MVA '92 IAPR Workshop on Machine Vision Applications Dec. 7-9,1992, Tokyo

A TEXTURE BASED SHAPE CONNECTION METHOD FOR 3-D SHAPE RECONSTRUCTION

Makoto MARUYA Keiji NEMOTO Yosuke TAKASHIMA
C&C Information Technology Research Laboratories
NEC Corporation
4-1-1, Miyazaki, Miyamae, Kawasaki, Kanagawa, 216 Japan

ABSTRACT

This paper describes a texture based shape connection method for reconstructing parts of an object shape into its entire 3-D shape. This method employs a stereo camera to obtain the parts of an object. First, this method finds overlaps between the parts, obtained from a number of different viewpoints, using texture. Then, the method uses the results for estimating the relative position-and-orientation between the parts. Finally, it reconstructs the entire shape by connecting the parts. The experimental results show that this method yields accurate reconstruction results, even when an object lacks shape features.

INTRODUCTION

Object modelling often consists of 3-D reconstruction from range data obtained from different viewpoints. Individual pieces of range data represent only a part of an object's shape, and we refer to them herein as "object part shapes". In order to reconstruct an object shape, we must first estimate relative position-and-orientations between object part shapes. Previous approaches to this estimation have included feature matching methods [1] and a hierarchical triangulation-based method [5]. Most approaches, however, have been shape-based, for which shape is the only data utilized in the estimation. This can be a serious problem when object part shapes do not contain sufficient features to achieve a unique estimation of relative position-and-orientations, in which case estimations may be especially susceptible to the influence of noise.

Intensity or texture data can be used here to overcome this difficulty. Vemuri, et al., for example, placed an object on a base plane marked with a pattern and used this pattern to help estimate relative position-and-orientations between object part shapes [2]. Maruya, et al. developed a texture based 3-D shape reconstruction method which uses the texture on an object's surface to aid in the estimation [4]. In this method, a stereo camera is used to obtain range and texture data, and parts of an object which lack shape features, such as a portion of a cylinder, can be reconstructed. The effectiveness of this approach has been severely limited, however, by the fact that the plane of the stereo camera has had to be maintained horizontally at all times at a specific height with respect to the object.

In the present study, we report on a modification of this method. The "horizontal" and "height" restrictions are eliminated by equipping the camera with angle meters. Since this method employs a simple stereo camera, and it can be moved without any restriction, it is especially appropriate for the reconstruction of large outdoor objects.

OBTAINING OBJECT PART SHAPES

We attached two angle meters to a stereo camera to measure the roll (α) and pitch (β) angles (see Fig.1). Pan angle and position of the stereo camera do not need to be measured because they can be successfully estimated by a proposed estimation method.

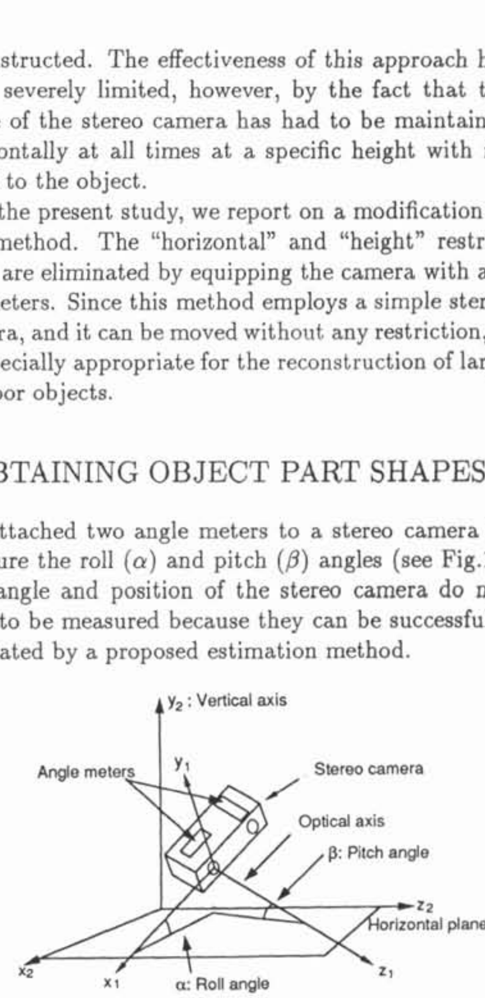


Fig.1 Stereo camera

The stereo camera moves around an object and obtains a sequence of stereo images. Each stereo image provides data sufficient to distinguish an object part shape from its background and to produce, using a conventional triangulation technique, a mesh representing the object part shape. The texture of the object part shape can be represented by attribute values attached to the vertices of the triangles which form this mesh.

An obtained object part shape is represented by a coordinate system (x_1, y_1, z_1) fixed to the stereo camera and inclined as shown in Fig. 1. The α and β

vary with the viewpoints, but they can be eliminated as factors by implementing the following coordinate transformation.

$$\begin{pmatrix} x_2 \\ y_2 \\ z_2 \end{pmatrix} = \boldsymbol{R}_x \boldsymbol{R}_z \begin{pmatrix} x_1 \\ y_1 \\ z_1 \end{pmatrix} \tag{1}$$

where

$$\boldsymbol{R}_x = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & \sin\alpha \\ 0 & -\sin\alpha & \cos\alpha \end{pmatrix}$$

$$\boldsymbol{R}_z = \begin{pmatrix} \cos\gamma & -\sin\gamma & 0 \\ \sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\sin\gamma = \cos\alpha \cdot \tan\beta / \sqrt{1 + \cos^2\alpha \cdot \tan^2\beta}$$

$$\cos\gamma = 1 / \sqrt{1 + \cos^2\alpha \cdot \tan^2\beta}$$

After this transformation, an object part shape is represented by a coordinate system (x_2, y_2, z_2). The coordinate systems vary with object part shapes, and the relation between the coordinate systems, or relative position-and-orientations of object part shapes, consists of four components: height difference h, relative positions on the horizontal plane (p, q), and pan angle θ (see Fig.2).

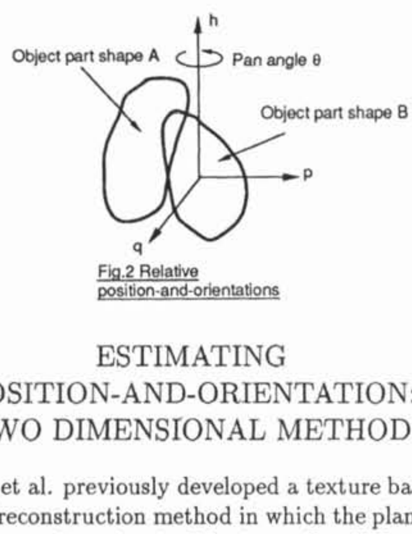


Fig.2 Relative position-and-orientations

ESTIMATING POSITION-AND-ORIENTATION: TWO DIMENSIONAL METHOD

Maruya, et al. previously developed a texture based 3-D shape reconstruction method in which the plane of a stereo camera is maintained horizontally all the times at a specific height with respect to the object. Let us review here this "two dimensional" method, since we can easily expand the two dimensional method to a "three dimensional" method.

In the two dimensional method, all object part shapes are viewed from same height, and relative position-and-orientations consists of only three components: relative positions of object part shapes on a horizontal plane (p, q), and pan angle θ.

The two dimensional method estimates these three components between 2-D object part shapes obtained from the intersections of object part shapes and a specific horizontal plane. This method consists of two processes: an overlap width estimation process and a mean square error minimization process.

Overlap width estimation process: In this process, we use texture data to estimate overlap width between two 2-D object part shapes obtained from neighboring view points. First, texture data are sampled at equal intervals, indicated as δt in Fig.3, along 2-D object part shapes. Then, cross-correlation of the sampled texture data in possible overlap areas between 2-D object part shapes is calculated, shifting the overlap width δt by δt. The overlap width which has the highest correlation is determined as being the overlap width, and sample points in the both estimated overlapped area are linked.

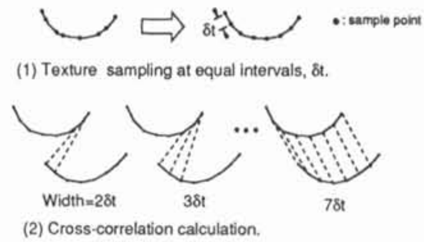


Fig. 3 Overlap width estimation

Mean square error minimization process: This process finds the relative position-and-orientation between 2-D object part shapes. The relative position-and-orientation which minimizes the the mean square error, which is defined here as the mean square sum of distances between linked sample points, are regarded as the estimated relative position-and-orientation.

Let $\boldsymbol{a}_i$ and $\boldsymbol{b}_i$ $(1 \le i \le N)$ be linked sample points, then the mean square error can be expressed as follows (see Fig.4):

$$E(p, q, \theta) = \sum_{i=1}^{N} \|\boldsymbol{a}_i - (M \cdot \boldsymbol{b}_i + \boldsymbol{r})\|^2 / N \tag{2}$$

where

$$M = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix},$$

$$\boldsymbol{r} = \begin{pmatrix} p \\ q \end{pmatrix}$$

The (p, q, θ) which minimize the mean square error is obtained by solving the normal equation of (2).

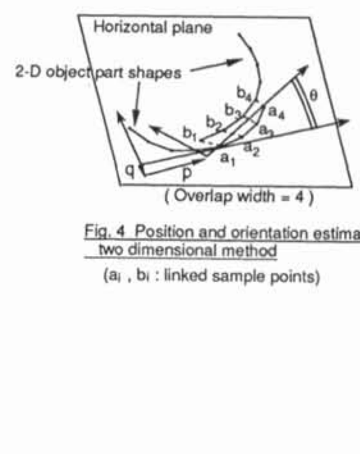


Fig. 4 Position and orientation estimation: two dimensional method

(a_i , b_i : linked sample points)

ESTIMATING POSITION-AND-ORIENTATION: THREE DIMENSIONAL METHOD

As described before, relative position-and-orientation of object part shapes consists of four components: height difference h, relative positions on the horizontal plane (p, q), and pan angle θ.

However, once the height difference h has been determined, the two dimensional estimation method can be used. Hence, in the three dimensional estimation, we first apply the two dimensional estimation method to obtain (p, q, θ) at every height difference. Then, we calculate a gap between object part shapes, we refer to it as a shape error, at each (h, p, q, θ). The (h, p, q, θ) which result in the minimum shape error are selected as the estimated relative position-and-orientation.

Now, we explain these processes to obtain relative position-and-orientation of object part shapes A and B, in detail.

Initial process: Set horizontal planes at equal intervals δh and compute intersections between the horizontal planes and object part shapes to get a group of 2-D object part shapes (see Fig.5). Next, set sample points along each 2-D object part shape at equal intervals δt. Then, sample shape data and texture data.

Two dimensional estimation process: Set the height difference h in steps of δh, and apply the two dimensional estimation method to each 2-D object part shapes of A and B located on the same horizontal plane (see Fig.6). Then, a group of (p, q, θ) is obtained.

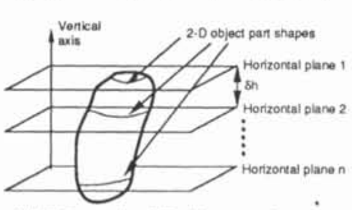


Fig.5 Generating 2-D object part shapes

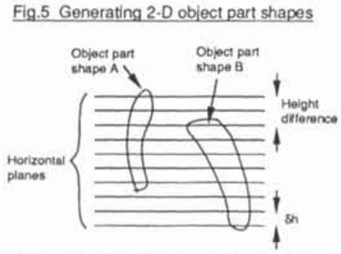


Fig. 6 Three dimensional estimation method (side view)

Shape error calculation process: First, make one-to-one links between sample points of A and that of B by finding the closest sample points to each other at height difference h and (p, q, θ) selected from the group of (p, q, θ). Next, calculate a shape error which is defined as the mean square error of the distances between linked sample points. Then, find (p, q, θ) which gives the minimum shape error at height difference h.

We don't use the linking results of the overlap width estimation for this calculation, because some results might have errors.

The two dimensional estimation process and the shape error calculation process are repeated at every height difference in steps of δh to find (h, p, q, θ) which give minimum shape error. The (h, p, q, θ) are regarded as the estimated relative position-and-orientation. After the estimation, two object part shapes are connected by triangulating both sample points.

EXPERIMENTAL RESULTS

We generated a gourd shape with a computer, and covered it with a random texture. The height of the gourd is 100mm, and the maximum diameter is 60mm. Three object part shapes, A, B, C were produced by cutting the gourd with planes parallel to the vertical axis (see Fig. 7). Each object part shape represent different part of the gourd (it can be seen from the texture), but certain overlap exist between A and B, B and C.

These object part shapes do not have sufficient features to achieve a unique estimation of relative position-and-orientations. However, they have sufficient texture data to achieve a unique estimation.

The relative position-and-orientation between A and B, height difference h, relative positions on the horizontal plane (p, q) and pan angle θ were estimated, and A and B were connected to form a shape A+B. Then, object part shape C was connected with A+B to form a shape (A+B)+C.

The reconstructed results were shown in Fig.8. Errors in relative position-and-orientation estimation are shown in Table 1. The results indicate that the estimation was carried out very accurately.

Table. 1 Estimation error ($\hat{h}$: estimated, h_0: true)

Estimation step	$\lvert\hat{h} - h_0\rvert$	$\lvert\hat{p} - p_0\rvert$	$\lvert\hat{q} - q_0\rvert$	$\lvert\hat{\theta} - \theta_0\rvert$
A+B	0	0.0000	0.0003	0.0327
(A+B)+C	0	0.0093	0.0009	0.2243
	(mm)	(mm)	(mm)	(degree)

CONCLUSION

This paper has presented a texture based relative position-and-orientation estimation method for 3-D shape reconstruction. The results of the estimation experiments showed that this method yields accurate results even when an object lacks shape features. Since this method employs a simple stereo camera, and it can be moved without any restriction, it is especially appropriate for the reconstruction of large outdoor objects.

References

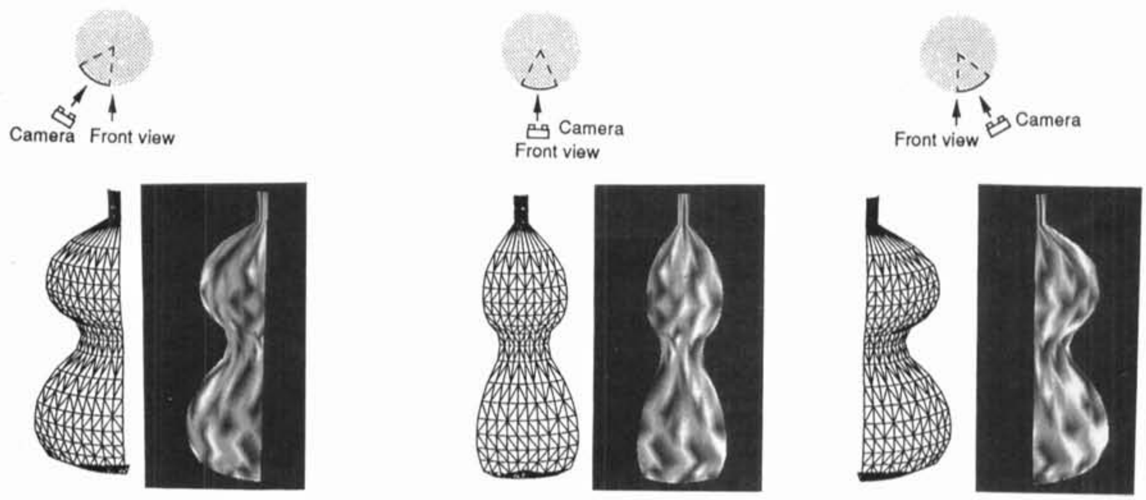
[1] B. Bhanu: "Representation and Shape Matching of 3-D Objects", IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol.PAMI-6, No.3, 1984

[2] B. Vemuri, J. Aggarwal: "3-D Model Construction from Multiple Views Using Range and Intensity Data", in Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, 1986.

[3] Reinhard Koch: "MODEL-BASED 3D SCENE ANALYSIS FROM STEREOSCOPIC IMAGE SEQUENCE" in Proceedings of ISPRS, 1992

[4] M. Maruya, K. Nemoto, Y. Takashima: "Texture based 3-D Shape Reconstruction from Multiple Stereo Images", in Proceedings of Intl. Conf. on Pattern Recognition, 1992.

[5] R. Bergevin, D. Laurendeau, D. Poussart: "Estimating the 3D Rigid Transformation Between Two Range Views of a Complex Object", in Proceedings of Intl. Conf. on Pattern Recognition, 1992.

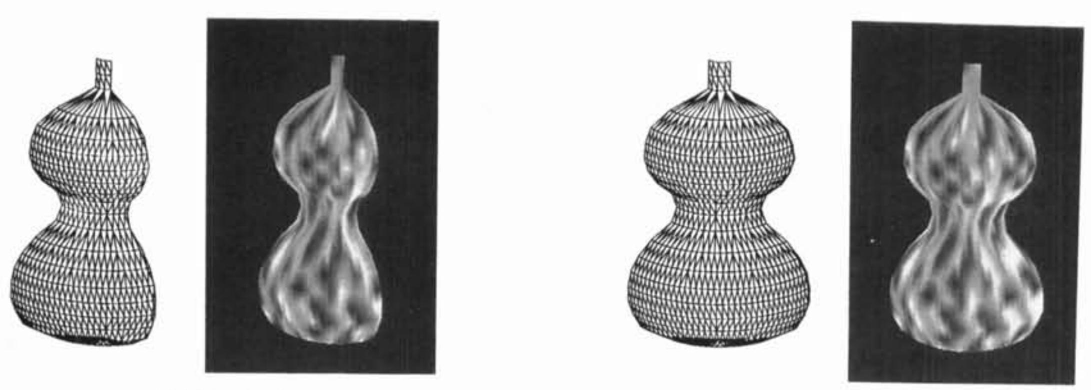


(1) Object part shape A

(2) Object part shape B

(3) Object part shape C

Fig. 7 Object part shapes (front view)



(1) Shape A+B

(2) Shape (A+B)+C

Fig. 8 Reconstructed shape (front view)
(δh = 5mm, δt = 1mm)