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Range Data Segmentation with Principal Vectors and Surface Types

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Abstract

A new method for segmenting range data including curved surface is proposed. The method is based on robust principal vectors calculation using ISL-primary-axis method.

First a normal vector and principal vectors are calculated for each data point. Next, maximum and minimum curvatures are calculated referring principal vectors. The surface type of each point is determined with values of the curvatures.

Then the surface is segmented by discontinuity of depth, normal vectors, principal vectors and/or surface types. The discontinuity information is stored in a special boundary image to reserve the reliability of each boundary points.

Each small region in the segmented image is merged into one of the neighboring regions. The border of the target region is segmented for each neighboring region and each segment is scored with length and reliability which reflects the discontinuity reason. The border segment with the highest score is erased.

The experimental result for actual range data is shown.

1. INTRODUCTION

Although range data has precise and dense description of three dimensional shapes of object surfaces, it is not suitable for building data base for object recognition because it does not have a structure describing intrinsic orientation of the surfaces. The structurized orientation information is important in rough pose estimation with partially occluded data at the first stage of object recognition.

When all the objects are polyhedrons, segmentation using discontinuity of surface normal vectors can achieve good results [(1)], but for objects with curved surfaces, we have to reserve the information of orientation for points inside each surfaces. The normal vector is not enough for the purpose, and we need other intrinsic features for representing objects.

The intrinsic features for structurizing range data have to satisfy the following two conditions. (1) They have to be determined by local partial data and (2) they have to be independent of viewpoint. These conditions are necessary to recognize an object usually occluded by itself or by other objects.

It is well known that an orthogonal frame which consists of two principal directions and a normal vector (fig.1) satisfies above conditions, but it was also known that it is sensitive to noise in data and the feature was not practical for real range data [(2)]. We found a new computation method to calculate principal vectors robustly [(3)] and made it practical in use.

In this paper, we introduce a method to segment range data using principal vectors and surface type discontinuity as the first step of structurizing range data. In section 2, principal vectors and curvature calculation using ISL is described. In section 3, the multi value boundary image which is used in merging sequence is explained. In section 4, the sequence of process of merging is described. In section 5, experimental results are shown. And in section 6, this work is summarized and future works are mentioned.

2. Principal Vectors and Curvatures Calculation using ISL

Principal vectors and max-min curvatures are calculated using ISL (Iso Slant Loop). ISL is a group of points {Q} defined for each point P which satisfy the following equation:

$$ {}^{t}\mathbf{n}_P \, \mathbf{n}_Q = c \qquad (1), $$

where $\mathbf{n}_P$ and $\mathbf{n}_Q$ are surface normals of P and Q respectively, and c is a constant. Approximately the shape

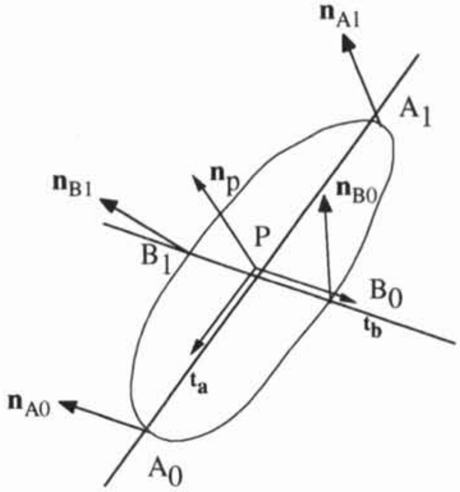

Fig.1 Iso-Slant-Loop

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of a loop becomes an ellipse which is long in the direction where curvature is minimum (fig. 1).

Principal vectors can be calculated as the eigen vectors of covariance matrix of a group of points {Q'}, where Q' is a foot of the perpendicular of Q onto the tangent plane of P. As {Q'} is on the plane, the eigen vector corresponding the smallest eigen value (must be 0) matches the surface normal, and the other two are on the tangent plane. The vector for largest eigen value, where variance of {Q'} is maximum, is equivalent to the principal vector of minimum curvature($\mathbf{t}_A$), and the vector for secondary largest eigen value, where the variance is minimum in the tangent plane, is equivalent to the principal vector of maximum curvature($\mathbf{t}_B$).

The minimum curvature value ρ_A is calculated by fitting a circle to the arc A_0PA_1, where A_0 and A_1 are intersection of the ISL and the plane spanned by **n** and $\mathbf{t}_A$. The maximum curvature value ρ_B is obtained from the arc B_0PB_1 as well.

Next, the surface type is determined with signs of maximum and minimum curvatures as; plane($|\rho_B| < \rho_{th}$), convex cylinder ($|\rho_A| < \rho_{th}$ and $\rho_B > \rho_{th}$), concave cylinder ($|\rho_A| < \rho_{th}$ and $\rho_B < -\rho_{th}$), convex ($\rho_A > \rho_{th}$ and $\rho_B > \rho_{th}$), concave ($\rho_A < -\rho_{th}$ and $\rho_B < -\rho_{th}$), convex saddle ($\rho_A < -\rho_{th}$ and $\rho_B > \rho_{th}$) and concave saddle ($\rho_A > \rho_{th}$ and $\rho_B < -\rho_{th}$), where ρ_{th} is a threshold (table 1).

3. Multi Value Boundary Image

After a normal vector, principal vectors and a surface type are given to each pixel of range image, a boundary image is created. The image is as same size as range image, and each pixel has bits indicating discontinuity of depth, normal vector, principal vectors and surface type. The discontinuity of depth is determined by distance of points, and ones for normal vector and principal vectors are determined by the differences of angles.

The discontinuities have levels of reliability, which is highest for depth and getting lower for normal vector, principal vectors and surface type. They reflect the stage of processing sequence. The feature of a discontinuity with lower reliability is calculated later, which means it may be more effected by noises or thresholds and regarded unreliable.

When one boundary pixel has more than one discontinuity bits, the one with highest reliability stands for the reliability of the pixel.

This boundary image is the first image for the merging process mentioned in the next section.

4. Process of Merging

As the first boundary image has a lot of small regions which does not reflects global surface structures, merging is necessary to remove small regions. In this work, regions with small width are regarded not significant and to be merged into large regions. We call them 'small' regions.

Following is the sequence of merging process for the boundary image mentioned in section 3.

(1) Preprocessing:

Short noisy cracks are removed and boundaries are thinned.

(2) Making of region list:

The boundary image is labeled into regions, and a list for regions is created. Each components of the list has some parameters for the region. The width of each region is measured and the list is sorted with width.

(3) Merging of texture regions:

Boundary image may have an area of small regions neighboring together. Such area is regarded as rough area where some features change very often in the local area. It is not easy and meaningless to analyze the surface structure of such group area. Therefore, in this paper, we call the group of small regions 'a texture region' and regard them as one region.

Actually, when two small regions are neighboring each other, the boundary between them are removed, and the result region is marked 'texture'.

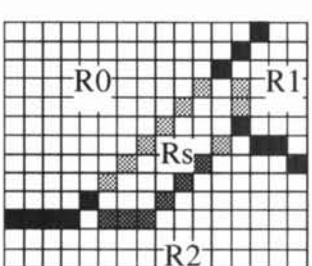
(4) Merging of small regions:

Merging starts from the smallest region until no small regions to be merged left. For each region to be merged (R_S), first track its boundary and find the neighboring regions {R_0, R_1, ...}. Then track the boundary point again and count the points for each neighboring region at the point and the reliability of the boundary pixel.

Fig. 2 shows an example of counting. Rs is the target region and {R_0, R_1, R_2} are neighboring. The table shows the sum for two levels of reliability and three regions. The

	- Max Curvature (ρ_B)		+
-	Concave	Plane	Convex Saddle
Min Curvature (ρ_A)	Concave Cylinder	Plane	Convex Cylinder
+	Concave Saddle	Plane	Convex

Table 1. Surface Types



	■ (dark)	▒ (shaded)	Total
R0	0	6	6
R1	0	2	2
R2	6	1	7

Fig.2 Example of Merging

boundary points which faces more than two regions (forking points) are not counted. In this example, the darker color is showing higher reliability.

After the count completes, find the longest boundary with lowest reliability in the table. In the example, R_2 has the longest border with R_S, but it is not chosen because the reliability of the pixels are high. Instead, R_0 has the lowest reliability boundary pixels, so it is chosen.

Then the boundary pixels between the destination region and the target region is removed and the target is merged into the destination. Because only one segment of the border is removed, the topological relation among other regions is reserved.

(5) Post-processing:

Short cracks are removed and boundaries are thinned.

5. Experiment

In this section, we show the result of segmentation on an actual range image. The scene is composed of a cone penetrated by a cylinder, a box under the cone and a bunch of hydrangea behind. The cone is 20 cm high approximately.

The scene is taken by our laser range finder[4].

Fig. 3-a shows the first boundary image of the scene. Different colors indicates the different boundary reliability. The noisy small regions depend greatly on noises in the range data and selection of thresholds. As the thresholds are selected to remain boundary candidates as much as possible, the image looks very noisy.

For example, the narrow triangle in the center of the cone is formed by boundary points with surface type discontinuities. The surface type out of this region is a convex-cylinder, and the one inside is a plane. The difference is caused by the thresholds for defining zero value of the curvature as explained in section 2. If the

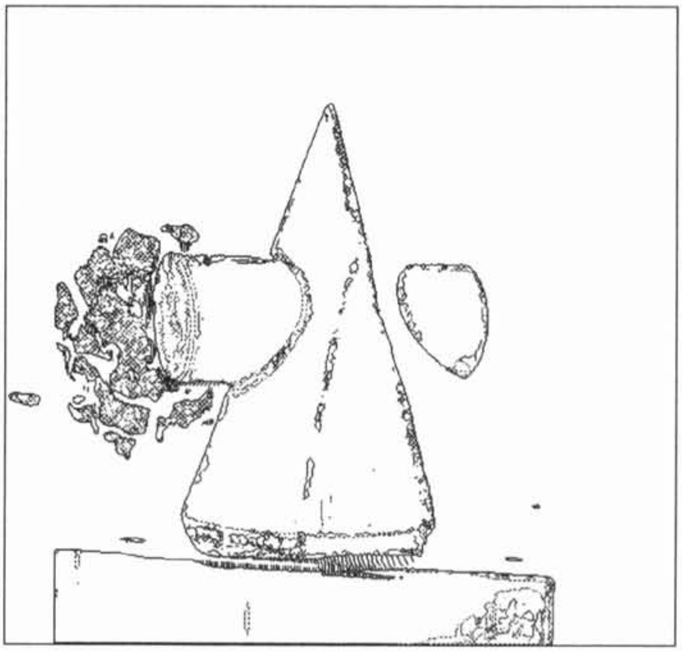


Fig.3-a Boundary Image

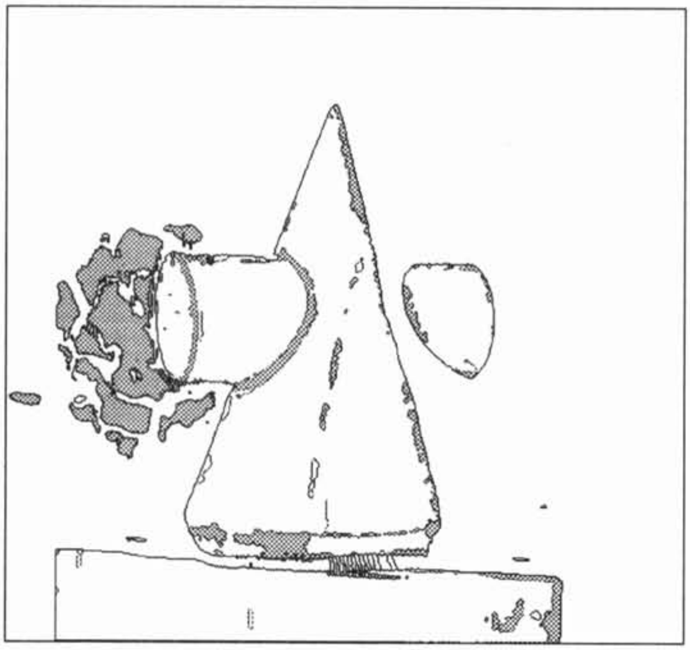


Fig.3-b Texture Regions

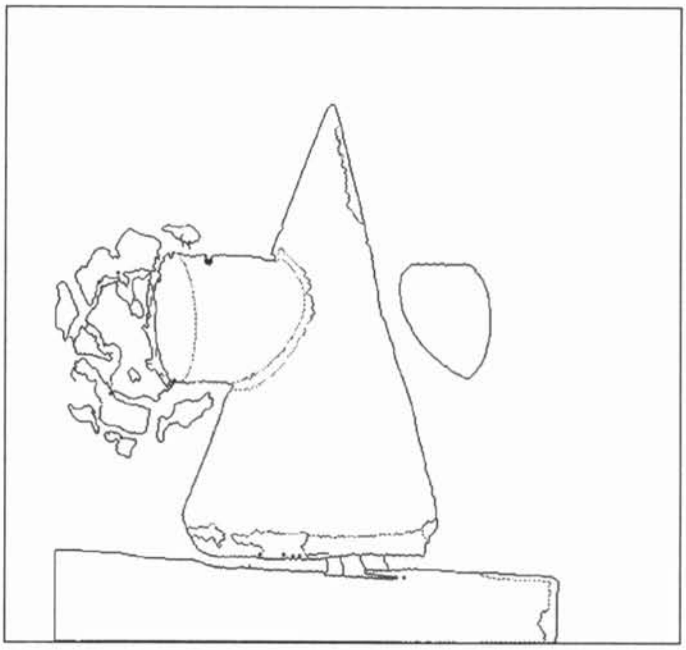


Fig.3-c Result of Merging

Fig.3 Experimental Results

threshold is controlled to eliminate this region, the true plane region (as the end of the cylinder or the box) may be more noisy.

Fig.3-b shows the result of texture regions merging. Texture regions are shown as grey area. When the regions are caused by unstable calculation of principal vectors near true geometrical discontinuity as the texture region ate the end of the cylinder, the region is tend to be a narrow region along the true edge. Then the result region for small neighboring regions becomes one of small regions and is going to be merged later.

Fig.3-c shows the result of small region merging. Most of small noisy regions are removed and large regions reflecting surface shapes are reserved. A narrow region at the intersection of the cone and the cylinder is reserved because it is slightly wider than width threshold (8 pixels in this scene). It has a concave-saddle surface type which is a reasonable interpretation of the area. This area is extracted by the ability of segmenting surfaces with different types.

6. Conclusion

In this paper, a new method for segmenting range data into regions is proposed. It is able to segment objects with curved surfaces which are smoothly connected but have different features. This method is based on the robust ISL-primary-axis calculation method for principal vectors. By robustly obtained principal vector, we can also calculate maximum and minimum curvatures which are not easily obtained by other method (as using quadric equation fitting) on real range data with noise.

The boundary image which is created at the first stage of segmentation reserves the information of how each boundary point is caused by and the information can be used in merging to erase border points which is not less significant.

The method is tested for a real range data and the result was good.

The next stage of this work is to describe the interior of each segmented surfaces using curvature lines which are derived from principal vectors.

In the future, we are going to apply this method in our program for automatic model building from range data. The models can be utilized as data base for our object recognition system.

References

(1) Oshima, M., Shirai, Y., "A Model Based Vision for Scenes with Stacked polyhedra Using 3D Data", Proc. '85 ICAR, pp.191-198 (1985)

(2) Kasvand, T., "Surface Curvature in 3D Range Images", Proc. ICPR 1986, 2, pp.842-845 (1986)

(3) Yoshimi, T., Tomita, F., "Robust Curvature Vectors Calculation from Range Data Using ISL Method", Proc. MVA'94, pp.506-509 (1994)

(4) Yoshimi, T., Ueshiba, T., Oshima, M., "Multi Light Sources Range Finder System", J. of the Robot Society of Japan, 9, 7, pp.803-812 (1991) (Japanese)