AN AUTOMATIC SYSTEM FOR THE MEASUREMENT OF FLAT WORKPIECES

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ABSTRACT

This paper reports on the development of an automatic photogrammetric system which is used for the dimensional control of large plain workpieces in industrial environments. The system consists of one or more standard video cameras, a video frame grabber and a NT workstation computer. A diffuse light source is used to illuminate the object space.

Plain objects may be measured by single image techniques such as projective rectification. In this case at least 4 control points are given in object space and are used to determine the perspective transformation between cameras and object space. Due to the selected cameras significant variations of principle point coordinates and distortion values have to be considered. Using self-calibrating bundle adjustment the parameter of interior orientation are calculated iteratively in order to get distortion-free image for the perspective transformation.

The measurement of the parts is performed by automatic line following using digital image processing. Approximate values of edge positions are calculated from existing CAD data of the object.

The system has been implemented in a production environment for concrete ceilings. These parts have to be controlled with an accuracy of about 5-10mm. First results have shown that a system accuracy of less than 3mm is given under industrial conditions. The time for a complete measurement of object edges is less than 1 second.

1 INTRODUCTION

1.2 Specifications

This report presents a real-time photogrammetric system which is used for the geometric shape control of large flat workpieces. As a first application the measurement and control of precast concrete ceilings was performed. The concrete parts are manufactured almost automatically in a computer-controled production environment.

The objective was to develop a system with the following specifications:

- High production rates (measurement time < 1sec)
- difficult environmental conditions (e.g. dust, vibrations, changing light conditions)
- processing of natural, non-targeted object structures
- high accuracy requirements for video images
- low-cost system
- interface to existing production control system

The spatial dimension of the concrete objects is up to approx. 10.0m x 2.5m. The required accuracy is specified to ±5mm in object space. Using a one-camera setup and standard video resolution (750 x 580 pixel) the relative accuracy of about 1:2.000 yields to an image accuracy of about 3/10 of the pixel size.

Due to the fast production rate the object surface can not be marked by artificial targets. Thus, the natural edges of the workpieces have to be located and measured automatically. Manual interaction is not permitted. After transformation of image measurement into equivalent values in object space a quality check is performed.

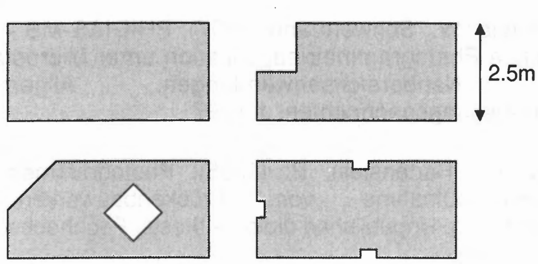


Figure 1: Variety of workpiece shapes

The workfloor control system delivers individual 2-D CAD data of the parts. Each precast concrete part may have another shape, i.e. outer dimensions as well as additional features such as holes, windows etc (Figure 1). On the one hand the CAD data is used to generate approximate values for the later edge detection in the images. On the other hand the data represents the nominal shape of the object used for the quality check.

Besides photogrammetric measurement the system should also be able to archive images and measurement results according to standards in quality assurance (DIN EN ISO 9000 ff.).

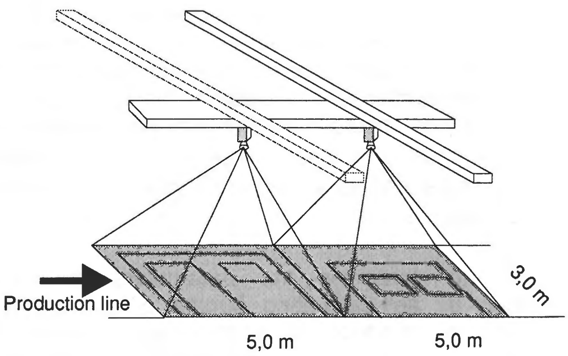


Figure 2: Principle system setup

1.3 Solutions

Figure 2 shows the principle system setup. One or more cameras are mounted above the production line. The system controller receives a signal and a part identification code from the production controller in order to start the measurement.

The objects are assumed to be flat enough for a single image compilation. If at least four control points are given each image can be rectified onto the reference plane of the control points using the well-known perspective transformations:

$$X = \frac{a_0 + a_1 \cdot x + a_2 \cdot y}{1 + c_1 \cdot x + c_2 \cdot y}$$
$$Y = \frac{b_0 + b_1 \cdot x + b_2 \cdot y}{1 + c_1 \cdot x + c_2 \cdot y} \qquad (1)$$

Equation (1) may only be used if the images have no distortion effects. Therefore the image coordinates x,y have to be corrected by the parameters of interior orientation which have to be calibrated in advance.

2 SYSTEM CONCEPT

2.2 Hardware Components

Image acquisition is performed by a standard ½" CCD video camera (European video standard CCIR, 25Hz, 768 x 572 pixel, frame transfer). It is equiped with a standard TV lens (f=8mm) which is not designed for high-quality photogrammetric purposes. The camera is protected against dust and oil by a closed camera housing.

The analog video signal is transfered to the computer system (NT workstation, Pentium-2, 128 MB RAM) which consists of a video frame grabber ITI AM-VS. The digitized images can be displayed in real-time either on a video monitor or directly as a window in the graphical user-interface.

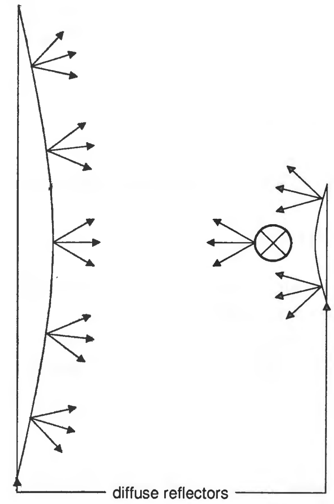


Figure 3: Diffuse illumination technique

Object illumination is performed by 300 W halogene spots. The light sources are used for indirect light reflection in order to generate a bright diffuse illumination (Figure 3). Direct light sources would yield to bright spots on the object surface, thus leading to CCD overflow in the sensor. In addition the optical representation of object edges is better with diffuse lighting.

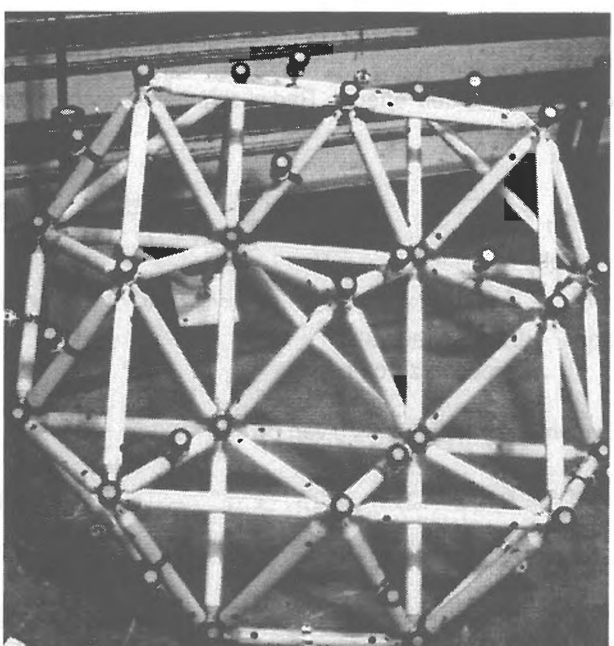


Figure 4: Testfield with control points

A testfield with known control points is mounted below the production line. Between two measurement cycles the system can be oriented again. For the control points circular alluminum targets are used which are relatively robust against mechanical disturbances. Retro-reflective targets can not be used in this environment.

2.3 Software Components

The system is running under Microsoft NT 4.0. The control software has been developed under Borland Delphi 3.0 which is able to integrate C-written procedures and libraries such as standard software for image processing.

3 SYSTEM CALIBRATION

3.2 Camera Model

Processing of analog video imagery yields to significant problems in image geometry. Line jitter and image affinity are well known (Beyer 1992). Standard TV lenses often do not meet photogrammetric requirements and have significant orders of radial and decentric distortion (Fryer 1996).

For this application the following set of parameters is used to describe camera geometry:

$x' = x'_P - x'_0$, $y' = y'_P - y'_0$ — image coordinates with respect to the principle point

$x'' = x' + \Delta x'_{aff}$, $y'' = y' + \Delta y'_{aff}$ — image coordinates corrected by frame grabber affinity whereby

$$\Delta x'_{aff} = C_1 \cdot x' + C_2 \cdot y'$$
$$\Delta y'_{aff} = 0$$

The correction terms $\Delta x'$ and $\Delta y'$ are functions of different distortion effects. Radial-symmetric distortion is defined by

$$\Delta x''_{sym} = x'' \cdot \frac{\Delta r'_{sym}}{r'} \qquad \Delta y''_{sym} = y'' \cdot \frac{\Delta r'_{sym}}{r'} \tag{2}$$

whereby

$$\Delta r'_{sym} = A_1 \cdot r'(r'^2 - r_0^2) + A_2 \cdot r'(r'^4 - r_0^4) + A_3 \cdot r'(r'^6 - r_0^6)$$

and r': image radius
r_0: second zero-crossing

Decentering distortion is given by

$$\Delta x''_{asy} = B_1 \cdot (r'^2 + 2x''^2) + 2B_2 \cdot x'' \cdot y'' \tag{3}$$
$$\Delta y''_{asy} = B_2 \cdot (r'^2 + 2y''^2) + 2B_1 \cdot x'' \cdot y''$$

The complete correction terms of image coordinates is then

$$x = x'' + \Delta x'_{sym} + \Delta x'_{asy}$$
$$y = y'' + \Delta y'_{sym} + \Delta y'_{asy} \tag{4}$$

This model is well-proven for different kind of photogrammetric cameras such as analog film cameras or digital still-video cameras (Godding 1995). In the case of low-cost video cameras, analog signal transfer and separate video digitizing the model yields to the following problem.

All parameters of interior orientation are defined with respect to the principle point, which should be the point of auto-collimation. This is true for most cameras where the the projection center is very close to the optical axis. In the case of large offsets in the principle point position the parameters of radial distortion A_1, A_2, and the parameters of affinity and sheering, C_1, C_2 are highly correlated with the coordinates of the principle point x'_0, y'_0.

In order to determine the parameters of interior orientation by self-calibrating bundle adjustment it is nessecary to introduce an a priori correction to the principle point coordinates. Iteratively the measured image coordinates are corrected by the residuals of bundle adjustment until the whole system becomes stable.

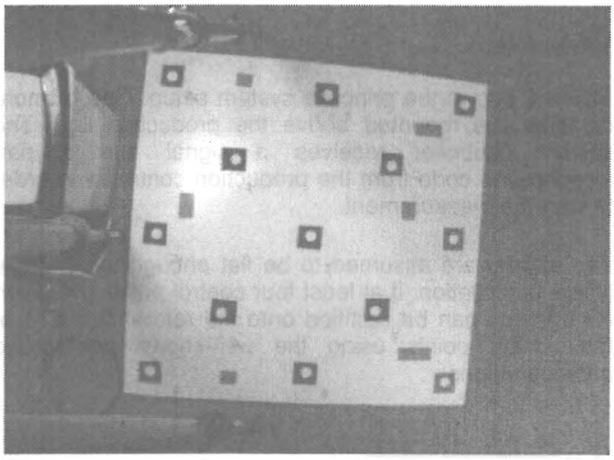


Figure 5: Distortion in original video image

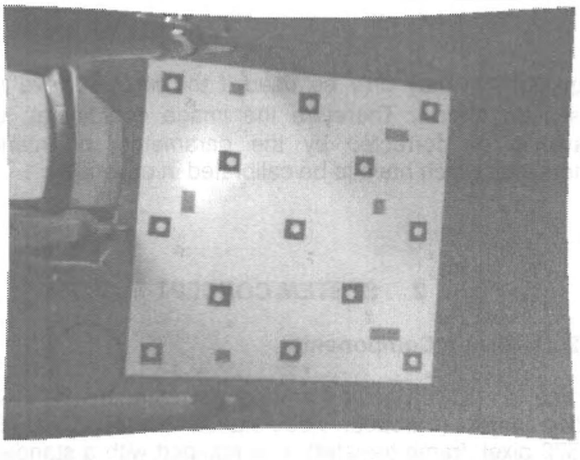


Figure 6: Video image corrected for distortion

Figure 5 and Figure 6 show the original video image with large radial distortion values and the corrected image after self-calibration.

3.3 Testfield Calibration

The CCD-camera has been calibrated by 13 convergent images of the testfield. Due to a large shift of the principle point and extreme values for radial distortion (see Figure 7), the observations (image coordinates) have to be corrected iteratively by the calibrated parameters of interior orientation. With the corrected observations the adjustment process has been started again until the system reaches convergency. In comparison to the first step of calibration the modified parameters lead to variations in image space of about 20µm. This effect is much poorer for lenses with larger focal length and less distortion.

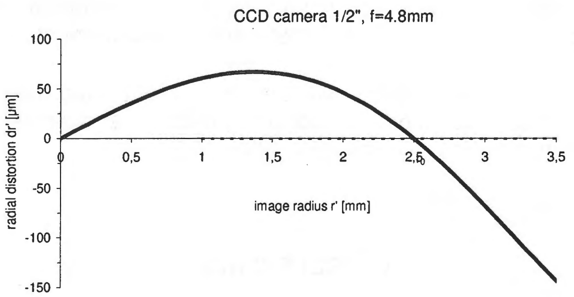


Figure 7: Radial distortion

The measurement accuracy after projective transformation of a flat (ΔZ < 5mm) surface (size 1.5m x 4m) has been determined to a standard deviation of s_{XY}=±1.2mm using the calibrated CCD camera. This result is equal to a relative accuracy of about 1:4000 and meets the requirements.

4 IMAGE MEASUREMENT

4.2 Point Measurement

The measurement of circular targets with high sub-pixel accuracy has been solved for more then ten years now (e.g. Luhmann 1986). The algorithm used in this application is based on a course point detection by a blob analysis algorithm which searches for point-wise patterns in the image. In a second step these approximate positions are used for a precise point measurement where the point center is calculated from a best-fit ellipse of the extracted contour points. The average point accuracy of well-defined targets is better than 3/100 of the pixel size.

4.3 Edge Measurement

The actual processing task is the extraction and measurement of non-signalized object edges. In the case of precast concrete ceilings the edges are disturbed by production failures (e.g. overflow of concrete), changing light conditions and different observation angles with respect to the camera (example in Figure 8). In order to improve the edge detection process a CAD data set of each part is transformed into approximate edge position values in image space.

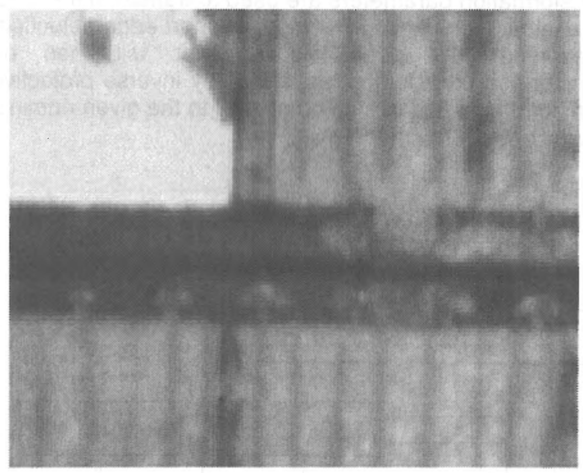
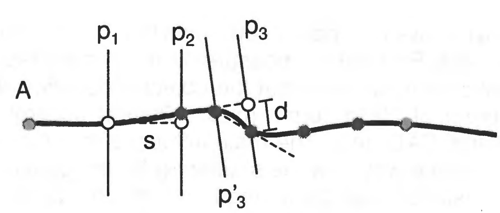


Figure 8: Edges on concrete part

Edge detection is performed by a self-adaptive line following process. Given a starting point and direction (from CAD data) the operator searches for the most likely edge in the neighbourhood of the current position. Using the *n* previous edge points the next edge candidate is predicted. For each successful edge location a set of edge attributes (e.g. edge width, curvature, contrast etc) is stored. The *n* previously determined attributes are used for a learning scheme in order to select the desired edge point out of many possible edge candidates.



o predicted edge position	p_i: image profile
• precise edge position	s: step width
A: starting point	d: offset

Figure 9: Line following

According to Figure 9 the operator adapts to the current line curvature. In the case that a profile offset *d* exceeds a given limit the step width *s* is automatically reduced in order to generate a denser point distribution for higher edge curvatures.

4.4 Transformation into Object Space

Figure 10 illustrates the complete measurement process. A given set of control points (adjusted for a reference plane) is detected and measured in the image. Under consideration of the interior orientation parameters the projective transformation (1) is calculated. The 8 transformation parameters are used to transform the CAD data into image space in order to support edge detection. The results of edge measurement will then be transformed back into object space by inverse projective transformation and can be compared to the given nominal values of the CAD model.

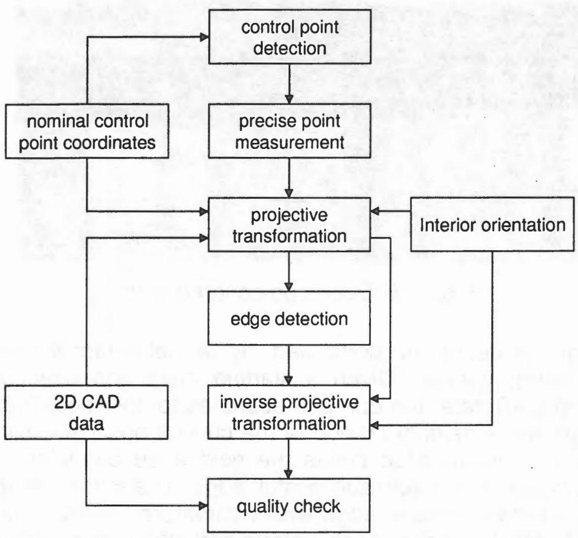


Figure 10: Measurement process

5 FIRST PRACTICAL RESULTS

A protoype system has been installed in the factory environment. First series measurements of manufactured parts have demonstrated that the objects show deviations in the order of 20 to 50mm (max. 100mm) according to the nominal CAD data. The main influence for production deviation is the way how the shuttering for the concrete of wet consistency has been mounted on the production platform. Figure 11 shows an example of real measurement results.

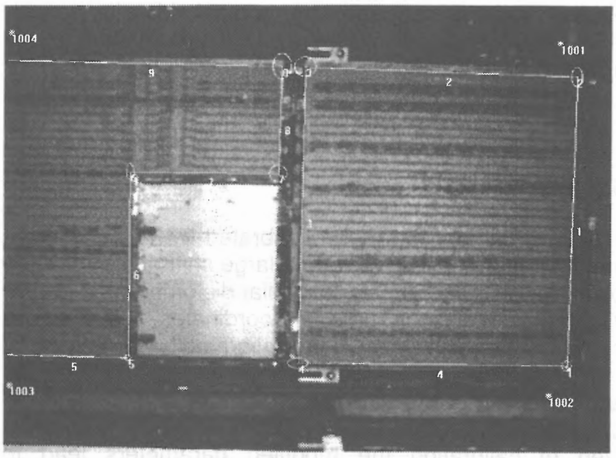


Figure 11: Measurement check

Due to these results this part of the process will change in order to ensure a higher geometric quality. A new shuttering system also serves for a better contrast and edge definition for the automatic edge measurement.

Further investigations will be carried out regarding a modified calibration method and a different system setup using cameras of higher resolution.

6 REFERENCES

Beyer, H. (1992): Geometric and radiometric analysis of a CCD-camera based photogrammetric close-range system. Mitteilungen Nr. 51, Institute for Geodesy and Photogrammetry, ETH Zürich.

Fryer, J.G. (1996): Camera Calibration. In Atkinson (ed.): Close Range Photogrammetry and Machine Vision.Whittles Publishing, Caithness, UK, pp. 156-179.

Godding, R. (1995): Ein photogrammetrisches Verfahren zur Überprüfung und Kalibrierung digitaler Bildaufnahmesysteme. Zeitschrift für Photogrammetrie und Fernerkundung, pp. 82-90, 2/93.

Godding, R. (1995): Neue Lösungen in der Nahbereichsphotogrammetrie durch die Kombination digitaler Systeme und moderner Auswerteverfahren. Publikationen der DGPF, Band 4, Hannover, pp. 261-269.

Luhmann, T. (1986): Automatic Point Determination in a Reseau-Scanning System. ISPRS Symposium, Comm. V, Ottawa.