

INFERRING MOTION OF CYLINDRICAL OBJECT FROM SHAPE INFORMATION

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ABSTRACT

This paper explores methods for Inferring motion of a cylindrical object from an image sequence. A local shading analysis method segments each image into spherical, cylindrical, and planar surfaces. The cylindrical surface is characterized with a direction of generating lines determined from spatial derivatives in the image. An extended reflectance map method is applicable to estimate gradients of base in consecutive frames if the lighting conditions are known.

Another approach to Inferring of motion is to use shape information which needs an additional constraint. If two planes of the object are not parallel, then the finding of correspondence between frames is easy. For the case of parallel planes, we introduce an additional assumption that the planes are orthogonal to the generating lines. This strong constraint is not sufficient for determining the surface normals from single view. The orthogonality also gives another constraint between a change in area of the base plane and that in length of generating line from the first to the second frames. Thus we can estimate orientations of the base plane from two views. Finally, motion parameters are estimated by correlating two shapes of the base boundary mapped from the two views.

1. INTRODUCTION

This paper explores methods for inferring motion of a cylindrical object, one of the most familiar shape classes for us, from an image sequence.

Recent studies on computer vision have exploited methods for interpreting changes in an image sequence as motion in 3-D space. Most methods find correspondence of feature points between frames and reconstruct 3-D structure of rigid objects (Ullman, 1979)(Nagel, 1981). The correspondence problem, however, is difficult especially for curved objects if their surfaces are without any markings.

We investigate methods for inferring motion of cylindrical object from two approaches. One is to analyze shading information to obtain the normals of surfaces which are useful for finding correspondence of base planes.¹ The local shading analysis (Pentland, 1982) is not applicable to estimate a normal at a point on a cylindrical surface if lighting conditions are unknown. With knowledge of the lighting conditions, we can determine motion between frames by an extended reflectance map method.

Another approach to inferring of motion is to use shape information. The method also needs an additional constraint. A trivial case is that two planes of the object are not parallel. We can easily determine correspondence of three points on the object between frames.

Difficulties in finding of correspondence appear when the two planes are parallel. Since we do not know orientation of the base plane, it is difficult to find correspondence of any point on the plane except its

centroid if the boundary is smooth. We introduce an assumption that the two planes are orthogonal to the generating lines, because many man-made objects satisfy this condition. This strongly constrains the surface normals of the object, but it is not sufficient to determine the normals. The orthogonality, however, gives another constraint between a change in area of the base plane and that in length of generating line from the first to the second frames. Thus, we can estimate orientations of the base plane in the two frames, and the motion parameters are determinable. The method is robust, because reliable parameters such as areas of base plane and lengths and directions of generating line in the two frames are used.

2. BASIC ASSUMPTIONS

Computational analyses in this paper assume the following four conditions.

- (1) The projection from scene to image is orthographic.
- (2) The scene contains a moving rigid object.
- (3) The object has a cylindrical and planar surfaces. Here, a cylindrical surface is defined as a surface covered with parallel lines (generating lines) passing through a closed curve.

We can segment an image projected from a scene containing unknown shaped objects into spherical, cylindrical, and planar surfaces if (4) is assumed. That is, we can test whether (3) is true or not. (4) The surface is Lambertian and of a constant albedo. The distribution of illumination is constant (a distant point source illuminant).

3. SHADING ANALYSIS

Pentland presented an interesting computational analysis of local shading without knowledge of lighting conditions (Pentland, 1982). It gives an estimate of surface orientation for an umbra (with equal principal curvatures) point on a Lambertian surface, and also identifies whether the surface is planar, singly or doubly curved at each point.

We use this algorithm for segmentation of image to find each surface and its property; spherical, cylindrical, or planar one. Figures 1 show examples of input images (256 by 256 8bit digital images of a moving cylindrical object synthesized by computer) and Figure 2 is the result of analysis of Figure 1 (a). From this picture we get information that the object has a cylindrical and a planar surfaces. Also another important feature of cylindrical surface; a direction of generating lines in image, is obtained.

If the orientation of the base plane is known, we can estimate the shape of the base by mapping its contour in image onto a plane (parallel to the base). Thus, we can find correspondence of each point on the boundary of the base between consecutive frames from which motion in 3-D space is determinable.

If analysis of shading can determine the normals

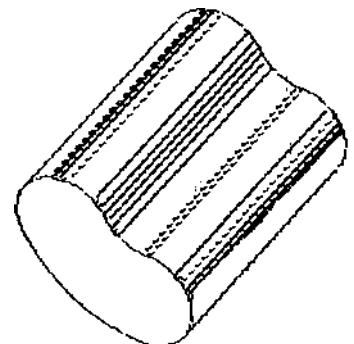
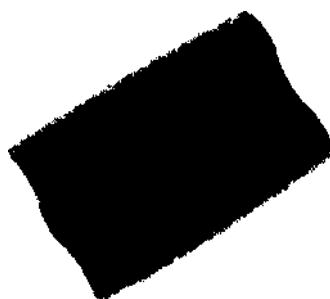
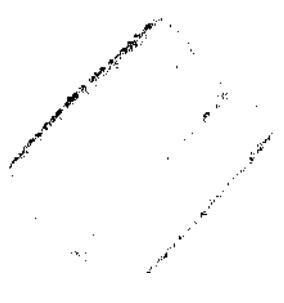


Fig. 1 Input images.

of cylindrical surfaces, they constrain the orientation of the base plane. The local shading analysis, however, cannot estimate surface normal of a point on a cylindrical surface without knowledge of lighting conditions. The detailed discussions appear in a companion paper (Asada and Tsuji, 1983).

If we know three parameters of illuminant (albedo times illuminant intensity and two parameters of illuminant direction), the surface normal is determinable by the local shading analysis. An alternative approach is possible under these conditions; an extension of the reflectance map technique proposed by Horn (Horn, 1977). Now we examine relations between orientations of cylindrical surfaces and the base plane. The analysis in the gradient space for investigating orientations of three planes which meet at a Fork joint is also useful to our case. Figures 3 show an image of cylindrical object and the gradient space representing orientations of surface patches of the object. Since we have found generating lines, the cylindrical surface in image is segmented into surface strips containing each generating line. Let G_i be a point in p-q plane representing the gradient of base plane. We select two arbitrary surface strips on the cylindrical surface and denote corresponding points in p-q plane as G_2 and G_3 . These three points are constrained by directions of three lines; a generating line and two tangents of the base boundary at the cross points of the selected surface strips. Thus, we need to know three unknowns, the location and size of the triangle $G_1G_2G_3$, to determine these surface normals. By utilizing intensity values of the surface strips and the base, these normals are determinable (Horn, 1977). The computation, however, is rather complex, because we need to find locations and

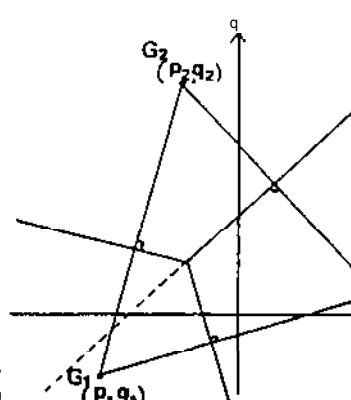
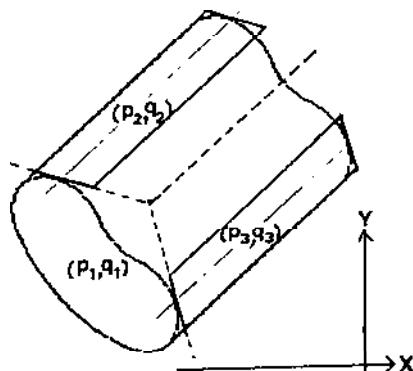


Fig. 3 Mapping to the gradient space.

(b)

Fig. 2 The result of surface classification for Fig. 1(a).

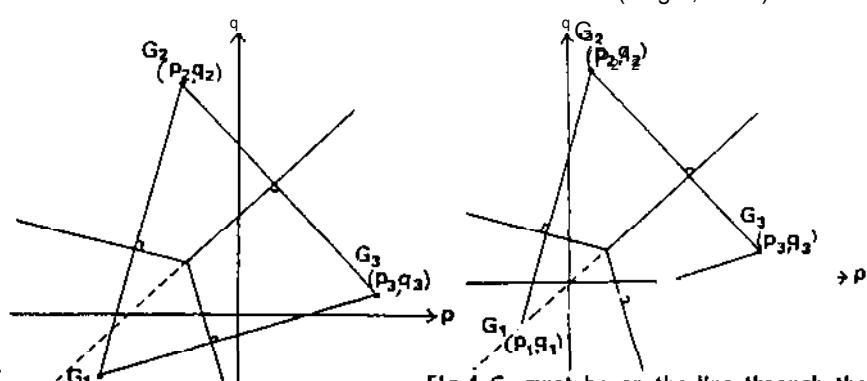
sizes of triangles of which vertices are exactly located on conic curves specified by reflectances of surfaces and the lighting conditions.

We propose a much simpler method to determine the orientations. First, the brightest generating line in the cylindrical surface is found and its intensity is measured. Its gradient is determined in p - q plane as points of contacts of lines with a conic curve specified by the intensity value in the reflectance map. The direction of the tangents are given as orthogonal to the generating lines. Therefore, the gradient of the base plane is obtained as cross points of a conic curve with the same reflectance as base and lines from the gradients of the brightest generating lines in p - q space. The lines are orthogonal to the base boundary at the brightest generating line in the image plane.

The companion paper (Asada and Tsuji, 1983) shows how we can estimate albedo times illuminant intensity if the illuminant direction is known. This paper does not exploit the shading analysis further. The following section discusses on methods for inferring motion from shape information; the direction of generating line and the boundary of base in the image!

4. INFERRING MOTION FROM SHAPE INFORMATION

At first we consider a simple case for which correspondence of points between frames is easily established. If two planes of cylinder are not parallel, we can find the longest (or shortest) generating line from the image. Thus, we can establish correspondence of three points, two end points of the longest generating line and the centroid of a visible plane, between consecutive frames, and the motion of object in 3-D space is determinable from three views (Nagel, 1981).



(b) Fig. 4 G1 must be on the line through the origin and parallel to the generating line.

Now, we deal with more complex case; the two planes are parallel and finding of correspondence' is difficult. As described in i the previous section three unknowns are undetermined without knowing the lighting conditions. Therefore, we need an additional constraint to estimate the orientations. Let introduce an additional assumption that the planes are orthogonal to generating lines. The orthogonality gives two constraints, thus one unknown is left undermined. The analysis in the gradient space becomes very simple (see Figure 4). A point representing the orientation of the base plane in p-q plane is on a line passing through the origin with the same slope of the generating line in the image plane. The undetermined unknown is the slant of the base plane (or a generating line) to the image plane. If we know the slant, the 3-D geometry of the object is completely determinable.

Note that the additional strong constraints are not sufficient to determine the 3-D shape of the cylindrical object from single view. We can, however, determine the shape from two views, A(1) and A(2), areas of the base plane and 1(1) and 1(2), lengths of generating line in the image in the first and second frames are measured. Their changes give us very useful information. Since we assume the orthogonality of generating line to base plane, there are strong constraints between these values. Simple computation yields the following relation,

$$\begin{aligned} R &= A(2)/A(1), S = l(2)/l(1), \\ \alpha &= \cos^{-1}((1-S^2)/(R^2-S^2))^{1/2} \end{aligned}$$

Where (1) is the surface slant of base at the first frame. Thus the normal of base plane is uniquely determined. From this information, we can map the contour of base onto a plane parallel to it in order to determine its shape. By correlating two mapped shapes of the base from the two views, we can establish correspondence of each point on the boundary of the contour between two frames. Therefore, the 3-D motion parameters are completely determined.

Figures 5 give the result of applying the method to the input images of Figures 1. Figures 5 (c) and (d) show the mapped contours from the images, and (f) displays how these two contours are correlated. The good coincidence' of two curves in shape means the precise correspondence between the two frames is established. The proposed method is robust because we use much more reliable shape parameters such as area of base and direction and length of generating line than intensity

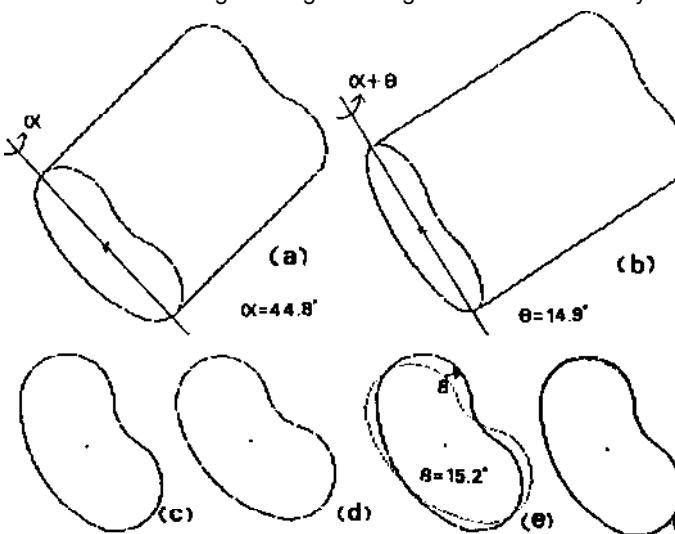


Fig.5 Experimental results.

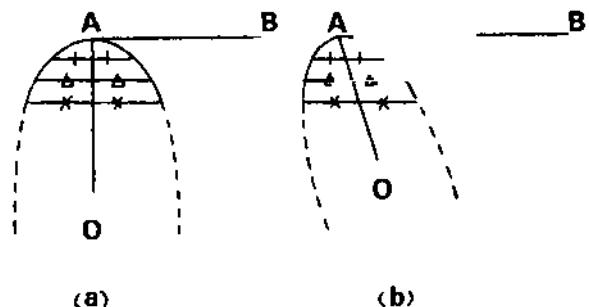


Fig. 6 Necessary condition for the orthogonality.

value of each point used in the usual shape from shading method. Thus, the estimated orientation has only a small amount of error, less than one degree for the synthesized images.

Generally speaking, we do not know whether the base is orthogonal to the cylindrical surface. A simple necessary condition for the orthogonality is obtained under - a condition that the cylindrical surface is approximated locally as a circular cylindrical surface.' If the circular cylindrical surface is orthogonal to the base, the line connecting A, the point of contact and O, the center of circle is also orthogonal to the occluding boundary AB in the image as shown in Figure 6 (a). That is, the proposed method is not applicable if the input image sequence contains any frame in which the angle BAO is far from 90 degree as shown in Figure 6 (b). The angle gives another constraint between the surface normals of object, but two unknowns per frame are left undetermined.

5. DISCUSSIONS

We have explored methods for inferring motion of cylindrical object from an image sequence. The shading analysis needs to know the lighting conditions to estimate surface normals. We argue the method is not reliable even if we have such information.

Analysis of shape information also needs an additional assumption,to determine the surface normals. If the planes are not parallel, it is easy to establish correspondence by finding the longest generating line. For the parallel case, we introduce an assumption that many man-made objects satisfy, the orthogonality of base to generating line. This constrains the surface normals and we can determine them from two views. The method is robust because we use only reliable parameters. Also we do not need the basic assumption (4) is strictly true. The shading analysis is only for classifying the regions and finding the directions of generating lines.

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