3D Modeling from Multiple Projections: Parallel-Beam to Helical Cone-Beam Trajectory

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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. The purposed technique can be adopted with various beam geometry including parallel-beam, cone-beam and spiral cone-beam geometry. 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.

Keywords: Image Reconstruction, 3D Rendering, Photographic Tomography, Helical Cone-Beam 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 stereo disparity [Bar82a-Dho89a], laser range finder [Bos98a-Oka98a], structured light [Sat94a-Boy14a], shape from shading [Hor89a-Pen93a], optical flow [Hor80-Bro97], etc.

In this research, we investigated the process for various beam geometry. In the simple case, the object is placed a long distance. In this case, each scan line on the images taken from different projection is served as the projection data for parallel-beam image reconstruction algorithm.

The parallel-beam geometry is not applicable due to the long focal-object distance (FOD). Cone-beam geometry can be used in the case of small FOD. However, when the long object is applied, in order to cover the whole part of object, the wide-angle lens must be used. This results in distortion of the resulting 3D model. To avoid the problem, the spiral cone-beam tomography is purposed. With the small pitch distance and small field of view on the camera, the trajectory of light from the object to the camera resembles a parallel ray and hence lessen the distortion problem.

This work is organized as the following: - Section 2 discusses theory involved in tomography in various beam geometry. Shape extraction process is provided in section 3. Section 4 explains the acquisition system. The results are provided in section 5. Discussions and conclusions are given in section 6.

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2. MODIFIED HELICAL CONE-BEAM RECONSTRUCTION ALGORITHM

The cone-beam process [Fel84a] can be modified to cope with long object. By changing path of camera to helix and using helical cone-beam reconstruction algorithm [Wan93a], the speed of acquisition and the resolution of results for long object are improved. Since we can simultaneously change the azimuthal angle and the z-level of camera while taking the projections, the time used to complete all projections is reduced.

And since we can place the camera close to the object, the details in the projections are enlarged. Mathematical model of the modified helical cone-beam reconstruction algorithm is given by [Wan93a]

$$f(x,y,z)=\frac{1}{2}\int_0^{2\pi}\frac{D_{SO}^{\;2}}{(D_{SO}-s)^2}R_\beta\left(\frac{D_{SO}\,t}{D_{SO}-s},\frac{D_{SO}\tilde{z}}{D_{SO}-s}\right)d\beta \qquad (2.1)$$

where $f(x, y, z)$ is the volumetric data, $R_\beta()$ is the two-dimensional silhouetted projection, β is the rotational angle, D_{SO} is the cone distance, (t, s) are the coordinates which are rotated from (x, y) by β, and $\tilde{z}$ is given by

$$\tilde{z} = z - \frac{h_p \beta}{2\pi} \qquad (2.2)$$

where h_p is the pitch of the helix turn.

3. SHAPE EXTRACTION PROCESS

The entire process for the shape extraction from a series of photographs is shown as a diagram in Figure 1. This process starts with capturing a number of images around the inspected object, which will be elaborated in section of imaging unit. 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 turn the captured images into binary format where the background is equal to zero and the foreground is equal to one. As a result, 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. When the binary images or the silhouetted projections are passed into the modified reconstruction algorithm described previously, the stack of enhanced pseudo cross-sections whose shape is comparable to its original is attainable. This stack of cross sections can be utilized in such applications as a 3D shape modeling, geometric measurement, and so on.

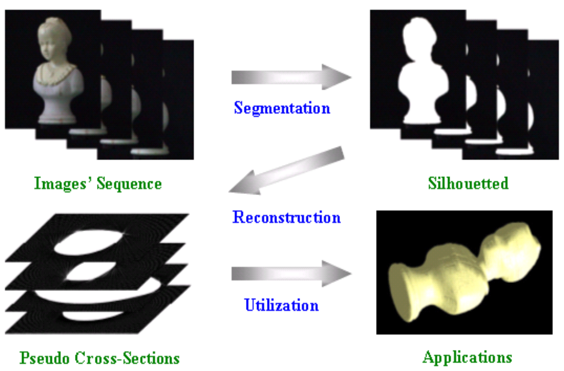

Figure 1. The process diagram of the photographic tomography

4. ACQUISITIONING SYSTEM

In order to collect a series of photographs from the inspected object, it is suggested to rotate the object about the origin i.e. its axis and take the photograph using a fixed camera rather than to move the camera around the vertex path. This idea is substantial for the object which is motionless and small to medium-sized, the common characters of most of the objects. By adhering to this idea, the imaging unit can be assembled simply from a few components, and less in complexity.

The imaging unit shown in Figure 2 is mainly composed of a digital camera, a controllable rotating platform and the translatable platform. The object is placed on the rotating platform and the camera is placed translatable platform which is on the dual rails. Controlled by a computer, the rotating platform is capable of rotating precisely to any specified angle, while the digital camera is capable of moving to the specified z coordinate. For cone-beam tomography, the camera is stationary while the object is rotated. In the case of spiral cone-beam tomography, the camera is translated when the object is rotated.

For simply extracting the silhouette from the photograph, the object is placed in front of the background contrasting from the color of object, and illuminated by an ambient light to avoid specula artifacts.

5. RESULTS

When only the surface of the object is needed regardless of an internal structure, it is advised to use the surface rendering techniques, the most prominent technique of which is the marching cube [Lor87a]. This technique uses the divide-and-conquer strategy to complete the surface; it breaks up the volumetric data into a number of small cubes and matches each cube with the pre-calculated surface pattern. Hence, it 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.

The surface of the object is created by segmenting the reconstructed data, calculating normal vectors for every polygon from gray levels of the same information, and then rendering using technique described above. Regarding to the conditions verified in the preceding chapter, the volumetric data of shown in Figure. 3 to Figure. 5 along with their solid models rendered in the distinctive viewpoints (cube size of the marching cube equals to one). It is noted assorted objects, whose surfaces are either Lambertian or non-Lambertian type, are reconstructed from their corresponding sequences of photographs. All of the investigated objects are that some objects use the number of projections twice as many as the specific value to make the gradient smoother.

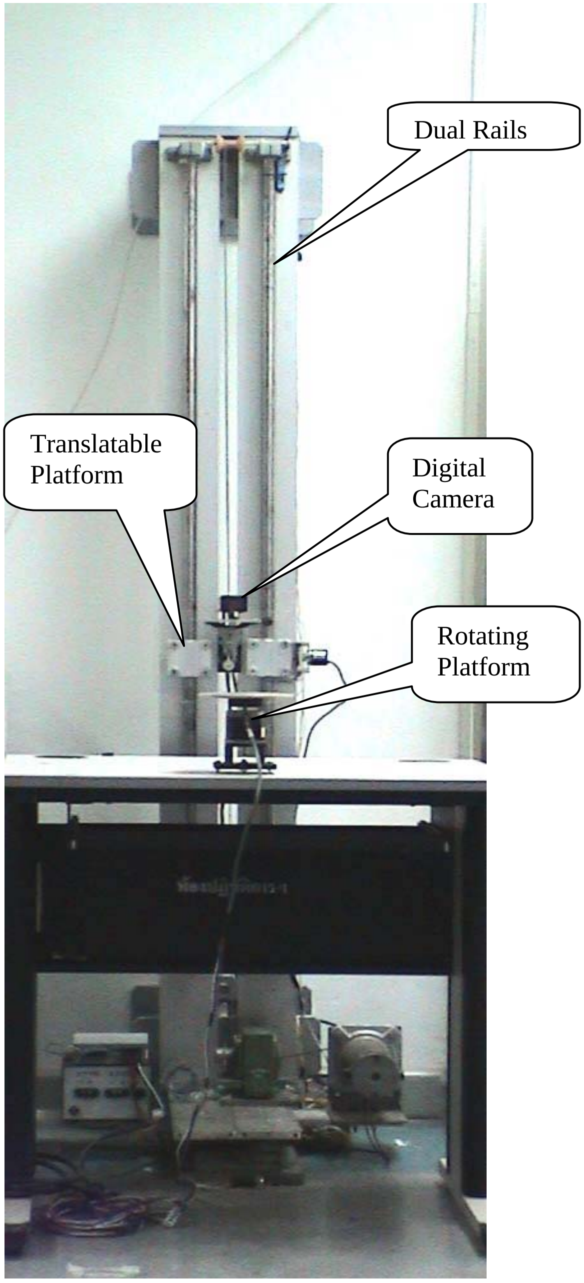

Figure 2. The prototype of an imaging unit for acquiring the sequence of photographs consisting of digital camera, rotating platform and translatable platform placed on dual rails.

Form the results, the process achieves successfully on the simple-shaped objects such as the woodcarving. Nevertheless, some information is missing in the high-detailed object caused by the totally concave problem. The ceramic cup is the best examples of this problem;

6. CONCLUSION AND DISCUSSION

The 3D shape extraction using photographic tomography is studied extensively. The main idea of the method is that the tomographic imaging is used to reconstruct the stack of pseudo cross-sectional images from a series of photographs taken around the object. The shape of the stack can closely resemble the shape of original object. Compared with other 3D shape extraction techniques, the equipment used to collect the data for this technique is much lesser in complexity. It mainly consists of the rotating platform and the digital camera which is locally available and affordable. Various beam geometry is also investigated in this paper. Parallel-beam geometry can be used when the focal-to-object distance is large. Conversely, cone-beam geometry can be used when the focal-to-object distance is small. Spiral cone beam is considered when the long object is modelled or when the perspective distortion is meaningful. Despite some drawbacks, the proposed technique is tested successfully to generate the shape of a variety of objects.

(a) **(b)**

Figure 3. Ceramic cup, (a) actual model and (b) rendered model (Az.70,El.15,Tw.10) (Cone-Beam: D_{SO} = 50 cm)

(a) **(b)**

Figure 4. Vase, (a) actual model and (b) rendered model (Helical Cone-Beam: 40 Prj/360°, number of turn = 3 D_{SO} = 47 cm and Pitch size = 256 pixel)

(a) **(b)**

Figure 5. Spray bottle, (a) actual model and (b) rendered model (Helical Cone-Beam: 40 Prj/360°, number of turn = 3, D_{SO} = 47 cm and Pitch size = 256 pixel)

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