A 3D curve grouping methods and its application

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Abstract—**This paper presents new improvements to point cloud segmentation on curve grouping techniques. The proposed method is based on the similarity conception. The developed approach groups the curves from the same objects into the same region well. The algorithm is simple and easy implemented in complex real scenes. The algorithm was performed in a real application and the results proved the proposed algorithm is feasible and practical.**

Keywords--point cloud; segmentation;edge-based; curve grouping; pneumatic caisson

I. INTRODUCTION

Point cloud segmentation processes are of great importance in numerous industrial applications including pattern recognition, reconstruction, robotics, civil engineering and other industrial applications. Generally, segmentation methods can be grouped into two categories edged based approaches and region based approaches. Compared to region-based methods, edge- based methods show some high performance, such as easy to use, simple control structure and more precise localization of surface boundaries[1-3].

A typical edge-based segmentation method have been described by Jiang and Bunk—UB segmentation algorithm, which first divides a scan line into several curves using fitting methods, then group curves into regions [2][4]. As UB method is fast and robust, some researchers have proposed many improved methods based on UB method, such as Min and Bowyer dilate edge pixels and solve the under segmentation problem of UB method [5, 6]. Bellon and Silva presented a new edge detection method which first smooth the range image by a mean filter, then detect step edges using gradient and divide crease edges using angle difference[7]. However, few studies have been done on the segmentation for the real complex scenes.

The work described in this paper is also edge-based and similar to the idea of UB, but employs a new curve grouping methods. Starting with a single-view point set, we detect the edges in each scan lines and the split each scan line into curve segments. After partitioning scan lines, for each cove segments, the similarities of curves are first obtained based on the conception proposed in this paper and then curve grouping are implemented based on the similarities of curves. Using curve grouping, relatively small number of regions can be obtained. Combined with feature extraction, we can group the regions into less number of larger regions.

The approach proposed in this paper has some advantages. Other edge-detection methods are dominated by the need to fit surface. However, because of inherent complex properties of real scenes, fitting methods has proven impractical in real complex scenes (For example, pneumatic caisson described in this paper). In comparison, the approach proposed in this paper only involves the similarities of curves and therefore does not require such a fitting method.

II. SIMILARITY BETWEEN TWO CURVES

We assume that edge detection has been done well and each scan line of point cloud has been split into a set of planar curve segments. The following definitions are presented for measuring the similarities among curves or surfaces. The concept is obtained by imitating the definition of curves distance presented in integral geometry[8].

Definition 1. Let C_1 and C_2 be two curves in R^3 and let $N_1(G)$ and $N_2(G)$ be the points at which they both are intersected by a variable plane G moving along a predefined direction (or path). Define the γ approach degree of C_1, C_2 with regard to G by the maximum distance of the two points

$$\gamma = \max D(N_1(G), N_2(G)) \qquad (1)$$

Where both $N_1(G)$ and $N_2(G)$ are on the curves respectively.

The segment of a curve is called a **similar path** when the variable plane intersects with the two curves simultaneously. The arc length of a similar path is called a **similar length**. For one curve, the ratio of the similar length to the arc length is called a **length ratio**. The ratio between the similar lengths of two curves is called a **similarity ratio**.

For example as shown in Fig.8, the approach degree of C_0 with C_1 is equal with that of C_0 with C_2, both of which are σ. The similar paths of C_0, C_1 are P_0P_1 and $P_0^{'}P_1^{'}$ respectively. The similar ratio of C_0 with regard to C_1 is P_0P_1/C_0.

Remark 1. Approach degree, similar length and similar ratio are all related to the similarity between two curves. The less the approach degree γ of two curves is, the more

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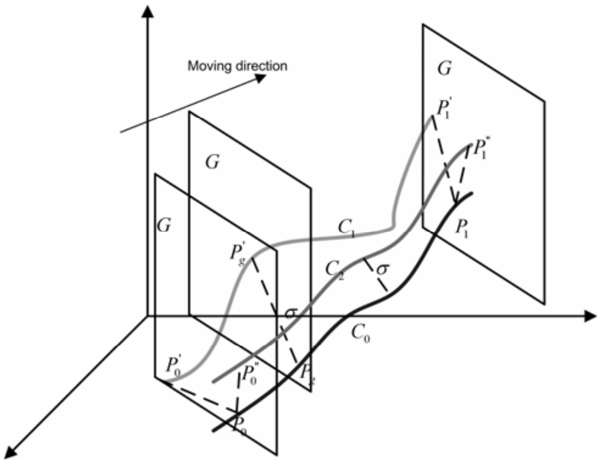

Figure 1. Diagrammatic sketch of similarity between two curves.

similar the two curves are. The longer the similar length is, the more similar the two curves are. The nearer to the ratio is 1, the more similar the two cures are. However, another important factor should be pointed out, the moving direction (or path) of the variable plane also carries weight on the above three parameters.

For example shown in Fig.1, even the approach degree of C_0, C_1 is the same with that of C_0 and C_2, as the similar ratio between C_0 and C_2 is nearer to 1 than that of C_0 and C_1. We see C_2 is more similar than C_1. However, if the similar path of C_2 was much more less than that of C_1, it would be a different matter.

III. CURVE GROWING ALGORITHM

As we have assumed a set of planar curve segments have been obtained. For a given curve, the following procedures are used to find a region which has a curve similar to the given one.

1. Given a curve from a scan line, find out all curves from the scan line which is adjacent to the first scan line.
   For example shown in Fig.2, $P_0'P_1'$ is the given curve which has two adjacent curves P_0P_1 and P_2P_3 in another scan line.
2. Set a normal for a variable plane and decide its moving path according to the two scan lines above. When the variable plane moves along the path, it may intersect with the two curves at two points simultaneously. The two points are called a pair of **correspondence points**.
   For example as shown in Fig.2, the variable plane P and the path are used to compute the similarities of the curves from the two scan lines.
3. Move the variable plane; select two pairs of corresponding sections from the both ends of the two curves respectively.

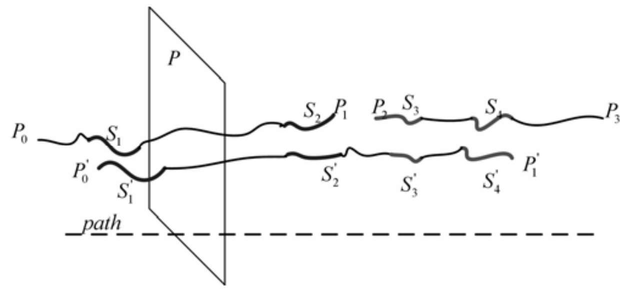

Figure 2. Schematic diagram of curve growing.

   For example as shown in Fig.2, for curves $P_0'P_1'$ and P_0P_1, the first pair of corresponding section is S_1 and S_1', and the second pair is S_2 and S_2'.
4. Compute the approach degree, the similar length and the similarity ration for each pair of corresponding sections.
5. If for the given curve, there exists more than one curve whose approach degrees of the two pairs of corresponding sections are less than the predefined threshold, add the given curve to the region which contains the curve with the longer similar path.
6. For the given curve, if only one curve whose approach degree is less than the predefined threshold, and the similar path is larger than the predefined threshold or the similarity ratio is larger than the predefined threshold, then add the given curve to the same region which contains the similar curve.
   For example as shown in Fig.2, the similarity length between $P_0'P_1'$ and P_0P_1 is more than that of $P_0'P_1'$ and P_2P_3, so, group the curve $P_0'P_1'$ to the region containing the curve P_0P_1.
7. For the given curve, if there is no curve satisfying the above conditions, and then create a new region for the given curve.
8. End until all curves are processed.
   Note. The reason for taking very short section for evaluation the similarity from two curves in step 3 is to accelerate the curve grouping speed.

IV. EXPERIMENT AND APPLICATION

The algorithm has been used in a subway pneumatic caisson in Shanghai, China. The 3D laser scanner used in the pneumatic caisson is shown in Fig. 3(a). The apparatus fundamentally consists of one 2D laser scan sensor (SICK LMS-291) which rotates around an axis with a step motor. With this 3D laser scanner, the point cloud (Fig. 3(c)) obtained inside of the pneumatic caisson can be provided for 3D reconstruction, measuring and monitoring of pneumatic caisson. A set of point cloud obtained from one 3D laser scanner have 200×722 points and the data are organized by the following array $\left[(r_{ij} \quad \alpha_{ij} \quad \beta_{ij})\right]_{200,722}$ Here, three parameters are all in spherical coordinate, and r is a distance value from a point in a object to the origin of the 3D laser scanner , α is a frame scan angle and β is a line scan angle. A range image is shown in Fig.3(c) in which direct-axis and cross axis are α and β respectively, and r is the height value.

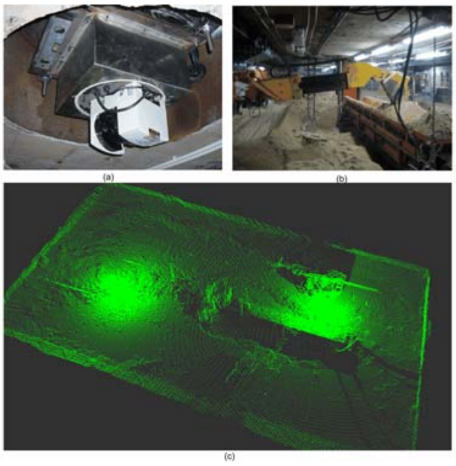

Figure 3. 3D laser scanners for pneumatic caisson. (b) the work chamber inside of a pneumatic caisson. (c) point cloud obtained by using two 3D laser scanners.

The first step is to partition each scan line into curve segments. In general, more than one 3D laser scanner is needed for scanning the whole space inside of the pneumatic caisson. For points of each scan line obtained from each 3D laser scanner, dividing and curves grouping procedures were operated in their local coordinates.

In order to split a scan line into planar curve segments, the following features are used in this application.

(1)The maximum value at each scans line or curve,

$M_i = \max(r_{i,j}(\alpha_i, \beta_j)) \quad i = 0, \cdots, n$ ()

$j = 0, \cdots, m$ (2)

Where M_i is the maximum of $r_{i,j}$ at the ith scan line.

(2)The differential-value of two neighbor points

$\Delta D_{i,j} = r_{i,j} - r_{i,j-1}$

$i = 0, \cdots, n$

$j = 1, \cdots, m$ (3)

(3)Quadric difference of two neighbor points

$\Delta^2 D_{i,j} = \Delta D_{i,j} - \Delta D_{i,j-1} \; i = 0, \cdots, n$

$j = 2, \cdots, m$ (4)

For each scan line, the partition process has several steps described as follows:

Step 1, if the point with the maximum value is not endpoint, split the scan line into two curves at the maximum point.

Step 2, if the differential–value of two neighbor points is over the threshold T_{D1} predefined, then split the curve into two parts at the point .

Step 3, if the quadric difference of two neighbor points is over the threshold T_{D2} predefined, then split the curve into two parts at the point.

Step 4, after segmenting all scans lines, curves set are obtained, where all points in a curve may belong to the same object.

We use four training samples to set the two parameters (T_{D1} and T_{D2}) which are set 70 and 40 respectively. Figure 4(1)(3) shows some three test results using the partition method proposed in this paper. By manually inspection, we can see the borders of wall, surface, excavators and other objects can be divided clearly.

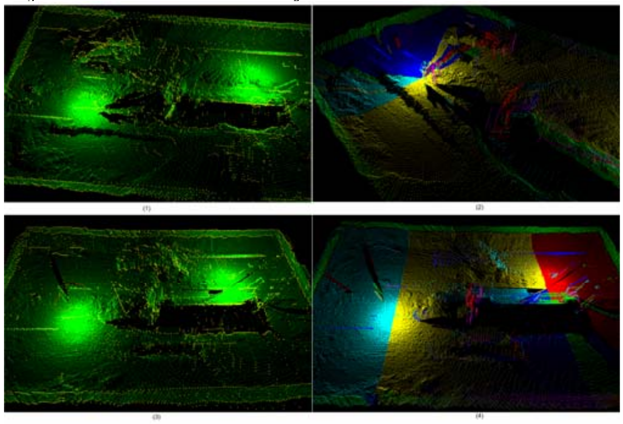

Figure 4. Example of partition and curve grouping: (1)(3) partition; (2) (3) curve grouping

The second step of the segmentation is curve grouping. In this application, we chose two points from both sides of each curve in order to evaluate the similarity between two curves. By using four training samples, the predefined similarity threshold was set to 12. The predefined similarity ratio threshold was set to 0.8 and the predefined similarity length was set to 8 points; both parameters were set according to our field experiment. For each scan line, the moving path of the variable plane is along the β axis. Three test results are shown in Figure 4(2)(4), there are 37 little regions and 79 little regions respectively.

In order to reduce the regions number obtained by curve growing, the final step, region refining, is necessary. The region refining is similar to curve grouping and has three steps. First, mean values of the points at small region border are computed according to above foundation. Then, we compute the distance values of the small region comparing with its neighbor regions. Third, a nearest neighbor region is found in its all neighbor regions, and if the distance value of the two regions is lower than threshold predefined, then merge two regions into one region. In this application,

By combining with the location of equipment inside of pneumatic caisson, the predefined threshold for region refining is set to 18. As shown in Figure 5(1)(3), not only surface and wall are divided and grouped well, but also equipment even two workers inside of the working chamber have also been detected. Figure 5(2)(4) shows the reconstruction results.

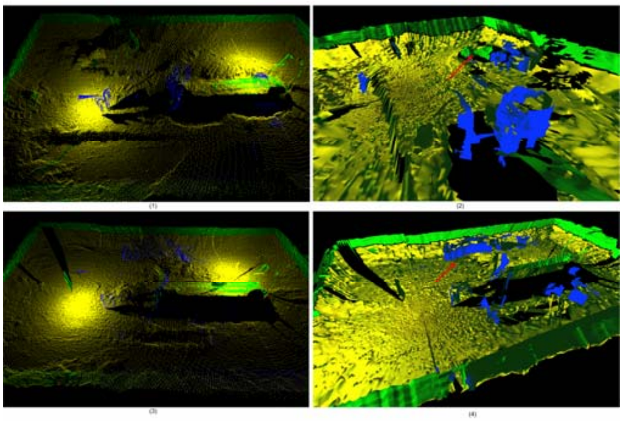

Figure 5. Example of region refining and reconstruction: (1)(3) region refining; (2)(4) reconstruction

V. CONCLUSION

This paper presents a new curve grouping approach to 3D point cloud segmentation. Unlike most previous approaches, which performed fitting surface function, we solved curve similarities and curve grouping. Because of this, our algorithm is very practical and can be used in the segmentation for a complex scene. Once curve grouping have been done, few regions can be obtained. The proposed method has been used in a practical project and the result show that the algorithm is robust and high efficiency.

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