Armin Grün / Herbert Kahmen (Eds.)

# Optical 3-D

# Measurement Techniques

Applications in GIS, mapping, manifactoring,
quality control, robotics, navigation, mobile mapping,
medical imaging, VR generation and animation

Papers presented to the conference
organized at
Zurich, Switzerland, September 22-25, 2003

## Poster Session

# PHOTOGRAMMETRIC RECONSTRUCTION OF ARCS AND LINES BASED ON ONE DIMENSIONAL POINT TEMPLATE MATCHING

**Yongjun Zhang [a, b]*, Zuxun Zhang [b], Jianqing Zhang [b], Haitao Wang [b]**
[a] College of Hydropower & Information Engineering, Huazhong University of Science & Technology, P.R. China
[b] School of Remote Sensing and Information Engineering, Wuhan University, Wuhan 430079, P.R. China
(yjzhang, zxzhang, jqzhang, htwang) @supresoft.com.cn

**KEY WORDS:** Photogrammetric Reconstruction, One-Dimensional Point Template Matching, Object Space Solution

**ABSTRACT:**
For lots of pipe-like and board-like industrial parts, the reconstruction of circles, arcs and lines is very important but hard to deal with in practice. A new approach to match and reconstruct circles, arcs and lines based on one-dimensional point template matching technique and immediate object space solution is presented. Model of one-dimensional point template matching is addressed. Circles and arcs can be reconstructed easily and accurately with this model. Lines are represented by small segments. The length of small segments is approximately equal to that of point window in circle and arc reconstruction. Arcs and lines, which are connected to each other, can be reconstructed by an uniform solution with additional constraints. Results of experiment are satisfying.

## 1 INTRODUCTION

The problem of three-dimensional reconstruction from images is one of the most active areas in computer vision and also close-range photogrammetry. Nowadays, CAD is widely used in manufacturing industries, and most parts have their corresponding CAD data. But due to manufacturing and other errors, the produced parts usually will not be exactly the same as designed ones, so precision evaluating and quality control with reference of CAD designed data receive much concern in industrial communities.

The mostly used measurement 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 cameras and two infrared LED lamps is used by (Kosmopoulos 2001) in measurement of gaps on the automobile production line, and results of about 0.1mm within an area of 80mm$\times$80mm are obtained. Along with the development of computer vision, two-dimensional automated visual inspection has been widely used in Printed Circuit Board areas (Moganti 1996).

Line photogrammetry is used in reconstructing of objects represented by polyhedral models (Debevec 1996, Heuvel 1999). In industrial areas, photogrammetric techniques are also used in 3D reconstruction of industrial installations (Vosselman 2000) and reverse engineering (Ermes 2000) with CAD models. Although all of these systems are semi-automatic and time-consuming, it shows a well potential in automatic 3D reconstruction. (Zhang 2002) has proposed a new method for automatic 3D reconstruction and visual inspection of sheetmetal parts with non-metric image sequences. Precision of 1/8000 has been obtained with a non-metric CCD camera.

* Corresponding author.

Multi-stage ellipse extraction technique is presented by (Muammar 1991). Least squares kalman filter is used in circle extraction by (Nixon 1993). (Zhang 2002) proposes a circle reconstruction technique based on immediate object solution.

This paper will present a new technique to reconstruct circles, arcs and lines by immediate object space solution. One-dimensional point template matching is addressed in section 2. Models of circles, arcs and lines reconstruction are discussed in section 3 detailedly. In section 4, experiments are done with a industrial sheetmetal parts. The reconstructed model can be used for measurement of producing imprecision or deformations. Finally, section 5 concludes the paper.

## 2 ONE-DIMENSIONAL POINT TEMPLATE MATCHING

Line template matching (Gruen 1985) is a two dimensional technique. Image window length is often more longer than 10 pixels. As shown in fig.1, the levelling rectangle represents the template in matching, while the dashed rectangle represents the image patch for matching. There is a small angle which must be eliminated after matching, so two unknowns $dy_1$ and $dy_2$ are essential in matching model to fit the small rotation angles between image patches and templates.

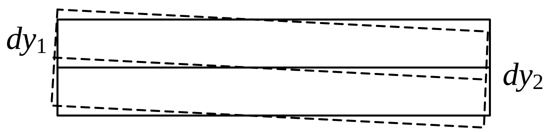


Fig.1 Two Unknowns in Line template matching

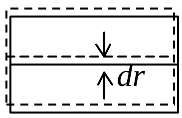


Fig.2 One Unknown in Point Template Matching

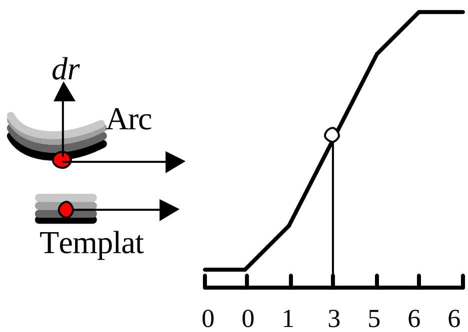


Fig.3 One Dimensional Point Template Matching

As we know, a line can be represented by colinear small segments. If image window of line template matching is subdivided into small segments, each with a length of 2-5 pixels, named "point segment", the rotation angles between standard template and small point segment can be

neglected. So we have only one unknown in matching. This is the basic idea of point template image matching.
Different from line template matching, there is only one unknown, the one dimensional shift *dr*, in point template matching, as shown in fig.2. Angles are assumed to be not existed, since the length of image patch is usually very short. Schems and standard template of point template matching is shown in fig.3.

## 3 RECONSTRUCTION MODELS

Camera parameters, which can be obtained with other techniques such as planar control grid (Zhang 2002), are treated as known in this paper. Since the end points of small line segments are results of template matching and also functions of space circles or lines, we relate the parameters of space circles or lines and images directly. Thus parameters of circles, arcs and lines can be obtained directly from several images by least squares template matching.

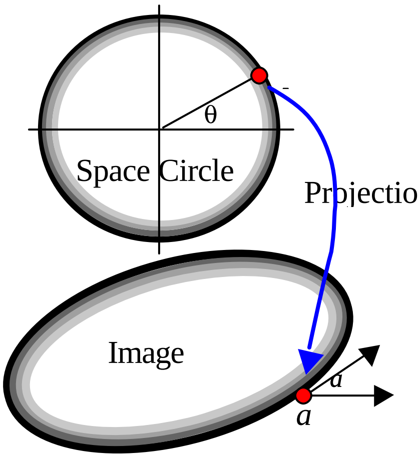


Fig.4 Projected image points of Circles or Arcs

Suppose the plane where circle or arc lies in is known. The camera orientation where the images are taken can be rotated to make the plane levelling. So the circle equation in the level plane is very simple.

$$\begin{aligned} X &= X_0 + R \cdot \cos\theta \\ Y &= Y_0 + R \cdot \sin\theta \end{aligned} \tag{1}$$

where $X_0, Y_0$ and R are the center and radius of circle or arc respectively, $\theta$ varies from 0 degree to 360 degree for circles, and from start angle to end angle for arcs.
In this paper, circles and arcs are dispersed by a number of points with certain intervals of different angle $\theta$, as shown in fig. 4. The upper is the space circle, and the lower is the projected ellipse with known camera parameters. Each point on the circle can be projected to its corresponding image point.
When equation (1) is substituted into collinearity equations, the following equations can be obtained

$$\begin{aligned} x - x_0 &= -f\frac{a_1(X_0 + R\cdot\cos\theta - X_S) + b_1(Y_0 + R\cdot\sin\theta - Y_S) + c_1(Z - Z_S)}{a_3(X_0 + R\cdot\cos\theta - X_S) + b_3(Y_0 + R\cdot\sin\theta - Y_S) + c_3(Z - Z_S)} \\ y - y_0 &= -f\frac{a_2(X_0 + R\cdot\cos\theta - X_S) + b_2(Y_0 + R\cdot\sin\theta - Y_S) + c_2(Z - Z_S)}{a_3(X_0 + R\cdot\cos\theta - X_S) + b_3(Y_0 + R\cdot\sin\theta - Y_S) + c_3(Z - Z_S)} \end{aligned} \tag{2}$$

Camera parameters are treated as known, Z is a fixed value after rotation. Then the unknowns are the center and radius of circle or arc. For certain angle $\theta$, the object point is projected into image and the tangential vector with angle $\alpha$ of circle or arc can be easily determined. A small window with length of 3-5 pixels taken the projected image point as center and $\alpha$ as tangential vector is rotated into horizontal, then one dimensional template matching can be made. The displacement $dr$ extracted by template matching as shown in fig.3 can be re-rotated back into raw image

$$\begin{aligned} dx &= dr \cdot \cos(\alpha + 90) \\ dy &= dr \cdot \sin(\alpha + 90) \end{aligned} \tag{3}$$

So the final error equations of circle or arc reconstruction can be written as follows

$$\begin{aligned} v_x &= A_1 \cdot dX_0 + A_2 \cdot dY_0 + A_3 \cdot dR - dx \\ v_y &= B_1 \cdot dX_0 + B_2 \cdot dY_0 + B_3 \cdot dR - dy \end{aligned} \tag{4}$$

Thus we can obtain the parameters of space circles directly from one or several images by Least Squares Template Matching (LSTM) with known camera parameters and initial values obtained either from CAD data or user interface.

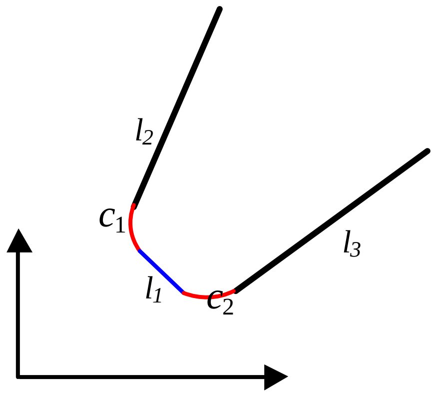


Fig.5 Industrial Parts with Arcs and Lines

In modern industry, many arcs in sheetmetal part are connected to lines. As shown in fig.5, two arcs $c_1$, $c_2$ and three line segments $l_1$, $l_2$ and $l_3$ are connected to each other. Generally, they are very difficult to reconstruct precisely. In this paper, we can get an uniform solution of all parameters of arcs and lines. For convenience of uniform solution, line segments are also rotated into a levelling plane, and can be represented as follows:

$$\begin{aligned} X &= X_s + i \cdot \Delta L \cdot \cos \beta \\ Y &= Y_s + i \cdot \Delta L \cdot \sin \beta \end{aligned} \tag{5}$$

where $X_s, Y_s$ is the start point of line, $\beta$ denotes the direction of the line, $\Delta L$ the length of small segment which is approximately equal to the length of point window in circle and arc reconstruction. So the line in the levelling plane can be represented by $X_s, X_s$ and $\beta$. Similar to circle reconstruction, the final error equations of line reconstruction can be written as follows

$$\begin{aligned} v_x &= M_1 \cdot dX_s + M_2 \cdot dY_s + M_3 \cdot d\beta - dx \\ v_y &= N_1 \cdot dX_s + N_2 \cdot dY_s + N_3 \cdot d\beta - dy \end{aligned} \tag{6}$$

So the circle or arc reconstruction equation (4) can be combined with line reconstruction equation (6) to get an uniform solution of arcs and lines connected to each other.

To ensure the stability of reconstruction, several geometric constrains should be added, such as the center of arc $c_1$ should lies on bisector of line $l_1$and $l_2$, the center of arc $c_2$ should lies on bisector of line $l_1$ and $l_3$, the three lines should be tangential to the two arcs, etc. The final model is indirect adjustment with constraints.

## 4 EXPERIMENTS

Basic reconstruction models of circles, arcs and lines are discussed in the above section. In this section, real image data will be used to test the proposed approach.

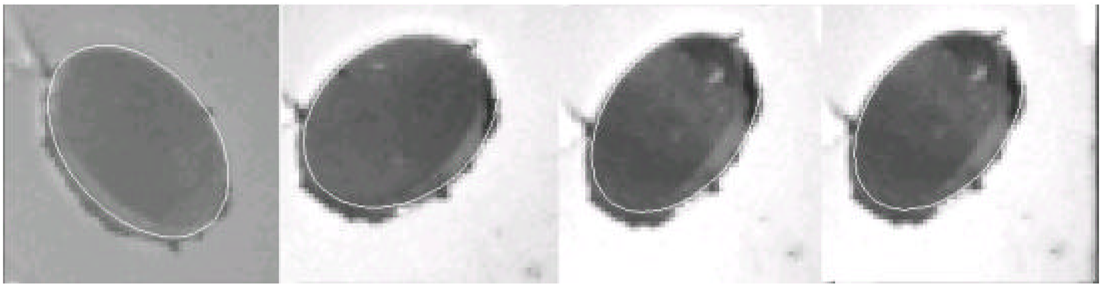

Fig.6 Initial projections of a circle in four images

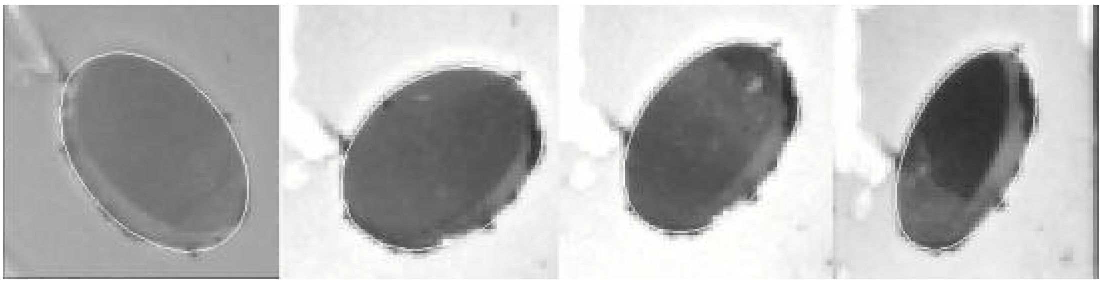

Fig.7 Reconstructed projections of a circle in four images

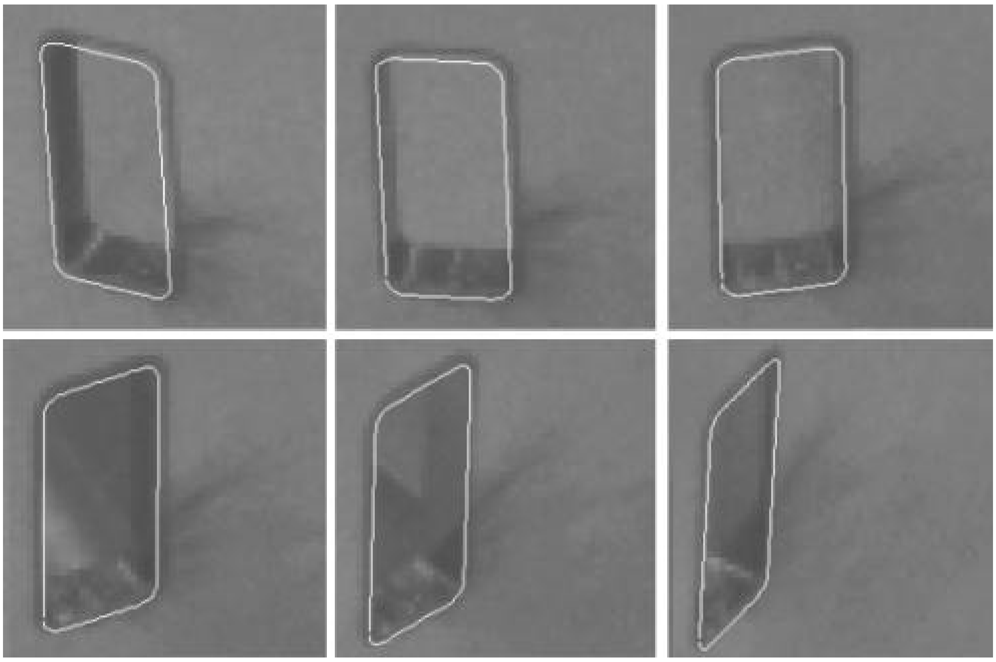

Fig.8 Initial projections of arc and lines in six images

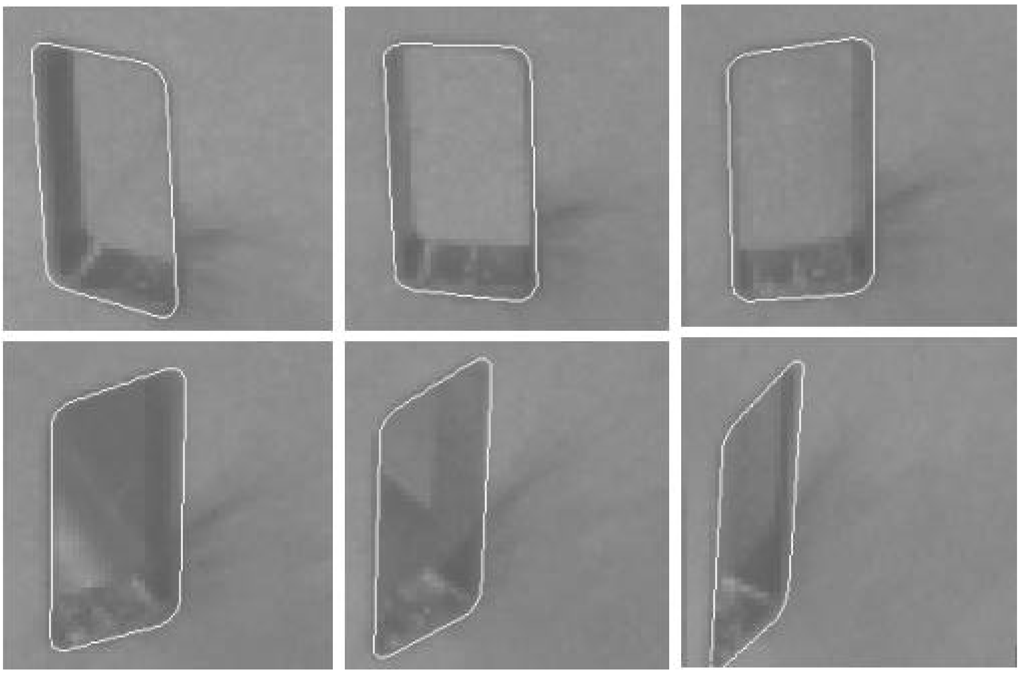

Fig.9 Reconstructed projections of arc and lines in six images

Fig. 6 shows a circle projected with original CAD designed data and known camera parameters. The reconstructed projections are shown in Fig. 7. As can be seen, although there are many dusts on the image, the reconstructed circles are almost fitted to actual image ones. The diameter of the reconstructed circle is 9.948mm, well fitted to its real value 10.00mm measured by callipers.

Fig. 8 shows the initial projections in 6 images of 4 arcs and 4 lines connected to each other. The length of the short line segments is about 12 pixels in image, even a few pixels for arcs. They are very difficult to reconstruct with common strategies. But for the proposed technique of object space solution with constraints, these can be reconstructed easily and stably. The projection of reconstructed model is well fitted to images, as shown in fig. 9.

## 5 CONCLUSIONS

A new approach of matching and reconstructing circles, arcs and lines on industrial parts based on immediate object space solution and one-dimensional point template matching is proposed. Known camera parameters, non-metric images, and CAD-designed data are used as source of information. Image features and geometric constraints are combined into the adjustment model.

Experiments of real images are very satisfying, which shows that the proposed technique has a promising potential in automatic 3D reconstruction and inspection of industrial parts mainly composed of lines and circles.

## REFERENCES

[1] Debevec P., 1996. Modelling and Rendering Architecture from Photographs: A hybrid geometry- and image-based approach [R], University of California at Berkeley.

[2] Ermes P, 2000. Constrains in CAD Models for reverse Engineering using Photogrammetry [C]. IAPRS, Vol. XXXIII, part B 5/1: 215-221.

[3] Gruen A., 1985. Adaptive least square correlation: a powerful image matching technique [J]. South African Journal of Photogrammetry and Remote Sensing, 14(3): 175-187.

[4] Heuvel F. A., 1999. A Line- photogrammetry mathematical model for the reconstruction of polyhedral objects [C], Proceedings of SPIE, Vol. 3641: 60-71.

[5] Kosmopoulos D, Varvarigou T., 2001. Automated inspection of gaps on the automobile production line through stereo vision and specular reflection [J]. Computer in Industry, 46: 49-63
[6] Moganti, M., Ercal, F., Dagli, CH, et al., 1996. Automatic PCB Inspection Algorithms: A Survey [J]. Computer Vision and Image Understanding, Vol. 63, No. 2: 287-313, 1996.
[7] Muammar H., M. Nixon, 1991. Tristage Hough Transform for Multiple Ellipse Extraction[C]. IEE Proc.-E, 138(1): 27–35, 1991.
[8] Nixon, M.S., 1993. Circle Extraction via Least Squares and the Kalman Filter. In Chetverikov, D. and Kropatsch, W., Eds. Proceedings Lecture Notes in Computer Science 719: 199-207.
[9] Steven S., 1999. Dimensional Inspection Planning for Coordinate Measuring Machines [D]. California: University of Southern California.
[10] Vosselman G., Tangelder J.W.H., 2000. 3D Reconstruction of Industrial Installations by Constrained Fitting of CAD Models to Images [C]. In: Mustererkennung 2000, G. Sommer, N. Krueger, Ch. Perwass (Eds.), series Informatik aktuell, Springer Verlag: 285-292.
[11] Zhang Y. J., 2002. Three-Dimensional Reconstruction and Visual Inspection of Industrial Sheetmetal Parts with Image Sequences [D]. Wuhan: Wuhan University (Ch)