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An Algorithm to Restore a Curved Object from Three Orthographic Views by Using Probablistic Relaxation Matching Method

Tomoyuki IWAMA[1] Takahiko HORIUCHI[1] Kazuo TORAICHI[2]
Hiromitsu YAMADA[3] Kazuhiko YAMAMOTO[3]

[1]Doctoral Program in Engineering, University of Tsukuba
[2]Institute of Information Sciences and Electronics
University of Tsukuba
1-1-1 Ten-nodai , Tsukuba, Ibaraki, 305, JAPAN
[3]Machine Understanding Division
Electrotechninical Lab. (MITI),
1-1-4 Umezono, Tsukuba, Ibaraki, 305, JAPAN

ABSTRACT

We present an algorithm to restore an curved object from drawings. Three orthographic views are utilized to represent many mechanical parts, polihedral objects, etc. Previous research have been proposed methods restoring objects automatically. We already proposed a method of restoring a polyhedral object from three orthographic views drawn with only straight lines. In this research, we developed this method to apply for curved lines in the drawing. Both our methods are able to determine the correspondence of true planes with candidate planes by probabilistic relaxation matching method, in spite of input data includes an error. And we describe algorithm to restore an object from three orthographic views included not only circle and arc but also other curved lines. It carry out by using multi-stage extraction algorithm and fluency function.

INTRODUCTION

Three orthographic views, made up with front view, top view, and side view is utilized for representing aspects of many kinds of object(e.g. mechanical parts, polyhedral object, etc) up to this time. As computer technology has developed, it is studied actively that research to restore the object automatically for document management and storage. Some of Authors have proposed an algorithm [1][2] to restore an polyhedral object consistent with a given set of three views composing of only straight lines. Though other previous algorithm have an assumption that the drawing data(the coordinates of vertecies) are precise, our algorithm is able to apply to automatic system inputted by an optical reader, which generates some coordinate input error, using probabilistic relaxation matching methods. The relaxation method[9] developed by A.Rosenfeld et al. achieved effective result on multi-dimensional optimization problem, such as field of image processing and pattern recognition.

On the other hands, in the case of treatment of curved lines, difficulty of problem is increased much more. For restoring objects comprising sections included curved surfaces, it has been reported effective results covering restricted object composed of planar, cylindrical, spherical, conical, or toroidal surfaces [5][6][7]. In this research, we aim to deal with three orthographic views consisting of not only straight lines but also curved lines. To accomplish it, we adopted a multi-stage extraction algorithm [3] and fluency function[4], which proposed by some of the authors. The extraction algorithm is practical as a method of extracting sharp corners of boundary lines, so-called joint points, and already applied to generate function-fonts of multi-symbols, based on a theory of fluency function proposed by one of the authors. The method of restoring object consists of five stages. Block diagram is shown in Figure.1. In the first stage, a set of three orthographic views drawing by solid lines and broken lines is input as a binary image by optical reader. The second stage is feature extraction stage. Each plane bounded on lines composed of a orthographic view, are extracted some specific points as their features, and classified types of plane. In the third stage, it is necessary to make a feature list and a neighboring plane list for correspondence between candidates and true planes by probabilistic relaxation operation. These lists are used to calculation of initial probability and compatibility coefficients on the next stage. A candidate wireframe model that includes every candidate planes, could obtained by projecting the three orthographic views. Imaginary candidate planes generated in the model should remove with relaxation operation. The fourth stage is face determination. True planes correspond with candidate planes on orthographic views using relaxation matching method, which utilizes probability between them. After calculation of compatibility coefficients and initial probability of matching, it begins iterating evaluation of existence probability on each candidate pairs. Though it is not assured that relaxation operation could always reach convergence to optimum solution, it determines correspondence based on local binary relations. The final stage is object construction. Each lines between adjacent joint point is represented as piecewise polynomial, so that the function provides information to restore the object. The remainder of this paper is arranged to experimental results and conclusions.

PRELIMINARIES

In this section, definition of terms are provided, and the characteristics of the object and problems are discussed briefly.

An object is a finite segment of three-dimensional space and is expressed with face, edge and vertex. The face could be distinguished to a planer or a curved surface. The edge have two category. One is a boundary line that exists on both actual object and orthographic views. And another is Silhouette line that appears on orthographic views only. The object can be interpreted uniquely and satisfies the following three conditions besides general rule of the three orthographic views.

(1) The three views are composed of only solid lines and broken lines and do not have additional lines and symbols.

(2) The object do not have any cavity surrounded by smooth wall.

(3) Each edgeline is owned jointly by even numbered faces.

Additional lines (such as center lines) are not treated. Condition(2) assumes that the objects are composed of convex surfaces only. Condition(3) assumes that empty cylindrical objects are not considered. In this paper, we take word "a plane" to represent an area surrounded by closed line on a orthographic views, regardless of a kind of line. The restoration problem is to reconstruct an object based on candidate wireframe model which contains every candidate planes from a set of three orthographic views.

FEATURE EXTRACTION OF THREE ORTHOGRAPHIC VIEWS

In this section, three kinds of planes and some specific points are extracted from three views, and each lines are registered as coefficients of piecewise polynomial function.

To obtain specific points, we adopted multi-staged extraction algorithm, which can detect acute angle cross point and tangent point among different line(eg. straight line, circle/arc and other line) as joint point. A joint point is defined as a point that curvature changes acutely on a line or that a type of line changes. The boundary lines between each adjacent joint points approximates using piecewise polynomial. Their parameters distinguish as a line, arc/circle and free line. First,boundaries are obtained from the three views by a basic method as follows: The three views are transformed into an $N \times N$ binary image. Boundaries $\{x_{i_1}, y_{i_1}\}_{i_1=1}^{n_1}$ are extracted out of the binary image by tracking the edge of the views according to an 8-neighbor connection. When boundary lines are tracked, the edge always exists on the left. Next, vertecies are extracted from each boundary line by the following conventional method[8].

At every point $(x_{i_1}, y_{i_1}), (i_1 = 1, 2, ..., n_1)$ of the boundary line, digital curvature is evaluated as

$$P_{i_1,c_1} = \frac{\mathbf{a}_{i_1,c_1} \cdot \mathbf{b}_{i_1,c_1}}{|\mathbf{a}_{i_1,c_1}||\mathbf{b}_{i_1,c_1}|}, \tag{1}$$

$$\mathbf{a}_{i_1,c_1} = (x_{i_1+c_1} - x_{i_1}, y_{i_1+c_1} - y_{i_1}), \tag{2}$$

$$\mathbf{b}_{i_1,c_1} = (x_{i_1-c_1} - x_{i_1}, y_{i_1-c_1} - y_{i_1}). \tag{3}$$

Here $\cdot$ denotes the inner product of vectors. If $P_{i_1c_1}$ is a maximum of digital curvature function $\{P_{i_1c_1}\}_{i_1=1}^{n_1}$ in the local interval $[i_1 - c_2, i_1 + c_2]$ and $P_{i_1c_1} > -c_3$, we take the point (x_{i_1}, y_{i_1}) as an vertex. Each boundary line between adjacent vertecies is approximated by straight lines. At this time, projections can be extracted at the cross point between a solid line and a broken line. If the length L between adjacent vertecies is less than c_4, both vertecies are reduced as the projection. A plane surrounded by an approximated line with a right-handed rotation is registered as "simple plane." A simple plane may be defined as a plane surrounded by only solid lines. If the area of the simple plane is narrow, the plane is not labeled because it is decided as broken line. Sequentially, division planes and complex plane are extracted and registered with flag w. A division plane may be defined as a plane surrounded by solid lines and broken lines. A complex plane may be defined as a plane that consists of some simple planes and division planes.

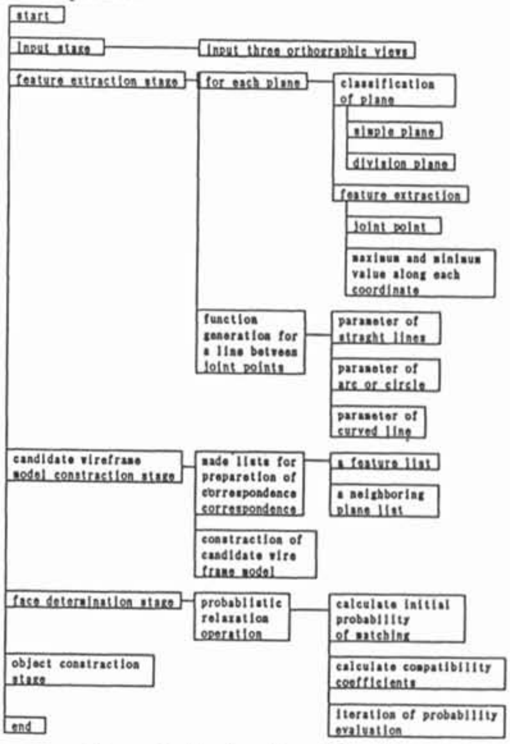

Figure 1: Restoration Algorithm

After merge and reduction of these points, they are determined and registered as final joint points. According to the joint points, each boundary lines between each adjacent joint points approximates using piecewise polynomial. Their parameters distinguish as a line, arc/circle and curved line. At the same time, maximum, minimum and extreme coordinate value is extracted along axis of each coordinate as another feature point.

CONSTRUCTION OF CANDIDATE WIREFRAME MODEL

In this section, it is constructed a candidate wireframe model that includes every candidate planes. And it is necessary to make a neighboring plane lists for correspondence between candidates and true planes by relaxation operation. Two plane divided by boundary line are defined as a neighboring plane each other. These lists are applied to calculation of initial probability and compatibility coefficients in the next stage. The candidate wireframe model is composed of its own features obtained by projecting the three orthographic views. Imaginary candidates generated in the model should remove with relaxation operation. Three of neighboring plane lists should be made for all extracted planes. The first neighboring plane list is for binary relation between two simple planes tangent each other. The first neighboring planes do not exist on the same face of restored object. If a feature point or a line could match with another one projected from the other views on the same axis, the two planes are registered on the second neighboring plane list. It means the two planes are adjacent faces on the restored object. The third neighboring plane list is introduced to distinguish a curved surface from a set of plane in the views. Since it is difficult enough to choose planes, which represents curved faces of true object, from only a orthographic views, we must consider the correspondence of information among three views. Two planes on the list have possibility to be projection of a curved surface. The information for each plane i is composed of their own features and three kinds of neighboring plane lists described as

$$O = [O_i]_{i=1}^{M^{(P)}}$$

$$= \left[[x_{i_m}, y_{i_m}, z_{i_m}]_{m=1}^{M_i^{(V)}}, w_i, \left[E_{ij}^{(1)}\right]_{j=1}^{M_i^{(1)}}, \left[E_{ij'}^{(2)}\right]_{j'=1}^{M_i^{(2)}}, \left[E_{ij''}^{(3)}\right]_{j''=1}^{M_i^{(3)}}, \right]_{i=1}^{M^{(P)}}, \quad (4)$$

where $M_i^{(V)}$ denotes the number of vertecies of plane i, and $M_i^{(1)}$, $M_i^{(2)}$ and $M^{(3)}$ denote the number of first-neighboring planes, second-neighboring planes and third-neighboring planes respectively. w_i denotes a flag of a kind of plane(eg. simple, division and complex). $E_{ij}^{(1)}$, $E_{ij'}^{(2)}$ and $E_{ij''}^{(3)}$ denote the number of j-th first-neighboring plane , j'-th second-neighboring plane and j''-th third-neighboring plane. $M^{(P)}$ denotes the total number of planes. The list is used to determine initial correspondence in next stage. The candidate wireframe model is constructed by the projection of every planes. However, it often happens that the corresponding vertecies between each view does not overlap exactly because the coordinates of three views include some noise such as sampling error. Therefore, the threshold c_5 is needed and vertecies within c_5 are considered as the same vertex.

DETERMINATION OF TRUE SURFACE

The fourth stage is face determination. Candidate planes on orthographic views correspond with faces of the object through relaxation operation.

First, the initial cost $p_{i(k)}^{(0)}$, which is the probability of the correspondence between the face i and the candidate face k, is determined. The initial cost depends on the distance between the origin of the coordinate axis and the candidate face. The initial cost is the local correspondence between a candidate plane and true faces. Global relations of each face is calculated by a relaxation method using coordinates and neighboring face list.

Next, three kinds of compatibility coefficients $r_{ij(k,l)}^{(1)}$, $r_{ij'(k,l')}^{(2)}$ and $r_{ij(k,l'')}^{(3)}$ are calculated. After calculation of compatibility coefficients and initial probability , it iterates evaluation of an candidate pairs existence probability.

The first-compatibility coefficients is to evaluate that candidate planes k and l do not exist on the same plane. The coefficients depend on the degree difference between candidates k and l. If the degree equals zero (i.e. k and l are parallel), the coefficients become low. Also, it evaluates the separation using the difference of vectors between faces. Though faces k and l are parallel, if both faces are separate, the coefficient becomes high. On the other hand, The second-compatibility coefficients is to evaluate the location of the faces. Both simple plane and complex plane must correspond to the faces which can be shown directly on a planer planes. The division plane does not show the top face. Thus, a surface which extends to the top face must exist on the polyhedral section around the plane. The third compatibility coefficients is to evaluate two planes which includes curved line segment cross each another along with respective coordinate axis.

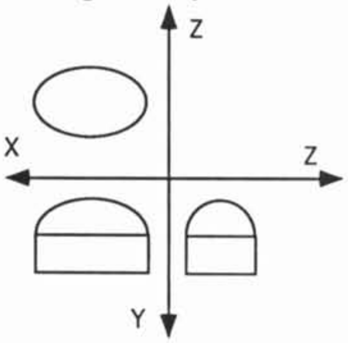

Figure 2: Three orthographic views for experiment

The coefficients depend on a flag representing a kind of line segment, and accord between feature points. This is important that two cross planes could survive through iteration of calculation.

In order to make the neighboring faces sound plausible, $p_{i(k)}^{(t)}$ is renewed as follows.

$$p_{i(k)}^{(t+1)} = \frac{q_{i(k)}^{(t)} \times p_{i(k)}^{(t)}}{\sum_k q_{i(k)}^{(t)} \times p_{i(k)}^{(t)}} \quad (5)$$

$$\begin{aligned} q_{i(k)}^{(t)} &= \sum_j \left\{ \max_l \left(r_{ij(kl)}^{(1)} \times P_{j(l)}^{(t)} \right) \right\} \\ &+ \sum_{j'} \left\{ \max_{l'} \left(r_{ij'(kl')}^{(2)} \times P_{j'(l')}^{(t)} \right) \right\} \\ &+ \sum_{j''} \left\{ \max_{l''} \left(r_{ij''(kl'')}^{(3)} \times P_{j''(l'')}^{(t)} \right) \right\} \quad (6) \end{aligned}$$

where faces l are the candidate faces for neighboring faces j, and l' are the candidate faces for neighboring faces j'. After $t-$times iteration, the field becomes wide and consistent correspondence is emphasized in the considering field and the value of $p_{i(k)}^{(t)}$ becomes high. In the iterating operation, it often

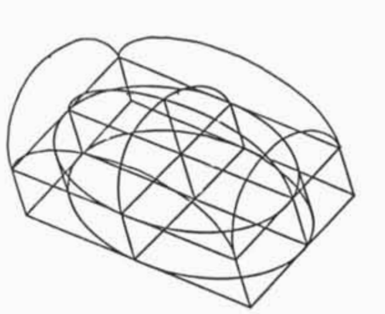

Figure 3: A candidate wireframe model

happens that the first-term in eq.(6) which is the compatibility of the first-neighboring planes can be 0. In this case, several simple planes correspond to the same surface. In order to solve the problem, we set $q_{i(k)}$ as 0. After several iterations, label k for i which corresponds to the maximum $p_{i(k)}^{(t)}$ is selected as the surfaces.

After the decision of all surfaces, the solid model is reconstructed by adjustment of coordinates for each vertecies.

CONSTRUCTION OF OBJECT

The final stage is object construction. Each lines between adjacent joint point is represented as piecewise polynomial, so that the function provides arbitrary coordinate data to restore the object. Any planar surface is easy to restore according to x,y and z coordinate of vertecies. On restoring a curved section of the object, we utilized information: each coordinate of joint points and maximum/minimum/extreme points, degree and coefficients of the function. Usually meshed indication is applied to construction, if the object have curved surfaces.

EXPERIMENTAL RESULTS

In this section, we must show experimental results. The three orthographic views as input is shown in Fig.2. Equipment for input is image scanner that is able to change dot precision from 75dpi to 600dpi(dot per inch). Though optimal dot precision depends on size and complexity of drawing, we usually set it 75dpi. Since it set to high resolution, the system based on a multi-stage extraction algorithm is able to detect slight variation of curvature and discontinuity. Because of increment of a number of joint point, it tends to increase the amount of calculation. Figure.3 shows the wireframe model which is constructed from the three orthographic views in Fig.2. One of examples is shown in Fig.4. This meshed expression is not normal,because of reduction of slice lines in order to obtain clear view, in spite of small sized indication. As a result, upper curved section is slightly distorted in spite of an ellipse as input. Present system could not generate modified object simply with feedback of distorting expression data. The problem is also of interest.

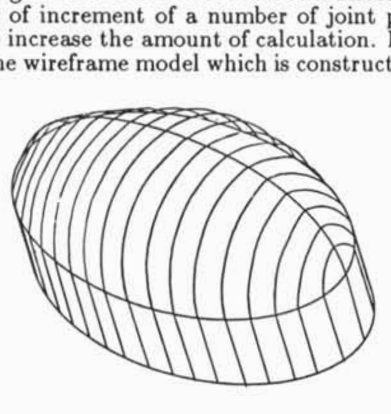

Figure 4: An restored object

CONCLUSIONS

In this paper, we proposed an algorithm to restore an object consistent with a given set of three orthographic views by using probabilistic relaxation matching method. Effectiveness of this algorithm is confirmed by experiments using many kinds of orthographic views. By application for an combinational problem, effect of reducing the amount of calculation are verified in the same of previous our research[1]. The present method must give a solution for noisy data to prevent calculation explosion, because the present method can absorb the data error probabilistically. In the future research, we are interested in complete automatic system to restore an curved object and implementation of it.

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