Rear-projection-based Full Solid Angle Display

Hiroo IWATA
Institute of Engineering Mechanics, University of Tsukuba, Tsukuba, 305 JAPAN
Tel: +81-298-53-5362
FAX: +81-298-53-5207
Email: iwata@kz.tsukuba.ac.jp

ABSTRACT

This paper presents design method of rear-projection based closed surface display for ultimate visual immersion. The display consists of a closed polyhedron screen. A viewer stands inside the polyhedron so that image covers full solid angle around the viewer. Optimum configuration of polyhedron is determined by two criteria: pixel efficiency and space efficiency. Through examination of these criteria, rhombic dodecahedron is chosen. We built dodecahedron screen with twelve projectors in which a viewer can stand. Space requirement of the display is 2.6m(D) x 2.6m(W) x 2.7m(H) so that it can be built in a normal size room.

1. Introduction

Visual immersion plays an important roll in virtual environment. A head-mounted display (HMD) provides full solid angle view of virtual space. However, field of view of HMD is limited because of its optical system. Field of view of human eye is approximately 200 degrees (lateral) and 125 degrees (vertical). It is difficult to develop head-mounted optical system which covers all the field of view. A large screen is used for virtual environment as an alternative of HMD. A dome screen or a cubic screen are proposed for the alternatives. Those screens requires theater-like large space, which restricts its general use for computer-human interaction. Moreover, existing configurations of large screen systems do not cover full solid angle around the viewer. This paper discusses about design of closed surface display which covers full solid angle. We set criteria in order to optimize space utility of the display system. The result shows that a closed surface display in which a viewer stands can be built in a normal size room.

2. Related Works on Closed Surface Display

2-1. Dome Screen

A dome screen provides a planetarium-like picture which covers large field of view. OMNIMAX theater is a typical display system of a dome screen[1]. However, planetarium-like projection system cannot cover full solid angle of the viewer. If two domes are connected to make a closed surface display, there is no room for the viewer.

2-2. CAVE

A cubic screen that surrounds a viewer is well known as the CAVE[2]. The CAVE is composed of four square screens. Those screens cover two thirds of full solid angle. The CAVE can be extended to a closed surface display by using six square screens. Problems of this configuration is discussed later.

2-3. Display without projectors

If closed surface is composed of light emitting device such as LED or fiber optics, spherical display which covers full solid angle can be constructed. Those specialized hardware is fairly difficult to develop and it leads to high cost. Closed surface display proposed in this paper is based on normal projectors.

3. Rear-projection Polyhedron Screen

Spherical screen is ideal for covering wide field of view. However, front-projection system normally used for spherical screen is impossible to extend to closed surface display. In case of such configuration, volume of projectors obstruct image on screen. For this reason, closed surface display must be composed of rear-projection screen.

Rear-projection screen must be divided into polygons. Thus, the shape of the closed surface display is polyhedron. There are many types of polyhedrons. The emphasis of this paper is which polyhedron is most suitable for the closed surface display. We set two criteria for determination of optimum configuration of polyhedron: pixel efficiency and space efficiency. We studied geometry of polyhedrons from these point of views[3][4]. Considering easiness of construction, such as number of projectors and independent display channels, this paper limits number of polygons of polyhedron up to 16.

4. Criteria 1: Pixel Efficiency

Aspect ratio of projected image and frame buffer of display channel is 4:3. Pixel efficiency means how many pixels from a projector are displayed on each polygon of the polyhedron. Typical polygons which consists polyhedrons are regular triangle, regular square, rhombus, pentagon and hexagon. We examined pixel efficiency of these polygons. Figure 1 shows dead pixels of rhombus.

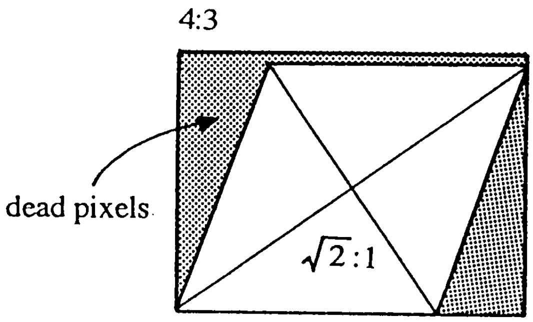


Figure 1. Dead pixels of rhombus

Pixel efficiency is determined by ratio of displayed pixels. Results of calculation of pixel efficiency are:

regular triangle: 43.3%
regular square: 75.0%
rhombus: 71.2%
pentagon: 54.5%
hexagon: 64.9%

The results shows that pixel efficiency of regular triangle and pentagon are low. We therefor chose regular square, rhombus and hexagon for polyhedron screen.

Convex polyhedrons are classified into five categories: regular polyhedron, semiregular polyhedron, zonehedron, prism and pyramid. Candidates for closed surface display were detected from these categories.

(1) regular polyhedron

Regular polyhedron is composed of congruent regular polygons and each vertex is surrounded by same number of polygons. Most of regular polyhedron is composed of regular triangles. Only cube satisfies the condition of pixel efficiency.

(2) semiregular polyhedron

Semiregular polyhedron is composed two or more types of regular polygons and each vertex is surrounded by same number of polygons. In this category, truncated octahedron satisfies the condition of pixel efficiency. Truncated octahedron has six regular squares and eight hexagons (Figure 2).

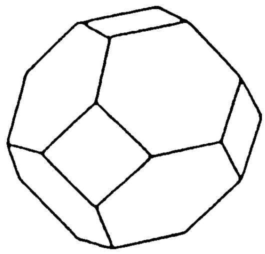


Figure 2. Truncated octahedron

(3) zonehedron

Zonehedron is composed of parallel polygons. Rhombic dodecahedron can be selected from this category. Rhombic dodecahedron is composed of 12 congruent rhombuses (Figure 3). Ratio of two diagonal lines of the rhombus is $\sqrt{2}:1$.

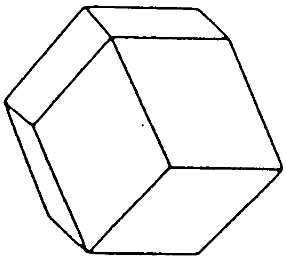


Figure 3. rhombic dodecahedron

(4) prism

Cuboid and hexagonal prism can be selected from this category. Aspect ratio of a face polygon should be 4:3 so that pixel efficiency is maximized (Figure 4).

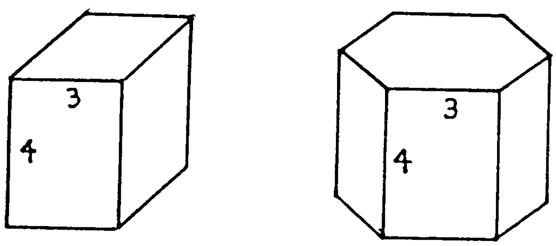


Figure 4. cuboid and hexagonal prism

(5) pyramid

Face polygons of pyramids are triangles whose maximum pixel efficiency is 50%. Thus, there is no candidate in this category.

5. Criteria 2: Space Efficiency

Major objective of this research is how to construct a closed surface display in a limited space such as a normal size room. Backyard of rear-projection screen makes dead space. Space efficiency is determined by the ratio of displayed volume of polyhedron to overall dead volume at backyard (Figure 5).

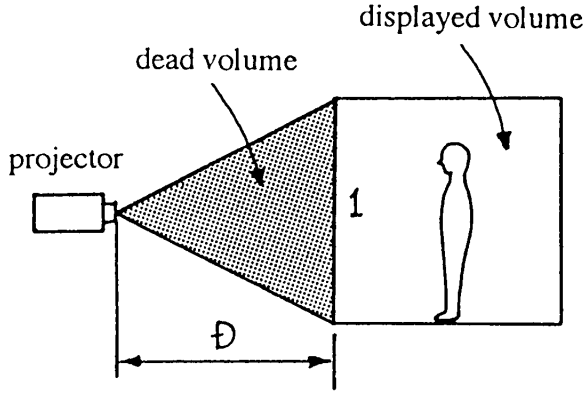


Figure 5. dead volume

Projection distance is described as D while screen height is 1. Results of calculation of space efficiency are:

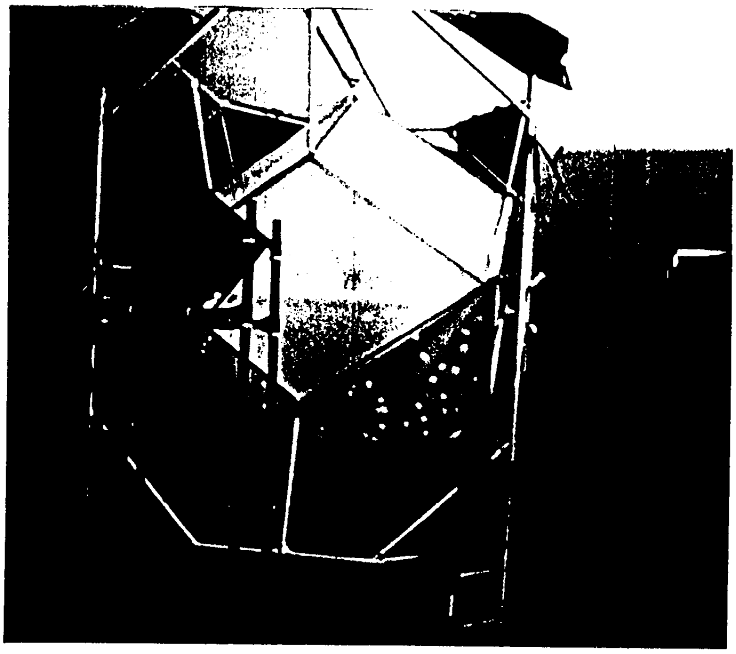
cube:	0.500 /D
truncated octahedron:	0.707 /D
rhombic dodecahedron:	0.867 /D
cuboid:	0.546 /D
hexagonal prism:	0.610 /D

The results shows that rhombic dodecahedron provides best space efficiency.

6. Prototype of Dodecahedron Screen

We constructed a closed surface display whose shape is rhombic dodecahedron(Figure 6). Figure 7 illustrates top view of the screen. Figure 8 illustrates side view of the screen. Size of the screen is 226cm(H) x 160cm(W) x 160cm(D). The dodecahedron is made by 24 aluminum frames. The screen is composed of 12 rhombic screen whose diagonal size is 68inch. Each screen is made of semitransparent paper. Twelve LCD projectors are set around the dodecahedron. Projection distance of each projector is 80cm. Overall space occupancy is 270cm(H) x 260(W) x 260cm(D). The viewer stands on a transparent floor made of acryl. Size of the floor is 40cm x 40cm.

Image of the display is presented on a CRT of SGI workstation. The image is divided into twelve windows and each window is taken by NTSC video camera. Each video image is delivered to a LCD projector.



Firgure 6. overall view of the system

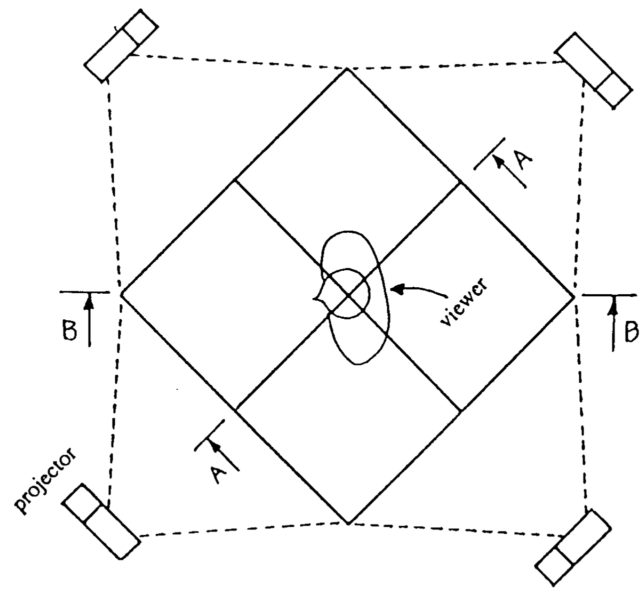
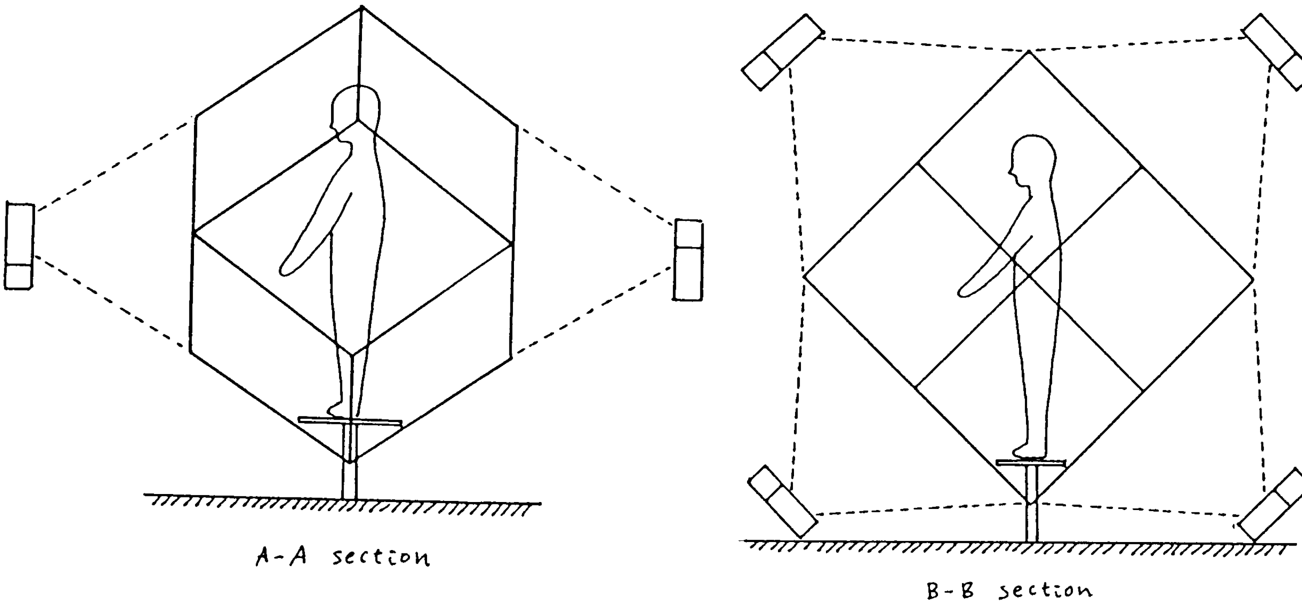


Figure 7. top view of the rhombic dodecahedron screen



Firgure 8. side view of the rhombic dodecahedron screen

7. Discussion

Compared to a cubic screen or extended CAVE, rhombic dodecahedron screen has advantages. Drastic difference is space utility. Six square screens require large backyard, especially high ceiling. As seen in Figure 8, dodecahedron screen maximizes utility of ceiling height. In case we use large projectors with long projection distance, light may be folded by mirrors at the floor and ceiling. The screen does not need more ceiling height because top and bottom polygons are set at angle of 45 degrees.

Another advantage is angle of vertex. Angle of each vertex of a cube seen from the viewer is 78 degrees. On the other hand, those of dodecahedron is 90 degrees to 120 degrees. Sharp angle of vertex spoils seamless presentation of the image.

We found a side effect of closed surface display. Viewers outside the screen can see half of the polygons, so that they can enjoy the image.

8. Conclusion

We proposed optimum design of closed surface display. Effectiveness of the method is exemplified by prototype using rhombic dodecahedron screen. Future work of this research will be experiments of human factor of the viewer who is surrounded by full solid angle image.

References

[1] Bolt,R.; The Human Interface, Lifetime Learning Publications (1984)

[2] Cruz-Neira,C. et.al.; Surround-Screen Projection-Based Virtual Reality, Proc. Of SIGGRAPH'93 (1993)

[3] Pugh,A.; Polyhedra, Univ. of California Press (1976)

[4] Wenninger,M.J.; Polyhedron Models, Cambridge U.P. (1971)