Strand Structures Detection for 2D Shapes based on Visibility

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ABSTRACT

Strand structures such as the tails or feelers are common to man-made or natural shapes. The knowledge of the strand structures which a shape possesses can be exploited in its matching, recognition, retrieval etc. Although a variety of methods in shape decomposition have been presented, there is still a need for a robust and versatile method to detect the strand structures, especially when the shapes have large deformation or noise. Based on the visibility of points, we design a shape descriptor and propose an effective method to detect the strand structures possessing in 2D shapes. An intuitive idea is that the points in strand structures can only see small number of points from their reference points inside the shape. Meanwhile, the visibility of a point is more robust than its convex-concave features. Extensive experiments have been done on shapes with various kinds of deformation and large noise, demonstrating the robustness and effectiveness of our strand structures detection method.

Keywords: Strand structure, visibility, shape analysis

1. INTRODUCTION

The shapes of objects both man-made and natural ones are often irregular. They usually consist of a main structure and strand structures as shown in Fig.1(a) or only some strand structures as shown in Fig.1(b). Such complexity brings more difficulty to calculation, huge matching cost and low accuracy when doing some tasks such as shape matching, recognition, retrieval and other operations on 2D shapes. Therefore, extracting strand parts of a shape is a important preprocessing step for the mentioned operations [1].

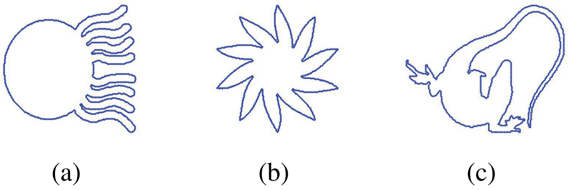
(a) (b) (c)

Figure 1. Examples of complex shape contours, which are selected from MPEG-7 data set [2].

Observing the details of the strand structures are often ignored when human recognize a shape, Andrew and Brent et al. [1] propose a method to extract the strand structures of shape contours and compare the base structure and the set of strand structures separately. They define a shape component as a strand structure if it meets three criteria: (a) attaching to a base structure, (b) with smaller size compared to the whole shape, and (c) thin and elongated. In order to extract the strand structures, they first triangulate the shape contour and construct a medial-axis tree which is the dual graph of the triangulation. Paths with long distance from a leaf node to its nearest joint node of the medial-axis tree correspond to branches of the shape. Then thresholds based on (b) and (c) are exploited to check whether the branches are strand structures or not. Generally speaking, how to obtain a meaningful shape decomposition has been considered as a fundamental problem in many shape-related areas [3]. Many shape decomposition methods based on convex-concave features [4–6], medial-axis, relatability [7] etc., are proposed in the literature. Most of these methods can be used to extract strand structures in the shape, too. However, the existing methods have the following problems:

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- The method proposed by Andrew and Brent et al.[1] cannot deal with shapes with only strand structures as pointed out by the authors.
- The local features like concaveness or negative curvature minima are usually used to extract meaningful parts of the shape. However, most of them are susceptible to noise, since concaveness or negative curvature minima is a local measure.
- In general, the existing strand structures detection method cannot yet provide entirely satisfactory solutions to handle the shape variations well, when substantial noise and deformations (Fig. 1(c)) are present.

In this paper, we present an effective strand structure detection method for 2D shape based on the visibility of each point on the shape. From a viewpoint, Katz et al. [8] propose a simple and fast operator–the hidden point removal (HPR) operator to determine the visible points on the shape. A robust extension to noise case is presented by Mehra et al. [9]. Inspired by the similar idea, Liu et al. [10] develop a part-aware surface-metric for dealing with 3D shapes based on the visibility of points. How can we extract strand structures by the visibility of points? A native idea is that if the viewpoint is located in a strand part of the shape, only some points of this part can be seen. In contrary, if the viewpoint is in the main part of the shape, much more points of the contour can be seen. Thus, if a threshold is set, we can make a decision whether the viewpoint is in a strand part or a main part based on visibility of the viewpoint.

Contributions: We propose a strand structure detection method, which handles shapes with noise and possessing deforming strand structures. We design a shape descriptor based on visibility and the descriptor is more effective than convex-concave features in strand structure detection.

2. METHODOLOGY

In this paper, we refer to shape S as the contour of the object O, and S is represented by the separated arc-length parameterized landmark sequence $S(n) = \{p_1, p_2, ..., p_n\}$ in a clockwise direction, where $p_i = (x_i, y_i)$ is the i-th point, with x_i and y_i as its corresponding coordinates.

2.1 Overview

Here, we focus on shape S with some strand structures $T = \{T_1, T_2, ..., T_m\}$, where T_i is the i-th strand structure and is represented by the corresponding points of $S(n)$. The aim of our strand structure detection method is to extract all the T_i correctly.

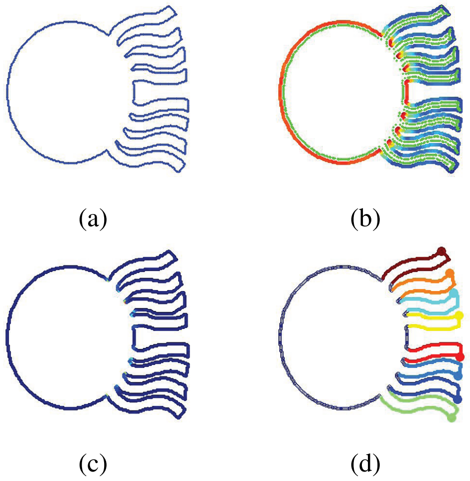

Figure 2. The overview of our strand structure detection method. (a) The shape from MPEG-7 data set [2]. (b) Reference point (illustrated in green color) construction and visibility computation. Blue color represents low visibility, and red color represents high visibility. (c) The descriptor exploited for detecting strand structures. (d) The detected strand structures.

The main process of the method consists of three steps: reference point construction, visibility computation and strand structure detection. Given a shape S represented by $S(n) = \{p_1, p_2, ..., p_n\}$, we first compute the reference point q_i for each p_i (Sec. 2.2). An example of reference point set is illustrated in green color in Fig. 2(b). Next, take each point q_i as a viewpoint, and determine the visible point set P_i on the shape S via HPR operator (Sec.2.3). The main observation is that P_i and P_j are similar for p_i and p_j located in the same strand structure part, otherwise are very different. Thus, an shape descriptor based on it is designed to detect the strand structure of S. Details of the algorithm is discussed in Sec. 2.4. Fig. 2 gives an overview of our strand structure detection method.

2.2 Reference Point Construction

To determine the visibility of a given point p_i on the shape S, its reference point q_i should be located inside S and near p_i. A natural choice is Eq. 1.

$$q_i = p_i + r * n_i, \tag{1}$$

where n_i is inward normal vector and r is the displacement. In experiments, we find that the value of r has little influence on the later visibility computation. Thus, $r = 5$ is selected in this paper. For points located at very thin regions, their reference points computed according to Eq. 1 are sometimes outside the shape. In order to avoid this, its reference point is chosen as the center of the maximal sphere inside the shape and tangent to the surface at the point. An approximate method for computing it is proposed by Liu et al.[10].

2.3 Visibility Computation

To evaluate the visibility v_i of a point p_i on the shape S, one can view from its reference point q_i and look for the visible points on S. HPR operator [8] gives a simple but effective method to accomplish this by a two-step process of inversion and convex hull computation. An illustration is in Fig. 3. First, each point on the shape S is inverted about the viewpoint q_i (the black point in Fig. 3) via an inversion function. A typical one is spherical inversion function, which for any point p_j, defined as Eq. 2

$$p'_j = p_j + \frac{2(R - \|p_j\|)}{\|p_j\|} p_j. \tag{2}$$

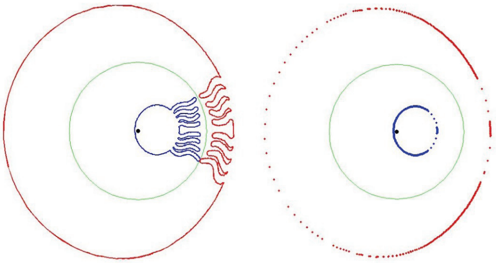
(a) (b)

Figure 3. The process of HPR operator. (a) Spherical inversion. The black point is the viewpoint. (b) Convex hull computation. Points in red color are on the convex hull, and points in blue color are visible from the black point.

Here, assuming q_i is at the origin, R is the radius of inversion. In Fig. 3, R is the distance between q_i and its farthest point of the shape. In the next step, the convex hull of all the inversion points p'_j and the origin q_i is taken. Points shown in blue color in Fig.3(b) in the original point set S are visible from q_i since their inversion points shown in red color get mapped onto the convex hull. Supposing the visible points are represented by a point set P_i, we simply defined the visibility v_i of the point p_i as the number of points in P_i.

2.4 Strand Structure Detection

Upon obtaining the visibility v_i and P_i of each point, the next step is to detect the strand structure based on these information. Supposing there is a strand structure T_i of the shape, one observation is that from the reference point of a point p_i belong to T_i, the visible point set P_i usually has a small number. Thus, a intuitive idea here is to detect the continuous points with low visibility value in S, which is illustrated in Fig. 2(d) in different colors. A threshold R for visibility can be introduced to tell whether a point belongs to a strand structure or not. However, in experiments, we find that the detection result is insensitive to the selected threshold. In order to increase the robustness of the detection, another descriptor s_i is introduced for each point p_i. s_i is computed by Eq. 3

$$s_i = \frac{\|P_{i-t} \oplus P_{i+t}\|}{\|P_{i-t} \cap P_{i+t}\|}, \tag{3}$$

where $\oplus$ is the symmetric difference of two sets. s_i measures the difference of the points seen by the neighbor points p_{i-t} and p_{i+t} of p_i. $t = 5$ is chosen in this paper. s_i will have higher value when p_i lies in a joint area of different parts.

Algorithm 1: Strand Structure Detection Algorithm.

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Input   : The weighted graph $G$, visibility vector $V$, The number $N$ of strand structures belong to the shape.
Output  : The strand structures $T = \{T_1, T_2, ..., T_N\}$ of the shape.
Detect_strand_structures_number $i = 0$
while $i <= N$ do
    Finding the point $p$ with minimum visibility value of $V$;
    Computing the distance $D(p, p_j)$ between $p$ and each point $p_j$ in $G$ by Dijkstra algorithm;
    $T_i = \{p_j | D(p, p_j) = 0\}$;
    Removing the corresponding elements in $V$;
    $i = i + 1$;
end while
```

Based on the two descriptors v_i and s_i of point p_i, a combined descriptor c_i is obtained and computed by Eq. 4

$$c_i = v_i^{\alpha} s_i. \tag{4}$$

p_i with lower c_i tends to lie in the strand parts. A threshold R is exploited to distinguish whether p_i is located in the strand structure or not. Larger α in Eq. 4 can increase the robustness of T. We select $\alpha = 5$ and $R = mean(c)$ for all the experiments in this paper. In order to detect all the strand parts of the shape effectively, a weighted graph $G = (P, E)$ is constructed as follows: all the points on S are selected as the nodes. An edge e_i links two neighbor nodes p_i and p_{i+1}, and the weight for it is set with zero if $\|c_i - c_{i+1}\| < R$, otherwise the weight is directly set with $\|c_i - c_{i+1}\|$. Then the strand parts are detected by Algorithm 1.

3. EXPERIMENTAL RESULTS

In this section, we evaluate the performance of the proposed strand structure detection method. The experiments are carried out on a computer with an Intel(R) P8600 2.4GHz CPU and 2GB memory. The codes are implemented in MATLAB 2010b. The implementation of HPR operator is provided by Katz et al. [8].

The strand structure detection tests are performed on (a) shapes with one main structure and many deforming strand structures (the first row of Fig. 4), (b) shapes with large deformations and a long strand structure (the second row), (c) shapes with only some strand structures (the third row), and (d) their corrupted versions (Fig. 5).

Now, we describe the parameters used in the experiments. We select the displacement $r = 5$ in Eq. 1, $t = 5$ in Eq. 3, $\alpha = 4$ in Eq. 4 as the default cases.

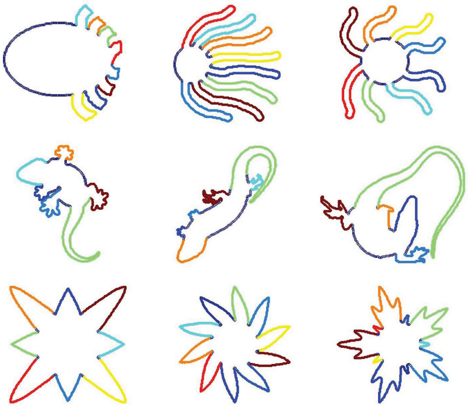

Figure 4. The results on shape with various kinds of strand structure.

3.1 Shapes with Various Kinds of Strand Structure

Shapes in Fig. 4 possess different kinds of strand structures. We perform the detection algorithm on each shape, and choose all the parameters in the default case.

The octopuses in the first row are selected from MPEG-7 shape database [2] which consist of one main body and eight arms existing in different gestures. Since in each shape, only a few points on the shape are visible viewing inside the arms of the octopus, our method correctly detects all the eight arms. The lizard in the middle row presents large deformations. It is difficult for classic method to capture its strand structures correctly, especially the long deforming tail. Our method can handle the problem and detect its head, feet and tail correctly. The flower shapes in the third row are constituted by only some leaves, and without main structures. Our method can deal with this kind of strand structures, too.

3.2 Experiments on Shapes with Noise

Noise is widespread in the shape data, which usually has significant impact on the performance of existing method. In order to evaluate the robustness of our method to the noise, we add varying amount of noise on the shapes in Fig. 4. The extended version of HPR proposed by Mehra et al. [9] is exploited to alleviate the influence of noise.

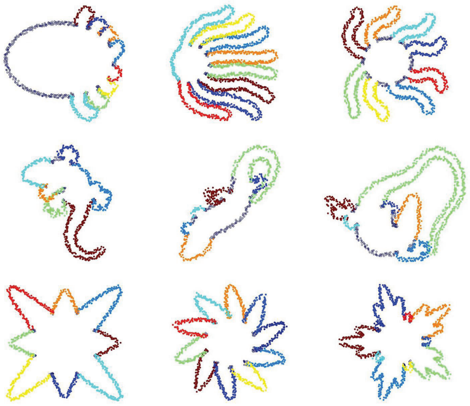

Figure 5. Strand structure detection results for the noisy version of the above shapes.

Each point on shapes in Fig.5 is added 6-pixel length additive uniform noise in normal direction. Some parts of the shapes are heavily corrupted, such as feet of the lizard and the small details of the last flower. We increase the threshold R used in Algorithm 1 as $R = 3 * mean(c)$ to avoid only extracting a part of the feet for the lizard, and other parameters are selected in the default case.

The detection results show that the strand structures extracted by our method are stable under noise, except for the strand structure colored in sky-blue of the second octopus. Meanwhile, the last flower has strand structures in different scales, the existing methods based on concave-convex feature are susceptible in this case due to heavy noise. Our method is more insensitive to noise and extracts all the strand structures with different scales, since visibility is a more global measure than concave-convex feature.

4. CONCLUSION

Based on the visibility of points on the shape, we propose an effective strand structure detection method. The main observation is that points located in strand structures have a limited view. Our method can deal with shapes consist of main structures and strand structures, or strand structures only, even these strand structures have large deformations and noise. In future work, we plan to explore more complex shape decomposition tasks that can fully exploit the visibility of points which reflects the size of their located parts.

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