Visualization Method of 3-D Data Field in the Higher Performance Volumetric-Swept Display System

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Abstract

In this paper, the visualization method of 3-D data field in volumetric-swept display system based on the helix rotation screen and Digital Micro-mirror Devices (DMD) is discussed. It often determines the degree to which the display is capable of accepting the parallel transfer of data and its potential for achieving a high voxel activation capacity. The more complexity the model, the more computing time and more pixels numbers that the generation method of helix slice may obtain on 2-D contour lines images. The superfaces algorithm that is one of the kinds of methods for simplifying polyhedral meshes is used to ensure that the images have good display shape approximation, decrease as far as possible for faces number of the model. Thus it can greatly reduce the storage capacity and the calculation speed in the 3-D display system.

Keywords: *True 3-D Display; Volumetric Swept Display; 3-D visualization method; superfaces algorithm*

1 Introduction

Human perception of the world with the eyes is three-dimensional objects, but for a long time due to the defect of the imaging technology was forced to accept such as photos, film and television, a two dimensional image. People can only uses of psychological depth cues, feel the physical depth of objects from displayed image. More than 50 years, many techniques all attempt to artificially recreate the depth cues we naturally perceive when viewing a real 3D object. These techniques simulate our visual system perceives its surroundings, for example, stereoscopic and autostereoscopic displays and so on. Stereoscopic imaging simulates binocular disparity cues by presenting slightly different images of the same scene to the each eye, which is interpreted by the brain as a single 3D image [1], such as 3-D movie and 3-D TV that try to go back the three-dimensional objects for Human eyes, but because of this imaging technology require special user-worn glasses may cause eye-strain, headache, and other discomforts. Autostereoscopic displays [2] expand the viewing area and enable the user to experience parallax through head-motion and allow the rendered images to be modified according to the user’s perspective and require no special glasses for stereoscopic viewing, but the correct viewing area and resolution are typically somewhat limited. These technologies for 3-D scene displays are still based on the 2-D planar framework and go against the natural 3-D environment requirement and can't provide people the real object depth information.

Each type of true 3-D display technique is able to depict image in such a way as to satisfy a number of the physiological and psychological depth cues. True 3-D display technology has actual imaging space which not only display the true physical depth cue, but also the object showed can be observed by walking around the 3-D image without any auxiliary equipment. Volumetric display techniques permit the generation, absorption, or scattering of visible light from a set of localized and specified regions within a physical volume. It stimulates the matter in the semitransparent imaging space with proper manner, and produces visible light voxel. A great lot of disperse light voxel reconstruct the image information in the true 3-D space [3, 4].

Volumetric 3-D display techniques can be separate into static volume display system and swept volume display system. The swept volume display may be classified as the manner of active lighting and the manner of passive lighting according to mode of the lighting voxel may be stimulated. And according to geometrical character of rotating screen, swept volume display system may be classified as plane and helix rotating screen volumetric-swept system.

The ability of volumetric display techniques to display 3-D information have long been the subject of investigation. The Perspecta™ 3D System is the first 3-D volumetric display system in world had been developed by Actuality Systems, Inc. The system's monitor adopt the unique Display technology, combined with conventional optical mechanical system, the structure and rendering algorithm pictures by 90 million pixels floating in the air of a real 3 D images, can from any angle watch fully meet the virtual reality effect [5, 6]. In China, the study of the 3-D display technology is still on the phase of principle exploring and experiment demonstrating.

2. Prior Work

The key technologies of the volumetric-swept display system techniques have been the subject of research for 10 years in Nanjing University of Aeronautics and Astronautics China. Three generations volumetric-swept display system prototypes based on such technologies is implemented and has a great progress during this period [7, 8, 9].

The volumetric-swept display system may be comprised three major subsystems that are described image space creation, voxel generation and voxel activation subsystem, and each of which can have a profound impact on the nature and quality of images depicted by the system.

The first prototype of the display system was accomplished in 2005. The volumetric-swept display unit incorporated a plane screen and used visible laser radiation for voxel activation. In this approach, the laser beam may be directed to any part of the screen surface, and by synchronizing the modulation of the beam to the rotation of the screen, voxels may be activated. The display unit architecture in this prototype support only sequential voxel activation, and their voxel activation capacity is determined by the time required create each voxel, and the image refresh period. The second prototype of the display system based on Digital Micro-mirror Devices (DMD) was completed in 2006. It utilized high speed DLP projector to project 2-D section image sequences of 3-D model onto plane screen, and formed 3-D image display [8]. The DMD modulate various light intensions into light-wave and parallel exporting to improve the transmission bandwidth of 3-D data in the voxel activation subsystem to arrive at activating multi-voxel once time [10]. The third prototype is developed by now which image space creation subsystem is based on Helix rotating screen and voxel activation subsystem is based on DMD and has dynamic hand gesture control interactive.

The shortage of the first and the second prototype system is: smaller imaging space, asymmetrical display luminance, lesser slices of 3-D model, existing serious dead zone, and fewer voxels, so existing serious deficiency on expressing complex 3-D model. These shortages will be improved by the third prototype which adopting helix rotation screen to construct an imaging space and by adopting passive mode, used SLM element to activate [11, 12]. The Figure 1 is the third prototype of the volumetric-swept display system which has higher performance.

Figure 1. The Third Prototype of the Volumetric-swept Display System

3. Visualization Method of 3-D Data Field in the Higher Performance System

The higher performance volumetric-swept display system employed the visualization method of 3-D data field in the implementation of a display unit. The method affects the nature of the manipulations that must be carried out on the image data stream. It often determines the degree to which the display is capable of accepting the parallel transfer of data and its potential for achieving a high voxel activation capacity. The voxel activation capacity *Na* (the maximum number of voxels) may be expressed as expression (1) [2]. It is limited by the time (*T*) required to create each voxel, by the number of voxels (*P*) that can be generated concurrently, and by the time available for each image refresh frequency (*fr*).

$$N_a = \frac{P}{T f_r} \qquad (1)$$

The DMD is composed by 16 blocks of Micro-mirror which resolving power is 1024x48. If system use one of the 16 blocks only, the *P* is 49152. So the voxel activation capacity of the display system based on DMD is more predominant than the system based on visible laser radiation. It is also from the expression that if *Na* is increased, *T* must decrease. This may result in a decrease in image intensity and it is necessary to achieve a balance between the voxel activation capacity and image brightness.

3.1 Visualization Method of 3-D Data Field

The method of visualization of 3-D image data in the volumetric-swept display system is that the 3-D model is reconstructed by a sequence of 2-D contour lines of the model. According to the character of the imaging space formed by plane rotating screen or helix rotating screen, the generation method for plane slice or helix slice of 3-D model is that 3D model data imported is sliced with plane or helix, and obtain disperse mapping from a 3-D image to a series of 2-D contour lines images. The generation algorithm of the slice of 3-D model needs to incise whole 3D data into *N* plane or helix slices. And there is 360/*N* degrees discrepancy of the revolving angle between each two slices [11, 12].

The voxel is a small cube formed by elongating the light pixel along circle in plane screen sweeping manner and formed by the pixel on the slice of helix that moves vertically between two helix slices along direction of helix axis in helix screen sweeping manner. The light pixel is image data that derived from a number of 3-D model sources and after suitable the visualization preprocessing be depicted with great clarity on volumetric systems. Figure 2 is an experiment result of a sequence of helix slices of a plane model.

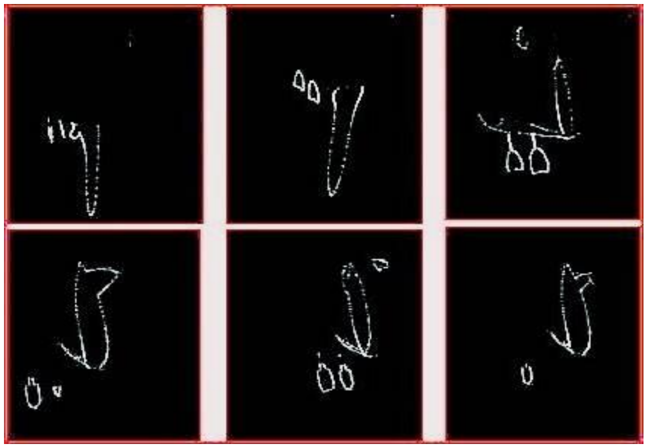


Figure 2. Experiment Result of Generation Algorithm for Helix Slices of an Airplane 3-D Model

The Table 1 is the comparisons of the computing time and the pixel numbers between algorithms of helix slices and plane slices of the different degrees of complexity 3-D models. The generation method of helix slice may obtain more pixel numbers on 2-D contour lines images and results in more calculation time than the plane slices generation method. And the more complexity the model, the more computing time and more pixels numbers on the helix slice.

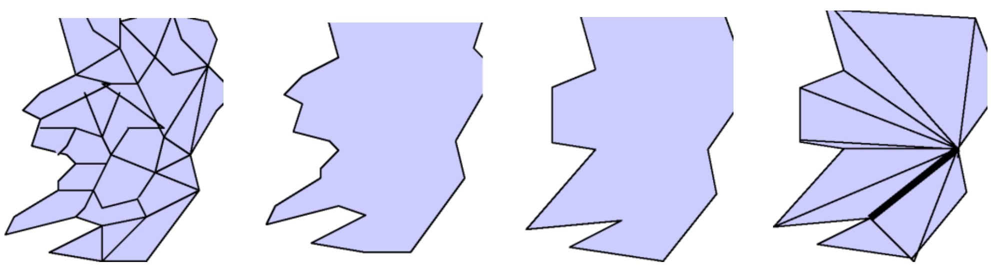
Table 1. Comparison between Algorithms of Helix Slice and Plane Slice

Model	Slice type	Triangle meshes	Time/ms	Pixel Numbers
Secondary planet	Helicoid	1140	562	9755
	Plane		56	1076
Airplane	Helicoid	2320	921	131655
	Plane		109	16675
Automobile	Helicoid	7322	1443	324265
	Plane		204	47317

Along with the development of the application requirements, the complexity of displayed model is virtually unlimited. We consider the throughput of voxel data, that is the pixel numbers on the helix slice, is no greater than voxel activation capacities. Strive to solve complex model of the process, storage, transport and draw in the display system, in addition to using higher performance hardware to deal with, and have to use a variety of visual techniques and algorithms. The most effective visual methods are complex model reduction method that reduces the number of facets, edges and vertexes of the complex model, and multi-resolution representation method that expresses a same model from coarse to fine resolution. If the number of the faces on the model is reduced, the display accuracy is inevitable decline. But that do not affect display effect in many cases. For example, if the distance between the model and imaging plane is further, no matter how accurate degree to which model, cannot express the details of the model. Under the premise to ensure that the images have good display shape approximation, decrease as far as possible for faces number of the model. Thus it can greatly reduce the storage capacity and the calculation speed. In this paper, the method of simplifying models to reduce the number of facets of the complex model and improve the performance in the real-time display system is discussed.

3.2 The Superfaces Algorithm for Complex Model Simplified

So far there are many classes and many methods of simplifying model internationally. Between these algorithms, the superfaces algorithm is one of the kinds of these methods for simplifying polyhedral meshes, and it more fit for complex model simplified in the volumetric-swept display system. This algorithm merge the meshes of original model to the simplified mesh approximates with a bounded approximation superfaces [13]. The Superfaces algorithm simplifies a mesh of a 3-D model in three steps: Superface creation, Border straightening and Superface triangulation. The Figure 3 is the outline of the superfaces algorithm.



(a)Original mesh (b)Superface creation (c)Border straightening (d)Superface triangulation

Figure 3. The Outline of the Superfaces Algorithm

1. Superface Creation Step

The superface creation step is showed in (b) of Figure 3. The step begins with the selection of an initial face that grows through a process of accretion. If faces satisfy the required merging criteria, border faces are merged into the evolving superface. The superface creation step stops merging when there are no more faces on its boundary that can be merged. There are three merging rules. These are the planarity rule, the face-axis rule and the no-foldover rule. In this paper, the planarity rule is used. The planarity rule is that all vertices V (v_x, v_y, v_z) on face f_b must be within a distance of ε/2 from each approximating plane P:

$$ax + bx + z = d$$

That is:

$$\frac{(a,b,1,-d)\cdot(v_x, v_y, v_z)}{\sqrt{a^2 + b^2 + 1}} \le \varepsilon / 2$$

The planarity rule ensures that each vertex in the original mesh is within ε of the simplified mesh being created.

2. Border Straightening Step

The border straightening step is showed in (c) of Figure 3. There are two procedures, that is maximal edge merging and edge splitting, to create superedges by straightening the superface perimeters. The maximal common edge merging procedure merge the perimeter between a pair of adjacent superface F and superface F_j which perimeter of F is $s_i = (v_1, v_2,\ldots,v_n)$ and maximal common boundary of F *and* F_j is $s_j = (v_{j1},v_{j2},\ldots,v_{jr})$ into a single superedge $L_j = \overline{v_{j1}v_{fr}}$. The edge splitting procedure is to compensate for over simplification mesh that is not within the required ε limit of all the vertices of the original mesh caused by the maximal common edge merging procedure. This procedure uses a standard polyline approximation method to split each superedge $L_j = \overline{v_{j1}v_{fr}}$. Let v_{jt} be that vertex in the $s_j = (v_{j1},v_{j2},\ldots,v_{jr})$ that is furthest from L_j. If the distance from v_{jt} to L_j, is greater than some threshold d_{max}, the L_j is recursively spitted the lines $L_1 = \overline{v_{j1}v_{ft}}$ and $L_2 = .\overline{v_{ft}v_{fr}}$.

3. Superface Triangulation Step

The superface triangulation step is showed in (d) of Figure 3. This step need to triangulate processed superfaces and simplify the 3-D model. The method project superface perimeter into the nominal approximating plane and get a projection (F') of the superface (F). If the projection F' is a starshaped polygon, that the nucleus of F' can be solved. A point (v) in the nucleus is connected to all vertexes of the starshaped polygon. The connecting lines is all in the polygon according to definition of the starshaped polygon, so the connecting lines from v to all vertexes of the starshaped polygon can realize superface triangulation. If there is no nucleus in the Polygon, F' polygon is decomposed into a series of star polygons. Then it can be realize superface triangulation.

3.3 Experimental Results

From Table1 comparison between algorithms of helix slice and plane slice, we know that the generation method of helix slice may obtain more pixel numbers on 2-D contour lines images and results in more calculation time than the plane slices generation method. We use the superface algorithm to simplify polyhedral meshes to improve performance in the real-time display system. The Table 2 is the result of algorithms of helix slice after simplifying polyhedral meshes. The error bound ε is 0.5.

Table 2. Result Algorithms of Helix Slice after Simplifying Polyhedral Meshes

Model	Origina mesh	Reduced mesh	Time/ms	Pixel Numbers
Secondary planet	1 140	445	247	4469
Airplane	2 320	905	583	82835
Automobile	7 322	2923	877	185614

From Table 2 we can see that the triangle count of 3-D models are reduced highly after simplifying polyhedral meshes, and that it result in the calculation time of slices generation method is shorten and pixels numbers on the helix slice is reduced obviously. Thus it can greatly improve the storage capacity and accelerate the generation method of helix slice calculation speed in real time display system.

4. Conclusions

The method of visualization of 3-D image data in the volumetric-swept display system is that the 3-D model is reconstructed by a sequence of 2-D contour lines of the model. The generation algorithm of the slice of 3-D model needs to incise whole 3D data into N plane or helix slices. And there is 360/N degrees discrepancy of the revolving angle between each two slices. The generation method of helix slice may obtain more pixel numbers on 2-D contour lines images and results in more calculation time than the plane slices generation method.

The method of simplifying models to reduce the number of facets of the complex model and improve the performance in the real-time display system is discussed. The superfaces algorithm is one of the kinds of these methods for simplifying polyhedral meshes, and it more fit for complex model simplified in the volumetric-swept display system. We used the superfaces algorithm to the simplified mesh approximates with a bounded approximation. And experimental results show that the triangle count of 3-D models are reduced highly after simplifying polyhedral meshes, and that it result in the calculation time of slices generation method is shorten and pixels numbers on the helix slice is reduced obviously.

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