THE OPTICAL TUBE MEASUREMENT SYSTEM OLM
- PHOTOGRAMMETRIC METHODS USED FOR INDUSTRIAL AUTOMATION AND PROCESS CONTROL

Werner Bösemann
AICON-Industrial Photogrammetry and Image Processing
Bültenweg 23
D-38106 Braunschweig
Tel.: ++49 / 531 / 34 45 01
Fax: ++49 / 531 / 34 45 04

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ABSTRACT

Qualitiy control and inspection has become a major tool in industrial production. New measurement systems have to be developed to fulfil these control mechanisms without interfering the production process. Because of the necessity of non interfering systems those have to be contactless. These requirements can be fulfilled by optical measurement systems.
The following paper will show an example of such an optical measurement system for measuring spatially bended tubes.There are numerous tasks to measure tubes for shape control in the industrial process. Tubes with different bends, curves and straight parts have to be compared with CAD data. These tubes could be flexible and therefore difficult to measure mechanically. The main problem is to fix the tubes. Another requirement is a short measurement time for shape control in the production line.
This new measurement system is specially designed for 3-dimensional measurement of tubes. The features of the tube measurement system are: non contact measurement, no elastic deformation of the tubes by the fixture, fast acquisiton tube geometric, flexible fixing unit, short measurement time by using digital image processing, variable measurement volume and high accuracy.

1. INTRODUCTION

The optical tube measurement system OLM is a system, which allows a contactless measurement of spatially bended tubes. Such spatially bended tubes are an important component of different industrial products like brake tubes or gas tubes from automotive or aircraft industry, or hydraulic tubes and refrigerant tubes from mechanic engineering and plant construction.

The OLM is an opto-electronic measurement system based on CCD-cameras, working on principles and algorithms of digital image processing and close range photogrammetry (Schneider, Sinnreich, 1990, 1992). The optical tube measurement system (OLM) is a powerful tool for a fast and precise 3-dimensional reconstruction of tubes of different types and shapes.

It is integrated in the production line via a computer network for online process and quality control.

2. SYSTEM CONFIGURATION

The measurements are performed in a socalled optical measurement cell. Several electronic cameras are mounted to a fixed frame, images from different views of the tube to be measured can be taken. The cameras are connected to a common PC as control unit. The illumination can be chosen either toplight or backlight.

2.1 Optical measurement frame

The mechanical construction consists of a stable ground plate and an aluminium frame which is connected to the ground plate and serves as camera fixture. On the white ground plate circular reference targets are marked in a regular raster. Additional reference marks are positioned on steal bars at the border of the measurement volume. These side points are necessary to perform a precise calibration of the camera configuration. The arrangement of the reference marks and the camera figures are shown in figure 1. Both sides, the back wall and the ceiling of the surface are closed to protect the cell against dirt and interfering external lights.

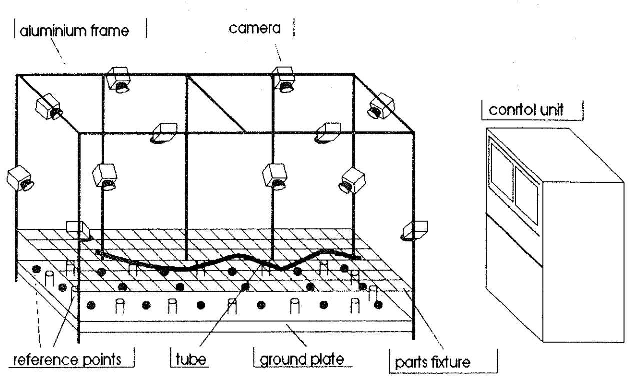

Fig. 1: Optical measurement cell

The illumination of the measurement volume is realised by neon tubes mounted on the ceiling of the measuring cell. For a homogeneous illumination of the measuring volume a milk glass plate is mounted infront of the flourescent tubes. Such a top illumination has the disadvantage that only dark and not specular reflecting tubes can be measured in front of the white ground plate. Metallic surfaces will show disturbing reflections in the tube contour. Optionally a light table can be installed on the ground plate, which enables to measure any kind and material of tube surfaces.

The parts fixture must hold the tube to be measured that way, that a deformation free positioning can be realized. Additionally the fixtures must be designed that way, that the user of the system can easily put different kind of tubes into the system without making any modification or adjustments to the parts fixture. Therefore a net of elastic material was chosen as parts fixture. By a low pre tension of the net, it can be achieved that any point on the net is supported according to the actual weight force of the tube.

2.2 Electronic hardware

The CCD cameras incorporated in the system are of the type JenaCam M-77m (by RJM). Those are monochrome CCD matrix-cameras with a 2/3 inch interline transfer sensor from Sony with 756 x 581 sensorelements and pixelsize of 11 microns. The pixelsynchroneous mode of operation makes this cameratype suitable for an utilisation in measuring systems with highest accuracy requirements (Bösemann 1990). As measurement and system computer a ´486 industrial PC is used, equipped with three frame grabbers of the type BFP-AT/20 (by Leutron). Each of the three frame grabbers is connected to four cameras via an interface board JCI 2/4 (by RJM) which allows a pixel synchroneous read out of the camera images with a resolution of 768 x 512 picture elements. Besides the VGA-monitor for the display of user interface and measurement results the camera images can be displayed on an additional video monitor.

3. SYSTEM CALIBRATION

3.2 Calibration during system setup

During the installation of the system in the production environment the coordinates of the controlpoints on the groundplate have to be determined at a higher level of accuracy. Therefore the controlpoint field was recorded with 26 digital images by a Kodak DCS 460. The images were processed with the digital photogrammetric station DPA-WIN (Peipe, Schneider, Sinnreich 1993).

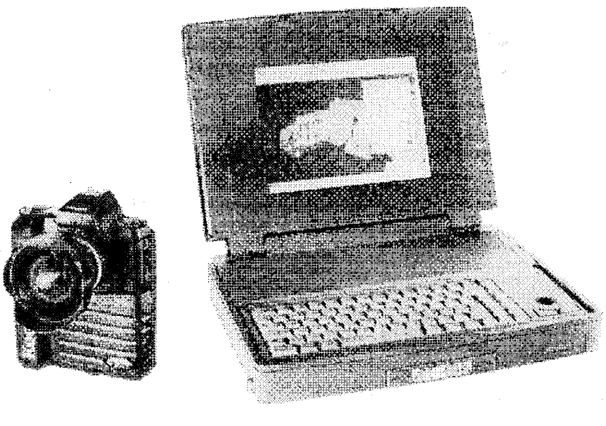

Fig. 2: Digital photogrammetric station DPA-WIN

The image measurement and the bundle triangulation resulted in an image accuracy of 0.23 µm and an object accuracy of 0.02 millimetre in the x- and y-direction and 0.04 millimetre in the z-direction. The results show a discrepancy between the x- and y-directions and the z-directions in the accuracy. This is caused by the very narrow environment due to the sidewalls of the measurement frame. Anyhow the accuracy is ten times higher than the achievable accuracy of the online CCD cameras. The DPA-WIN with the Kodak DCS 460 is also used for periodical on-site calibration of the system which has been performed approximately every twelve month.

3.3 System calibration

For the calibration of the whole system, the reference marks on the ground plate are measured automatically with high precision in the different camera images with methods from digital image processing. The positions and orientations of the cameras can be calculated together with parameters of the imaging optics. This calibration of the camera setup is the basis for the later precise 3-dimensional determination of the shape in a bundle adjustment of the tube.

In the calibration procedure the exterior orientation of each camera has to be estimated with high precision. Therefore the black circular reference marks on the ground plate are automatically measured in each image. The calibration menu give the opportunity to test the calibration and to calculate new calibrations. In the calibration test only the reference marks are measured in the images and the differences to the calibration are displayed. From this information the user can decide whether a new calibration is necessary or not. Calibration test and calibration running completly automatical without any user interaction. Since the measuring and calculation times for a new calibration are short it is recommended to perform a new calibration at least daily.

4. EVALUATION PROCEDURE

The digital images were processed by methods from photogrammetry and image processing which were used to derive threedimensional coordinates of the bend points of the tube. In a second step these threedimensional coordinates were used for a CAD comparison using a socalled optical gauge.

4.1 Measurement principle

Spatially bended tubes can be described in several ways. For the description and the display in CAD systems a tube is reduced to its center line. The tube can be described as a spatial polygon, with the theoretical bending points given by the intersection of two following straight parts and with the start- and endpoints of the tube. From the coordinates of the polygon now the theoretical bending elements can be calculated. This bending elements are the distance of two following theoretical bend points, the angle between two following straight elements and a rotation angle calculated from four following bend points. For the calculation of real bending elements only the length between theoretical bend points has to be calculated with tube diameter and bending radius. Since all the necessary bending elements can be calculated from the theoretical bend points, the following description of the measuring principle is reduced on the evaluation of theoretical bendpoints in image and object space.

The measurement of a tube is performed in several steps. First images of a tube from all cameras are frozen in the computer. Then the contour of the tube is detected automatically and measured precisely by contourline reducing the contour to the centerline in every image. Straight elements and curves are then extracted from the measured tube contour. The intersection of straight elements deliveres the position of the theoretical bend points in the images (Figure 3). If a bend point can be detected in at least two images, the 3-dimensional theoretical bend points in object space can be calculated by intersecting the imaging rays.

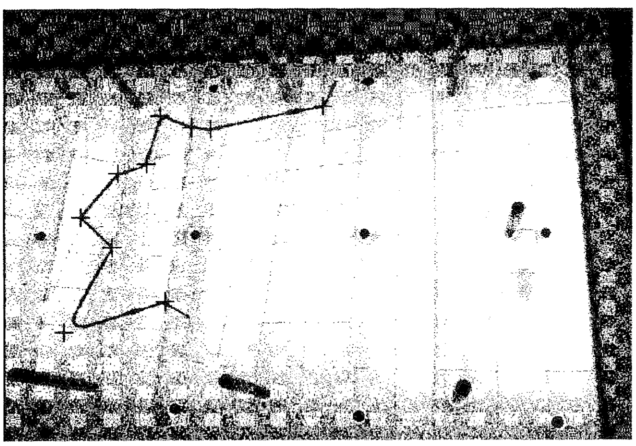

Fig. 3: Digital image with bend points

4.2 Optical gauge

In this mode of operation the theoretical bending elements of a tube are measured and afterwords compared to the data of a reference tube. Additionally the coordinates of the bend points can be exported in a CAD readable format like VDA-FS. In a menu the user can adjust import parameters of the tube like approximate diameter or adapter length. When starting the measurement, the user is prompted to choose the reference tube from the data base, to put the tube into the measuring cell and to start the measurement. In order to control a correct position of the tube in the measuring cell the images of the different cameras can be viewed on the video monitor. After the automatic measurement of the tube a table shows which parts of tube could be measured correct and complete. By repositioning of the tube in the cell and a following repeated measurement even difficult or large tubes can be measured completely.

For the measurement of unknown tubes two different ways can be selected. First, the CAD data of a similiar tube exists in the database. This is often the case when for example tubes which are bend from CAD data are adjusted manually in the production process. In this case the measurement runs automatically and similiar to the optical gauge. Results of the measurement are then imported to the database as mastertube data.

Second, if no information about shape and geometry of the tube exists, the measured points have to be confirmed by the user to ensure a complete measurement and a correct sorting of the bend points.

For each type of tube to be compared in the optical gauge the reference data are stored in a database. The menu point allows to choose different database functions, the input of data either manually by an editor or by a CAD interface, to visualize tube shape graphically and to rename or copy tubes.

5. TECHNICAL DATA

5.1 Measuring volume

The realized measuring volume is 2.500 mm x 1.000 mm x 700 mm. It is planed to realize two different types of measuring cells. A compact small cell with a measuring volume of about 1.500 x 1.000 x 700 mm and a large cell with a measuring volume of about 4.000 x 1.200 x 700 mm.

5.2 Tube spectrum

In the optical tube measurement system tubes of different shapes, diameters, materials and surface properties can be measured. The following limitations have to be considered: For tubes with small diameters or tube ends with female screws, the tube ends have to be signalized with special adapters. With top light illumination only tubes with dark, nonspecular surfaces can be measured. This limitation is not valid for measuring cells with a light table on the ground plate. At the time only bend points with bending angles larger then five degrees can be measured precise and reliable. Furthermore between two bend points a straight part of at least 10 mm length must be visible, that means that no bend points can be measured which go arc in arc.

5.3 Accuracy

Several tests with different types of tubes have shown that the individual bend points can be measured with accuracies better then 0.5 mm.

5.4 Measuring times

The time for a measurement depends on the length of the tube and the number of the bend points to be measured. But even for long and complicated tubes measuring times below 1 minute can be reached.

6. INTEGRATION IN THE PRODUCTION LINE

The OLM is now integrated in the production line for an automated process and quality control. Therefore the OLM provides an interface to several different types of bending machines. This interface consists of different data structures depending on the manufacturer of the bending machine. The measurement data can be send to the bending machines either via a local area network or using an existing factory network (e.g. Eathernet). Due to the link between measurement system and bending machine a direct process control can be provided. A feed back cycle allows the online correction of the bending machines. After measuring and comparing a tube with CAD data a correction data set is created and send back to the bending machine until the bended tube complies with the CAD data.

Besides this inline quality control the OLM is also used for the setup of the bending machines to evaluate the springback correction for every tube type.

6.1 Springback correction

Every type of tube and material has its own springback behavior. Therefore every tube and every bend needs a unique degree of overbending which has to be determined to achieve a CAD compliance of every bend. These correction values for each bend and length can be derived in at least three iterations. The former way of using wooden gauges took up to thirty or more iterations until the final shape and setup of the machine had been achieved.

7. CONCLUSION

The OLM is a completely digital measurement system for inline process and quality control using photogrammatric and digital image processing algorithms for the threedimensional reconstruction of bended tubes. The OLM is a powerful and efficient tool for quality control in industry. Major characteristics are contactless measurement, no elastic deformation of the tubes by the fixture, high speed acquisiton of the tubes, flexible fixing unit, short measurement time, variable measurement volume and high accuracy. With a growing number of installed systems, optical measurement systems will become a significant tool in quality control and inspection.

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