曲面構造復元のためのテクスチャからの面パラメータ推定

小川直澄　寺内睦博

広島大学

テクスチャは単眼静止画像からでさえ，対象表面の３次元構造に関する重要な情報を提供する．そのため従来，テクスチャの特徴を用いて物体表面の３次元構造を復元する様々な手法が提案されてきた．しかし，それらのほとんどが平面構造復元に関するものであるため，本論文ではその拡張として，一様なテクスチャを持つ曲面構造復元に関するアプローチを提案する．本手法においては，対象曲面は局所平面の集合として与えられ，あらかじめ得られていると仮定する基準局所平面の差分統計量と他の局所平面の差分統計量との比較によりそれぞれの局所平面のパラメータ推定を行う．

The Estimation of Planar Surface Properties from Texture toward Reconstruction of a curved Object

Naozumi Ogawa and Mutsuhiro Terauchi

Department of Circuits and Systems,
Faculty of Engineering, Hiroshima University
Higashi-Hiroshima, 724, Japan

Texture provides an important information on a 3D structure of a surface even from stationary monocular view. Accordingly, various methods have been proposed to reconstruct a 3D surface by using its feature. But most of them were for planar surface reconstruction. Then, in this paper, we present an approach to reconstruct a curved surface with uniform texture. A curved surface is considered to be a set of local planes, and it is reconstructed approximately as a result of estimating properties of local planes by comparing with a properties of standard plane which is given previously.

1. Introduction

The process of reconstructing a 3D shape from a 2D image is one of the important problems in computer vision. Generally, the issues of the 3D shape reconstruction from a monocular view is to become ill-posed problem, so it is not guaranteed that the solution is unique. Accordingly, in order to solve this problem, some additional assumptions are necessary about the object or the surface. When we human being observe a surface covered with a peculiar pattern (texture) even from a monocular view image, we perceive surface orientation because of distortion of the texture on the image. So, it is effective to utilize a texture for 3D reconstruction, when it exists on the object surface, from a monocular view image.

The method to estimate the surface orientation from the distortion of the texture is called *shape-from-texture* problem. Various methods have been proposed to solve this problem. Assuming that a texel, which constitutes texture, is distributed equally, Gibson proposed the procedure to estimate the orientation of the surface of the object using the distortion of texel density caused by perspective projection[1]. Ohta computed the orientation of the object surface by estimating vanishing points from the areas of texels and their distortions caused by perspective projection[2]. These methods are based on a condition that the structure of texel has been already known. It is, however, not easy to extract a particular texel on the surface.

On the other hand, Witkin directed his attention to the direction of edges in texels. He estimated the surface orientation from the probability density function of edge directions under the parallel projection on condition that the directions of edges on the object surface are assumed to be isotropic[3]. Furthermore, Aloimonos gave attention to "edge element", which is components of texel, and extracted the surface orientation from the inhomogeneity of the total length of edges in each local region on the image[4].

In the above methods, although the texture is gray level image essentially, it is hard to say that the change of the gray level had been utilized effectively. Furthermore the elements of edge was not able to be extracted exactly. Therefore, it was required to estimate the surface orientation directly from the gray levels of the original image. Then, Matsushima et al [5] proposed the method to estimate the surface orientation by using the difference statistics of the gray levels, which depends on the distance and direction on the image. On the basis of the assumption that any region on a textured plane of the object has the same probability density function of the difference statistics, they formulated the relation between the distortion of the probability density function and surface orientation under perspective projection. But it is necessary to use more than two difference statistics in order to estimate the surface orientation.

Thus, the research on planar surface reconstruction using texture have been made by so many researchers. But there is just a few studies on curved surface reconstruction. Therefore, we propose an approach to reconstruct a curved surface with uniform statistic feature. In our method, the projected image of the curved surface is segmented to many local surfaces, then their features are estimated assuming as if they are planar. The problem is that there is a case in which the feature of the texture isn't reflected significantly according to too small size of the local planar surface. So, we don't estimate the parameters of the local planes using four difference statistics for each, but do comparing only one difference statistics of the standard plane with that of the other local plane.

2. Reconstruction of the Curved Surface

When we deal with the problem of reconstruction of curved surfaces, it is necessary to consider what a curved surface is like. For example, the approach to use a global surface model like a quadric surface etc. is considered. But this approach has problems that it restricts an object of curved surface and that the number of parameter to be estimated is large. And, another approach is to approximate it by a set of local surfaces, for example planes or quadric surfaces. When we approximate by local surface with the higher order, it is better approximation of a curved surface. But because the number of parameters to be estimated is larger, it is more difficult to obtain the size of local surface enough to include the feature of the texture. Thus, in this study, we approximate a curved surface by a local plane because the number of parameter is a few, hence it enables us to use similar method of plane reconstruction. Now, The method we propose is as follows.

《The method of curved surface reconstruction》

step1: Image Segmentation

Generally, various surfaces are projected in addition to the object to be extracted. To reconstruct a 3D structure of each surface, it is necessary to extract surfaces covered with the same textures. Moreover, if the surface is curved, the observed texture uniformity is distorted because of the gradient in addition to the perspective distortion and there might exist occlusions. Thus, the aim in this step is to extract the region with one homogeneous texture, and to find occluding boundaries in the region.

step2: Approximation by the local planes

The surface is segmented into many local patches where their size is large enough to reflect the feature of the texture significantly. In addition, the size and the shape of each patch should be the same in order to compute and compare their statistic features.

step3: Decision of the standard region

A region which appears mostly like a plane among them is selected. From the estimation of surface properties of the plane, the standard difference statistics is obtained. For this judgement, all of local regions are estimated their orientations approximating each as plane.

step4: Estimation of parameter of local plane

The estimation of parameters of each local plane is performed by comparing the standard difference statistics with the difference statistics of each local plane. Then, the abstract shape of the curved surface is reconstructed as the set of these local planes.

In terms of the reconstruction of the curved surface, there is no restrictions about the geometric relation as the constraint where every windows lie on the same plane, which is always utilized in planar surface reconstruction. Therefore we need to consider the depth(the relative distance between standard plane to object plane) and the rotation on the textured plane when we compare the features of the object plane with those of the standard plane. In this paper, assuming the standard plane has been obtained already, we propose a method to estimate the parameters of the rest local planes.

3. Geometric Relation Between the Object plane and the Standard Plane

Coordinate Systems and Perspective projection

The 3D coordinates system $OXYZ$ as shown in Fig.1 is introduced to formulate the perspective projection, where its origin is set at the optical center of the lens. The image plane ouv is placed orthogonal to Z axis (sight axis) and its origin o at $(0, 0, f)$, where f is the focal length. The distance between the origin O and standard plane is set to E. The orthogonal coordinates plane

$O'UV$ is placed parallel to the image plane and its origin at $(0, 0, E)$, where the axis U on the plane is parallel to the axis u on the image plane. Therefore the surface normal unit vector w is uniquely defined by slant α and tilt β as $w = (\sin\alpha\cos\beta, \sin\beta, \cos\alpha\cos\beta)$.

Next we consider the relation between line segments on both planes.

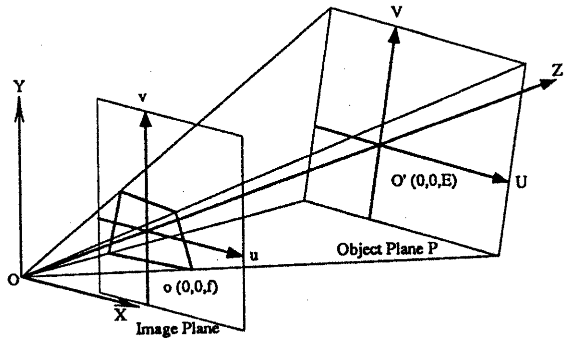

Fig.1 The coordinate systems and the perspective projection.

The length and direction of line segments on both planes

If a straight line on the object surface is projected onto the image under the perspective projection, then the length and direction are changed. Let's here assume a line whose length is L, direction θ' and the terminal point at (U, V) on the object surface. And let's here assume a line whose length is l, direction θ and the terminal point at (u, v) on the standard surface. The relation between L and l, θ' and θ are given as follows,

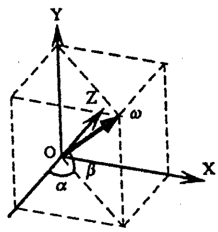

Fig.2 The surface normal unit vector ω.

$$L = D\frac{Eac\sqrt{\{(c-adv)\cos\theta + d(b+au)\sin\theta\}^2 + \{bv\cos\theta + (a-bu)\sin\theta\}^2}}{(ac-bcu-dv)\{ac - bc(u + l\cos\theta) - d(v + l\sin\theta)\}}\, l \qquad (1)$$

$$\theta' = \tan^{-1}\left[\frac{bv\cos\theta + (a-bu)\sin\theta}{(c-adv)\cos\theta + d(b+au)\sin\theta}\right] + \phi \qquad (2)$$

But considering about planes with the uniform statistics feature, the corresponding parallel line segments between standard plane and object plane do not always exist. And even if there exist line segments on each plane, each parameters aren't estimated from only Eqs.(1) and (2). Therefore, we use the difference statistics which is defined in terms of distance and direction on the image as the feature that represents texture.

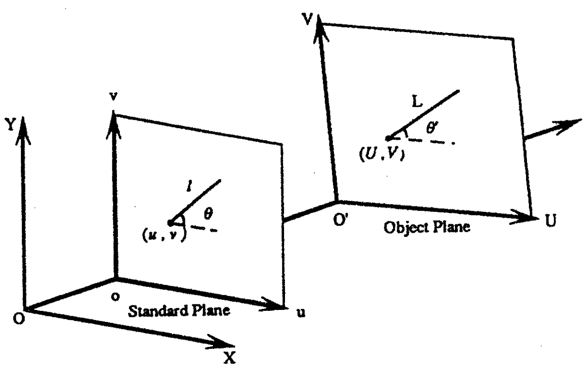

Fig.3 The relation between standard plane and object plane

4. Estimation of Curved Surface parameters using Difference Statistic

In our research the main purpose is to estimate the parameter of the object plane. In general an object plane is projected onto an image which is deformed under the perspective projection. Furthermore we assume the texture as the pattern represented by probability density function, here we introduce the gray level difference statistics which is considered as the texture representation in the polar coordinates. The pattern deformation in the image is caused by the deformation of the coordinates projected onto the image. If we could know how the coordinates or the pattern were deformed, we could obtain the parameters of the object surface using the geometry of projection. In our study the probability density function of gray level difference statistics, i.e. the pattern is assumed to be the same everywhere on the object plane. By using the assumption and the geometry of the projection we can obtain the parameters of object plane.

Method of orientation extraction

The gray level difference statistics is a probability density function $P(K \mid l, \theta)$ of absolute value K of intensity difference between a point and another point with a distance l and a direction θ from its position. Let's assume that the characteristics of texture can be represented by the gray level difference statistics which depends on the distance and direction on the image .

Under the condition that the probability density function of gray level difference statistics is the same over all local regions on the object plane, the probability density functions Pm and Pn in local regions on the standard plane and the object plane respectively hold the following relation,

$$Pm\left(K \mid Lm,\ \theta' m\right) = Pn\left(K \mid Ln,\ \theta' n\right), \qquad (3)$$

when, $Lm = Ln$, $\theta' m = \theta' n$ on the object surface. On the other hand, when the object surface is projected onto image plane, the difference statistics is distorted by perspective projection. Therefore, Eq. (3) is not held in any local regions. However, as for lm and ln, and θm and θn if the line segments on each plane are found corresponded, the density functions in the image are equal.

$$Pm\left(K \mid Lm,\ \theta m\right) = Pn\left(K \mid Ln,\ \theta n\right) \qquad (4)$$

Therefore, the orientation of the surface plane can be computed if we can find lm, ln, θm and θn satisfying Eq.(4) using a couple of density functions in the local regions on the image. It is, however, impossible to solve analytically these distances and directions, because the density function can not be anticipated in advance.

Here we introduce the following cost function:

$$J = \left| Pm\left(K \mid Lm,\ \theta m\right) - Pn\left(K \mid Ln,\ \theta n\right) \right| \qquad (5)$$

Then we estimate the surface orientation by searching α, β, ϕ and D which minimize the above cost J .

Outline of the algorithm

We show the flow of the algorithm for extracting surface parameter. First, an image of standard plane and the object plane is given as input. On each plane the size of local patches and the maximum distance $lmax$ for computing the difference statistics is determined. Next, the range for θ is set between 0 and π , and each difference statistics is computed. The initial values of the parameters α, β, ϕ and D on the object image are assigned. The corresponding values ln and θn in the standard image is computed from Eqs (1) and (2) , and then cost J is computed from Eq (5). Finally the values which minimizes the cost J are estimated by updating the values of α, β, ϕ and D respectively.

First of all, the distance D is searched. Next, the rotation that minimizes cost J is determined. Then the orientation is estimated. Finally, the initial value of each parameter is set to each estimation, and the parameters that minimize cost J is determined by searching all of them.

Algorithm for searching parameters

In order to get the parameters values of the object plane which minimize the cost J in Eq(5), we may just compute the cost J for all α, β, ϕ and D over a range -90°≤ (α and β) ≤90°, 0°≤ ϕ ≤ 180°, 0.5≤ D ≤2.0 respectively. However, it is very wasteful. So an random search algorithm which finds the suboptimal values is introduced as follows[7].

[1] Search of the orientation

1) Choose 20 sets of (α, β) in the range between -30° and 30° randomly, and compute the cost for each set.
2) Decide a center position $(\alpha, \beta)_{min}$ which minimizes the cost J out of 20 sets, and let the minimum cost be J_{min}.
3) Compute costs J for 20 sets (α, β) in the range between -10°and 10° around the center position $(\alpha, \beta)_{min}$ randomly, and let the minimum cost be J'_{min}
4) If the relation between J_{min} and J'_{min} is $J'_{min}<J_{min}$

then a set α, β which realizes the cost J_{min} is substituted into the center position $(\alpha, \beta)_{min}$ and jump to 3).

else reduce the search range 1° and jump to 3)

where, not reduce the range less than 2°; (the minimum range is 2°).

5) If the center position is not be replaced in 10 times iteration, then the position is assumed to be an estimation (α^*, β^*)

[2] Search of all parameters

Basic flow of algorithm is the same as the above search. The search values of each parameter estimation of α, β and ϕ is between -10° and 10° around the initial estimation. And the search value of parameter estimation of D is between -1.0 and 1.0 around the initial estimation. From this, we obtain a suboptimal estimation.

Interpolation of distribution matrix of difference statistics

In general, an image is constructed of pixels which are sampled discretely. Therefore it is impossible to compute the difference statistics for all direction and length. In other words, the length is obtained discrete value, that is, l =1, 2, ... , for only in a pixel distance, and the direction is obtained when θ =0°, 45°, 90°, 135° for satisfiable number of data, i.e. neighboring closely each other. So, in order to obtain for all length and direction the difference statistics is necessary to be interpolated. The difference statistics is interpolated by approximating by local quadric surface[8].

5. Results

Our method dedicated above is applied for synthesized textures and real textures in order to show its performance.

(1) Simulated texture

The simulated texture surfaces generated using MRF model with Gibbs distribution is shown in Fig 4 and 5, in which the size of the image is 512 by 512 pixels and the intensity varies 1 to 10. Fig.4 shows the standard surface whose parameters are assigned as $\alpha=\beta=0°$, ϕ =0° and D =1.0. Fig.5 shows the object surface whose parameters are assigned as $\alpha=\beta=10°$, ϕ =10° and D =1.2. The results for these images are shown in Table 1.

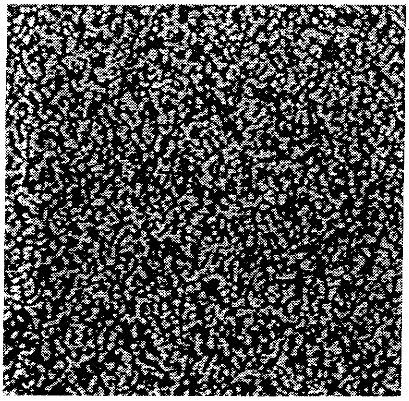

Fig.4 The standard surface with simulated texture
(α,β=0°, ϕ= 0°, D=1.0)

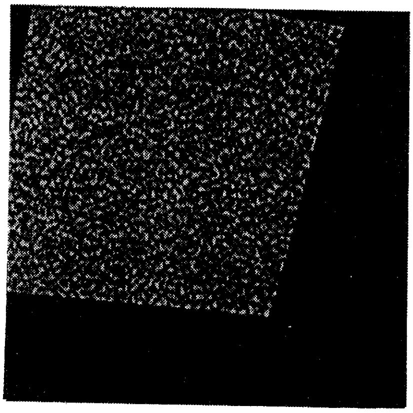

Fig.5 The object surface with simulated texture
(α,β=10°, ϕ= 10°, D=1.2)

Fig.6 The standard surface with texture of straw
(α,β=0°, ϕ= 0°, D=1.0)

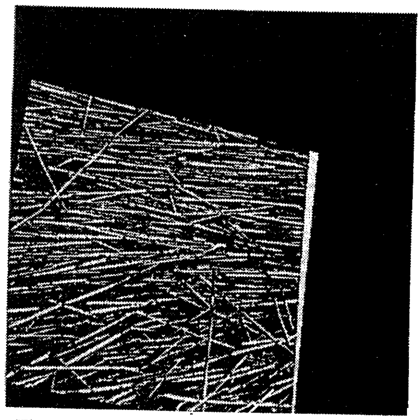

Fig. 7 The object surface with texture of straw
(α,β=10°, ϕ= 10°, D=1.2)

Table 1 The experimental results to the surface with simulated texture

		Orientation (α, β), Rotation ϕ Relative distance D
Experiment 1	True values	(10°, 10°, 10°, 1.2)
	Means	(7.5°, 8.67°, 10.5°, 1.29)
	Standard deviations	(2.81, 7.55, 0.548, 0.043)
Experiment 2	True values	(15°, 12°, 12°, 1.3)
	Means	(14.5°, 12.2°, 10.0°, 1.29)
	Standard deviations	(3.73, 1.83, 0.00, 0.013)

Table 2. The experimental results to the surface with texture of straw

		Orientation (α, β), Rotation ϕ Relative distance D
Experiment 1	True values	(10°, 10°, 10°, 1.2)
	Means	(8.0°, 14.3°, 9.83°, 1.40)
	Standard deviations	(1.67, 3.88, 2.40, 0.028)
Experiment 2	True values	(15°, 12°, 12°, 1.3)
	Means	(12.3°, 12.3°, 12.5°, 1.54)
	Standard deviations	(2.73, 4.46, 0.548, 0.044)

(2) Real texture

The surfaces with real texture of straw are shown in Fig.6 and Fig.7. This texture is quoted from the book "Textures"[9]. Fig.6 shows the standard surface whose parameters are assigned as $\alpha=\beta=0°$, $\phi=0°$ and $D=1.0$. Fig.7 shows the object surface whose parameters are assigned as $\alpha=\beta=10°$, $\phi=10°$ and $D=1.2$. The results for these images are shown in Table 2.

These experiments show that the properties of planar surface are extracted roughly though they are not still precise sufficiently.

6. Conclusion

In this paper, we proposed the method to reconstruct the curved surface with uniform texture as the extension of the method which utilized the difference statistics to reconstruct the planar surface. On basis of the assumption that the curved surface could approximated by local planes with a uniform statistics feature, we reconstruct the abstract curved surface composed by these local planes.

As the precision of the estimation of parameters is affected by the error which occurs in interpolating the difference statistics, we need to improve the current method.

Reference

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