Method of Making the Distribution of Voxels Uniform within the Volumetric 3D Image Space

LIN YUANFANG, LIU XU, XIE XIAOYAN, LIU XIANGDONG and LI HAIFENG
State Key Laboratory of Modern Optical Instrumentation, Zhejiang University, Hangzhou 310027, Zhejiang, China
TEL:86-571-8795-2432, e-mail: linyuanfang@zju.edu.cn

Keywords : ***Volumetric 3D display, Distribution of voxels, Uniform, 3D voxel array, 3D reference point array***

Abstract

By defining a uniform 3D reference point array corresponding to the 3D voxel array and abandoning voxels whose deviations from their respective reference points exceed a given tolerance, the distribution of voxels within the volumetric 3D image space gets uniform, effects of non-uniform distribution upon the image reconstructing are eased.

1. Introduction

Volumetric three-dimensional (3D) display systems permit the generation, absorption, or scattering of visible radiation from voxels within a transparent image space[1]. Due to persistence of vision, viewers can perceive a 3D image. Based on current advanced science and technologies, we developed a volumetric 3D display system utilizing a rotating LED panel[2]. As showed in Fig.1, the LED panel rotates to provide multiple display planes within the 3D image space.

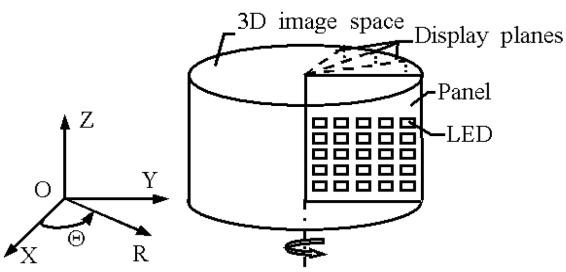


Fig.1. A LED panel rotates to provide multiple display planes within the 3D image space.

The objective of this paper is to discuss the distribution of voxels within the volumetric 3D image space and present a method of making it uniform so as to ease effects of non-uniform distribution of voxels upon the image reconstructing.

2. Theory

Each LED is instantaneously addressed while the panel is in rapid rotation, producing multiple voxels during each cycle of rotation. Assumed that each LED in Fig.1 is responsible for the production of 8 voxels along its own respective circumferential rotation path, then the 5×5 LEDs in Fig.1 will produce 5×5×8 voxels within the volumetric 3D image space. These voxels form a 3D voxel array, as Fig.2 shows.

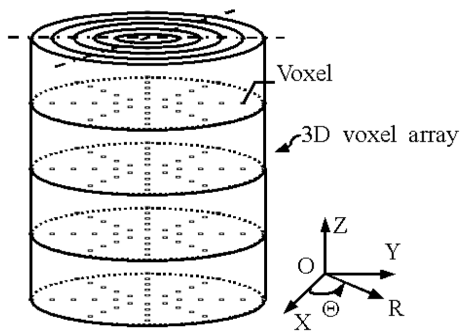


Fig.2. A 3D voxel array composed of 5×5×8 voxels.

Since LEDs are arranged equidistantly into a 2D array on the panel, the linear velocity of each LED varies in proportion to its corresponding distance from the axis of rotation. This leads to different interspaces between voxels in the direction of the LED panel's rotation. It is apparent that under the cylindrical polar coordinate system (RΘZ) and Cartesian coordinate system (XYZ) established in Fig.2, voxels are lined up equidistantly in directions of R and Z respectively, but not equidistantly in the direction of the panel's rotation due to the different linear velocities of LEDs. It means that referring to the Cartesian coordinate system, the distribution of voxels is non-uniform.

To overcome the above-mentioned non-uniformity within the volumetric 3D image space, we present a method as follows.

First, define a uniform 3D reference point array corresponding to the 3D voxel array, wherein each reference point is arranged at the same interspace along the directions of X, Y and Z, as showed in Fig.3. Besides, the interspace of reference points needs to be greater than or equal to the interspace of voxels.

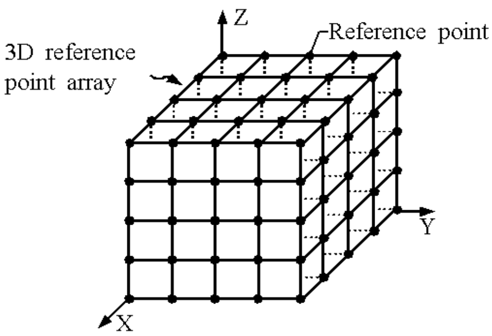


Fig.3. A 3D reference point array composed of 5×5×5 reference points

Second, superpose the 3D reference point array over the 3D voxel array as illustrated in Fig.4, wherein assumed that the two arrays are composed of 5×28×28 reference points and 5×40×128 voxels respectively.

Third, compute the deviation of each voxel from its respective reference point. For example, given the Cartesian coordinates of any voxel and any reference point is (x_{vox}, y_{vox}, z_{vox}) and (x_{ref}, y_{ref}, z_{ref}) respectively, then we can compute the deviation d:

$$d = \sqrt{(x_{vox} - x_{ref})^2 + (y_{vox} - y_{ref})^2 + (z_{vox} - z_{ref})^2} \quad (1)$$

Finally, judge whether the following conditional inequality is satisfied or not,

$$d \leq e \quad (2)$$

wherein e denotes the maximum tolerance permitted when positions of the voxel and the reference point don't coincident. If it is satisfied, reserve the voxel, otherwise, abandon the voxel. That is, abandon voxels whose deviations from their respective reference points exceed the given tolerance and reserve voxels whose deviations from their respective reference points don't exceed the given tolerance.

The distribution of voxels gets uniform by adopting the above-mentioned method, as showed in Fig.5(a) and Fig.5(b). They differ in the ratio of the reference point interspace to the voxel interspace.

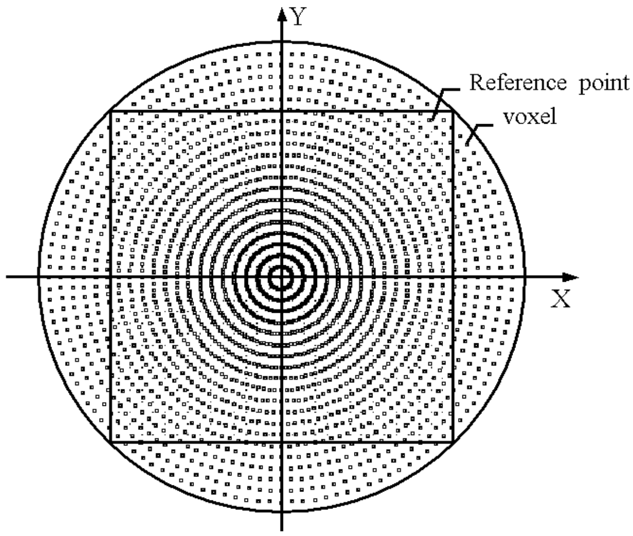
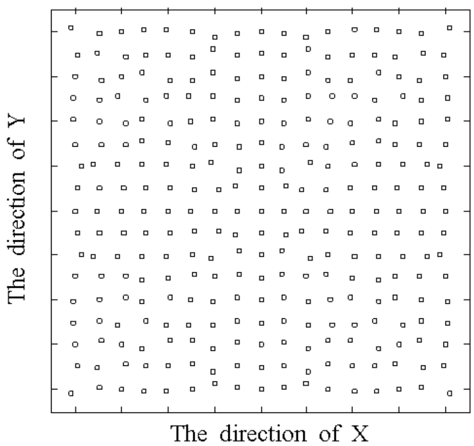
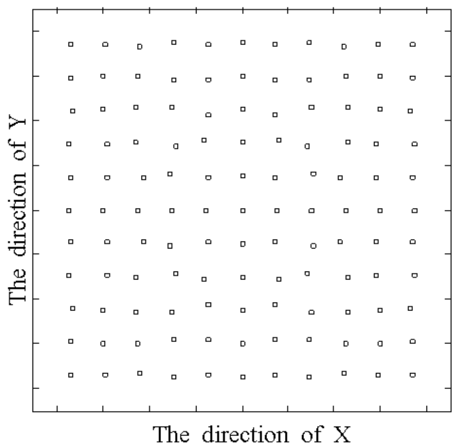


Fig.4. Planform of a 3D reference point array superposing over a 3D voxel array.



(a) Reference point interspace=2×Voxel interspace.



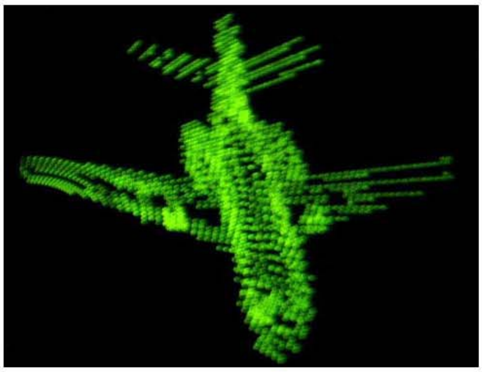
(b) Reference point interspace=2×Voxel interspace.

Fig.5 The distribution of voxels gets uniform.

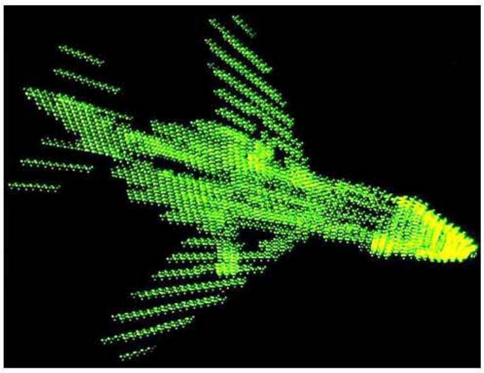
3. Experiments and discussions

To verify the feasibility and effectivity of the above-mentioned method of voxel distribution unifying, experiments were done utilizing our LED volumetric 3D display system, wherein LEDs are arranged into a dot matrix with 64 rows and 256 columns on a thin panel, the external dimension of LED is 1.6 mm × 0.8 mm × 0.6 mm, which can produce a 3D voxel array composed of 512 × 256 × 64 voxels and display 3D scenes statically or dynamically within a ϕ292 mm × 165 mm cylindrical volumetric 3D image space.

Obviously, as a consequence of the non-uniform distribution of voxels within the volumetric 3D image space, the image quality of reconstructed 3D scenes will vary when they are positioned within different regions of the 3D image space or oriented in different ways. For example, Fig.6 shows the different reconstructed images of a same plane when its right wing (Fig.6(a)) and its head (Fig.6(b)) is positioned around the axis of rotation respectively.



(a) The plane's right wing is positioned around the axis of rotation.

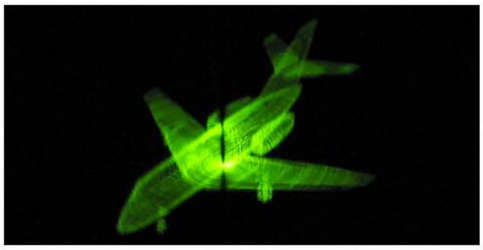


(b) The plane's head is positioned around the axis of rotation.

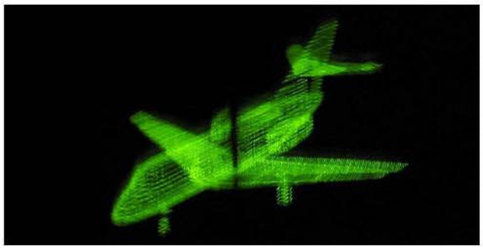
Fig.6 Different reconstructed images of a same plane which is oriented in different ways.

From Fig.6(b), we can find that the reconstructed plane's head was excessively brighter than the other parts. The reason for this is that the mismatching of the geometrical characteristics with the electrical characteristics of LEDs causes duplicate mapping and overlap of voxels around the axis of rotation, which was analyzed in the reference[3].

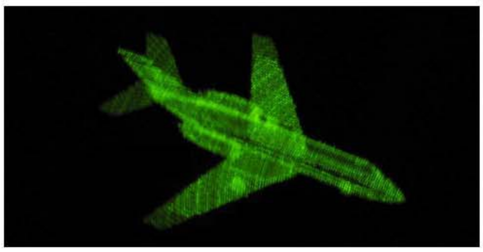
The above-mentioned method could help to ease the effects of non-uniform distribution upon the image reconstructing. Here take Fig.7 for example, before adopting the method, the reconstructed plane's center around the axis of rotation was excessively brighter than the other parts (Fig.7(a)). After adopting the method, not only the above-mentioned excessively brighter phenomenon disappeared (Fig.7(b)), but also the variations in the image quality of the reconstructed plane caused by the different orientations was eased, as showed in Fig.7(b) and Fig.7(c).



(a) The plane's center is positioned around the axis of rotation. Before adopting the method.



(b) The plane's center is positioned around the axis of rotation. After adopting the method.



(c) The plane's head is positioned around the axis of rotation. After adopting the method.

Fig.7 Reconstructed images of a same plane under three different circumstances.

4. Summary

In the volumetric 3D display systems utilizing a rotating LED panel, the linear velocity of each LED varies in proportion to its corresponding distance from the axis of rotation, this leads to different interspaces between voxels in the direction of the LED panel's rotation and hence a lack of uniformity with respect to the distribution of voxels.

A method of making the distribution of voxels uniform within the volumetric 3D image space is presented. It includes four primary steps, i.e., define a uniform 3D reference point array corresponding to the 3D voxel array, superpose the two arrays, compute the deviation of each voxel from its respective reference point, abandon voxels whose deviations from their respective reference points exceed the given tolerance and reserve voxels whose deviations don't exceed the given tolerance. As a consequence, the distribution of voxels gets uniform.

Although the reconstructed 3D scenes has lower resolution due to the amount decrease of voxels after adopting the method, nevertheless, it is a low-cost feasible and effective method. Experimental results show that effects of non-uniform distribution of voxels upon the image reconstructing were eased.

Our work provides good guidelines for further researches of the volumetric 3D display. Part of this work and the foregoing statements are applicable to those volumetric 3D display systems utilizing other rotating 2D panels[4].

5. Acknowledgements

The work was supported by hi-tech research and development program (863 program) of China and by China Postdoctoral Science Foundation. Besides, we thank all the members in the 3D volumetric display study group in the state key lab of modern optical instrumentation for working together and developing the display system with us.

6. References

1. B. G. Blundell, A. J. Schwarz, “The classification of volumetric display systems: characteristics and predictability of the image space”. *IEEE Transactions on Visualization and Computer Graphics*, **1** (1), pp.66-75(2002).
2. Y. F. Lin, X. Liu, X. J. Zhang, Y. Yao and X. D. Liu, “Volumetric 3D display system based on rotating dot-matrix LEDs”. *IMID’04 Technical Digest*, pp.440-441(2004).
3. Y. F. Lin, X. D. Liu, X. Liu, X. J. Zhang, “The analysis of voxel attributes in three-dimensional volumetric display system based on the rotation of a two-dimensional display panel”, *Acta Photonica Sinica*, **33**(4) , pp.476-479(2004).
4. B. G. Blundell, A. J. Schwarz and D. K. Horrell, “Volumetric three-dimensional display systems: their past, present and future”, *IEE Engineering Science and Education Journal*, **10** (5), pp.196-200(1993).