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TOTAL INTERNAL REFLECTION IN A FILTER STACK FOR SIDE IMAGE MITIGATION IN A CURVED LIGHTGUIDE

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Abstract

A system is provided for removing extraneous side images produced by light emitted at high angles from a display in a head mounted display (HMD), which results in light rays traveling along undesired paths that bounce one or three times from a worldside surface of a lightguide in the HMD, instead of the two bounces along the path taken by the light that forms the primary image. The system includes an optical element that couples the display to a prism to provide light to a lightguide in the HMD. The optical element is fabricated using a stack of prisms having surfaces at different angles relative to a surface of a prism used to couple the light rays into a lightguide of the HMD. Light incident upon the prism stack at relatively high angles, e.g., light traveling along paths that would bounce one or three times in the lightguide, is totally internally reflected at the interfaces between the prisms so that the high angle light rays are directed out of the path that couples the light into the HMD lightguide.

Background

Head mounted display (HMD) systems include a micro display that emits an image into a full width, half maximum (FWHM) cone that has an opening angle of approximately 20°, centered approximately normal to the display surface. As illustrated in FIG. 1, light rays that form a primary image for display to a user wearing the HMD are emitted at lower angles relative to the axis of the cone. These light rays are coupled into the lightguide of the HMD and bounce twice from a world side surface of the lightguide before entering the eye of the user. Light rays that are emitted at higher angles relative to the axis of the cone are also coupled into the lightguide of the HMD. High angle light rays bounce from the worldside surface either one or three times before entering the user's eye. The high angle light rays create side images in addition to the main image. The dim blurred side images interfere with the user's view of the world and detract from the experience of using the HMD.

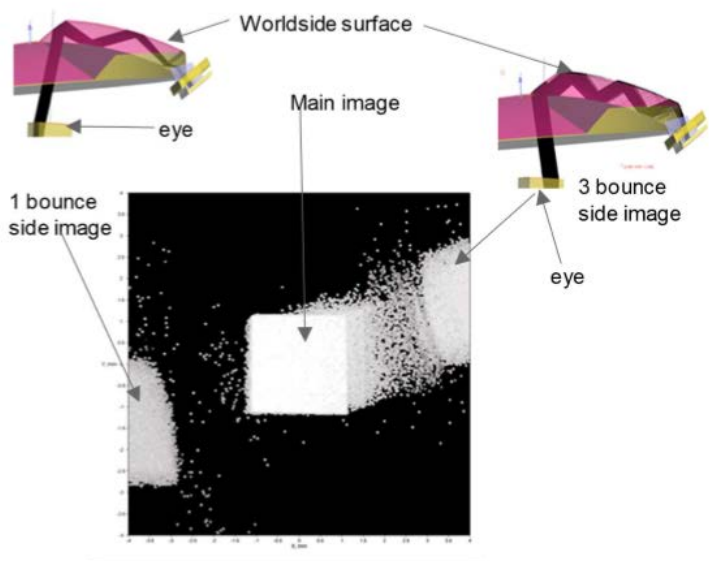

Fig. 1

Description

An example HMD, as shown in Figure 2, includes two see-through eyepieces that provide image light to a user along with a view of the surrounding environment. The image light may be augmented reality data that provides information of one or more objects in the surrounding environment. Additionally, the image light provides other information to the user such as text messages, email messages, phone call information, *etc*. The HMD includes electronics and a display unit to project the image light to the user. The electronics are either coupled to a secondary electronics device that provides the data for generating the image light, or the electronics include wireless communication technology that allows for the receipt of the information via a wireless network, such as bluetooth, Wi-Fi or cellular.

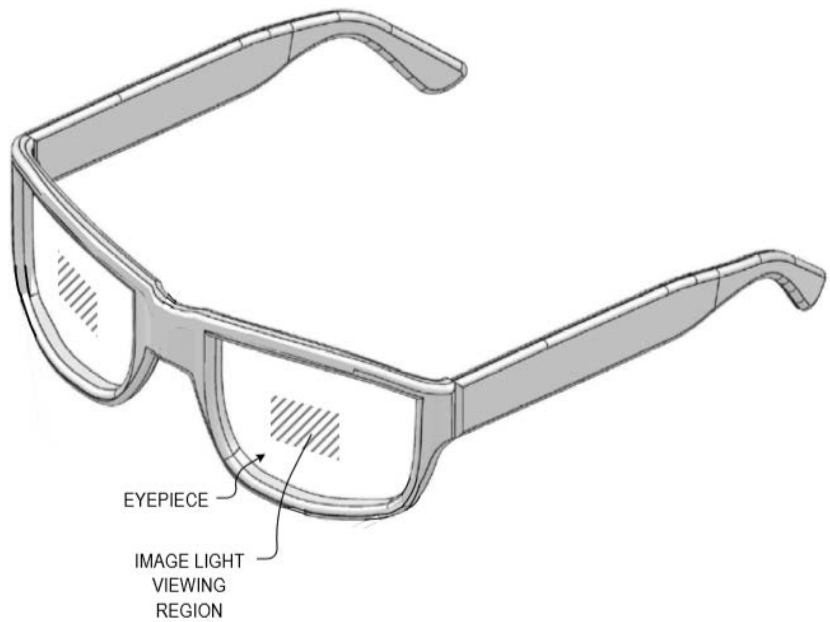

Fig. 2

Each eyepiece includes a lightguide that provides an optical pathway for the image light to propagate from the display unit to the image light viewing region, which is arranged to be aligned with the user's eye. The lightguide relies on total internal reflection (TIR) for propagating the image light from an input coupler to an output coupler, which redirects the light out of the HMD and toward the eye of the user in the image light viewing region. The eyepieces may additionally include vision correction lensing for the user or absorbing sunglass coatings. The present disclosure provides a filter to remove high angle light rays that form side images in the image seen by the user, thereby improving the overall quality of the images used by the user wearing the HMD.

An example of an optical structure suited for an HMD is shown in Figure 3. The tan regions represent the display system that generates light rays and the purple regions represent the optical structure that filters rays at high incident angles and allows rays at lower incident angles to pass through for coupling to a lightguide in an HMD system such as the system shown in FIG. 2. Only light rays from a single pixel of the display are shown.

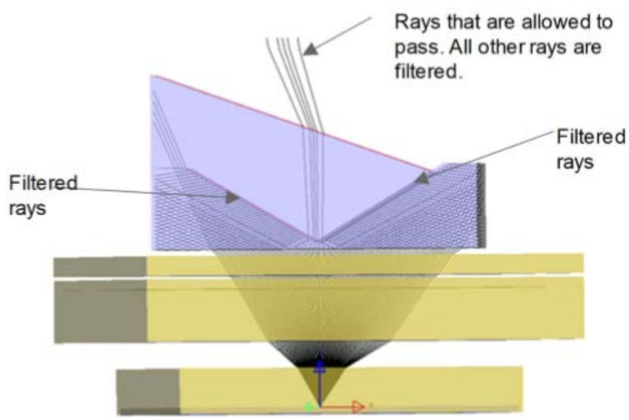

Fig. 3

Whether or not a ray passes through an airgap in the V-shaped groove is determined by the incidence angle of the ray and the critical angle for total internal reflection of the V-shaped groove. The critical angle is determined by the materials that are used to fabricate the optical structure. The slopes of the V-shaped groove are adjusted such that only rays that are incident on the surfaces of the V-shaped groove below a certain design incidence angle are allowed to pass. Aligning the filter axis with the linear polarization of the display (for p polarization incidence) improves efficiency of the filter by reducing Fresnel reflections in the optical structure. However, artifacts are produced in the image by light incident on the "point" of the V-shaped groove, *i.e.*, the region in which the angle of the V-shaped groove changes to form the V-shape. Rays in the fillet impinge on the point of the V-shaped groove at the wrong reflection angle and are not totally internally reflected, which allows the light to enter the lightguide of the HMD and produce the image artifacts.

To address this drawback, embodiments of the angle filter disclosed herein are implemented using two or three standard prisms deployed in sequence or stack configuration. For example, two prisms can be configured to reject light at high angles by total internal reflection. One of the prisms rejects the light rays that would travel along the one-bounce path to the eye of the user and another prism rejects light rays that would travel along the three-bounce path to the user's eye. The stack of prisms is configured to correct for lateral color and telecentricity at the display. The three prism embodiment is used to provide additional degrees of freedom (angles, glass type, *etc*.) relative to the two prism embodiment if needed to meet all the design requirements for the HMD. The prisms can be fabricated of glass and standard prisms are relatively inexpensive. The airgap between the prism should be large enough that rays cannot cross the gap beyond the TIR angle through coupling by evanescent wave. The gap should be kept as small as possible to minimize the distance glancing rays travel parallel to the glass surface, which can blur the image. For example, the airgap can be within the range 5-20 microns. If the size of the airgap is below approximately 1 micron, the evanescent wave can couple rays across the airgap even if they have an angle of incidence that is even beyond TIR. Some rays exiting near TIR will be glancing to the surface and pass a long distance laterally crossing the air gap. This blurs the final image. Antireflective coatings are used to improve efficiency in some cases.

FIG. 4 illustrates a stack of prisms that includes three prisms configured to form an angle filter. The three prisms in the stack are labeled by 1, 2, and 3 in FIG. 4. Interfaces between the prisms are oriented at different angles relative to a display that provides light representative of an image for display.

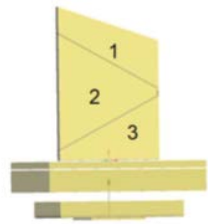

Fig. 4

FIG. 5 illustrates ray paths from a micro display through an angle filter and a lightguide in an HMD, which focuses the light rays that pass through the angle filter onto the pupil of an eye of a user wearing the HMD. The angle filter and the prism shown in FIG. 5 are implemented using the prism stack shown in FIG. 4. For example, the interfaces between prism 1, prism 2, and prism 3 filter the incident high angle light rays using total internal reflection. The prism 1 shown in FIG. 4 is used to implement the prism shown in FIG. 5.

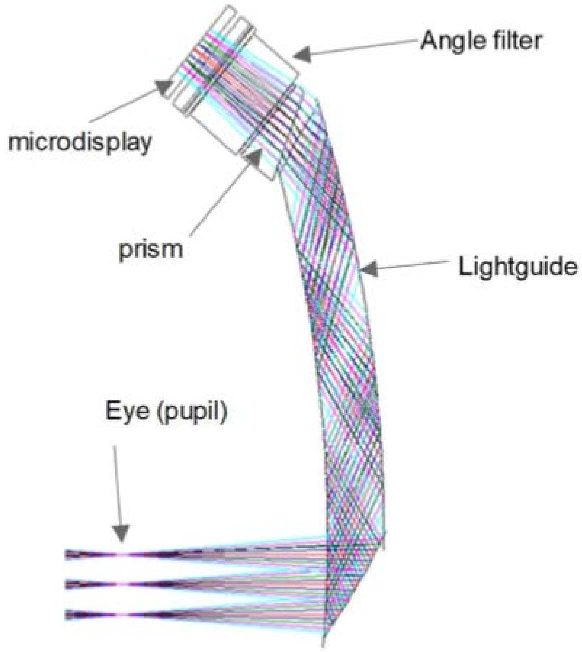

Fig. 5