Basics of 3D Digital Image Correlation

Introduction

Image Correlation techniques has proven to be a flexible and useful tool for deformation analysis. With the use of two cameras, even three-dimensional can be carried out. The principle of this technique is quite easy to understand and opens a nearly unlimited, range of applications.

For 3-dimensional measurement, two cameras are used. If the object is observed by two cameras from different directions, the position of each object point is focused on a specific pixel in the camera plane. If the positions of the two cameras relatively to each other, the magnifications of the lenses and all imaging parameters are known, the absolute 3-dimensional coordinates of any surface point in space can be calculated, (fig. 1). If this calculation is done for every point of the object surface, the 3D surface contour of the object can be determined in all areas, which are observed by both cameras. However, it is important, that the object surface shows enough structure to allow the algorithms to correlate identical points from both cameras.

3D correlation system.

Principle of Digital 3D Correlation

In classical image correlation the deformation of an object is determined by observation with a CCD camera. Then a digital image correlation process determines the shift and/or rotation and distortion of little facet elements determined in the reference image. Such correlation algorithms can determine the maximum of the displacement with an accuracy of up to 1/100 pixel. This procedure allows the determination of the object deformation in a plane parallel to the image plane of the camera.

The correlation algorithm based on the tracking of grey value pattern in small local neighborhoods. Is $G(x, y)$ the grey value of a pixel with the coordinate x and y inside of the subset or facet the correlation algorithm minimized the sum:

$$\sum_{x,y}\left(G_t(x_t, y_t) - G(x, y)\right)^2$$

where $G_t(x_t, y_t) = g_0 + g_1 G(x_t, y_t)$ and

$$x_1 = a_0 + a_1 x + a_2 y + a_3 xy$$

$$y_1 = a_4 + a_5 x + a_6 y + a_7 xy$$

By the variation of the illumination parameters (g_0, g_1) and the parameters of the affine transformation ($a_o ... a_7$) an accuracy for the matching of better than 0.01 pixel can be achieved.

Once the 3D contour has been determined, the second step in digital 3D correlation is the measurement and determination of the three-dimensional deformation of the object surface. This process is carried out by correlation of the images, taken by both cameras with their original reference images.

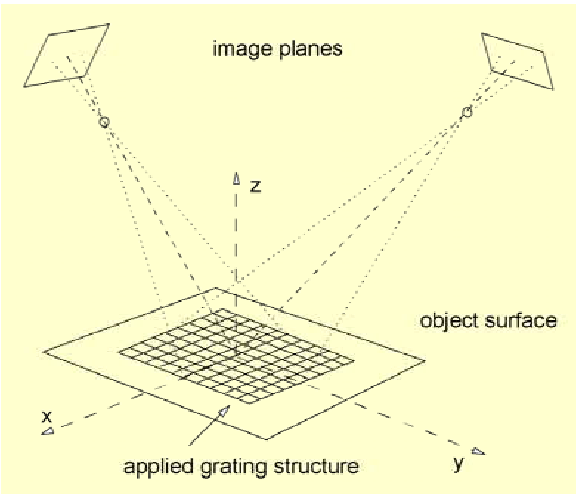

Fig. 1: Principle of 3D image correlation with 2 cameras

In fig. 2, the displacement vector of a surface element is shown. The center point P has been displaced from the reference state u to the deformed state v. Additionally, the surface element has been rotated, tilted and distorted.

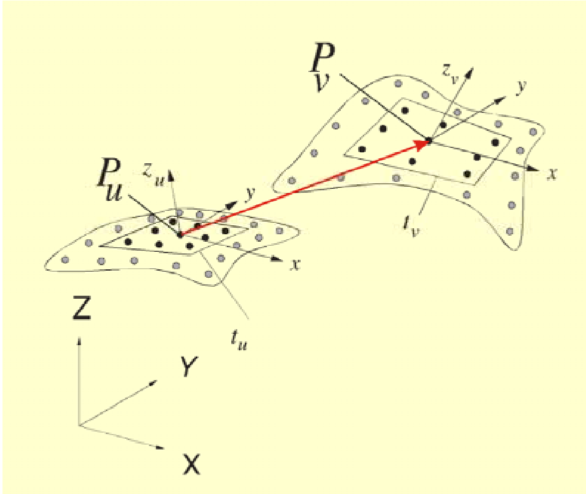

Fig. 2: Determination of the three-dimensional displacement vector

With the known displacement vectors of each surface point and the reference contour, the strains can be calculated. They can be derived either directly by the differentiation of the displacements of adjacent surface points or by the analysis of the distortion of each local facet, which has been used for correlation.

Calibration Procedure

However, in the practical application of 3D image correlation techniques some basic conditions have to be observed. As example, the calibration of the cameras has essential influence on the performance of the complete system. Therefore, in order to make a useful measuring instrument, the calibration procedure must be integrated into the complete system design and must be as simple as possible.

The following parameters have to be determined:

1. Intrinsic parameters, such as focal length of the lenses, principle point of the lenses, radial distortions of the lenses, tangential distortions of the lenses
2. Extrinsic parameters, such as translation vector, rotation matrix

In a first step, the intrinsic parameters are determined. A test plate, fig. 3, is manually moved in front of the camera. The camera records different positions of the test plate, which give sufficient data for the complete calibration procedure. The software online registers the nodal points of the test blade and automatically captures the different images. Image acquisition takes just some seconds and after some more seconds the calibration of the intrinsic parameters is finished.

The main parameters such as focal length and principal point are displayed on the monitor for control by the operator. Additionally, the maximum error is displayed.

For calibration of the extrinsic parameters the test plate is positioned in front of both cameras, simultaneously. The software is then able to calculate all extrinsic parameters just from this single image.

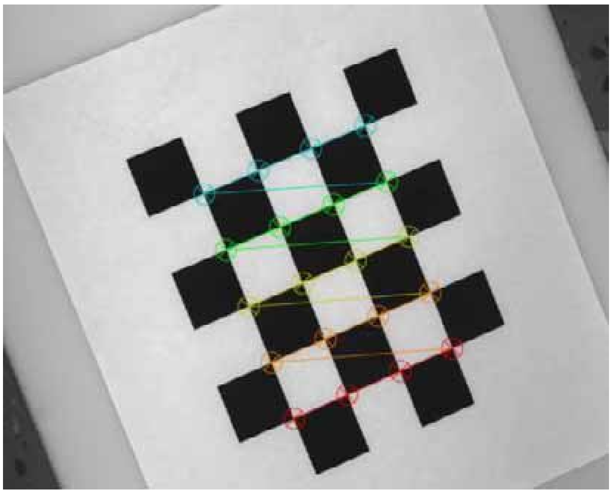

Fig. 3: Calibration plate with determined nodal points

A joint development project between Technical University Braunschweig, Institute for Production Metrology – a leading institute in image correlation techniques and Dantec Dynamics GmbH led to a new Digital 3D Correlation system, which offers some significant improvements of the technique.

Application

For the characterization of material parameters far into the range of plastic deformation the correlation technique is a powerful tool. As an example for the application of this technique in factual mechanics, the following series of images shows the result of a fracture mechanics test, carried out at University of the Army, Munich.

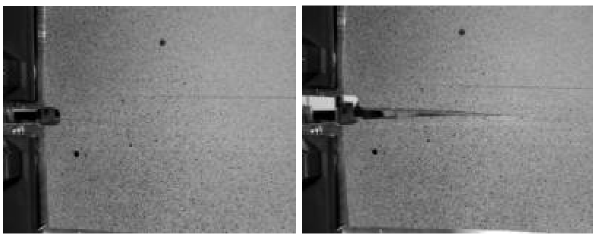

Fig. 4: *Live images from the test*

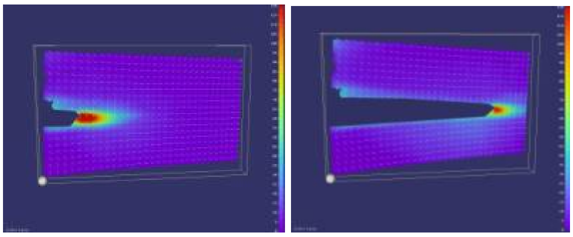

Fig. 5: Fracture test of an aluminum plate with Digital 3D Correlation; top: live images, bottom: calculated principal strains

The specimen was loaded with a hydraulic cylinder and observed with a Digital 3D Correlation system with two cameras (res. 1300 x 1024 px) at a frame rate of approx. 16 Hz. Fig. 4 shows an extract of the recorded images and the calculated strain fields of this measurement series is shown in Fig. 5.

The data analysis tools allow the determination of the location and amplitude of maximum strain. Fig. 3 shows the live image of standard test sample, the full field information of the principal strain 1 and the maximum value of the principal strain as a function of the elongation of the tensile test machine.

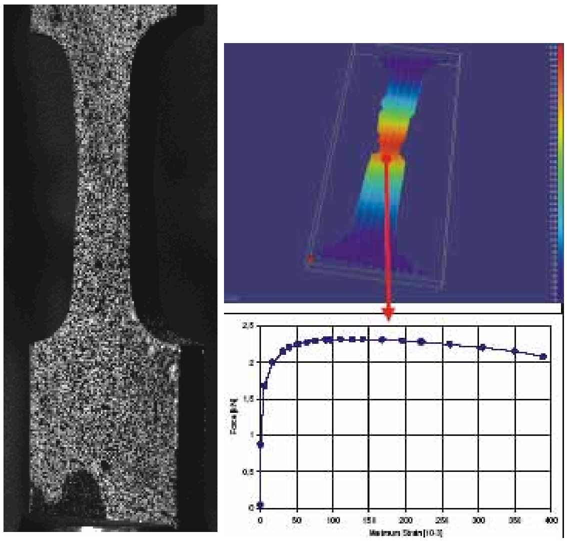

Fig. 3: *Live image, full filed display of the principal strain 1 and the maximum of the principal strain 1 over the elongation*

Summary

The development of new digital 3D correlation algorithms has significantly enhanced this technique and especially improved the calibration and handling of the system. First measurements show the high potential for fracture mechanics, material testing, and component investigation applications.

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