3D Reconstruction of Industrial Sheetmetal Parts with Hybrid Point-line Photogrammetry

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ABSTRACT

An approach for three-dimensional reconstruction of industrial parts with non-metric image sequence and hybrid point-line photogrammetry is proposed. Non-metric image sequence and CAD-designed data are used as source of information. The strategy of our approach is to reconstruct the parts automatically with points and line segments extracted from imagery. Hybrid point-line photogrammetry is used to reconstruct sheetmetal parts accurately, and the reconstructed model can be used for visualization and inspection. The reconstruction system can run automatically and fastly. The output of hybrid point-line photogrammetry is the final 3D geometric model of the part. Results of real images of several parts are very satisfying, which shows a promising potential in automatic 3D reconstruction of widely existed industrial parts mainly composed of points and lines.

Keywords: Image sequence; Least squares template matching; Hybrid point-line photogrammetry; 3D reconstruction

1. INTRODUCTION

Three-dimensional (3D) reconstruction from images is one of the most active areas in computer vision and also close-range photogrammetry communities. As we know, CAD is widely used in manufacturing industry recently, and most parts have their corresponding CAD-designed data. Thus precision evaluating and quality control of industrial parts with reference of CAD data receives much concern in industrial communities.

The mostly used inspection equipment in industry communities is still Coordinate Measurement Machine (CMM). But the speed of CMM is still a major problem to be resolved (Steven 1999). Stereo vision technique with two CCD camera and two infrared lamps is used by (Dinitrios 2001) in inspection of gaps on the automobile production line, and results of about 0.1mm within an area of 80mm×80mm are obtained. Along with the development of computer vision, two-dimensional automated inspection has been widely used in Printed Circuit Board areas (Moganti 1996). But up to now, most 3D reconstruction and inspection systems are time-consuming and impractical.

Line photogrammetry is a technique that has well potential in reconstructing of existing objects mainly represented by polyhedral models. Several approaches have been proposed to reconstruct architectures in the last years (Heuvel 1999). In industrial areas, photogrammetric techniques are also used in 3D reconstruction of industrial installations (Vosselman 2000) with CAD models, although it is semi-automatic and time-consuming.

Based on the advantage of line photogrammetry, a new approach to reconstruct sheetmetal parts with hybrid point-line photogrammetry is proposed in this paper. Two error equations of adjustment by condition equations can be obtained with one image line observation for reconstruction. To reduce the cost of the reconstruction system, just one non-metric CCD camera is used. A planar grid is fixed on a rotation table for camera calibration and offering initial values of camera parameters for reconstruction. Industrial part to be reconstructed is put on the grid. Image sequence is obtained while the table rotating.

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2. MODEL OF HYBRID POINT-LINE PHOTOGRAMMETRY

Generally，the CAD-designed coordinate system of the industrial part will not be identical with the world one, there are often rotations and translations. They must be converted into an unified coordinate system for precise reconstruction. In the following line-related equations, (X^0, Y^0, Z^0) represents the coordinate of part point under part coordinate system, (X, Y, Z) represents its corresponding coordinate under world coordinate system, ($\Delta X^0, \Delta Y^0, \Delta Z^0$) and ($\varphi^0, \omega^0, \kappa^0$) translations and rotations respectively. (X_P, Y_P, Z_P) and (X_Q, Y_Q, Z_Q) coordinates of the part points under world coordinate system.

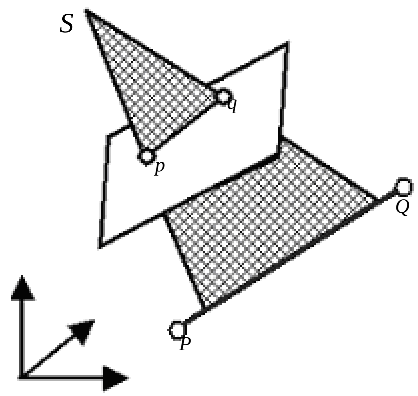

Fig.1 Coplanarity between space and image lines

As shown in fig. 1, the image line *pq*, space line *PQ* and the projection center *S* should be coplanar, while *p* and *P*, *q* and *Q* are not necessarily correspondences, which is the most important advantages of line photogrammetry. A straight line in the image can be parametrised in several ways. Although two parameters suffice for representation of an image line, four image coordinates of two end points are used here, because it is singularity-free and easy to setup error equations.

The coplanar equation among *p, S, P* and *Q* is (Zhang 2002):

$$\begin{vmatrix} u_p & v_p & w_p \\ X_P - X_S & Y_P - Y_S & Z_P - Z_S \\ X_Q - X_S & Y_Q - Y_S & Z_Q - Z_S \end{vmatrix} = 0 \tag{1}$$

where (u_p, v_p, w_p) is the model coordinate of *p*; (X_S, Y_S, Z_S) is the coordinate of projection center *S*. So the error equations can be written as follows

$$\begin{aligned} & A_1 dx_p + A_2 dy_p + A_3 d\varphi + A_4 d\omega + A_5 d\kappa + A_6 dX_S + A_7 dY_S + A_8 dZ_S + A_9 d\varphi^0 + A_{10} d\omega^0 + A_{11} d\kappa^0 + \\ & A_{12} d\Delta X^0 + A_{13} d\Delta Y^0 + A_{14} d\Delta Z^0 + A_{15} dX_P^0 + A_{16} dY_P^0 + A_{17} dZ_P^0 + A_{18} dX_Q^0 + A_{19} dY_Q^0 + A_{20} dZ_Q^0 + F_X = 0 \end{aligned} \tag{2}$$

where $A_1 \sim A_{20}$ is the partial derivatives for each unknown terms and F_X the constant item. Besides the coplanar equation among *p, S, P* and *Q*, there is another equation among *q, S, P* and *Q*. The linear form is similar to equation (2).

For parts that are very simple or there are a few line segments in image, the geometric configuration is very poor. In this case, grid points should be combined into the adjusmtent model to ensure the reliability and precision of adjustment. Error equations of grid points have the following form:

$$\begin{aligned} v_x &= B_1 d\varphi + B_2 d\omega + B_3 d\kappa + B_4 dX_S + B_5 dY_S + B_6 dZ_S + B_7 dX + B_8 dY + B_9 dZ - l_x \\ v_y &= C_1 d\varphi + C_2 d\omega + C_3 d\kappa + C_4 dX_S + C_5 dY_S + C_6 dZ_S + C_7 dX + C_8 dY + C_9 dZ - l_y \end{aligned} \quad (3)$$

Please refer to (Zhang 2002, Wang, 1990) for more detail about the coefficients of error equations. If the coordinates of grid points are treated as known, terms of (*dX, dY, dZ*) should be removed from the error equations. The model of hybrid point-line photogrammetry is composed of equation (2) and (3), which can be used to reconstruct industrial parts.

3. EXPERIMENTS

A software, which can run automatically and fastly, is developed according to the above algorithms to reconstruct industrial parts mainly composed of points and lines. The software has been tested with real image data of several parts taken by a pre-calibrated CCD camera. Firstly, Image sequence is acquired by CCD camera automatically while the table turns around its center controlled by computer. Image points of the grid and lines of the part are obtained by LSTM simultaneously with image acquiring. Then 3D CAD model of parts can be reconstructed accurately with hybrid point-line bundle adjustment.

The industrial part to be reconstructed is put on the planar grid, which is fixed on the turntable. The CCD camera is fixed on a tripod with a distance of about 600mm to the part. A sequence of 25 images for the part is taken with equal angle intervals while the table turns around its rotating center. One images of the sheetmetal parts with dimension of about 150mm are shown in fig. 2. Image corners of grid are detected as the cross of line segments fitted to each corner. Image line observations are obtained with LSTM in a local search window with initial values projected by the CAD-designed data and the camera parameters offered by the grid. Note that occlusions must be detected in advance of line template matching to reduce mismatches. White lines in fig. 2 are matched image lines of the parts. As can be seen, they are well fitted to real image edges.

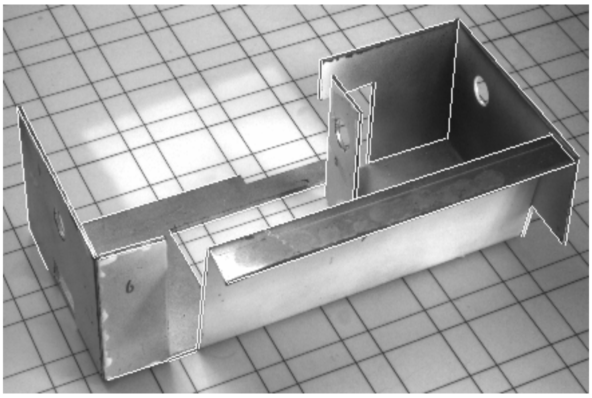

Fig.2 One image of the part

Left part of fig. 3 shows the initial values of line segments of the part. As can be seen, the initial image lines are usually several pixels away from the real image edges of the part. Although there are many rusts on the part that can be seen clearly, the matched image lines are well fitted to the real image edges, as shown in right part of fig. 3. Actually, the matching precision is higher than 0.05 pixels.

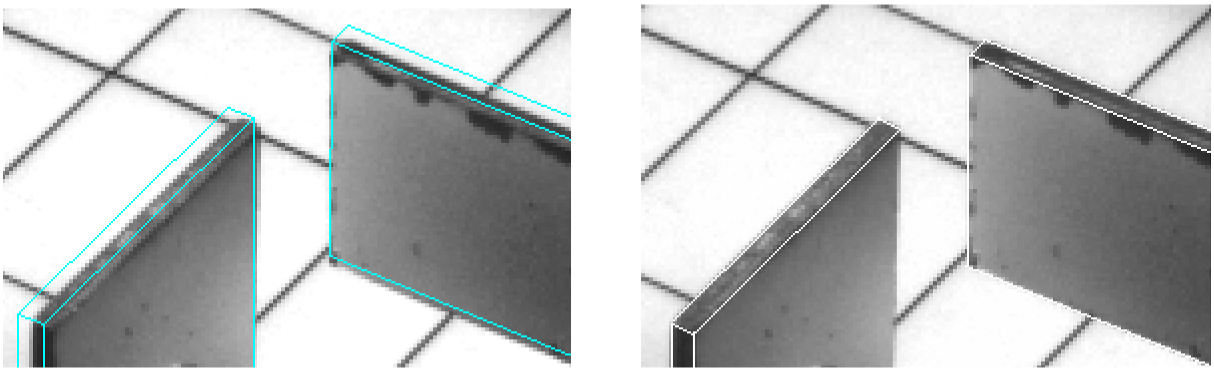

Fig.3 Initial values and matching results of part edges

In the hybrid point-line photogrammetry of reconstruction, designed coordinates of part points are used as initial values. The reconstruction system can generate the final CAD model within 30 second for each part in a PIV personal computer. Results of reconstruction are visulized with OpenGL and can be used for inspection automatically or interactively. 3D visual views of the reconstructed models are shown in fig.4.

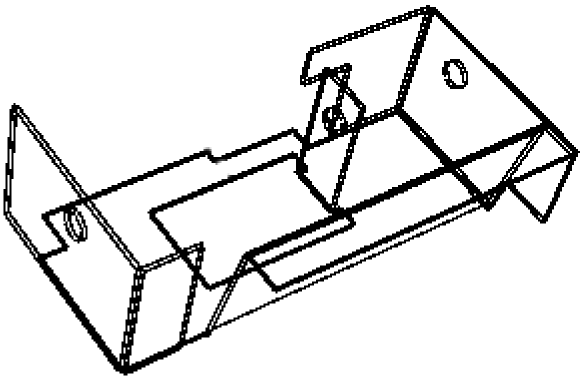

Fig.4 Reconstructed 3D view of the part

In order to check the precision of our reconstruction system, 25 distances between lines and planes on sheetmetal parts are measured manually by calipers and compared with which computed by the reconstructed model, results are shown in fig. 5. In fig. 5, “Producing imprecision” means distances between lines, planes or lines to planes measured by calipers manually subtracting the corresponding designed distances from CAD data. “Computed imprecision” means distances computed with the reconstructed model subtracting the corresponding designed distances.

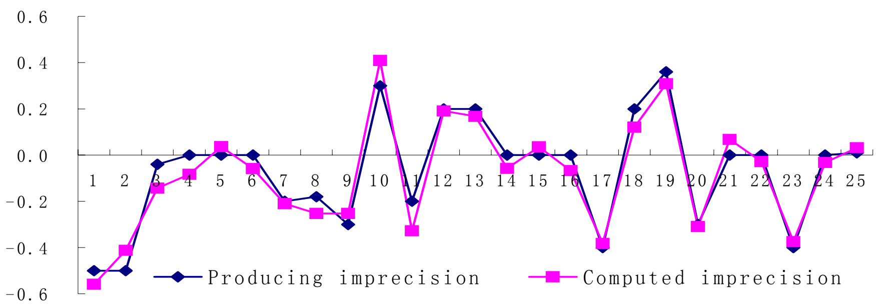

Fig.5 Imprecision of the part

It can be seen from fig. 5 that the largest "producing imprecision" of the part is about 0.5mm, i.e., the maximum difference between the produced part and the designed CAD model is 0.5mm. Note that all imprecision larger than 0.1mm can be detected accurately by our system. The RMS error of deviation is 0.070mm. The relative precision, which can be calculated as the ratio of RMS against the distance between camera and the part, are higher than 1/8500 (0.07mm/600mm≈ 1/8570), which shows the precision of our system when manually measured distances are treated as errorless. But in fact, distances measured by calipers manually cannot be errorless, so the actual precision of the reconstruction system should be even higher than 1/8500.

4. SUMMARY

A novel approach for 3D reconstruction of industrial parts mainly composed of line segments with non-metric image sequence and CAD-designed data is proposed. Hybrid point-line photogrammetry technique is used to reconstruct the parts accurately, and results of reconstruction can be used for visual inspection.

Experiments of real images are very satisfying. The relative precision is higher than 1/8500, and all imprecision larger than 0.1mm can be detected accurately. The proposed reconstruction technique also has the advantages of low cost of hardware, high precision of reconstruction and can run automatically and fastly. It shows a promising potential in automatic 3D reconstruction of widely existed industrial parts mainly composed of points and lines.

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