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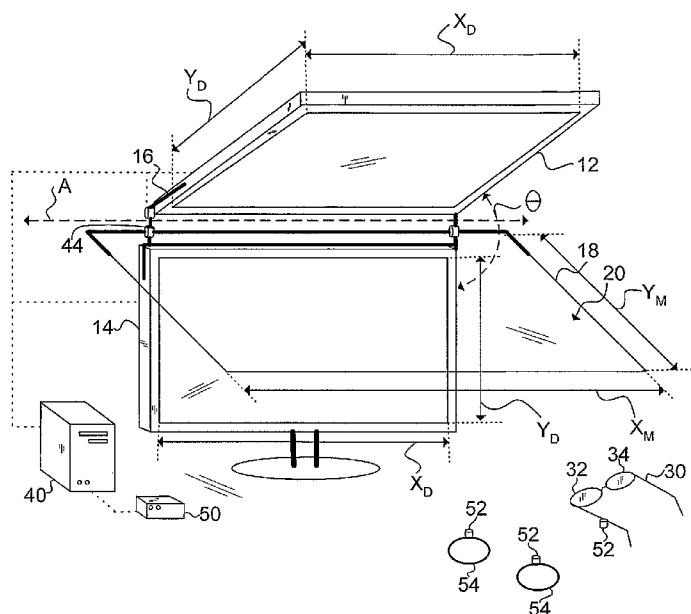
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(54) Title: VIRTUAL REALITY DISPLAY SYSTEM



(57) Abstract: One example system of the invention is a virtual reality system for displaying a viewer centered stereoscopic image. This example system comprises first and second displays arranged about an axis at an orientation angle of at least about 90° to one another. A polarizing filter is adjacent to each of the first and second displays. A half-mirror is arranged about the axis and approximately bisects the orientation angle. The half-mirror has a width and a height, at least one of which is at least 10% greater than a corresponding of the first and second display width and height.

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VIRTUAL REALITY DISPLAY SYSTEM

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TECHNICAL FIELD

A field of the invention is virtual reality displays and systems.

An additional field of the invention is stereoscopic displays.

STATEMENT OF GOVERNMENT INTEREST

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This invention was made with United States government support under contract number CNS 0420477 awarded by the National Science Foundation ("NSF"). The United States government has certain rights in the invention.

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BACKGROUND ART

Many current three-dimensional displays are based either on imaging techniques that achieve an apparent stereo by perspective views or on two presented images which are separated so that a viewer's right and left eyes see their respective images which are differentiated by polarization characteristics. Many of these displays are designed to view stereoscopic images and/or images that offer a depth of field (e.g., three dimensional image). Two images separated or distinguished by polarization are superimposed or

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may be displayed time sequentially to give an image which appears to be continuous.

Stereoscopic and similar display systems that accomplish these effects have been known for some time. One general configuration includes
5 first and second monitors disposed at an approximate right angle to one another, with a half-mirror approximately bisecting the two monitors. The first monitor provides a left eye image and the second provides the right eye image. The angular polarized light transmitted from one monitor is flipped when a viewer views the image as reflected by the half-mirror, while the angular
10 polarized light from the second monitor remains in its original state when viewed by the user through the non-reflecting portion of the half mirror. One image thereby arrives at the user with one polarization and the second with a different polarization. If the user wears glasses with different filters for each eye, the two different polarizations can be resolved whereby the user observes
15 distinct left and right eye images. A perception of depth is thereby achieved.

This basic configuration has been used for some time, with many improvements proposed from time to time. United States Patent No. 2,845,618 discloses an early example of such a device, while United States Patent No. 6,703,988 discloses an example of a much more recent improvement. In
20 addition to these disclosures, a number of additional display systems have been proposed with the goal of improved displays.

For example, when plasma screen technology became available they were used to generate field-sequential stereo. In practice, however,

plasma screens were found to be difficult to incorporate in such systems. They were electromagnetically noisy making them incompatible with electromagnetic trackers, which may be used in some applications including virtual reality systems. Also, the displays refreshed at 60 Hz which meant that
5 the stereo images refreshed at a mere 30 Hz - resulting in considerable eye-strain for viewers. Also, the red and green phosphors did not decay as quickly as the blue resulting in considerable cross-talk in the left and right-eye images.

A number of additional recently developed systems are commercially available. Auto-stereoscopic displays have recently been
10 marketed to take advantage of the low cost of LCD monitors. While these displays are suitable for viewing stereoscopic images, they are not well suited for viewing viewer-centered stereoscopic images because they require that the viewer keep their head stationary and straight in order to see the correct pairs of vertically interleaved images. Furthermore, many of these displays achieve a
15 maximum effective resolution of only about 800 x 1200 pixels. Finally, displays used in these systems tend to be relatively small.

To attempt to address some of the current limitations of autostereo displays, a barrier-strip autostereo display was developed that uses a moving virtual line screen synchronized with viewer-centered perspective to
20 enable a viewer to move their head and to tilt it slightly during viewing. While successful, 3/4 of the screen's native resolution is used to reduce moiré effects since 4 pixels are rendered for each anti-aliased stereo pixel. Furthermore,

precise low-latency head tracking is needed to ensure that the stereo images are perfectly aligned with the viewer at all times.

Other problems in the art related to incompatibility with head movement. Many current systems use linear polarizers to polarize one of both
5 of the display images, with a user wearing linear polarized glasses to resolve the image. When the user tilts their head, however, stereo imaging is lost due to the linear polarized glasses. Still other problems relate to the field of view of stereo images. A limited field of view limits a user's movement to the left or right, and further limits the ability of a single system to be viewed by multiple
10 users.

DISCLOSURE OF INVENTION

One example system of the invention is a virtual reality system for displaying a stereoscopic image. This example system comprises first and
15 second displays arranged about an axis at an orientation angle of at least about 90° to one another. A polarizing filter is adjacent to each of the first and second displays. A half-mirror is arranged about the axis and approximately bisects the orientation angle. The half-mirror has a width and a height, at least one of which is at least 10% greater than a corresponding of the first and
20 second display width and height.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 illustrates an example system of the invention;

FIG. 2 is a partial cutaway of a portion of a display of the system of FIG. 1;

5 FIG. 3 schematically illustrates an aspect of an example system of the invention;

FIGS. 4A-4D are schematics useful to illustrate some advantages of example systems of the invention over prior art systems;

FIG. 5 illustrates a second example system of the invention;

10 FIG. 6 schematically illustrates a third example system of the invention in an open position; and,

FIG. 7 schematically illustrates the example system of FIG. 6 in a closed position.

15 BEST MODE FOR CARRYING OUT THE INVENTION

One example embodiment of the present invention is a desktop virtual reality (VR) system that offers high-resolution, a wide range of view, and high-visual-acuity passive-stereo visualization on a single-computer-driven system. FIG. 1 is a schematic illustration of one example system 10. The system 10 includes first and second displays 12 and 14 supported by an adjustable frame 16 and oriented to one another at an angle θ . The frame 16 was built using extruded aluminum parts, and allows for adjustment of the angle θ by pivotal adjustment about an axis A. The angle θ may be adjusted as

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desired, but will generally be greater than 90° and less than about 140°. Larger angles may be useful in some applications.

Any number of different displays 12 and 14 will be suitable for practice of the invention. In many systems, beneficial results can be obtained through use of relatively large and high resolution displays. Some example
5 monitors useful in invention embodiments are at least 30 in. monitors, others are at least 32 in., and still others are at least 40 in. It will be appreciated that when discussing displays herein, the use of dimensions unless expressly noted otherwise will refer to the standard diagonal screen measurement used in
10 industry. By way of example, reference to a “32 in. monitor” will be understood to be reference to a monitor having a diagonal measurement of 32 in.

In the example system 10 the monitors are 30 in. Apple Cinema Displays from APPLE CORP., California, United States. One benefit of using
15 relatively large monitors, with an example being at least 30 in. size, is viewing angle. Given that the 30 in. screen is 25 in. wide in the horizontal direction, when viewed from a comfortable distance (with an example being approximately 24 inches) the user’s field of view is about $\arctan(25/2 \times 1/24) \times 2 = 55^\circ$. Given that the visual acuity of a display can be computed as
20 $20/(\text{FOV} \times 1200/\text{resolution})$, therefore, the visual acuity of the example system 10 is about $20/(55^\circ \times 1200/2560)$, which is approximately 20/26.

Use of widely commercially available monitors may be beneficial for cost, reliability, interoperability, and other reasons. In addition to the Apple

Cinema Displays, other suitable commercial displays include the NEC Mitsubishi Multisync LCD4010-BK 40" LCD display from NEC MITSUBISHI (Japan), the Mitsubishi MDT461S 46" LCD display from MITSUBISHI (Japan), JVC GM-H40L2GU 40" LCD display from JVC
5 (Japan), ViewSonic N3751w 37" LCD display from Viewsonic Corp. (USA), and others. One advantage of using LCD displays 12 and 14 is there relatively high level of brightness. This allows them to be readily used under normal office and other lighting environments.

Displays 12 and 14 of the invention also preferably achieve a
10 high resolution not available in the prior art. The example Apple Cinema 30 in. displays have a resolution of 2560 x 1600 pixels (i.e., greater than 4 mega pixel total resolution). Other systems of the invention will utilize other displays to achieve even greater resolution. One example is the IBM T221-DG5 QUXGA-W 22.2 in. LCD display from IBM Corp. (New York, USA). This display
15 provides a resolution of 3840 x 2400 pixels (i.e., greater than 9 mega pixel total resolution). These levels of resolution are not available in systems of the prior art, and will be of particular value in many applications where great image detail is desired. Relatively large displays are one example of an application for which enhanced resolution will be of significant benefit.

20 To achieve even greater resolution, other example embodiments of the invention replace each of the displays 12 and 14 with a plurality of displays in a tiled configuration. For example, replacing the displays 12 and 14 with a set of 4 IBM T221-DG5 QUXGA-W 22.2 in. LCD displays would result

in each display 12 and 14 having a total size of about 45 in. and a total resolution of over 36 megapixel. Arrangements of 4 x 4 tiled displays, 4 x 6 tiled displays, 6 x 6 tiled displays, and 6 x 8 tiled displays are contemplated. Many other tiled configurations are possible and will be apparent to those knowledgeable in the art. Software or other means may be provided to split an image across the plurality of tiled displays to result in a single composite image. LCD displays also offer an advantage in their elimination of flicker. Many systems of the prior art that use cathode ray tube screens, by way of example, are subject to some degree of flicker due to the use of an electron gun scanning across the screen to produce an image.

A half mirror 18 is arranged between the displays 12 and 14 about the axis A and approximately bisects the angle θ . The term "half mirror" will be understood by those knowledgeable in the art. As used herein it is intended to be broadly interpreted as any media which has one substantially reflecting surface and an opposite surface that is substantially transmissive. An example of a half mirror 18 is one in which one surface is only partially covered with silver reflecting media, with an example being about 50% or 60% coverage. In the example system 10, a 6 mm half-silvered glass mirror with 40% refractivity and 60% reflectivity was used (often referred to as a "40/60" coating). Other half mirrors will likewise be suitable.

A thinner mirror, for instance, may be used, but it has been discovered that when using larger half mirrors useful with large displays, greater thicknesses are desirable to add strength and rigidity. A thickness of at

least about 6 mm is one example thickness believed to be useful, while in other systems a thickness of at least about 8 mm may be useful. A polarization-preserving half-silvered acrylic mirror is another example half mirror that will be useful in practice of the invention. The half mirror 18 is arranged with its
5 reflective surface 20 oriented to face the uppermost display 12.

In operation, a user that views the half mirror 18 will observe an image displayed by the display 12 reflected from the mirror's reflecting surface 20 superimposed with a second image displayed by the display 14 that is transmitted through the reflecting mirror's non-reflective surface opposite from
10 the reflective surface 20. If the two displays 12 and 14 simultaneously show cooperating stereoscopic images (e.g., left and right eye imagery), stereoscopic viewing can result. By way of example, if the display 12 is displaying an image recorded from a left eye perspective while the display 14 shows an image recorded from a right eye perspective, a viewer will observe stereoscopic
15 imagery including one with three-dimensional depth.

In order to accomplish this, however, a user must resolve the left and the right eye imagery. Put another way, the user must be able to view the image originating from the display 12 and from the display 14 with different eyes. This can be accomplished in several different manners, using different
20 structural configurations. The example system 10 is configured to deliver images from each of the displays 12 and 14 with different polarizations, and then "decode" the different polarizations when they arrive at the user for viewing by different eyes.

Polarization is accomplished using polarizing filters 22 that cover each of the displays 12 and 14. Since the light from large LCD screens is polarized vertically, the addition of the quarter-wave plate creates circularly polarized light. While the light passing through the half-silvered mirror is polarized in one circular direction, the light from the top LCD screen reflecting on the mirror is polarized in the opposite direction. A viewer wears a pair of circularly polarized glasses to resolve the stereo image.

FIG. 2 shows a portion of each of the displays 12 or 14 in partial cutaway. The filter 22 substantially overlies the screen 24 of each of the displays 12 and 14. The filter 22 has been laminated between two transparent acrylic sheets 26 for rigidity. Although different polarizing filters 22 are suitable for use with different example systems of the invention, with examples being linear or circular polarizers, the filter 22 is a quarter-wave plate with the fast axis oriented at 45 degrees. The filter 22 has been laminated between two polarization-preserving acrylic sheets 26 for rigidity and then attached to the display 12/14. The filter 22 is substantially coextensive with the LCD screen 24. The filter 22, acrylic sheets 26 and screen 24 may be attached to one another using adhesive, mechanical fasteners, or the like.

In the example system 10, the filter 22 was obtained from the American Polarizer Corp., Reading Pennsylvania, United States. It is an Acrylic Laminated Quarterwave Retarder with retardance of 140 nm and its fast axis at 45 degrees. Its dimensions are 18 in. x 27 in. x 0.070 in. thick.

Other retardances, fast axis orientation, and dimensions will be useful with other invention embodiments.

The use of the quarter wave plate 22 to achieve circular polarization has been discovered to be particularly well suited for use with liquid crystal display (LCD) displays that are larger than about 17 in. (or in some cases larger than about 19 in.). LCD screens smaller than about 17 in. (or in some cases about 19 in.) emit linear polarized light at a 45 degree angle. Larger LCD screens, however, emit linear polarized light at zero degrees. Linearly polarized light at 45 degrees when reflected off a mirror will produce linearly polarized light at 45 degrees. However, light polarized in a vertical angle will still produce polarized light at zero degrees when reflected. As a result, it has been discovered that light emitted from LCDs that are larger than about 17 in. (or in some cases 19 in.) cannot rely on linear polarizers. It has been discovered that a useful means to create oppositely polarized light is through circular polarization. The quarter-wave plate 22 that converts linearly polarized light to circular polarized light has been discovered to be effective.

Light from the display screen 24 of either of the displays 12 or 14 will exit the quarter wave plate or filter 22 with a circular polarization. When the circular polarized light from the upper display 12 reflects off of the reflective surface 20, it “flips” polarization. That is, it reverses its rotational direction. The circularly polarized light from the lower display 14, however, doesn’t undergo any change as it passes through the non-reflective surface of the mirror 16. As a result, images from the displays 12 and 14 will arrive from

the mirror 18 to the user in different circular polarizations phases: a first phase from the lower display 14 that is not reversed by the mirror 18 and a second image from the top display 14 whose polarization undergoes reversal at the mirror 18.

5 The user is required to resolve these different polarizations. In the example system 10, this is accomplished through use of wearable glasses 30. The glasses 30 include two lenses 32 and 34, each of which are a circular polarization filter that are oriented in an opposite direction of one another. The lens 32 and 34 are composed of a right-circular polarized and a left-circular
10 polarized filter. Accordingly, one lens 32 will resolve the image originating from the display 12 and the other lens 34 will resolve the image from the display 14. In this manner, the user views stereoscopic imagery.

Many systems of the prior art rely on the 45 degree polarization that is naturally emitted from smaller (with an example being less than 17-inch)
15 LCD screens. This polarization is therefore reversed by a reflective surface so a user can wear linear polarized glasses to resolve the stereo. In the case of larger displays such as those contemplated for use with the present invention (and others that do not emit 45 degree polarized light), however, it has been discovered that linear polarizing filters will not provide the required separation
20 of display images, since larger LCD screens emit linearly polarized light in the vertical direction (rather than at 45 degrees). The reflection of light polarized in the vertical direction from a reflective surface such as the mirror 18 will not re-orient the light at 90 degrees. Accordingly, displays that transmit vertically

polarized light (with an example being LCD displays that are larger than 17 in.) used with linear polarizing filters will result in the images from each of the displays arriving at the user with the same polarization. No resolution to separate the two images is thereby possible, at least through polarization techniques.

In addition to allowing use of displays that transmit linear polarized light (such as displays 12 and 14), the circular polarizing filters 22 provide other advantages as well. For example, use of circular polarization has been discovered to provide superior performance over linear polarization for allowing movement of a user's head relative to the system 10. Put another way, use of circular polarization has been discovered to provide increased freedom of movement of a user's head while maintaining stereo when compared to linear polarization. Users are able to tilt their head sideways while still resolving two different images to each of their eyes. This is not possible with linearly polarized stereo of the prior art.

Referring now to the schematic of FIG. 3 by way of illustration, as a user U tilts her head in the general direction of either of arrows A away from a vertical axis V when using a system that relies on linear polarization, stereo is lost. This occurs since the orientation of the linear polarization filter on the user glasses is critical to resolving the linear polarized light coming from the system S. This critical dependence on orientation, however, does not exist for circularly polarized light – the angle of orientation of a circular filter does not affect its ability to filter circularly polarized light.

This provides a system of the invention such as system 10 that uses circular polarized filters important benefits and advantages over systems of the prior art that relied on linear polarized filters, including an increased tolerance for user movement. These benefits and advantages may be of particular value in applications such as virtual reality simulations, gaming and the like where users are expected to move their heads (including tilting movement) in response to changing imagery.

It is also noted, however, that in some applications this increased field of user movement may not be necessary, and that in such applications linear polarizing filters will be suitable for practice of the invention. In many applications, however, an increased field of user view will provide very valuable benefits and advantages. In addition to the above examples, other applications will also benefit from an increased field of user view. One additional example is large scale displays that may be viewed by multiple users simultaneously. Examples include engineering, satellite and map imagery, astronomy, geology, gaming, entertainment, and other applications in which multiple users may wish to collaboratively view a stereoscopic image simultaneously. Systems of the prior art have offered a limited ability to achieve a suitable field of user vision for accommodating many of these multi-user applications.

An additional aspect of the present invention has been discovered to offer particular utility for addressing these unresolved needs. In particular, some example systems of the invention include a mirror that is significantly

larger than either of the displays. Referring again to FIG. 1, the half-mirror 18 has a horizontal width X_M that is wider than the horizontal width X_D of either display 12 or 14 (in most, but not all, applications, the dimensions of the displays 12 and 14 will be identical). The half-mirror 18 also has a vertical height Y_M that is larger than the height Y_D of either display 12 or 14.

It has been discovered that providing a mirror 18 having a larger width X_M (and/or height Y_M) than that of the displays 12 or 14 provides a significant improvement over systems of the prior art that utilize a mirror having substantially the same dimensions as the displays. These advantages can be best illustrated through consideration of the schematics of FIGS. 4A and 4B. FIG. 4A illustrates a user viewing a system of the prior art S_{OLD} which includes a mirror M having a width X_M and height Y_M that are substantially the same as the width X_D and height Y_D of each of the system's displays D . As shown, when a user is located off center from the system and views the mirror from an angle (as opposed from viewing it directly from center), only a limited field of view having a width F is available on each of the displays D . This may be further illustrated through the simplified schematic of FIG. 4B representing a user U viewing a display D through mirror M to achieve a field of view across the display D of F . FIG. 4B also schematically illustrates a viewing zone $VZ1$ in which a user must be in order to see the full width of the display D .

FIGS. 4C and 4D contrast the prior art system S_{OLD} with schematics illustrating an example system S_{NEW} of the present invention, with

the user U positioned at the same position as she was in FIGS. 4A and 4B. Referring now to FIG. 4C, in the system S_{NEW} the mirror M has a width X_M and height Y_M that are substantially larger than the width X_D and height Y_D of either display D. As shown, the wider mirror allows for a user to enjoy a much
5 larger width of field of view F on the displays D when the user views the system from off center. This is further illustrated through the simplified schematic of FIG. 4D showing user U viewing display D through a mirror M that is wider than the display D and thereby achieves an enhanced width of image F on display D. FIG. 4D also illustrates a viewing zone VZ_2 in which a
10 user may observe the full width of the display D. As illustrated, the viewing zone VZ_2 is significantly larger (in the horizontal direction) than is the zone VZ_1 of FIG. 4B.

Although not illustrated by FIGS. 4A-4D, it will be appreciated that in addition to achieving a wider field of view F, mirrors that have a larger
15 height Y_M than the display height Y_D will likewise achieve an increased field of view in the vertical direction as a user views the mirror from a position that is vertically off center.

The degree of size difference between the mirror width and height and that of the display will vary with application. Generally, as the
20 mirror size increases the distance that a user can move off-center while continuing to observe a full screen increases. These benefits must be balanced, however, against inconveniences that arise from a mirror that is overly large and bulky. It is believed that in many applications, a useful balance is achieved

through use of mirrors that have a width X_M at least about 10% greater than the display width X_D . In other systems the mirror width X_M is at least about 20% wider, in others at least about 25% wider, and in others width X_M is at least about 30% wider, and in still others it is at least about 40% wider. In some
5 systems of the invention the mirror height Y_M will be at least about 10% greater than display height Y_D , in others height Y_M is at least about 20% greater, and in others height Y_M is at least about 30% greater.

Those knowledgeable in the art will be able to appreciate the valuable gain achieved in field of view through these increased widths.
10 Straightforward geometrical calculations can be made, for example, using the schematics of FIGS. 4 A-D to show the increased field of view (VZ_1 of FIG. 4B) for a user at a given distance from the display.

It is believed that in many applications, including those in which multiple users crowd around a system to view the same image simultaneously,
15 an increase in width X_M may be more beneficial than an increase in height Y_M . Accordingly, in one system of the invention the mirror width X_M is at least about 20% greater than the display width X_D , while the mirror height Y_M is between about 10% and 20% greater than the display height Y_D .

The mirror 18 that is larger than either of the displays 12 and 14
20 provides unexpected benefits, as described herein above. It is believed that systems of the prior art relied on mirrors that were the same size as their displays for many reasons. For one, the larger mirror 18 of the present invention presents a larger footprint for the system 10 that requires additional

space and presents other challenges over systems of the prior art that use a smaller mirror. It is suspected that these factors may have prevented others from modifying systems of the prior art. It has been discovered, however, that these factors are significantly outweighed by the benefits and advantages that
5 the larger mirrors of the present invention provide.

Having now provided a discussion of structural and operational aspects of example systems of the invention with respect to viewing images, further detail is appropriate regarding control of systems of the invention and generation of images on the displays 12 and 14. Operation of the system 10 is
10 controlled by a controller 40, which may be, for example, a processor based device such as a computer. It may include one or more processors, a memory, multiple ports for inputting and outputting data and signals, and other components that are generally know.

The controller may further include one or more hardware and
15 software components for operating the system 10, with examples including software components for generating and/or processing left and right eye image data to be displayed on displays 12 and 14, software drivers and hardware components for operating the displays 12 and 14, and the like. Specialized hardware and software for driving displays and for generating image data are
20 widely commercially available, with examples including display drivers available from manufactures (including APPLE Corp., California, United States) and specialized graphics processors.

The system 10 is contemplated as being a passive system, (although other systems of the invention could be active), meaning that the controller 40 displays left and right eye images simultaneously and relies on the user to resolve them. The left and right eye images displayed on the displays
5 12 and 14 may comprise still images, sequential images, continuously moving images (e.g., movies), and combinations thereof. Examples include two and three dimensional engineering drawings, movies, computer generated graphics, maps, satellite imagery, and the like. The controller 40 may utilize standard stereo off-axis projection calculations to generate viewer-centered perspective,
10 even in response to movement of a user's head position or orientation.

The controller 40 in the example system 10 utilizes a commercial graphics card with two dual-link DVI outputs, such as the nVidia Quadro FX 4400 available from NVIDIA Corp., California USA. Other suitable components include two nVidia Quadro FX 3400 synchronized by a SLI
15 connector. This latter alternative required a powerful power supply to drive both cards. In addition, it allowed for full resolution on both displays, but not in clone mode. As a result, the former component may be desirable in many applications over the latter. Many other commercial graphics cards are useful in practice of the invention, including those that are suitable to display at the
20 maximum resolution on both LCD displays 12 and 14 when operated in clone mode.

In the example system 10, the controller 40 is configured to address the need to flip the image displayed on the top display 12 so that the

image reflected from mirror 18 does not appear reversed. This is accomplished through a software component operating on the controller 40. Although commercially available drivers such as nVidia ForceWare stereo drivers (version 77.77 available from NVIDIA Corp., California United States) allow applications showing full-screen clone-mode stereo to flip the orientation of one of the images, it has been discovered that these are not appropriate for some applications of the present invention. Although these drivers allow fixed-viewpoint applications such as DirectX games or OpenGL CAD applications to work in stereo without any modification, they cannot be used for viewer-centered perspective because the driver does not support user head position and orientation tracking. Instead, these drivers assume a fixed head position with horizontal eye alignment and a constant inter-ocular distance making them unable to achieve some of the benefits of the system 10.

The present invention includes a more general method for implementing viewer-centered perspective through operation of the controller 40. A software program operating on controller 40 achieves this. In particular, the projection matrix for an image is vertically flipped by swapping the *top* and *bottom* parameters used to specify the projection. In OpenGL software code, for example, this amounts to swapping the 3rd and 4th parameters to “glFrustum” or “glOrtho.” Those skilled in the art will appreciate that other commands will be useful to achieve this when using other programming languages.

It has also been discovered, however, that flipping the projection in this manner has a side effect that must be corrected. For example, it results in the reversal of the winding of all polygons. In computer graphics, back-face culling is often used to determine whether a polygon of a graphical object is visible depending on the orientation of the camera. Back-face culling commonly uses winding to distinguish back from front facing polygons, thus a flipped projection will invert the effect of the back-face culling mechanism. In OpenGL code, the front-face winding can be reversed with a call to `glFrontFace(GL_CW)` prior to the rendering of the flipped view. Those skilled in the art will appreciate that other commands will be useful to achieve this when using other programming languages.

Depending on the installed orientation of the displays, the flip may be either vertical or horizontal. A horizontal flip behaves just as a vertical flip, but requires the swapping of the left and right projection parameters. The polygon rewinding requirement remains the same. In the event that both a horizontal and a vertical flip is necessary, no polygon rewinding is necessary, as the rewindings of the flips cancel out. A generalized display configuration mechanism should include flags to enable a horizontal or vertical projection swap, and should enable polygon rewinding on the exclusive-or of these flags. One example system of the invention includes a software component that uses such a mechanism.

The controller 40 may also be linked to the frame 16 for controlling the angle θ as well as the position of the bisecting mirror 18. In

particular, the frame 16 may include a pivoting gear drive 42 connected to the display 12 and a pivoting gear drive 44 connected to the mirror 16. Each gear drive 42 and 44 is linked to the controller 40, which is configured to operate each of the drives. Through their operation, the controller 40 may alter the angle θ and/or the position of the bisecting mirror 18. This can be useful and convenient when different sized users or different numbers of users, for example, use the system 10.

The example system 10 further includes a tracking system connected to the controller 40. Tracking systems are generally known in the art, and detailed description herein is therefore not necessary and will not be provided for sake of brevity. The tracking system is useful to track motion and orientation of one or more user's position, including their head and one or both hands. The tracking system may determine one or more of position, tilt and rotation. Many commercially available tracking systems are suitable for use with the system 10, with one example being the FLOCK OF BIRDS system from ASCENSION TECHNOLOGY CORP., Burlington, Vermont, USA.

The example tracking system shown in FIG. 1 is wireless, and includes a locator 50 and a plurality of sensors 52. One or more sensors 52 are held on the glasses 30, and one sensor 52 in on a hand held interaction device 54 which may be configured, for example, for wearing on a user wrist or hand. Other example systems of the invention may use glove sensors which respond to movement of a user's hand such as gripping motion, twisting, individual finger movements, and the like. The locator 50 is configured to determine the

location and orientation of each of the sensors 52 in three dimensional space through any of various technologies, with an example being light (such as infrared), sound, electrical signal, and the like. The example system 10 uses a tracking system that employs DC magnetic technology, which has the
5 advantage of not requiring a line of sight between locator 50 and sensors 52.

The locator 50 is linked to the controller 40 which is configured to operate the tracking system and to process data provided by it. As a user's hands and head move about with sensors 52 attached thereto, their movements and positions are tracked. As a user tilts or turns his head, the position and
10 orientation of the sensor 52 on the glasses 30 can be used to determine head position and orientation, including tilt and/or rotation. An absolute distance between the user's head and the mirror 18 can be determined, as well as a distance for each particular of the user's two eyes.

The controller 40 can use this data to change the user perspective
15 and other aspects of the left and right eye images being displayed on the displays 12 and 14 to maintain stereo imagery for the user. Further, the controller 40 can manage virtual objects that are displayed by one or more of the displays 12 and 14 that can be "touched" and otherwise manipulated by a user. The controller 40 can determine when a user's hand (with a bracelet with
20 a sensor 52 attached) has moved into a location where the user "sees" a virtual object. The virtual object may be moved or other actions may be taken in response to further detected movements by a user.

In operation the tracking system may require initial calibration. For example, the controller 40 may provide test screens and request specific movements by a user to specified locations to calibrate itself. Although the tracking system of the system 10 has been illustrated as being suitable for use
5 by one user, other example systems of the invention may include multiple passive users wearing polarized glasses to observe the stereo images, or may include multiple interaction devices for simultaneous use by the multiple users.

The present invention also contemplates controlling the system 10 through manipulation by a user of virtual objects displayed on the displays
10 12 and 14. Virtual buttons, knobs, switches and the like may be displayed, and operated through manipulation by a user's hand and head movements that are detected by the locator 50 and controller 40. In some systems of the invention, for example, the angle θ can be controlled through such operation. A user desiring to change the angle θ might manipulate virtual knobs and dials, with
15 the controller 40 operating the gear drive 42 in response.

It will be appreciated that the system 10 is but one example of a system of the invention. Many alterations, equivalents, and modifications may be made without departing from the scope of the invention as claimed below. By way of example, FIG. 5 illustrates a second example system 110 of the
20 invention that has been configured for positioning on a tabletop. The system 110 is similar in many respects to the system 10, and like element numbers will be used in the 100 series for convenience and clarity.

The system 110 is configured for desktop use, and includes displays 112 and 114 supported by frame 116 and positioned at a 90° angle to one another. The displays 112 and 114 are 19 in. LCD displays emitting linear polarized light. Each is fitted with a quarter wave plate for producing circular
5 polarized light. A 40/60 half mirror 118 approximately bisects the displays 112 and 114. The mirror 118 has a width that is substantially wider than the displays 112 and 114. A processor based controller 140 is generally consistent with the controller 40 described above, and processes left and right eye images, communicates them to the two displays 112 and 114, and otherwise controls
10 operation of the displays 112 and 114. The controller 140 is linked to each of the displays 112 and 114.

The frame 116 is configured in a different manner than the frame 16 of FIG. 1. The frame 116 may be made of suitable materials selected for strength and rigidity while maintaining a relatively low weight and cost.
15 Example materials of construction include metals such as aluminum, steel alloys, and even rigid plastic. The materials should be compatible with the system 110 – steel is not appropriate if using an electromagnetic tracking system. The frame 116 includes an overhead rack 160 to which an upper display 114 is mounted. The frame 116 further includes a generally U-shaped
20 base 162 that sits on the tabletop. First and second posts 164 connect the overhead rack 160 to the base 162. Cross members 166 connect the posts 164 to the overhead rack 160, and also are pivotally connected to the mirror 118.

An adjustable support 168 connects the base to the mirror 118 at each of its side. The length of the support 168 may be adjusted to cause the mirror 118 to pivotally move relative to the cross members 166 and thereby change its angle of orientation relative to the user U. The support 168 may
5 comprise, for example, an adjustable piston, or cooperating telescoping arms with an internal gear drive for adjusting length. The support 168 may be linked to the controller 140 for automated adjustment.

The user U using the system 110 is wearing glasses 130 that are equipped with two quarter wave plates set in the same phase to resolve the left
10 and right images the user views from the mirror 118. The system 110 also includes a tracking system. Unlike the tracking system of the system 10, however, the tracking system of the system 110 is not wireless – it is connected by a wire 170 to the system 110. The tracking system includes a sensor attached to the glasses 130 for tracking the user's head position and orientation.
15 The user U may also provide input to the controller 140 through hand movement, with examples including a hand mounted sensor, a mouse wired to the controller 140, a keyboard, or other device(s).

FIGS. 6-7 illustrate still an additional system 210 of the invention. The system 210 shares many common components with the systems
20 10 and 110, and like element numbers have been used in the 200 series for clarity and convenience. For sake of brevity, description will not be provided herein concerning elements of the system 210 that are consistent with those of systems 10 or 110, and description of those systems may be had through the

above provided discussion. By way of example, the displays 212 and 214 and mirror 218 are generally consistent with those suitable for use with the systems 10 and 110. The mirror 218, for example, is at least 10%, and may be at least 20%, 30% or 40% wider than the displays 212 and 214, and likewise may have
5 a height that is at least 10% or at least about 20%, 30% or 40% greater than the height of the displays 212 and 214.

Additionally, the displays 212 and 214 are liquid crystal displays that emit linearly polarized light, and include circular polarizing light filters. They may be at least about 20 in., at least about 30 in., or at least about 40 in.
10 in diameter. The displays 212 and 214 may have a resolution of at least about 4 megapixels, or of at least about 9 mega pixels. Some elements of the system 210 are different from the system 10 and 110, however. Discussion of these elements is provided below.

The system 210 is configured for portability, and includes a
15 collapsible or foldable frame 216. The collapsible frame is shown generally at 216, and includes a base 302 and a base support arm 304 that is pivotally connected to the base 302 at a first end 306. A second support arm end 308 is connected to a gear mechanism shown generally at 310 that includes first and second gears 312 and 314 that are rotatably engaged with one another whereby
20 rotation of one cases rotation of the second. The two gears 312 and 314 each rotate about an axial hub 315 which is mounted on a connecting arm 316. The rotatable gear 312 includes a connector 318 that connects it to the base support arm 304, and the rotatable gear 318 includes a second connector 318 that

connects it to a top support arm 320. The connectors 318 are fixedly connected to the gears 312 and 314, so that they rotate with the gears. The top support arm 320 supports the upper display 212 near a first end, and a counterweight 322 is connected to a distal second end. A half mirror 218 is connected at approximately a right angle to the connecting arm 316. The half mirror 218 bisects the angle θ that the displays are oriented to one another at.

The frame 216 is collapsible. As used herein in this context, the term “collapsible” is intended to be broadly interpreted as meaning foldable or the like. FIG. 7 illustrates the system 210 in a closed or folded position. The base support arm 304 may be pivotally folded between its upright position (FIG. 6) and its closed horizontal position (FIG. 7). The support arm 304 include a peg 324 that rides in a slot 326 cut in a guide bracket 328 that is on the base 302. The slot 326 may include notches at its two ends for locking engagement of the support arm peg 324. The guide bracket 328 further rotatably holds a base support arm pin 330 about which the arm 304 pivotally rotates. The slot 326 limits travel of the support arm 304, and provides locking engagement to hold the arm 304 in its open upright position (FIG. 6). The base 302 may be configured in a general U-shape (when viewed from above) or other configuration to provide stability on a tabletop or the like.

Once the base support arm 304 is in a locked upright position (FIG. 6), the top display 212 may be pivotally moved into position. The gear mechanism 310 allow pivotal movement of the upper support arm 320. Importantly, as the upper support arm 320 is pivotally moved, the gear

mechanism 310 maintains the half mirror 218 in a bisecting position between the displays 212 and 214. This is accomplished through operation of the rotating gears 312 and 314 together with the connecting arm 316. As the base support arm 304 pivots upward and the gears 312 and 314 rotate, the half mirror 218 that is rigidly connected to the connecting arm 316 at about a 90 degree orientation remains in a desired bisecting position. The top display 212 and bottom display 214, however, change position relative to the gear mechanism 310 since the connectors 318 rotate with the gears 312 and 314.

The gear mechanism 310 is lockable, so that when the lower support arm 304 is in a locked upright position the gear mechanism 310 may likewise be locked to hold the position of the display 212 and mirror 218. An example locking mechanism includes the pin latch 332 which is effective to prevent the gears 312 and 314 from rotating. Many other locking mechanisms are contemplated for use with the invention, including cams, pins, levers and the like. The gear mechanism 310 also allows for adjustment relative to the base support arm 304 when it is in a locked position. This allows for the position of the top display 212 and mirror 218 to be adjusted relative to the lower display 214 as desired. This may be useful, for example, to adjust the position of the upper display 212 and mirror 218 to accommodate a taller or a shorter user.

The counterweight 322 eases the pivoting adjustment of the top support arm 320, as does the connection of the upper support arm 320 to the gear mechanism near its midpoint 334. These elements likewise have been

discovered to be beneficial in maintaining the center of gravity of the system 210 centered over the base 302. The counterweight 322 has also been discovered to provide a useful adjustment mechanism – it may be changed as desired to balance the top support arm 320 (and to shift the center of gravity of the system 210) in response to use of a heavier or lighter top display 212. The system 210 also includes cushions 336 that are useful to cushion the displays 212, 214 and mirror 218 when the system is in a closed, folded position (FIG. 7).

It will be appreciated that the system 210 may also include other elements. For example, a case (not illustrated) may be provided for ease of transport. A controller is also contemplated, which may be, for example, a stand alone portable computer (not illustrated) that can be connected to the displays 212 and 214 for driving the system 210. Tracking system components can also be provided and connected to the controller, with examples including the glasses 30, bracelets 54, locator 50 and sensors 52 of FIG. 1 for tracking a user's head movement and orientation, and hand movement. Further structural elements of the frame 216 can be provided, with examples including additional adjustable supports for easing pivoting movement and further stabilizing the top and bottom supports 304 and 320. Examples include one or more adjustable gas shocks connecting the two supports 304 and 320 to one another and/or to the base 302.

The above discussion and attached FIGS. describe example systems of the invention. It will be appreciated that these are examples only,

and that other systems of the invention may be configured in other ways, may include additional or fewer components, and may be configured in different ways. The above discussion is not intended to limit the scope of the invention as claimed below, and descriptions of various system elements and components
5 are intended to be given their broadest possible interpretation.

CLAIMS:

1. A virtual reality system comprising:
first and second displays arranged about an axis at an orientation
5 angle of at least about 90° to one another;
a polarizing filter adjacent to each of said first and second
displays; and,
a half-mirror arranged about said axis and approximately
bisecting said orientation angle, said half-mirror having a width and a height, at
10 least one of said width and said height at least about 10% greater than a
corresponding of said first and second display width and height.

2. A virtual reality system as defined by claim 1 wherein said
half mirror has a width at least about 10% greater than said first and second
15 display width, and wherein each of said first and second displays have identical
height and widths.

3. A virtual reality system as defined by claim 1 wherein said
half mirror has a width at least about 30% greater than said first and second
20 display width.

4. A virtual reality system as defined by claim 1 wherein said
half mirror has a width at least about 30% greater than said first and second

display width, and a height at least about 10% greater than said first and second display height.

5 5. A virtual reality system as defined by claim 1 wherein said half mirror has a width at least about 20% greater than said first and second display width, and a height at least about 10% greater than said first and second display height, and wherein said polarizing filters are configured to provide circular polarization.

10 6. A virtual reality system as defined by claim 1 wherein said polarizing filters comprise circular polarizers configured to provide circular polarization.

15 7. A virtual reality system as defined by claim 1 wherein said polarizing filters comprise quarter wave plates.

 8. A virtual reality system as defined by claim 1 wherein said first and second displays comprise liquid crystal displays that emit linear polarized light in a diagonal direction.

20

 9. A virtual reality system as defined by claim 1 wherein said first and second displays are each at least 30 in. diagonal LCD displays and have a resolution of at least about 4 megapixels.

10. A virtual reality system as defined by claim 1 wherein said first and second displays are LCD displays having a resolution of at least about 4 megapixels, and wherein said polarizing filters are configured to convert light
5 emitted from each of said displays to circular polarization.

11. A virtual reality system as defined by claim 1 wherein said first and second displays each have a resolution of at least about 9 megapixels and each emit linear polarized light, said polarizing filters configured to
10 convert said linear polarized light to circular polarization.

12. A virtual reality system as defined by claim 1 and further comprising:

a controller linked to said first and second displays for processing
15 left and right eye image data and for causing said first and second displays to display said left and right eye image data;

glasses with polarization filters configured to resolve said right and left images; and,

wherein said first and second displays each comprise liquid
20 crystal displays having a diameter of at least about 30 in. and each have a resolution of at least about 4 megapixels.

13. A virtual reality system as defined by claim 1 and further comprising:

a controller linked to said first and second displays for processing left and right eye image data and for causing said first and second displays to
5 display said left and right eye image data; and,

a tracking system for tracking position and orientation of a user's head, said tracking system linked to said controller, said controller further configured to respond to movement of said user's head by adjusting said left and right images whereby said user continues to observe stereoscopic imagery
10 as said user head changes one or more of position and orientation.

14. A virtual reality system as defined by claim 1 and further comprising:

a controller linked to said first and second displays for processing
15 left and right eye image data and for causing said first and second displays to display said left and right eye image data; and,

a tracking system for tracking the position of a user's hand, said tracking system linked to said controller, said controller further configured to provide one or more virtual objects in said imagery, to track said hand position
20 to determine when a user manipulates said one or more virtual objects, and to respond to said manipulation by changing said left and right imagery.

15. A virtual reality system as defined by claim 1 and further comprising:

a controller linked to said first and second displays for processing left and right eye image data and for causing said first and second displays to
5 display said left and right eye image data; and,

a frame supporting said first and second displays and said half-mirror, said frame adjustable whereby said angle between said first and second displays may be changed, said frame linked to said controller and wherein said controller is configured to cause said adjustment.

10

16. A virtual reality system as defined by claim 1 and further comprising a collapsible frame supporting said first and second displays and said half-mirror, said collapsible frame comprising:

a base;

15 a base support arm pivotally attached to said base and supporting said first display;

a top support arm supporting said second display; and,

a gear mechanism adjustably linking said base support arm to said top support arm and configured to pivotally move said top support arm as
20 said base support arm is pivotally moved, said half mirror connected to said gear mechanism, said gear mechanism configured to keep said half mirror at said bisecting angle as said top and base support arms move.

17. A virtual reality system as defined by claim 16 wherein said first and second displays comprise liquid crystal displays having a diameter of at least about 30 in. and emitting linear polarized light, wherein said half mirror has a width at least about 20% greater than said first and
5 second display width, and wherein said polarizing filters comprise quarter wave plates configured to convert said linear polarized light to circular polarization.

18. A passive virtual reality system for displaying a
10 stereoscopic image comprising:

first and second displays arranged about an axis at an angle of at least about 90° to one another, said first and second displays being adjustable about said axis relative to one another on said frame, said first and second displays each having an identical width and height and a viewable diameter of
15 at least about 30 in., said first and second displays each transmitting linear polarized light;

a quarter wave filter covering each of said first and second displays and configured to provide said linear polarized light transmitted from each of said first and second monitors with a circular polarization;

20 a half-mirror arranged about said axis and approximately bisecting said angle, said half-mirror having a width at least about 20% greater than said display width and a height that is at least about 10% greater than said display height;

glasses wearable by a user and including polarizing filters for each of a left and a right eye;

a tracking system configured to track position of at least one user's head and hand; and,

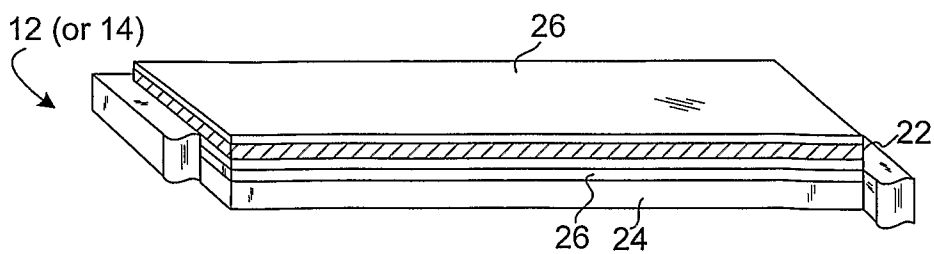
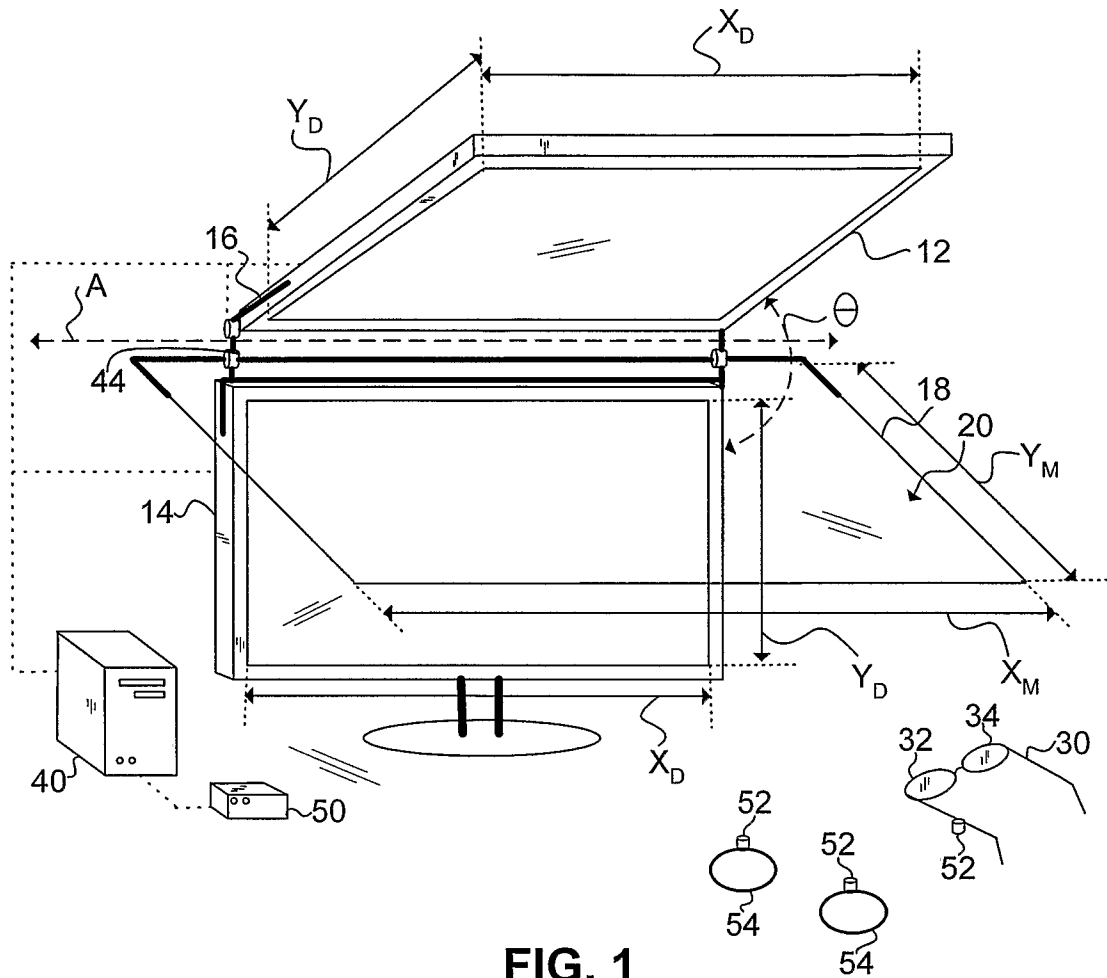
5 a controller linked to said first and second displays for processing left and right eye image data and for causing said first and second displays to display said left and right eye image data, said controller configured to generate and image of a virtual object on said first and second displays, said controller linked to said tracking system and configured to adjust said left and right
10 imagery to maintain stereoscopic imagery regardless of said user head position, said controller configured to track motion of said user hand to determine when said virtual object is being manipulated by said hand and to respond to said manipulation by changing said left and right imagery.

15 19. A passive virtual reality system as defined by claim 18 and further including a collapsible frame supporting said first and second displays and said half mirror, said collapsible frame configured to maintain said half mirror at said bisecting angle as said first and second displays are adjusted about said axis relative to one another.

20

20. A passive virtual reality system as defined by claim 18 wherein said mirror has a width at least about 30% greater than said display

width, and wherein each of said first and second displays have a resolution of at least about 4 mega pixel.



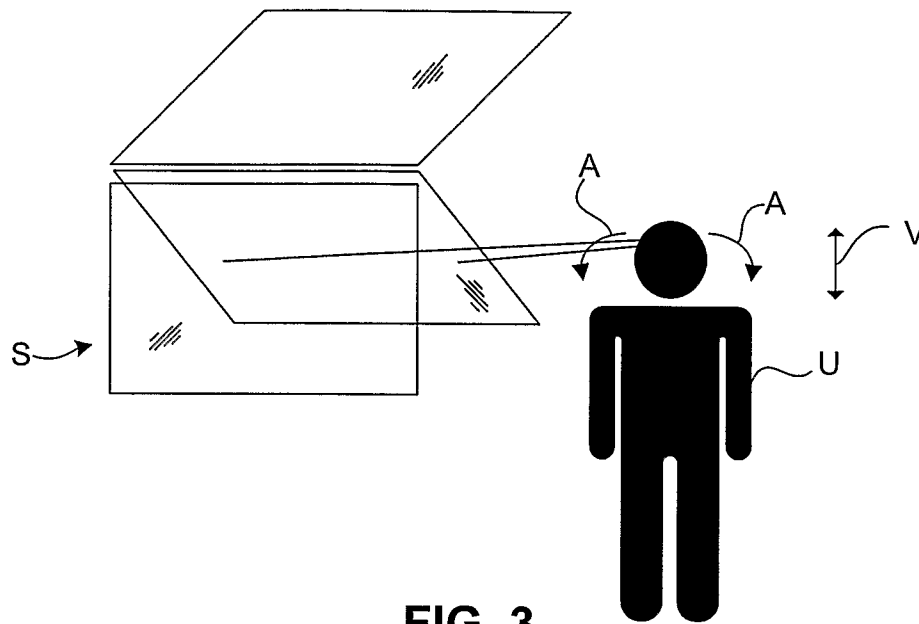


FIG. 3

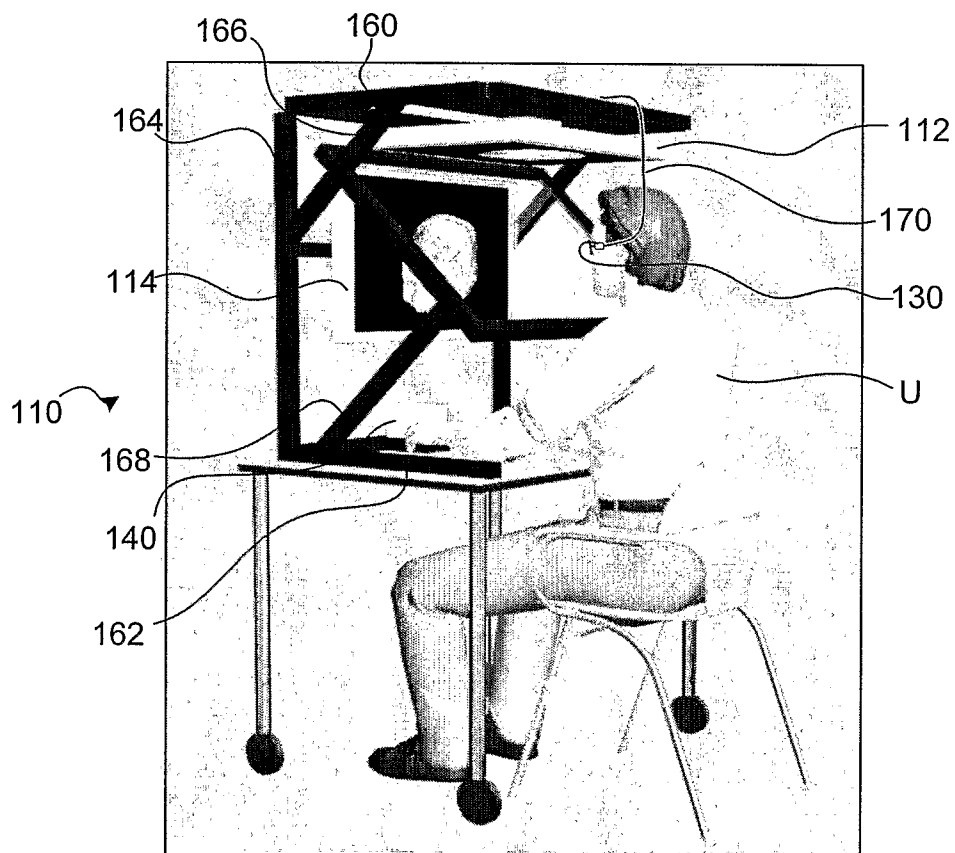
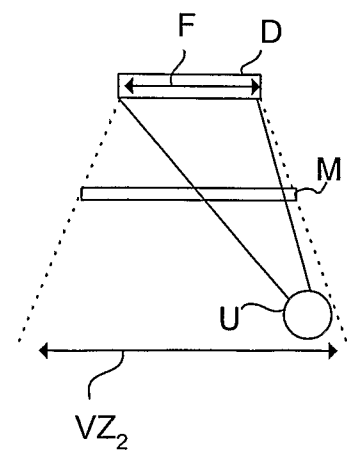
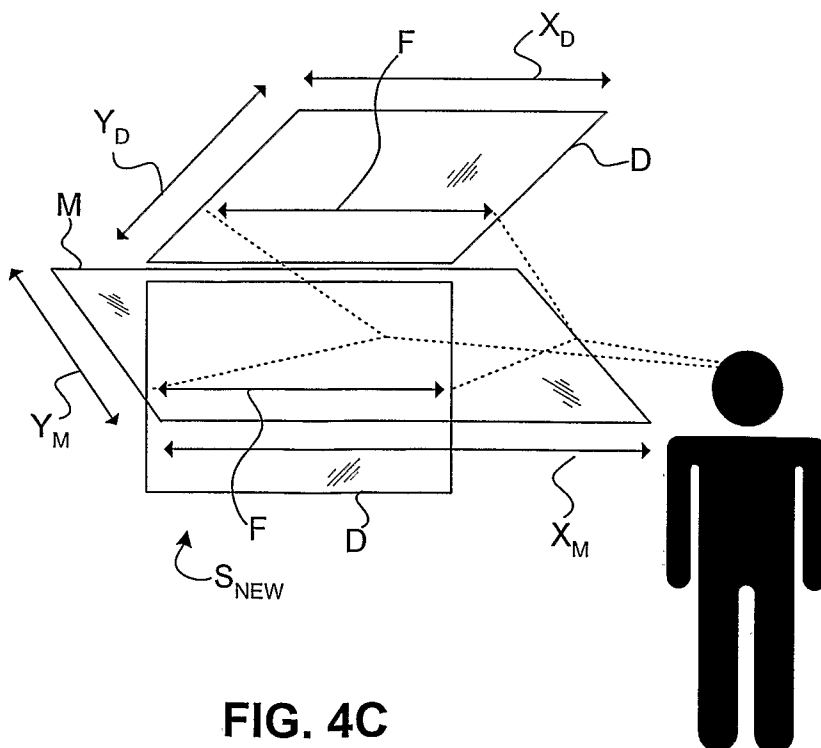
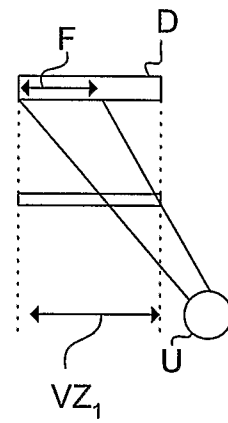
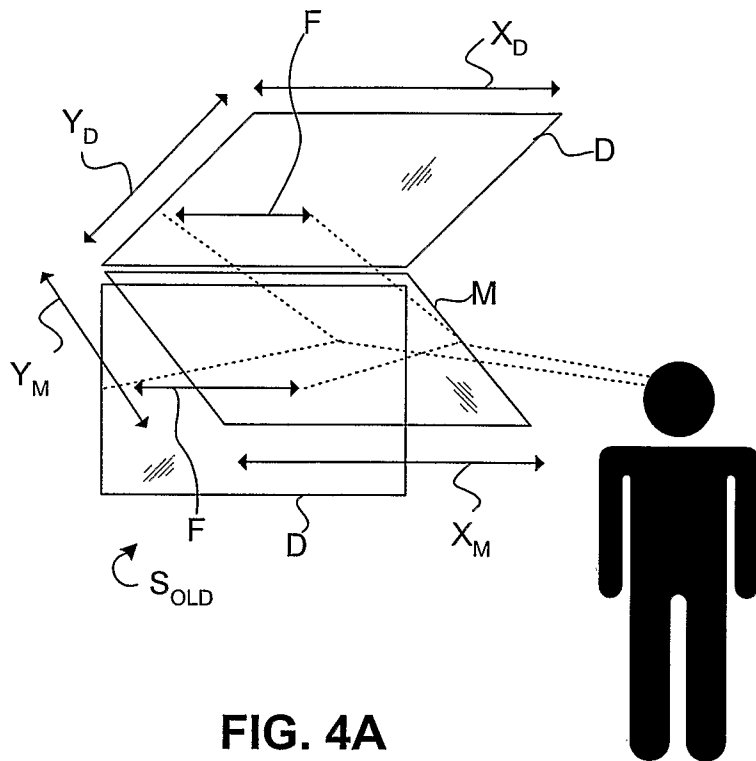


FIG. 5



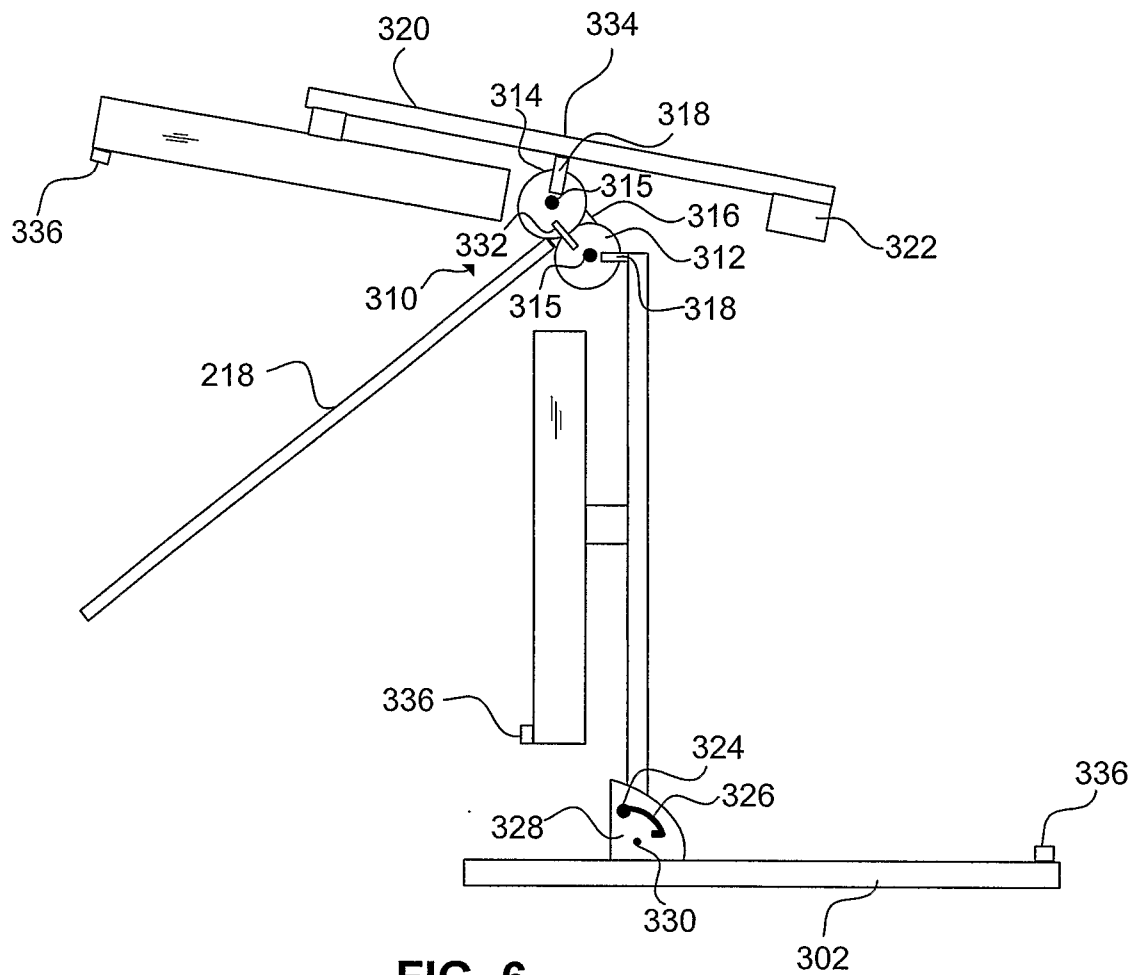


FIG. 6

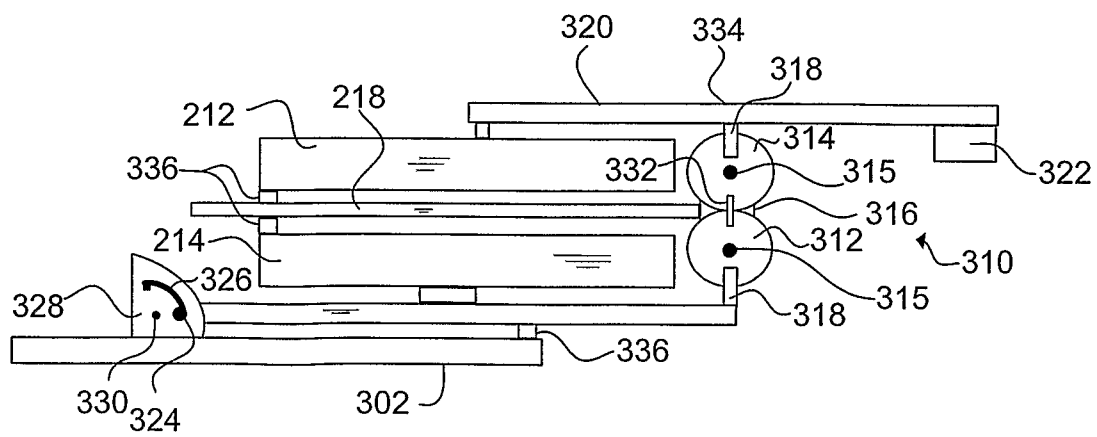


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2006/045525

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04N13/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 63 316036 A (SONY CORP) 23 December 1988 (1988-12-23) abstract; figures 1,3,4,6	1-4,8,9, 12 7,11, 13-20
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X Y	US 2002/113868 A1 (PARK TAE SOO [KR]) 22 August 2002 (2002-08-22) abstract; figure 4	1,8-12 18
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☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search

11 April 2007

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27/04/2007

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INTERNATIONAL SEARCH REPORT

International application No

PCT/US2006/045525

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

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