

## OPTICAL 3-D-MEASUREMENT SYSTEMS FOR QUALITY CONTROL IN INDUSTRY

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### PURPOSE:

There is a wide range of applications of close range photogrammetry and image processing. The major fields in industry are control of production, quality inspection, research and development. In addition e.g. medicine or space technology are possible. Optical three dimensional measurement techniques have several advantages, e.g. short measurement time, measurement without contact, variable volume and location. The hardware components and the image processing algorithms will be described briefly and examples of industrial applications will be presented.

**KEY WORDS:** Image processing, Machine Vision, Photogrammetry, Robot Vision, 3-D

### 1. INTRODUCTION

Quality control and inspection has become a major tool in industrial production. 100% control and error free production are necessary to reduce production costs and throw outs. The result is a reduced usage of resources as power or material. To achieve these goals new measurement and production techniques have to be introduced to allow new quality control mechanism.

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 as best.

The following paper will give three examples of those measurement systems to show the wide range of possible applications. The technical realization, advantages and disadvantages are described. The well known basic algorithms of photogrammetry and image processing are not described in detail.

### 2. OPTICAL TUBE MEASUREMENT SYSTEM

#### 2.1 The Task

Nowadays tubes in an automatic production line are bended and fitted automatically to the product with robots. Unfortunately robots do not always bend tubes in the nominal shape because of mechanical limits and other disturbances. Tubes that do not match with the correct shape can not fit into their final position on the product automatically. A wrong bended tube leads to an interruption of the production process, if the robots tries to fit the wrong bended tube. This is a very cost intensive process. Therefore it is necessary to detect a wrong tube shape earlier in the production process. The shape control of the tubes has to occur directly after the production of a tube.

This measuring task is done usually by wooden gauges. These gauges have the disadvantage, that they do not give any numerical data about the tube shape but only the result 'does fit' or

'does not fit'. Additional gauges are usually made for only one tube shape, so for every tube shape a single gauge is necessary. The large number of different gauges that are necessary to control every different tube shape and the space in the production area they need is cost intensive. These disadvantages of gauges make a single measurement system for all tube shapes interesting.

The requirements for a tube measurement system are a short measuring time, a contact less measuring and a measurement volume that covers all possible tube shapes. At least a sufficient accuracy of about  $\pm 0.5$  mm has to be achieved. A system that fulfills these requirements based on photogrammetric and image processing methods has been developed and first practical experiences have been made (Schneider, 1990).

#### 2.2 Hardware Components

The system consists of a measurement frame with fixed mounted CCD cameras (Bösemann, 1990). A granite plate is used as bottom platform. Reference points are attached to this temperature stable plate. The position of these reference points is measured with high accuracy to serve as control points for the camera calibration. The fixture of the tube is performed with an elastic net to avoid a deformation of the tubes due to their own weight (Fig.1).

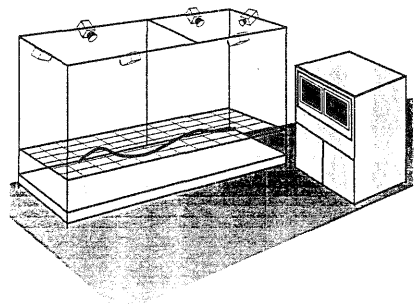


Fig.1: Schematic system configuration

The whole system is controlled by an industrial PC with image processing boards. The image processing components are a digital multiplexer, a camera interface and a transputer based processing board. The cameras deliver a digital signal, which is shuffled by the interface board into the memory of the transputer board. The number of cameras to be used is independent of the processing unit and the measuring frame and has to be applied to the complexness of the tubes to be measured. The more bends the tubes can have the more cameras are necessary to be sure that every bend point can be recorded by at least two cameras.

The whole background of the measurement frame is white to achieve a high contrast between tubes and background. In the images the tube is projected as a black polygon on a white background (Fig.2a).

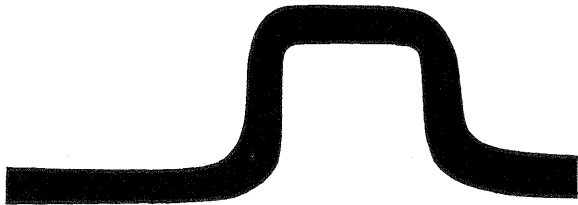


Fig.2a: Tube in digital image

### 2.3 Software

The processing of the digital images captured by the CCD-cameras runs in several steps.

In the first processing stage in every image the center line of the tube is extracted (Fig.2b). In a second stage these center line is splitted up into straight parts and bends. Following straight parts are connected, the intersection is the projection of a bend point into the image (Fig.2c). The result of the image processing are the image coordinates of these intersection points.

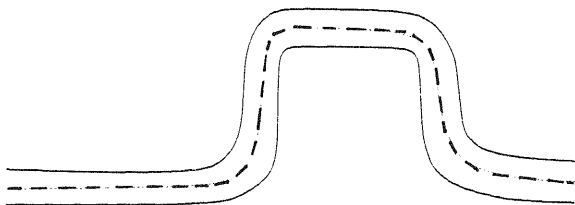


Fig.2b: Extracting tube center line

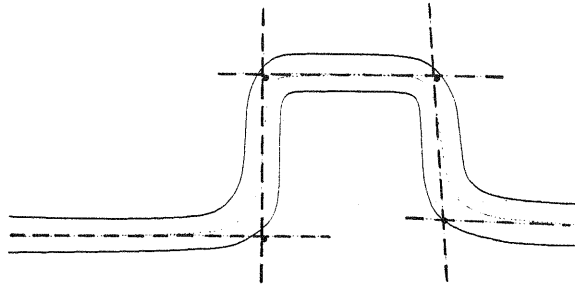


Fig.2c: Intersecting straight tube parts

If every image is processed, image coordinates of bend points are available. The 3-D-coordinates of these bend points can be derived by ray intersection in space. Therefore the interior and exterior orientation of the cameras has to be known.

These orientation parameters can be derived simply by a spatial resection of the images over the reference points. Therefore the reference points are also measured in the images. This system calibration is not performed every time a tube is measured, but only if a change in the orientation is detected. This changes can simply be detected by a continues observation of the image coordinates of some reference points. If any changes occur, a calibration can be started.

The major difficulty of this system is the matching of homologous bend points in the images. If a plane modelled by two following straight tube parts is perpendicular to an image plane, the bend point between the two straight parts can not be detected in the image. This case occurs very often, if the tube is bended very complex. In that case a special algorithm has to match the homologous projections of bend points. This is done by a ray intersection and the restriction of a minimized spatial distance of projection rays. Every intersection of two projection rays with a spatial distance under a predefined threshold is calculated. The resulting 3-D points were combined to clusters with a predefined maximum radius. Now homologous points can be detected as matching the same cluster.

The resulting 3-D coordinates of the bend points can be used to derive the distances between bend points and the bend angles. These are the parameters to control the bend roboters and can be used for a nominal and actual shape comparison.

### 2.4 Practical Experiences

First practical experiences have shown, that this method can be established to control the shape of automatically bended tubes. The achievable accuracy of a single bend point in the images is about  $\pm 0.1$  pixel, the global accuracy depends on the projecting scale. The first established system with 6 CCD cameras and a measurement volume of 1.5 m x 1.0 m x 0.5 m achieves an accuracy of  $\pm 0.5$  mm for one coordinate.

The limits of the system are bend angles less than 10 degrees and straight parts shorter than 30 mm. Those bendpoints are hardly to detect in the images and can therefore not be measured with a sufficient accuracy.

### 3. OPTICAL ROBOT CALIBRATION SYSTEM

#### 3.1 The Task

Nowadays robots are programmed off line. Off line programming means a teaching of robots using a computer simulation program. Due to technical limits in the mechanical moving of a robot arm, there is a difference between the programmed positions of a robot arm and the real position. Due to this difference a correction of the robot movement has to be considered. This difference can be measured with the robot calibration system and correction polynoms for the different ankles can be derived. Using this correction for the simulation, the accuracy of the real robot movement can be increased (Peipe, 1989).

#### 3.2 Hardware Components

3 or 4 CCD-cameras are mounted on the basic framework to observe the measuerment volume. The measurement volume can be flexible depending on the work space of the robot and the required accuracy.

For the detection and measurement of the robots tool center point a specially designed star signalized with three retro reflecting targets is mounted to the tool center point. The position of the targets relative to the tools center point is calibrated. For calibration purposes a scale bar can be attached to the tool center point with two retro reflecting targets on both ends and a calibrated distance and position to the tools center point.

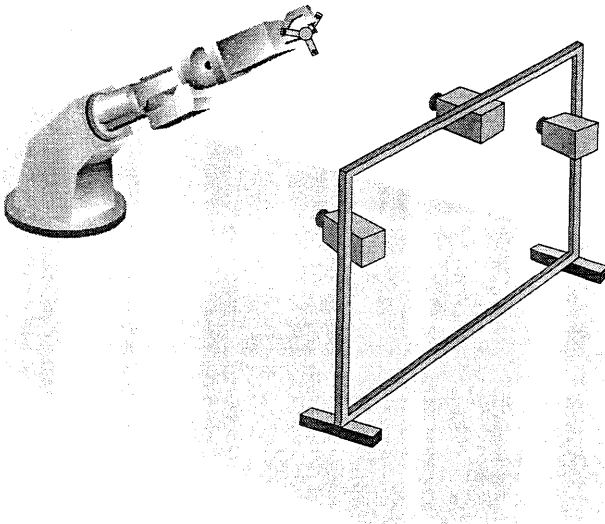


Fig.3: Schematic system configuration

The calibration system is designed as a subsystem of the robot control unit. The system is compatible to different robot control systems and can be implemented with some additional hardware for the image processing unit to the robot control systems.

#### 3.3 Calibration Process

The calibration of a robot consists of two steps, the calibration and the actual measurement.

In the first step transformation from the robot coordinate system to the world coordinate system is derived. Therefore the scale bar is attached to the tool center point of the robot and is moved in different positions covering the whole work space. In every position all cameras record an image of the scene and the image coordinates of the projected points will be measured. Every single image of one camera will finally put together to only one image with all image points.

The image coordinates are processed in a bundle adjustment with the image coordinates as observations and camera positions and world coordinates of the scale points as unknowns (Wester-Ebbinghaus, 1985). Using the robot coordinates of the scale points as approximate values in a free net adjustment the transformation of the robot coordinate system and the world coordinate system can be derived in the same process. In this case the datum of the world coordinate system is defined as the best fit model of the adjusted coordinates into the robot coordinate system.

In the second step the actual calibration process is performed. The robot is now attached with the measuring star and moves special figures covering the whole work space. Every time the robot stops, the cameras capture an image and the image coordinates of the targets on the star are measured. The spatial coordinates of these points are simply calculated by a ray intersection in space. The coordinates of the three points deliver the coordinates of the tool center point and the orientation of the tool center.

In a third step these coordinates and the orientation of the tool center are compared with the robot coordinates and orientation in the robot coordinate system. The differences between these coordinates are used to derive the correction polynoms for the ankles.

First experiments in the lab have shown that the achievable accuracy is about  $\pm 0.05$  pixel in the image coordinates. The whole system is still in the prototype stage, but the first results show that a sufficient accuracy can be achieved. Major impact on the system have the vibrations of the robot. Because of the prediction that the cameras are mounted stable on the frame and do not change their position relatively to the robot a loss in accuracy can occur, if these prediction is not fulfilled.

#### 4. OPTICAL CORNER FITTING MEASUREMENT SYSTEM FOR AIRCRAFTS

##### 4.1 The Task

A corner fitting of an aircraft can be described as an angle iron that connects wing and body. Due to the high sensitivity of this junction the corner fittings have to be manufactured very precise.

Because of mechanical limits every aircraft of the same type is slightly different to each other so the shape of the corner fittings has to be adapted to every aircraft. Therefore a measurement system is necessary to measure the spatial position of the surfaces, the corner fittings are attached to. With the result of this measurement every corner fitting can be manufactured unique with a numeric controlled milling machine (Rüther, 1989).

The major requirements to this system are an easy handling, high accuracy and high recording and processing speed. The problem is a very small work space in the wing of the aircraft. The corner fittings have a size from 0.5 m x 0.3 m to 0.8 m x 0.5 m. The whole work space is about 3.0 m x 1.0 m x 0.8 m. In this workspace the user has to fulfill the whole measurement work.

##### 4.2 System Configuration

Due to the very small work space the image recording device has to be very small and the processing unit has to be placed outside the aircraft. The camera module is a JenaCam 28 CCD camera with shutter and an external pixel synchronous control unit and 8.0 mm lens.

The processing unit is a PC based transputer network with four transputers for parallel image processing.

The surfaces are targeted with a film. A special pattern of coded targets is printed on the film. Every target consists of a circle in its center, the actual target and a coded ring around this circle that keeps the coded identification information. The targets are set up in a grid of about 20 mm grid width. So the surfaces of every corner fitting are signalized with about 150 to 200 targets.

Additionally a scale bar has to be put in the scene to allow a scaling of the derived point coordinates.

##### 4.3 Measurement Procedure

The measurement procedure starts with attaching the target film onto the surfaces to be measured. Then the user captures one image after the other of the surfaces. Every image is processed automatically after it is recorded. The transputer system allows a parallel recording and processing without any pauses. The communication with the user working in the wing and the processing unit outside is performed by a small monitor that shows a live image of the camera and additional information about the actual processing status.

The image processing runs automatically. In this process the coded targets in the images were first detected, then the coordinates of the center point measured and finally the code ring decoded to get the identification information for every target.



Fig.4: Coded target

If all necessary images are recorded, the image coordinates are also available. Before the coordinates of the points can be calculated using a bundle adjustment, initial values for the object coordinates and the exterior orientation have to be provided.

The initial values for the coordinates are already available because the target film is attached always at the same position of the aircraft. Because of the same shape, coordinates once measured can be used as initial values every time. The initial values for the exterior orientation can be derived by a spatial resection over the initial coordinates.

The following bundle adjustment delivers the coordinates of the surface points which can be used for the numeric controlled milling machine.

#### 5. CONCLUSION

These examples have shown the wide range of possible applications of optical 3-D measurement systems. More systems are already in the planning stage and with a growing number of installed systems optical measurement techniques will become a significant tool in quality control and inspection.

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