3D Shape Extraction Using Photographic Tomography with Its Applications

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ABSTRACT

Tomographic imaging is a technique for exploration of a cross-section of an inspected object without destruction. Normally, the input data, known as the projections, are gathered by repeatedly radiating coherent waveform through the object in a number of viewpoints, and receiving by an array of corresponding detector in the opposite position. In this research, as a replacement of radiographs, the series of photographs taken around the opaque object under the ambient light is completely served as the projections. From the process of tomography, the outcome is the stack of pseudo cross-sectional image. Not the internal of cross section is authentic, but the edge or contour is valid. Several applications can implicitly take advantages from the stack of contour, for instance, 3D true-colored modelling and geometric measurements. Nevertheless, the process has a problem to extract the highly concave-shape object due to the blind of camera by the occluded patches.

Keywords

Image Reconstruction, 3D Rendering, Marching Cubes, Photographic Tomography

1. INTRODUCTION

Shape extraction is the first step of many 3D applications, including a 3D modelling, object recognition, robot navigation, machine inspection, geometry measurement, and so on. To satisfy these applications, it requires an appropriate shape extraction method. Nowadays, several shape extraction systems are proposed, and each one is suitable in the limited range of applications. Some of those, including stereoscopy, laser range finder, structured-light projection, and shape from shading, will be reviewed here concisely.

The first 3D perception method, which was explored for a long time, is stereoscopy [Dho89a]. Its concept is simulated from human visual system by using two images from two different angles to perceive the depth of the scene. Practically, an orientation of each camera as well as a correspondent problem is elaborate, and the decision for the points of landmark must be done manually. Laser range finder technique [Bos98a] straightforwardly measures the distances from the viewer to points on surfaces in the scene by using the time-of-flight of a laser beam. Giving a high precision of a depth map, the "Laser Plane Range Finder" [Cen03a] is claimed about 0.5 mm in depth's resolution. Commonly, the machine is fragile and costly. Structured-light projection technique [Mea70a] projects some light patterns, for instance – plane or grid, onto a surface of the object, captures the scene, and then computes the shape from the distorted light. This has a main advantage in that the discontinuity and monotony of the surface are abruptly replaced by the readily-computed artificial light pattern. This method, similar to the stereoscopy, suffers from the correspondent problem. Shape from shading [Zha99a] the shape information could be inferred from only a monocular image if the illuminating position and the surface property were known. However, the result sensitively depends on the surface's reflectance property. For some kinds of images, never does the shape from shading provide a correct solution.

In the tomographic process, by directly replacing the projections of an object with the silhouetted photographs from sufficient viewpoints, one can acquire the pseudo cross-sections of an object, which

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means that only the outlines are correct, regardless to the internal regions [Ger99a, Joh99a]. Therefore, the *photographic tomography* could be inferred as the one of a shape extraction system capable of reconstructing the volumetric data of an object from the sequence of photographs taken around the object. The advantages of the shape extraction using photographic tomography are as the following:-

- Giving the full 3D shape of an object in an individual process with neither image registration nor other supplementary techniques.
- Disregarding to both material property and light position.
- Using locally available, less complicated, and affordable equipment.
- Working on a simple and well-developed reconstruction problem.
- Having an ability to adjust the accuracy, depending on the resolution of photographs.

Nevertheless, the prerequisites of tomographic process applied to photographs for 3D shape extraction that should be denoted here are as the following:-

- The inspected object is a convex shape, or not a totally concave occlusion.
- The center of a rotation and the center of photographs is an identical line.
- For easily segregating the object from a background, the color of background is recommended to be contrasting.

This work is organized as the following: - Section 2 discusses theory involved in modified tomography. Applications of the photographic tomography are provided in section 3. Discussions and conclusions are given in section 4.

2. TOMOGRAPHIC IMAGE

The relation between the camera system and the cone-beam geometry has been proved in [Joh99a]; consequently, the well-developed algorithm for general tomography can be applied to photographic tomography with a few alterations. To simplify the algorithm, the geometry can be assumed as the parallel beam rather than cone beam if the source (inspected object) and the detector (camera) are separated in the sufficient distance [Pin01a]. The related theory is the radon transform or parallel projection and the modified backprojection.

2.1 Radon transform

The Radon transform of the function *f(x,y),* denoted as $P_\theta(t)$ is defined as its line integral along a line inclined at angle θ from the axis and at the distance *t* from the origin [Ani89a], written mathematically as:-

$$P_\theta(t) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)\delta(x\cos\theta + y\sin\theta - t)dxdy \qquad (1)$$

Practically, the function *f(x,y)* is the cross-sectional image, and the function $P_\theta(t)$ is the projection at the different angle. For this research, the projections are quite different because they are the photographic images which are taken from scene radiation of the opaque object rather than integration through the object.

2.2 Modified backprojection

Many algorithms are available to reconstruct the cross section [Kak88a], but the filtered backprojection is appropriate for the task at hand. The backprojection process can be thought as the process that smears all the projections across a 2D reconstruction plane. Star artifacts, caused by limiting view of the projections, are always introduced in the reconstructed images, and can be reduced by filtering the projections by ramp filter before doing backprojection. For the photographic tomography, it is recommended that all-pass filter is preferable, and the star artifacts can be easily eradicated by thresholding the output image. Mathematical model of the modified backprojection is given as

$$f(x,y) = \int_0^\pi P_\theta(x\cos\theta + y\sin\theta)d\theta \qquad (2)$$

2.3 Shape extraction process

The process starts with capturing a number of images around the half of inspected object. As stated before, the method concerns only the shape or outline of the object; therefore, the segmentation procedure, the thresholding for high-contrasting image or the blue-screen technique for the others, is brought up to segment the captured images to be binary where the background is equal to zero and the foreground is equal to one. Consequently, this kind of shape extraction algorithm can extract the shape of any object regardless of the type of surface either the Lambertian or non-Lambertian surface. The binarized images or the silhouetted projections then pass into the modified reconstruction algorithm described previously, yielding the stack of enhanced pseudo cross-sections whose shape is comparable to its original. This stack of cross sections can be utilized in such applications as a 3D shape modelling, geometric measurement, and so on.

3. APPLICATIONS

In the earlier section, the process of acquiring the volumetric data of the object by the tomography is presented. As a result, several applications can derive the benefits from the volume of data. Some of the applications are demonstrated in this section, including 3D shape modeling and geometric measurements.

3.1 3D Shape Modelling

3.1.1 3D shape modelling.

When only the surface of the object is needed regardless of the internal structure, it is advised to use the surface rendering technique, the marching cube [Lor87a]. This technique delivers the continuous surface made up of an enormous number of linked triangles. However, the marching cube only illustrates the first-order interpolated frontier of the object. The rendering technique, together with the Gourad [Gou71a] and Phong [Pho75a] shading and illumination, can closely resemble the real surface properties which response to the specula and ambient lights.

Form the results in Fig. 1, it can be inferred that shapes of the object are almost analogous to their originals. Nevertheless, some information is missing with the high-detailed object caused by the concave problem.

3.1.2 Shape Modelling with True-Colored Mapping.

In the prior subsection, only the shapes of the models are rendered regardless of their factual colors. In order to display them with the true colors, the supplementary process must be brought up. Generally, the texture mapping technique is employed to attain this option; however, this technique requires the user cooperation to identify the matching points between the texturing image and the rendered model, and the specula artifacts of the non-Lambertian surface make the texture looks unreal while the viewpoint is changed. Another technique which takes an advantage from the tomography needs less collaboration from the user due to the consistency of the geometry.

The set of color photographs taken from around the object serving as the projections are split into 4 components composed of red, green, blue, and alpha channel. The alpha channel is actually the silhouetted projection used in the preceding subject. These 4 channels of projections are *separately and simultaneously* backprojected and normalized to impede the saturation of individual color. Consequently, the outputs of the reconstruction are 4 stacks of cross sections ready to be rendered by the modified marching-cube algorithm. In the modified algorithm, all of the color channels are combined and converted into the true-color cross-sections and then segmented to separate the foreground from the background using solid cross-sections reconstructed from the alpha channel.

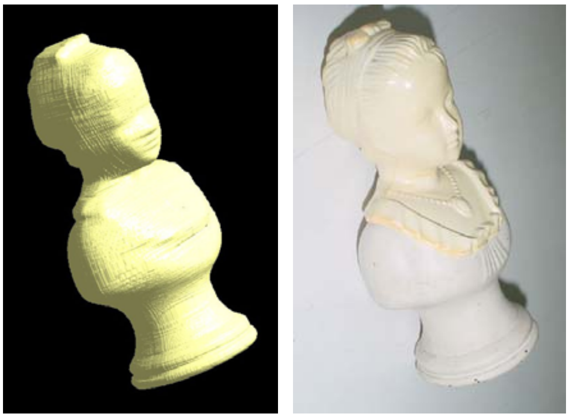
(a) (b)

Fig 1: Mannequin, (a) actual model and (b) rendered model.

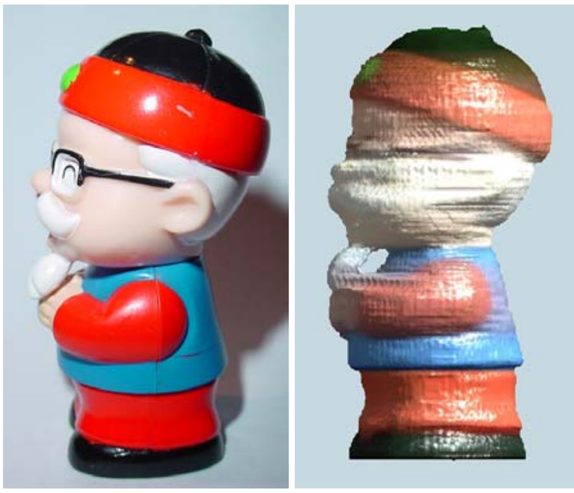
(a) (b)

Fig 2: Chinese doll, (a) actual model and (b) true-colored model.

The original image and the true-colored image of the object in the similar viewpoints are revealed in Fig. 2. Even though the projections have the specula artifacts because of the shiny surface, the model rendered using color plates from the tomography does not express such persistent artifacts (the occurrences of specula in the rendered model are generated later from the lighting model) because the spots of luster are averaged down during the backprojection process. The separations between colors in the vertical direction is apparent, e.g. in the junction of shirt and trousers, whereas those in the horizontal direction is a bit obscure, e.g. in the joints of body and arms. The model's color resulting from the smearing of the backprojection is faded out compared with that of the archetype. However, the overall outcome is acceptable if the process is considered as automation. It is noted that the rough surface results from the limitation of image resolution and the linear interpolation of rendering algorithm.

3.2 Geometric Measurement

The straightforward technique by counting the number of over-thresholded voxels is used to measure the volume of the object, followed by converting it to the physical value using Eq. 3.

$$Volume = \frac{N}{(ppl.)^3} \tag{3}$$

where N is the number of over-thresholded voxels, and ppl is the pixel per a physical length (e.g. centimeter). The results of volume measurement are shown in Table 1 along with the true volumes measured by the Eureka, and the errors in percent.

The differences between the exact and estimated volumes are remarkably low for such convex-shaped objects as the mannequin or the sphere. Contrarily, the calculated volume of the sharp-cornered object like the foam cube is significantly high. This mistake arises from the improper positioning of the object *and* the inadequate viewpoint.

Object	**True Volume $(cm)^3$**	**Estimated Volume $(cm)^3$**	**Error (%)**
Sphere	36.087	35.344	-2.059
Foam Cube	4.492	5.05	12.422
Wood Carving	70.00	65.408	-6.560
Mannequin	310.00	310.525	0.169
Hourglass	67.50	70.394	4.287
Roman Doll	53.00	54.428	2.694

Table 1: The estimated volume compared to the true volume of the specified object

4. CONCLUSION AND SUGGESTION

The 3D shape extraction using photographic tomography and its applications are revealed in this paper. The method to extract the shape from the object is applied from a simple concept of tomography and has a number of advantages compared with the conventional methods. Even though this method has a foible for concave-shaped object, the overall results of each application, including 3D modeling and geometric measurements, are substantially acceptable.

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