3D-SHAPE RECONSTRUCTION BASED ON RADON TRANSFORM WITH APPLICATION IN VOLUME MEASURMENT

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ABSTRACT

In this paper, we have adopted a novel method for 3D-shape reconstruction. We derived a volumetric data which is constructed from a stack of cross-section images- the so-called tomographic image. Each of the cross-section images is computed from a series of photographs taken at a number of angles around the object. A corresponding intensity profile (row) on each digitized photograph resembles a projection data, which can be used to reconstruct the cross-section image. Once the volumetric data is obtained, iso-surface of the object is extracted using the well-known marching-cube algorithm before being rendered with a conventional surface-rendering technique. Unlike conventional 3D-shape reconstruction (3D-shape recovery) method of using stereo pairs of camera, our technique does not suffer from laborious corresponding problem. Nor does it require a sophisticated scanning system as it does in the laser range finder. Our purposed method is tested to perform 3D-shape reconstruction of a variety of objects. The application of our purposed method for volume measurement is also presented in this paper. The results are very promising

Key words: Filtered back-projection, 3D-shape reconstruction, 3D-shape recovery, 3D-object reconstruction, surface rendering, marching cube and 3D visualization.

1. INTRODUCTION

3D-shape reconstruction is vital in many applications including robot navigation, machine inspection, 3D object recognition, distance measurement, level control, profilometry, displacement measurement, and so on. Many techniques have been purposed including stereo disparity [Barna82 and Dhond89], ultrasonic [Lamel97 and Barsh99] or laser range finder [Behei86, Bosch98, Okada98, and Sanso00], structured light [Boyer87, Hu89, Sato94, Meado70, Kratt93, and Sato85], etc. In this paper, we purpose an alternative technique for 3D-shape reconstruction, which exploit the concept of image reconstruction from projection. In this technique, a series of photographs is taken at a number of angles around the object. Each intensity profile (row) of the digitized photograph taken from different angle is then served as a radon-transformed data, which is used for reconstructing the cross-section image. Once the cross-section images of all profiles are constructed, volumetric data are obtained from a stack of the reconstructed cross-section images. Surface rendering is then performed on the volumetric data. The advantage of that this technique is that it requires only a digital camera, or normal camera with a scanner, requires no mechanical scanning and a laborious correspondence problem.

This paper is organized as follows. Section 2 briefly discusses the theory involved in image reconstruction from projection. Section 3 explains the implementation and result of purposed method. Application for volume estimation is presented in section 4. The discussion and conclusion are given in section 5.

2. TOMOGRAPHIC IMAGE RECONSTRUCTION FROM PROJECTION

An important problem in image processing is to construct a cross section of an object from several images of its trans-axial projection- a so-called tomographic image reconstruction. Many algorithms exist for image reconstruction including as Fourier [Stark81], Filtered backprojection [Herma80, Janse92], and ART [Gordon70] and ISRT [Gilbe70]. In this paper we use a well-known Filtered backprojection for image reconstruction in which the reconstruction is performed in the Fourier domain by multiplying the frequency response $|\xi|$ of the one-dimensional filter with the Fourier transform of the projection before back-projecting the inverse transform of the result, that is [Jain89]

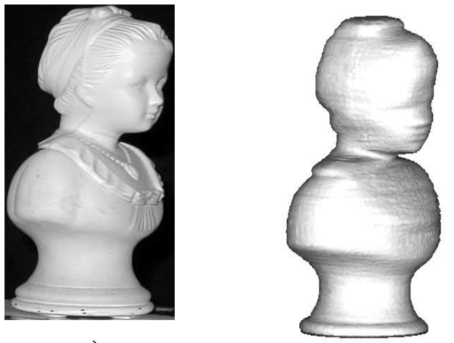
$$f(x,y) = \boldsymbol{B}\boldsymbol{F}^{-1}\{|\xi|\cdot \boldsymbol{F}\,[g(s,\theta)]\} \qquad (2.1)$$

where the backprojection $\boldsymbol{B} = \int_0^{\pi} g\,(x \cos\theta + y \sin\theta)\, d\theta$, $\boldsymbol{F}$ is the one dimensional Fourier transform and $\boldsymbol{F}^{-1}$ is the one-dimensional inverse Fourier transform. In this paper, we exploit the idea of tomographic process to construct a cross-section of the object by taking a series of photographs at a number of angles around the object. In this case, light reflected from the object acts as a source of a tomographic process. A series of the corresponding profile of the image taken at a number of angles around the object can be used to construct the cross section image of the object. The volumetric data is then constructed from a stack of cross-section image of all horizontal line. The object is then extracted and rendered.

Figure 3.1 Configuration of the system

3. IMPLEMENTATION AND RESULT

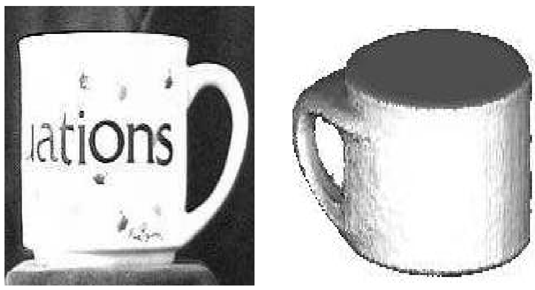
Figure 3.1 shows configuration of the system, basically consisting of the rotating platform and digital camera. The tested object is placed on the rotating platform. The platform is capable of rotating with a resolution of 1 degree per step. A photograph



a) b)

Figure 3.2 a) Original Mannequin; b) surface-rendered mannequin. (Number of layer: 196, number of angle: 60)

is taken using the digital camera. To minimize the perspective effect, we used a high focal length. The resolution of the digital camera is 640×480. After each exposure, the platform will be rotated once at a setting angle. Using the first intensity profile (row) of every digitized image, tomographic image of the first slice is reconstructed. The reconstruction is repeated for all of the 480 rows. The 2D reconstructed image is then stacked to form a volumetric data set. The iso-surface is extracted using the marching cube algorithm. The iso-surface is then illuminated and shaded using widely used Phong [Phong75] and Gouraud [Goura71] shading or illumination model. Figure 3.2 b) shows the resulted surface-rendered mannequin using the number of projection of 60.



a) b)

Figure 3.3 a) Original coffee cup; b) 3D model of coffee cup (number of layer: 62, number of projection: 72)

The purposed algorithm has also been tested to perform 3D model on a variety of objects. As for an example, figure 3.3 b) shows the resulted 3D model of a coffee cup. The number of projection for the coffee cup is 72.

4. APPLICATION IN VOLUME ESTIMATTION

Volume measurement is essential in many applications. When calculated fat percentage of the human body, for example, the volume of the body is required. To estimate the volume of the object, we extract *x-y* coordinate of sectional contour of the reconstructed cross-section image. The sectional contour is derived by performing edge detection on the cross-section image and then simply locating the position of pixel constituting the detected edge. Once 2D coordinate of all sectional contours is computed, we stacked 2D coordinate of all sectional contours according to the position of the contours in z direction-yielding the z coordinate and hence the 3D coordinate of the object. 3D coordinate of the mannequin is shown in figure 4.1. To calibration for the *x* and *y* axis, we measure the width and length of the object and then correlated the measured width and length respectively to the number of pixel spanning lengthwise and widthwise of object image. The *x* and *y* coordinate of the tested mannequin are calibrated respectively as 0.575 mm/pixel and 0.669 mm/pixel. To compute the volume of the object, we first computed the area bounded by the sectional contour. We time the calculated area with slice thickness. Slice thickness is derived by dividing the height of the object by number of sectional contours which is 0.798 mm/slice. We repeated the process for every slice; while accumulated the result to yield the estimated volume of the object. Table 4.1 compared the true volume of the object and the estimated volume of the selected object. The true volume is derived by measure the volume in cubic centimeter of the water that is replaced by object when submerging object in the water.

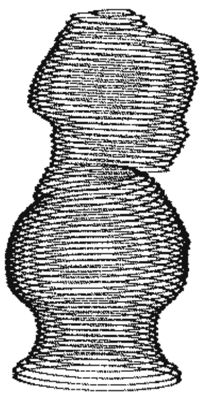


Figure 4.1 Extracted 3D coordinate of mannequin

OBJECT	TRUE VOLUME	ESTIMATED VOLUME	% DIFFERENCE
Light bulb	90	92.8700	3.19
Lotion Bottle	410	424.5200	5.98
Mannequin	310	320.5972	6.64

Table 4.1 Comparison between the true volume of the object and the estimated volume (cm^3)

5. DISCUSSION AND CONCLUSION

We purposed a new method for 3D-shape reconstruction in which a volumetric data is derived from a stack of a cross-section image constructed from a series of photograph taken at different angles around the object. Each of the corresponding horizontal line of the digitized image is served as a projected data used for the image reconstruction from projection. A reconstructed 2D tomographic image is stacked to form a volumetric data. Marching cube algorithm is then applied to the volumetric data to extract an iso-surface. The extracted iso-surface is shading and illuminating using surface rendering technique. The advantage of our purposed technique is that it does not have to solve correspondence problem and it does not require some sort of sophisticated mechanical scanning system, which is often slow and fragile. Our technique does have two limitations. Firstly, it fails to correctly model parts of the surface of the object that are highly concave. This is because the out line of the concave part is invisible from the camera view. Secondly, beam geometry used for the image reconstruction from projection is parallel beam. The photographic process obviously projected light on the film perspectively. To minimize the perspective effect, the photograph of the object is taken at the farther distance (high focal length). Solution similar to the fan-beam geometry used for image reconstruction from projection needs to be addressed to solve the problem of perspective effect. Despite some drawbacks, out purposed technique is tested successfully to generate 3D-rendered surface and to perform volume measurement on a variety of objects

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