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

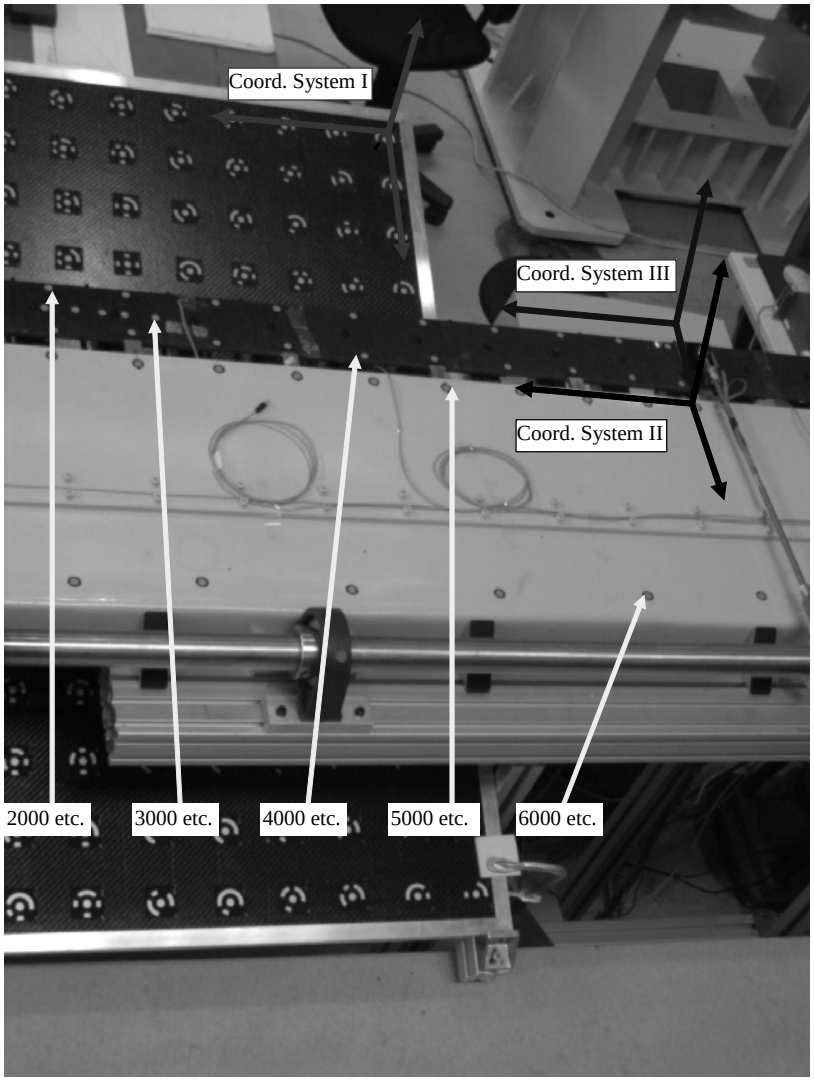
3.1. Deformation Measurement of an Aircraft Wing

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 d7metric[5] 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 mm^3 of the object. The imaged targets are automatically detected and measured