

PHOTOGRAMMETRIC 3-D DIGITIZING FOR DEFORMATION ANALYSIS – NEW DEVELOPMENTS AND APPLICATIONS

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Abstract: Close-range photogrammetry is a useful tool for precise and reliable measurement of objects and object changes. Several photogrammetric 3-D metrology systems using off-the-shelf CCD and CMOS cameras are available. Advanced data processing tools have been developed, namely automated image measurement and very fast and robust software for 3-D object restitution. In the paper, the state-of-the-art of photogrammetric measurement systems is illustrated by some application examples with regard to deformation analysis.

1. Introduction

Optical 3-D measurement systems based on photogrammetric methods are increasingly and successfully applied to the digitization of the actual state of objects. Object movements and deformations can be derived from the differences of repeatedly measured point fields. For quite some time, digital image acquisition devices and digital data processing have been almost exclusively used in order to photogrammetrically capture and document an object. Flexible and automated user-friendly 3-D measurement systems guarantee the fast, precise and reliable object reconstruction.

In this paper, some remarks on photogrammetric systems are complemented by the presentation of application examples with reference to deformation analysis:

- First, a digital metric camera was used for deformation measurement of parts of an aircraft wing recorded at various 3-D positions and under different load conditions. The results served as experimental verification of finite element simulations.
- The second application describes deformation analyses for a structural test of a helicopter. Different load cases have to be analysed to verify the capabilities of the structural design. Therefore the helicopter is mounted into a jig and different loads are applied by hydraulic stamps. The movement of the structure leads to deformations which can be tracked by means of photogrammetry.
- The third example deals with strain analyses for sheet metal forming. During set up of stamping tools the strains and thickness of the sheet metal have to be analysed to avoid wrinkles or cracks. Therefore a known reference grid pattern is etched onto the sheet metal before stamping. After the stamping process the deformed grid is measured by means of photogrammetry and the deviations from the known reference grid allow the calculation of the strain parameters.

2. Photogrammetric Measurement Systems

Basically, photogrammetry [1] is a measuring method to virtually reconstruct object surfaces by optical triangulation using two or more images taken from different exposure stations. Object details are measured in the images. Hereby, the centres of markers attached to the object can be determined automatically with subpixel accuracy by digital image processing methods. The 2-D coordinates of the image points are then combined by bundle triangulation resulting in 3-D coordinates and image orientations in object space. Depending on the required accuracy of the object reconstruction, the cameras used can or must be calibrated simultaneously with the adjustment process.

A lot of CCD and CMOS cameras are available on the market at reasonable cost. Consumer-type cameras provide ever increasing resolution, digital SLR cameras are becoming less expensive. But these cameras have been designed for the mass market, not with regard to photogrammetric demands. They may be influenced by imperfections of the sensor and instabilities of the camera itself (lack of mechanical robustness, automatic focusing, zoom lenses, interchangeable lenses, etc.). Test measurements are necessary to check the photogrammetric suitability of such cameras. In Germany, a test procedure for image-based 3-D measuring systems has been developed, the VDI/VDE guideline 2634 (Part 1: "Optical 3-D measuring systems - Imaging systems with point-by-point probing"). Following this guideline, the system performance is evaluated by determining the 3-D coordinates of targets attached to several measuring lines of a spatial testfield. Distances between the targets are calculated and compared with their calibrated values in order to define the maximum length measurement error which is characteristic for the photogrammetric quality of both the camera used and the measurement system [2].

Target measurement and bundle adjustment can be performed automatically, very fast and robust by an up-to-date 3-D measuring system [4]. The software generates the automatic measurement process if a number of coded targets can be recognized. This enables the automatic matching also for non coded targets. Recently, "natural" features such as contour lines, boreholes, etc. can be detected and observed too.

In addition, the combination of photogrammetric methods with other (optical) measurement techniques, e.g. laser tracking, laser scanning, fringe projection systems, proves to be an advantage.

3. Application Examples

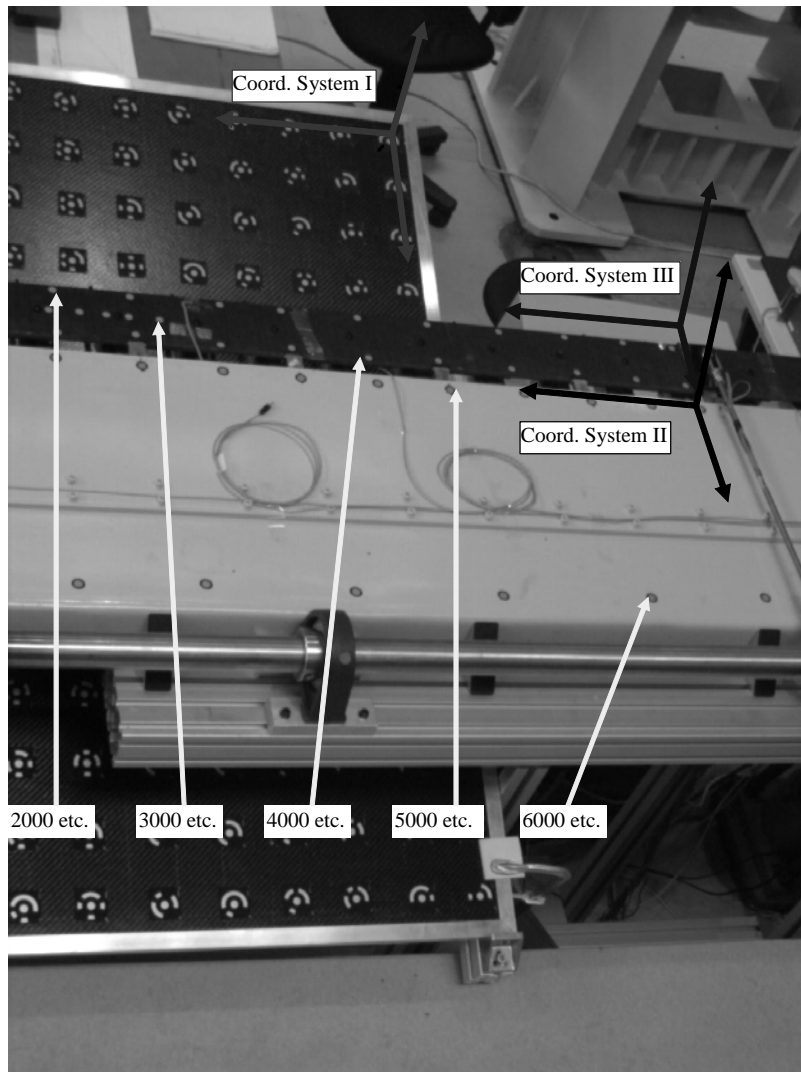
3.1. Deformation Measurement of an Aircraft Wing

Some parts of an aircraft wing are to be investigated, i.e. deformations of these parts caused by different load conditions at different positions in object space are to be detected and determined. The results of the photogrammetric measurement are used to experimentally verify numerical simulations performed with the finite element method [3].

Fig. 1 shows the laboratory test set-up:

- the pre-stressed cantilever (stands for the wing) and the approx. 10 cm wide trailing edge attached to the wing, both marked with retroreflective circular targets,
- two calibrated scale bars and a reference plate with a lot of coded targets defining a stable coordinate system during the deformation measurement.

Figure 1: Test set-up for deformation measurement



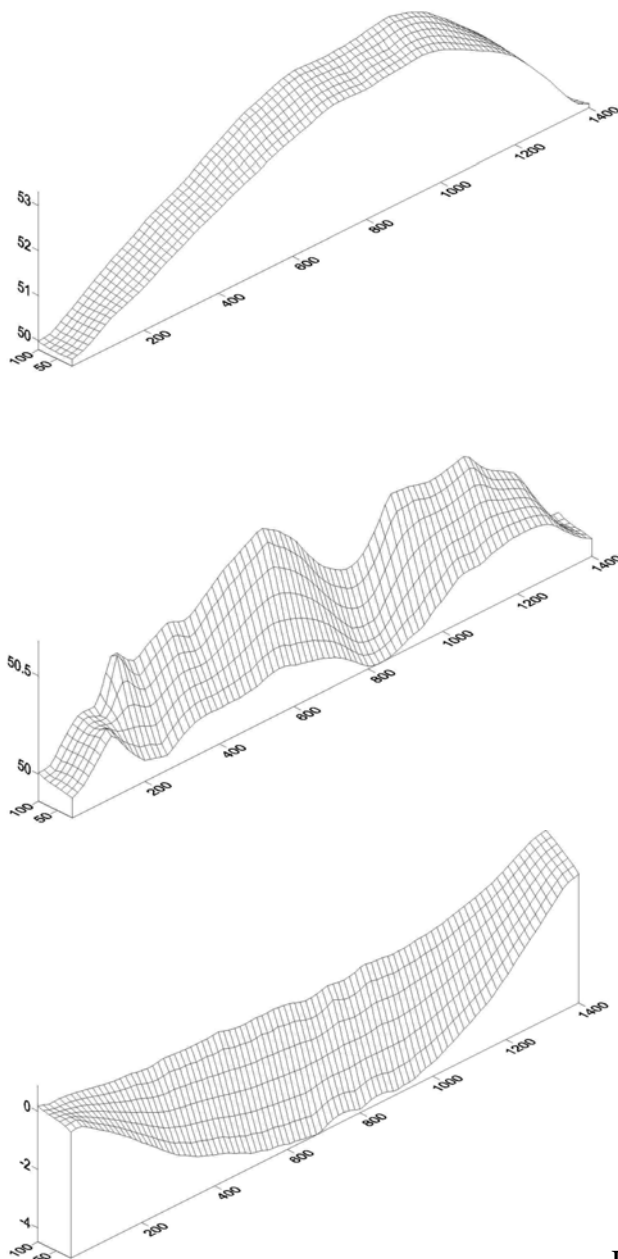
A Rollei d7metric⁵ digital camera is applied to capture a series of image sets, each representing an actual state of the object. The 5 megapixel SLR camera (2/3" CCD chip, 2552 x 1920 pixel, 7 mm wide angle lens) provides high stability of the interior geometry due to its metric characteristics (fixfocus, no zoom, rigid connection between lens and CCD sensor; [3]).

More than 30 test measurements with the differently pre-stressed cantilever and various positions/rotations of the trailing edge have been photographed. The images cover 1400 x 1200 x 400 mm³ of the object. The imaged targets are automatically detected and measured

with the AICON DPA-Pro software [4]. After the bundle adjustment, the standard deviations of the object coordinates (RMS) amount to $s_x = 0.015$ mm, $s_y = 0.017$ mm, $s_z = 0.030$ mm.

Based on the photogrammetric results, deformations are calculated by 3-D similarity transformations between two epochs, in each case. Figs. 2-4 show deformations as Z-coordinates for different object states: the trailing edge at the beginning of the test series, then with differently pre-stressed cantilever, finally its deformed shape after a 45° rotation against the starting position.

Basically, it can be stated that the deformations obtained by photogrammetry establish a satisfying correspondence with the results of the finite element simulations.



Figures 2-4: Deformations of the trailing edge

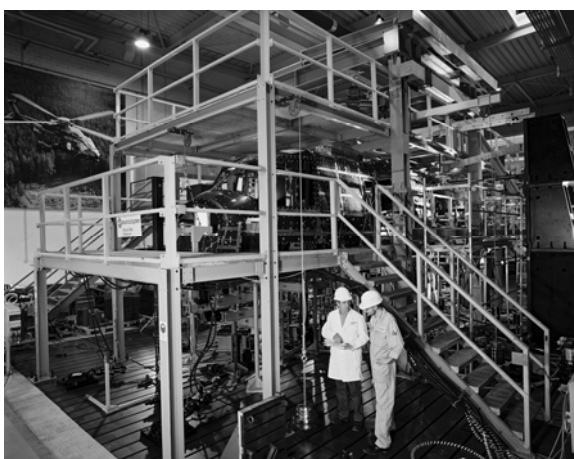
3.2. Fatigue Test of the Helicopter NH90

Before a helicopter or aircraft receives its final approval for flying, several investigations including life-time and fatigue tests have to be performed. This example shows the structural test of the Helicopter NH90 designed and manufactured by Eurocopter. The dimensions of the helicopter are: 13.8 m in length, 3.8 m in width and 4.2 m high (Fig. 5).



Figure 5: NH90 Helicopter

For the fatigue test the NH90 is mounted in a jig equipped with hydraulic cylinders at the rotor blade root and the chassis (Figs. 6 and 7). The hydraulic cylinders induce forces into the structure as resulting from take off and landing. Take off is simulated by pulling the rotor blade root upwards, landing is simulated by pushing the chassis upwards with a force equal to the helicopter's weight.



Figures 6 and 7: NH90 mounted in a jig

The deformation of the helicopter's structure is to be measured by photogrammetry [5]. To reduce the amount of work only one half of the NH90 is surveyed, assuming that the behaviour of the other half is correspondent. The helicopter is signalised with approx. 5.200 retroreflective targets and 8 scale bars are equally distributed along the object.

The 350 photogrammetric images have been taken with a 6 megapixel camera. As the helicopter is partly covered by jigs and fixtures, a large number of images is necessary to assure a full coverage of the helicopter's surface and to provide sufficient number of rays for each point. The images are processed quickly with AICON's automatic photogrammetry software DPA-Pro. The achieved average object coordinate accuracy (RMS) is +/- 0.2 mm.

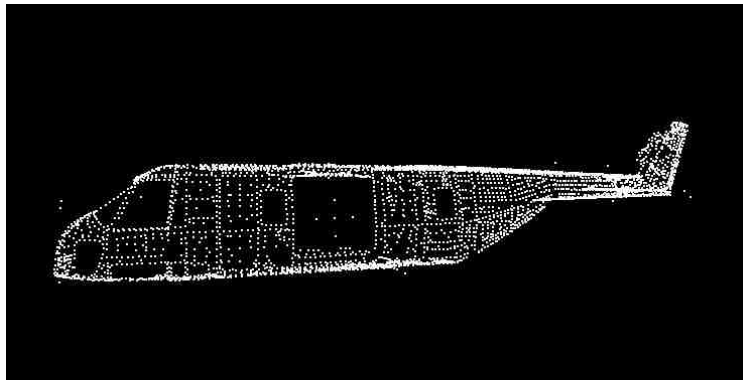


Figure 8: Resulting point cloud

Different load steps have been simulated during the structural test and compared using the AICON 3D Studio Software. The software automatically references to pre-selected undeformed points and calculates the deformations at the remaining points. The results can be presented as point cloud (Fig. 8), point cloud with deformation vectors (Fig. 9) and as graphic image overlay. The graphic image overlay allows the display of the deformation vectors in any image to simplify the localisation and interpretation of a deformation relative to the structure.

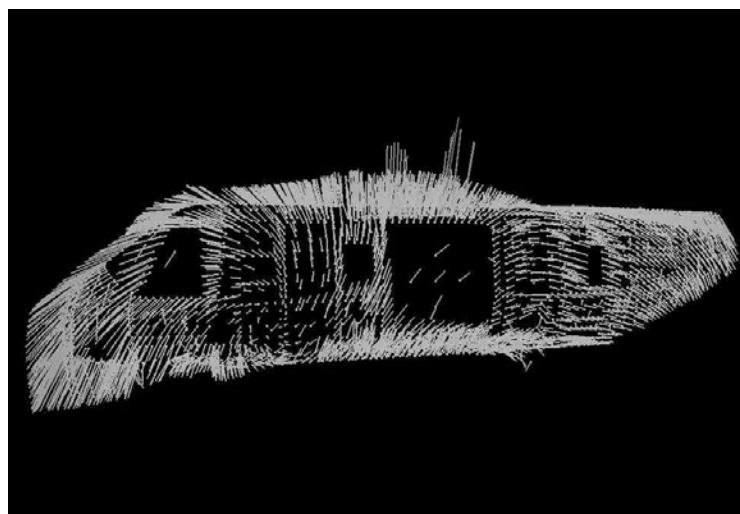


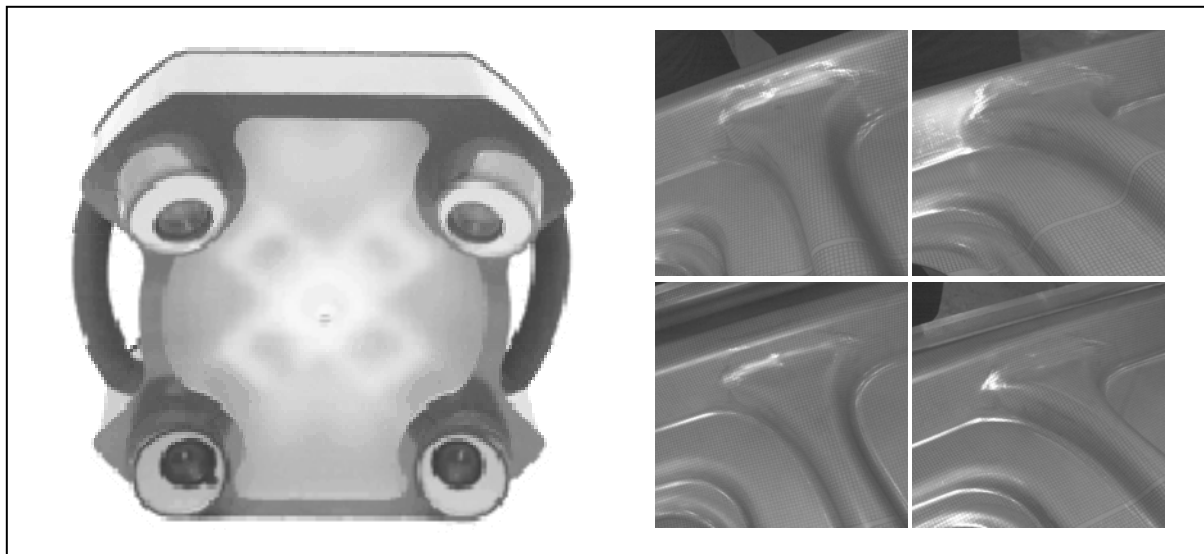
Figure 9: Deformation vectors at the NH90

Photogrammetry has been proven to be the preferable tool for this task because of the flexibility in the narrow environment and the capability to measure a very high number of points in a very short recording and processing time.

3.3. Strain Analyses for Sheet Metal Forming

Sheet metal forming is a major tool in many modern production processes. Flat sheets of metal are clamped around the edge and formed into a cavity by a punch. The metal is stretched by membrane forces so that it conforms to the shape of the tools [6]. For an efficient use of the material it is necessary to set up a robust stamping process in which necking and wrinkling or even the appearance of cracks is avoided. Therefore the strains and thickness of the sheet metal have to be analysed during the set up of stamping tools as well as for production monitoring and quality assurance throughout the whole process chain.

Different methods for the estimation of strain parameters are available [7]. One of the most sophisticated techniques is based on the use of photogrammetry and the logical application of fundamentals of differential geometry [8, 9]. Before stamping a known reference grid pattern is etched onto the plane sheet metal. After the stamping process the deformed grid is measured by means of photogrammetry. Images are taken with a hand held camera head equipped with four CCD cameras (Fig. 10). The camera head has also an integrated illumination unit to guarantee constant and controlled lighting conditions. The relative orientation of the four cameras is derived by test field calibration beforehand.



Figures 10 and 11: Four camera head of the VIALUX AutoGrid system [10] and images of a deformed sheet metal

The four images taken by the cameras cover the same area of the sheet metal recording the deformed grid (Fig. 11). The image coordinates of the grid points are derived automatically by image processing algorithms and the 3D coordinates are calculated by ray intersection of corresponding grid points.

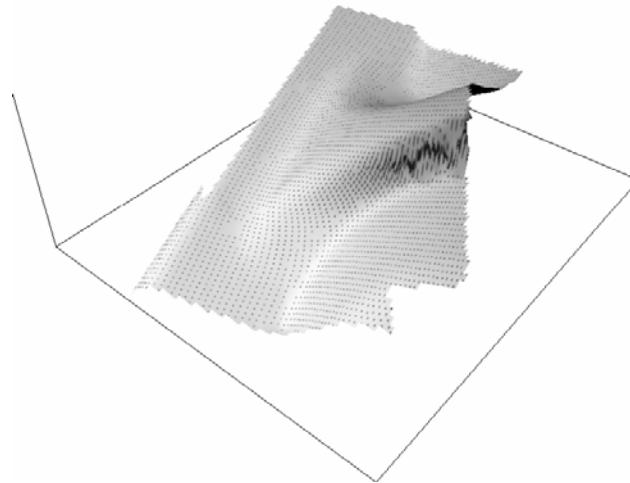


Figure 12: Point cloud of the observed grid points on the deformed surface

The deformation parameters of the sheet metal can be derived by comparing the observed coordinates of the deformed (Fig. 12) with the non-deformed state. Fig. 13 shows the resulting deformation parameters as strains, thickness and thinning for the example. Systems like VIALUX AutoGrid which are based on the described application are proved well suited for a variety of applications in deep drawing and hydroforming as well as for different materials including aluminium alloys, stainless steel and fibre reinforced composites.

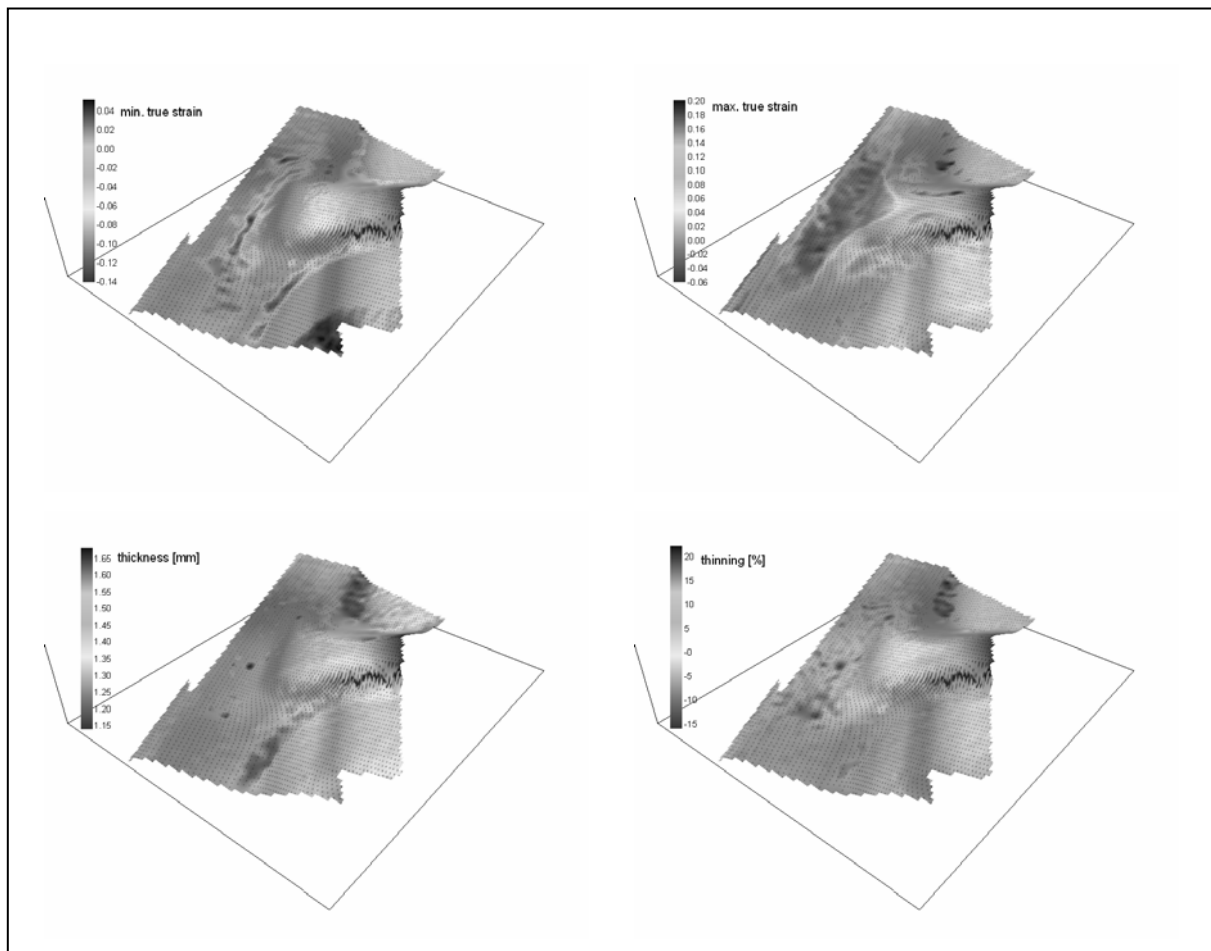


Figure 13: Resulting true strains, thickness and thinning for the example

4. Conclusion

Over the last years, advanced techniques in digital data acquisition and improved data processing tools have led to high acceptance of photogrammetric metrology systems, also for the purpose of deformation measurement. Requests for accuracy, flexibility, automation, speed, robustness and user-friendly handling of these systems can be fulfilled to a large extent.

5. References

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