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PROJECTION SCREENS FOR VOLUMETRIC 3-D DISPLAYS

BACKGROUND

[0001] Spatial 3-D displays such as Actuality Systems Inc.'s Perspecta® Display create 3-D imagery that fills a volume of space and that appears to be 3-D to the naked eye. One such spatial 3-D display is described in U.S. Pat. No. 6,554,430, "Volumetric three-dimensional display system." This display is formed in the shape of a transparent dome and contains a rotating screen orientated vertically within the dome. As the screen spins it displays a previously recorded image for example at every 1 degree of rotation for 360. Human persistence of vision combines these images to create a 3-D view of the previously recorded image. This display with its vertical dome shape can be placed on top of a tabletop for example. One feature of this type of 3-D display is that the imagery provides motion parallax in every direction; in other words, it is a full parallax display.

[0002] Another spinning screen volumetric display is Actuality Systems Inc's lenticular display screen system as discussed in U.S. Pat. 6,487,020.

[0003] Thus, it is known that it is possible to create a three-dimensional image by illuminating a rotating two-dimensional surface. A series of points or trajectories (i.e., vectors) is displayed by controlling the time-varying illumination of a projection surface. As the projection surface sweeps out a 3-D volume, many points in the 3-D volume can be illuminated. Due to the persistence of human vision, if a point is repeatedly illuminated for a brief interval with a repetition period, for example 1/20 of a second, the point appears to be illuminated without flickering. Thus, by illuminating a display screen which undergoes rapid periodic motion to sweep out a volume of space, a true volume-filling (i.e., volumetric) 3-D display can be achieved.

[0004] Another system is described by Ketchpel (U.S. Pat. No. 3,140,415). His system utilizes a phosphorescent rotating screen that is illuminated by a fixed electron gun. His approach, however, is characterized by "dead zone" regions which are not addressable or accessible by the illumination source. For example, when the angle between the screen's plane and the impinging illumination beam is small, it is difficult to draw imagery of high detail. In such regions, the imaging volume has picture elements (i.e., voxels) that are plagued with low spatial accuracy. Schwarz and Blundell attempted to solve this problem by using a similar phosphorescent screen system and illuminating it with two electron guns, each responsible for illuminating the screen during different angular segments (IEEE Proc.--Optoelectron., Vol. 141, No. 5, October 1994, pp. 336-344). This helps eliminate the dead zone but requires duplicate illumination, computation, and aiming systems and circuitry.

[0005] Another system was patented by Max Hirsch in 1961, see Hirsch, Max, "Three dimensional display apparatus" U.S. Pat. No. 2,967,905. Hirsch developed a parascope like device with the output of a CRT display being reflected to a rear projection screen. The entire apparatus is rotated at about 25 cycles per second and a three dimensional image is formed by natural human persistence of vision by sweeping out a display volume.

[0006] Tsao et al. (U.S. Pat. No. 5,754,147) disclose a volumetric display which attaches an off-axis mirror to the rotating display unit. They describe a display that is made of three subunits, namely, an optical data generator, an optical interfacing unit, and a rotating unit with display means. Their optical data unit includes an image projector whose generated images are projected into a complex of coaxially rotating mirrors. The mirrors rotate at a different speed than the rotating display screen. They relay light to another mirror, which rotates off-axis with the display screen at approximately 10 Hz. Their optical interfacing unit includes 5 to 10 miniature mirrors.

[0007] Garcia Jr., et al (U.S. Pat. No. 5,042,909) employed a rotating screen illuminated by vector-scanned laser light. As their screen rotates, a system of computer-controlled scanners steers laser light onto it. This technique exhibits some of the same characteristics of vector-based displays. For instance, only a low percentage of the addressable volume may be used in a given image.

[0008] Favalora (U.S. Pat. No. 5,936,767, entitled "Multiplanar Autostereoscopic Imaging System," discloses a raster-based imaging system that is computationally simpler than the vector scanned systems and uses fewer moving parts than some of the systems described above.

[0009] Veligdan et al. (U.S. Pat. No 6,755,534) discloses a prismatic optical display wherein a spatially modulated light beam is projected, reflected, and redirected through a prismatic optic panel to form a video image for direct viewing thereon.

[0010] One class of 3-D display creates volume-filling imagery by optically projecting a sequence of patterns onto a projection surface undergoing rapid periodic motion. 3-D displays using this principal are generally called multiplanar volumetric displays because the 3-D imagery is composed of a set of planes (or arbitrary surfaces, or "slices.")

[0011] Examples of swept-screen multiplanar 3-D displays are:

[0012] Dorval, R.K., *et al*, "Volumetric three-dimensional display system," U.S. Pat. No. 6,554,430.

[0013] Favalora, G.E., "Volumetric three-dimensional display architecture," U.S. Pat. No. 6,487,020.

[0014] Hirsch, Max, "Three dimensional display apparatus" U.S. Pat. No. 2,967,905.

[0015] To illustrate one example in operation, a source of 3-D data may deconstruct the desired 3-D scene into a series of approximately 200 slices and project the slices from a projector at a rate at or above 5,000 patterns per second onto a projection surface which sweeps (rotates) a 3-D volume at or above 20 Hz. If the projection surface is used in both front- and rear-projection modes, then the corresponding angular velocity is half than that required by a projection surface which is viewed in either (but not both) front- or rear-projection.

[0016] In some arrangements, the projection screen and a set of relay and fold optics are mounted together on a rotating platform.

[0017] Typically, the size of swept-screen 3-D displays is limited by the practicality of rotating large structures which house relay optics. This situation is alleviated if the relay optics can be removed or minimized, or if the radius of the base of the rotating structure can be minimized.

[0018] Therefore, the need exists for a swept-screen 3-D display whose projection screen is illuminated at an angle that is or is nearly perpendicular to the normal vector of the screen. The emergence of several ultrathin, wedge-shaped, or waveguide-based display technologies helps enable this feature.

[0019] The first set are prismatic "edge on" displays such as the displays described in:

[0020] 1. Biscardi, C. *et al*, “Ultrathin optical panel and a method of making an ultrathin optical panel,” U.S. Pat. No. 6,301,417; and

[0021] 2. Veligdan, J. T., *et al*, “Prismatic optical display,” U.S. Pat. No. 6,775,534.

[0022] The second set are optical "wedge" displays such as:

[0023] Travis, A. R. L., *et al*, “Optical Design of a Flat Panel Projection Wedge Display,” The 9th International Display Workshops (IDW) 2002, Hiroshima, Japan, 4-6 December 2002, paper FMC6-3, pp. 461-464.

[0024] Travis, A., *et al*, “Flat panel display using projection within a wedge-shaped waveguide,” Conference Record of the 20th International Display Research Conference, Sep. 25-28 (2000), Palm Beach, Florida, USA, pp. 292-295, the Society for Information Display. See also U.S. Patent No. 6,608,961 "Optical System Including a Planar Waveguide" to Travis.

[0025] In most of the displays described above, a high-speed projector illuminates the ultrathin optical panel and any associated relay optics, which together form a rotating assembly. The rotating assembly spins at or above 3600 rpm.

SUMMARY OF THE INVENTION

[0026] A 3-D display is created comprising a rotating optical element for displaying 3-D images as the rotating optical element rotates. In an embodiment, a projector projects images through the rotating optical element and wherein the rotating optical element comprises: an entry section located in a plane parallel to a projector plane of the projector; an internal light guide section which guides the image by total internal reflection; and a display surface oriented substantially perpendicular to the entry section.

BRIEF DESCRIPTION OF THE FIGURES

[0027] Embodiments will now be described, by way of example only, with reference to the accompanying drawings which are meant to be exemplary, not limiting, and wherein like elements are numbered alike in several Figures, in which:

[0028] Figure 1 is a side view of an embodiment of a display.

[0029] Figure 2 is a perspective view of a screen element of a display.

[0030] Figure 3 is perspective view of a wedge screen element.

[0031] Figure 4 is side view of a wedge screen element.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0032] Referring to Figures 1 and 2, a first embodiment is shown. A projector (200) which may of several types such as a DMD micro mirror device for example, illuminates an ultrathin optical panel (210) using a first relay mirror (215) and a second relay mirror

(220). The ultrathin optical panel and relay mirrors are mounted to a rotating cakepan (225); together these form a rotating assembly (330). The cakepan may be rotated by a motor not shown. The ultrathin optical panel has an optically transparent body (212) (or waveguides (212)) and a prismatic first side (211). The series of images from the projector (200) appears at the second side (213) for display, i.e., output.

[0033] The ultrathin optical panel (210) should coincide with an axis of rotation (230) of the rotating assembly (330).

[0034] The position of the one or more relay mirrors (215), (220) can take any form required to ensure that the illumination hits the panel's prismatic first side (211) at the proper incident angle.

[0035] A second embodiment is shown in Figures 3 and 4, which show the invention in the context of a "wedge" display. This may be fabricated with a lighter assembly than the units discussed above because the relay mirrors are eliminated as discussed below in detail.

[0036] Here, a projector (200) illuminates an ultrathin wedge which is mounted to a rotating assembly (330). In this case, the 3-D display can be constructed without any separate relay optics or mirrors, i.e., no rotating cakepan or relay mirrors are required.

[0037] A projector (200) or a projector centered on the axis of rotation (201) is mounted stationary to an enclosure (not shown). Its light is guided by a lens (305) into a slab waveguide (310), which directs the light to a collimating lens (315) and thereafter to a wedge waveguide (320). The light undergoes one or more reflections within the wedge, due to total internal reflection, and emerges from a display surface (213). It may be desirable to also mount a diffusing screen (325) to the display surface (213). Thus, the projector 201 does not necessarily need to rotate and no relaly mirrors or cakepan is necessary.

[0038] Again, the rotating screen assembly (330) should be oriented such that the axis of rotation is tangential to the display surface (213).

ADDITIONAL ALTERNATE EMBODIMENTS

[0039] Swept-screen 3-D displays whose display surfaces are ordinary (omnidirectional) diffusers which create 3-D images composed of voxels with hemispherical radiative profiles. Therefore, all voxels appear translucent, and the imagery does not appear to have solid surfaces. This known as the "occlusion" problem.

[0040] This problem can be alleviated by using display surfaces having nonstandard radiative characteristics. For example, the screen can be composed of cylindrical or hemispherical lenslets. This would allow the system to generate better approximations of a desired 3-D lightfield, and thus create 3-D scene elements which appear to occlude each other. Alternatively, the screen can be a substantially unidirectional diffuser.

[0041] This idea can also be appropriated for stationary 3-D displays, such as spatially-multiplexed autostereoscopic displays, like lenticular displays. Another family of 3-D displays are static-screen multiview displays. For example, the display surface can be a lenticular or hemispherical lens array and kept stationary while being illuminated as described above.

[0042] Of course, there are many ways to construct the claimed displays using the principles taught herein. The specific embodiments we describe are only a few among the set of all possible constructions that fall within the scope of the claims.

[0043] While the invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims. Moreover, the use of the terms first, second, etc. do not denote any order or importance, but rather the terms first, second, etc. are used to distinguish one element from another. Furthermore, the use of the terms a, an, etc. do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item.

What is claimed is:

1. A 3-D display comprising:

a rotating optical element for displaying 3-D images as the rotating optical element rotates;

a projector for projecting images through the rotating optical element;

wherein the rotating optical element comprises:

an entry section located in a plane parallel to a projector plane of the projector;

an internal light guide section which guides the image by total internal reflection; and

a display surface oriented substantially perpendicular to the entry section.

2. The 3-D display of claim 1 wherein the rotating optical element is rotated by a rotatable cakepan and wherein the cakepan is connected to a motor which turns the cakepan.

3. The 3-D display of claim 2 wherein at least one relay mirror is located in the cakepan for relaying images from the projector to the rotating optical element.

4. The 3-D display of claim 1 wherein the projector is a digital micromirror device (DMD).

5. The 3-D display of claim 1 wherein rotating optical element is wedge shaped.

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ABSTRACT

A 3-D display is created comprising a rotating optical element for displaying 3-D images as the rotating optical element rotates. In an embodiment, a projector projects images through the rotating optical element and wherein the rotating optical element comprises: an entry section located in a plane parallel to a projector plane of the projector; an internal light guide section which guides the image by total internal reflection; and a display surface oriented substantially perpendicular to the entry section.

FIG. 1

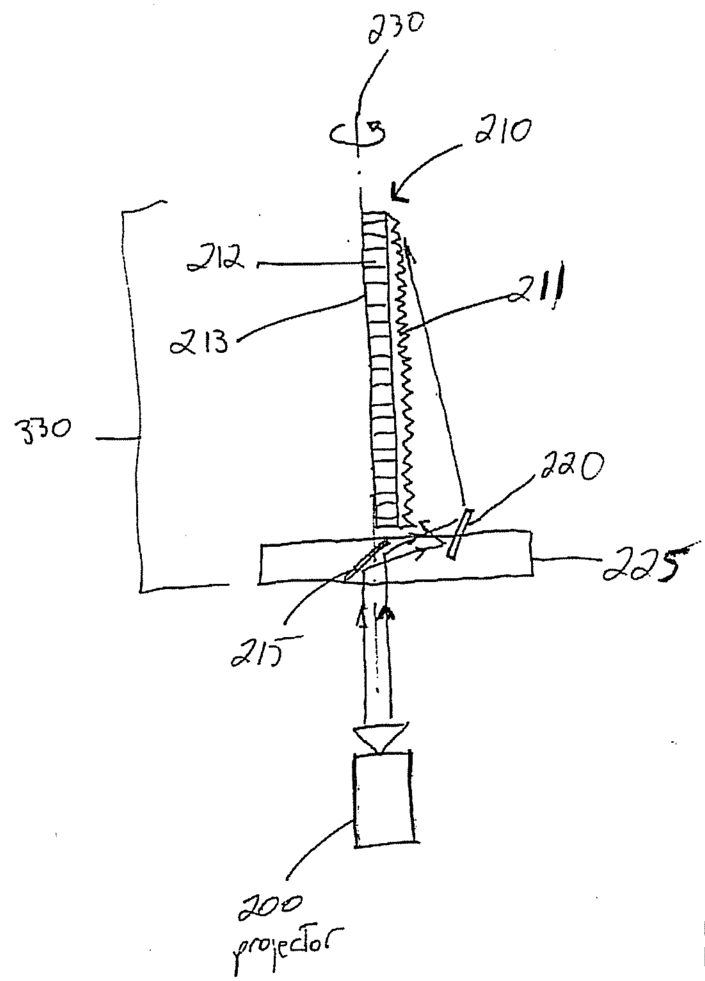


FIG. 2

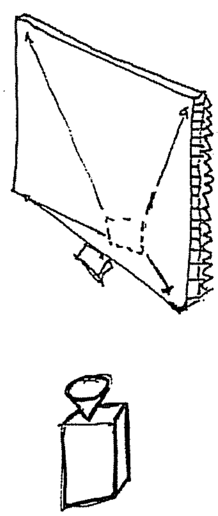


FIG. 4

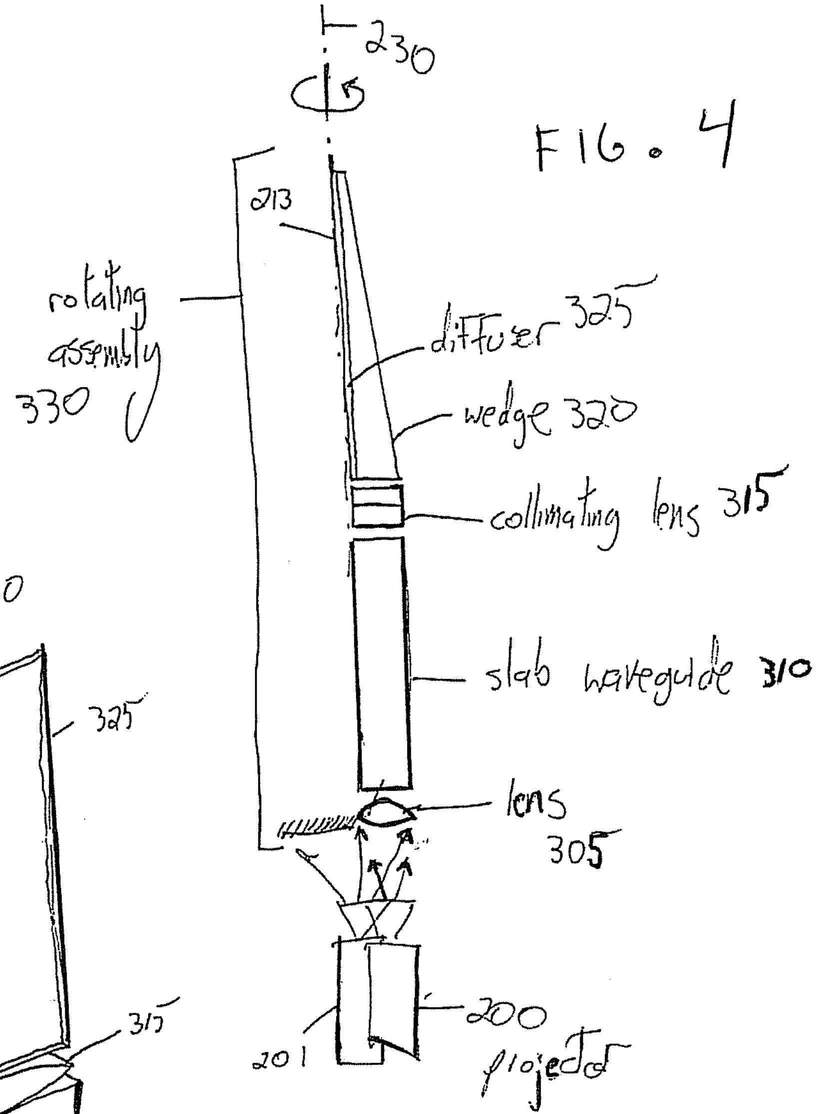
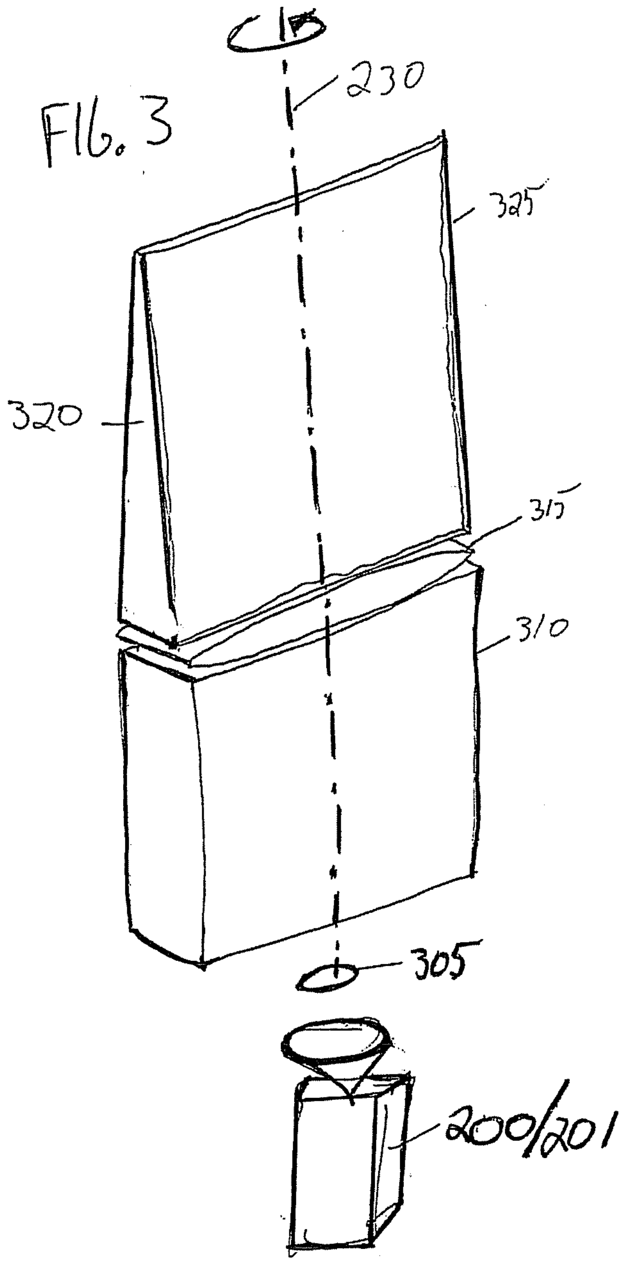

230
213
rotating assembly 330
diffuser 325
wedge 320
collimating lens 315
slab waveguide 310
lens 305
201
200 projector

FIG. 3


230
325
320
315
310
305
200/201