of images of a calibration target in different orientations (rotations around all three axes). Two example images are shown in Figure 7. From the images of the calibration target, calibration parameters for the two cameras as well as their relative orientation can be determined fully-automatically [8]. Once the system is calibrated, images of the specimen undergoing deformation are acquired.



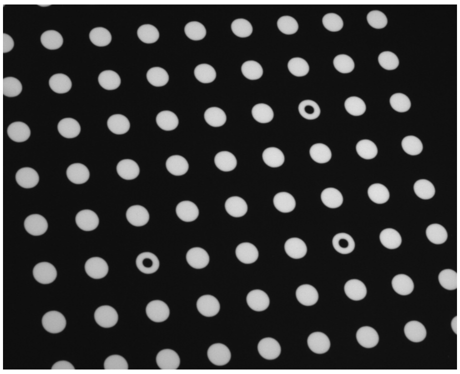
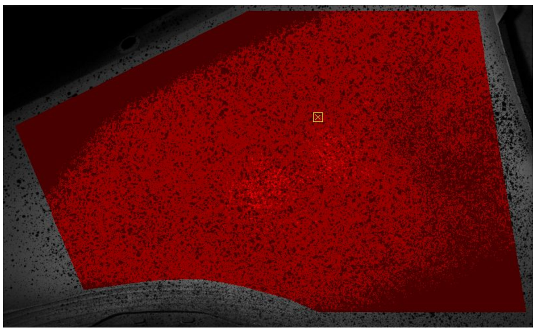


Figure 4: Example images of the calibration pattern taken from camera 1 and camera 2.

3 Example

Impact tests on car body parts are used for FEM model verification. A test with a dummy simulates e.g. the impact of a pedestrian on a car engine hood. The car hoods contour change can be measured time-resolved and the derived out-of-plane displacement gives e.g. information about the application of energy in the dummy head. Additionally the maximum deflection of the hood shows, if there is enough energy absorbing space between hood and engine.

In the following the measurement of an impact (hammer with 9.1m/s velocity) to the outside of a mudguard is described. Figure 5 shows the left and right image of the inner side of the mudguard with applied speckle pattern. The imaging area is about 700mm width. Figure 6 shows the object contour, that is measured from the two speckle images. Figure 7 shows a grey scaled time series of the out-of-plane-displacement.



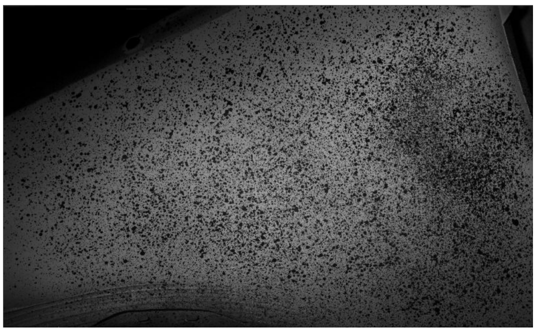


Figure 5: Left and right speckle pattern image of the inner side of the mudguard. The left image shows the analysed region (dark ROI) and the impact location as bright rectangle.

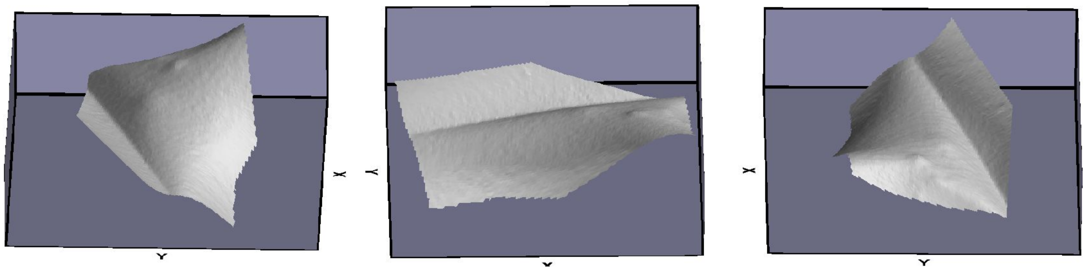


Figure 6: Measured mudguard contour: left, center and right view. Two previous impacts lead to plastic deformation of the part.

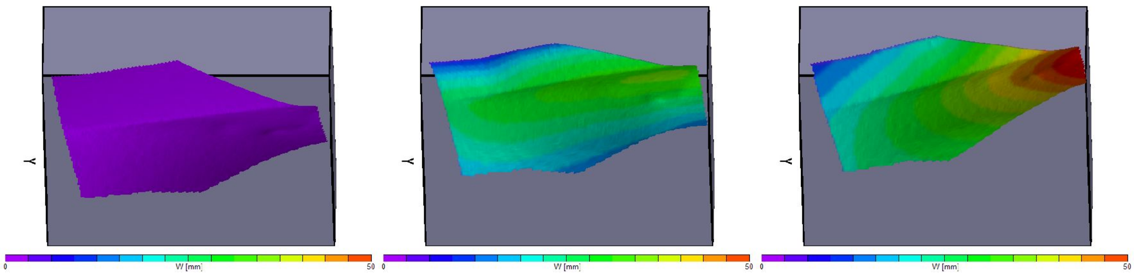


Figure 7: Grey scaled (0...50mm) out-of-plane-displacement *w* during impact for times t0=0ms, t1=7.5ms, t2=15ms. The time resolution of the measurement was 0.25ms.

From the displacement map the local velocities and accelerations can be calculated. Figure 7 shows the values for the impact position.

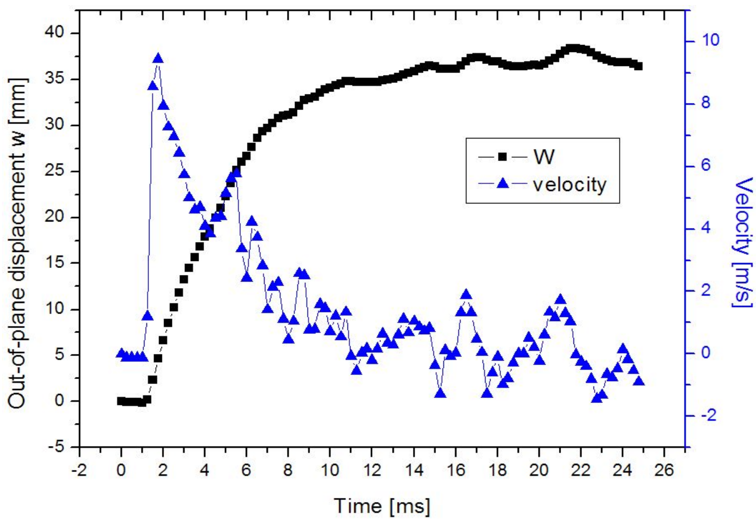


Figure 7: Out-of-plane displacement *w* and velocity at the impact location. The weak fixing of the part leads to a rigid-body-movement and therefore the locally measured displacement is not elastic.

The maximum velocity is located at the impact position and measured with 9.45m/s. The non-elastic material of the hammer leads to a very high acceleration of 29.4×10^3 m/s² at the impact position.

4 Summary and Conclusion

In this paper, we have provided an overview of an accurate technology to measure non-contact and full-field displacement, deformations and strains. The simple and robust setup is well-suited to both laboratory and field conditions and minimal specimen preparation is required. In combination with high speed cameras this technology can be easily used for highly dynamic impact and crash tests.

The key points of the technology and analysis software are:

- Curved or planar objects from 5mm to several meter in size
- Accuracy unaffected by large in-plane rotations or translations
- Includes effects of perspective in image analysis
- Cameras can be calibrated and moved to test site
- Accuracy up to +/-0.01 pixels in displacement (e.g. 0.01mm at 1000mm measurement field with mega pixel camera)
- Accuracy > 200 microstrain
- Strain levels in excess of 100% have been successfully measured
- Complex loading (combined tension/torsion, compression, pressurization etc.)
- Quasi-static to ultra-high speed events.

5 References

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