Technology Reports

Head-mounted Display　VR　Field-of-view

Expanding Viewing Angle in Head-mounted Displays Considering Field-of-view Characteristics

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The market for head-mounted displays is growing dramatically. A head-mounted display provides a sense of immersion and presence, but to deepen these features, the viewing angle must be widened. This, however, has generally required multiple displays and complicated optics in which manufacturing cost and weight have been issues. Focusing on the differences between central vision and peripheral vision, NTT DOCOMO has developed a technique for expanding the viewing angle of a head-mounted display at low cost with a lightweight configuration by using an arrangement of lenses with different levels of magnification.

1. Introduction

A Head-Mounted Display (HMD) is a type of display device worn on the head to present images or video to the user. Many consumer-oriented HMDs have recently come on the market thanks to price reductions in high-definition displays and high-performance CPUs and GPUs.

HMDs displays like PlayStation® VR*1 and Google Cardboard™*2 shown in **Figure 1** are called "immersion-type" or "non-transparent-type" in which a non-transparent display is placed in front of the user's eyeballs to present images.

At present, such commercially available immersion-type HMDs can be further divided into two main types depending on the implementation format.

(1) The first type (hereinafter referred to as "integrated HMD") comes equipped with displays and CPUs that are specially designed for HMDs. The PlayStation VR mentioned above is an integrated HMD.

(2) The second type (hereinafter referred to as "add-on HMD") provides only a case and

*1 PlayStation® VR: A VR system marketed by Sony Interactive Entertainment Inc. PlayStation and its logo are registered trademarks of the same.

*2 Google Cardboard™: A head-mounted display provided by Google, Inc. and a trademark or registered trademark of the same.

(a) PlayStation VR　　　(b) Google Cardboard

*SONY and the SONY logo are registered trademarks of Sony Corporation

Figure 1　Examples of commercially available HMDs

lenses as in the Google Cardboard viewer. It can be used as an HMD by then inserting a smartphone into the viewer. The greatest advantage of an add-on HMD is that it can be achieved at very low cost since it enables users to use their own smartphones that they are already familiar with. On the other hand, while an integrated HMD enables the use of a specialized high-resolution display for each eye, an add-on HMD can mount only one display since it uses an ordinary smartphone. Such a display has not been designed particularly for an HMD. As a result, the performance of an add-on HMD is inferior to that of an integrated HMD that can mount displays having specialized dimensions and resolution.

The performance of an HMD can be evaluated by a variety of criteria, but a particularly important one is viewing angle. This is an index of the user's range of vision when wearing an HMD. In a Virtual Reality (VR) environment, a wide viewing angle can give rise to discomfort or nausea, i.e., VR sickness, but it can also deepen a sense of immersion and presence [1]. "Immersion" is the extent to which the user has a sense of being in the VR environment, while "presence" is the extent to which objects or persons appear to be in the VR environment. Both immersion and presence can have a big effect on the quality of the user experience in a VR environment, so achieving a wide viewing angle to improve these sensations has been the subject of much research for some time.

Many of those studies, however, assumed the need for complicated optics (a generic term for devices and equipment using refraction, reflection, etc.) and multiple displays, so achieving a practical design was difficult because of jumps in cost and weight among other reasons.

Against the above background, NTT DOCOMO has proposed a technique for expanding the viewing angle of an HMD at low cost with a lightweight configuration by focusing on human field-of-view characteristics [2]. In addition to convex lenses placed in front of both eyes, this technique surrounds each of those lenses with a Fresnel lens*3 having a higher level of magnification. As a result, the user is presented with a blurred image in the peripheral visual field through the Fresnel lenses thereby expanding the viewing angle. In this article, we describe this technology and proposed technique.

2. Human Field-of-view Characteristics and Related Technology

2.1 Central and Peripheral Vision

Although there are a variety of opinions, the human field of view is generally said to be approximately 180 degrees in the horizontal direction and 90 degrees in the vertical direction. On the other hand, a human being does not recognize all objects within that field of view equally. The field of view of a person closely observing some object can be divided into central vision that includes that object and its neighborhood and peripheral vision that covers the area outside of the above. It is known that central vision and peripheral vision have different features regarding shape and color perception, response to temporal changes, etc. [3]. One of these features is resolution. Compared with central vision, the resolution of peripheral vision in humans is low resulting in only fuzzy recognition.

The research of HMDs focusing on this feature has been proposed.

2.2 Related Technology

Xiao et al. [4] proposed an HMD equipped with arrays of full-color Light Emitting Diodes (LEDs) and a diffuser sheet*4 placed around the convex lenses in front of the user's eyes.

In that research, the colors of the LEDs surrounding the convex lenses are synchronized with the image within the HMD, and the synchronized light irradiates the user's peripheral visual field making it appear as an image with low resolution. For the user, this has the effect of expanding the viewing angle. This technique makes use of the fact that such a low-resolution image does not detract from the naturalness of the entire image given that the user is capable of only fuzzy recognition in peripheral vision. In addition, this technique requires no complicated optics or great increase in weight, but it does require many electronic components including a number of full-color LEDs and a microcontroller for image/LED synchronization processing as well as a battery to drive the above. Applying this technique to an add-on HMD is therefore difficult in terms of manufacturing cost.

2.3 Proposed Technique

Taking the above issues into account, NTT DOCOMO proposes a technique for expanding the viewing angle of an HMD at low cost with a lightweight configuration by using two sets of lenses with different levels of magnification. This technique can be applied to either an integrated HMD or add-on HMD. As in the technique of Xiao et al., the proposed technique makes use of the characteristic

*3 Fresnel lens: A lens that refracts and diffuses or concentrates light through the use of concentrically etched grooves. It features a thin, lightweight configuration compared with ordinary lenses.

*4 Diffuser sheet: A sheet that diffuses irradiating light and weakens optical directionality.

that the user is capable of only fuzzy recognition in peripheral vision.

A prototype device implementing the proposed technique is shown in **Figure 2**. As shown, this prototype is equipped with two types of lenses having different levels of magnification. The first type consists of convex lenses placed in front of both eyes. These convex lenses (focal length*5: 44 mm; diameter: 25 mm) are provided to present a clear image in the user's central visual field. The other type consists of Fresnel lenses (focal length: 25 mm; dimensions: W70 × H68 × D2 mm) with high magnification that surround the convex lenses. These high-magnification Fresnel lenses are provided to fill the peripheral visual field with a blurred image that the user can only vaguely recognize. The following can also be offered as a reason for using Fresnel lenses. Since the size of the display is limited, the magnification factor must be increased and the lens itself made larger to present an image on a broader scale. With convex lenses, however, increasing the magnification factor also increases lens thickness thereby increasing lens weight. Fresnel lenses, in contrast, can remain thin and light even when increasing the magnification factor, so this is another reason for their adoption. In addition, the center of each lens lies 39 mm from the surface of the corresponding display.

This mechanism can be explained using glasses for near sightedness as an analogy. While the scenery seen through the glasses appears clear and distinct, the area outside the glasses appears blurred to the user. However, if this blurred area outside the glasses cannot be seen at all, the user will sense a narrow field of view. In other words, the proposed technique achieves a wide viewing angle by starting with a convex lens portion corresponding to the inner side of such glasses and then adding high-magnification Fresnel lenses for generating an image in the area corresponding to

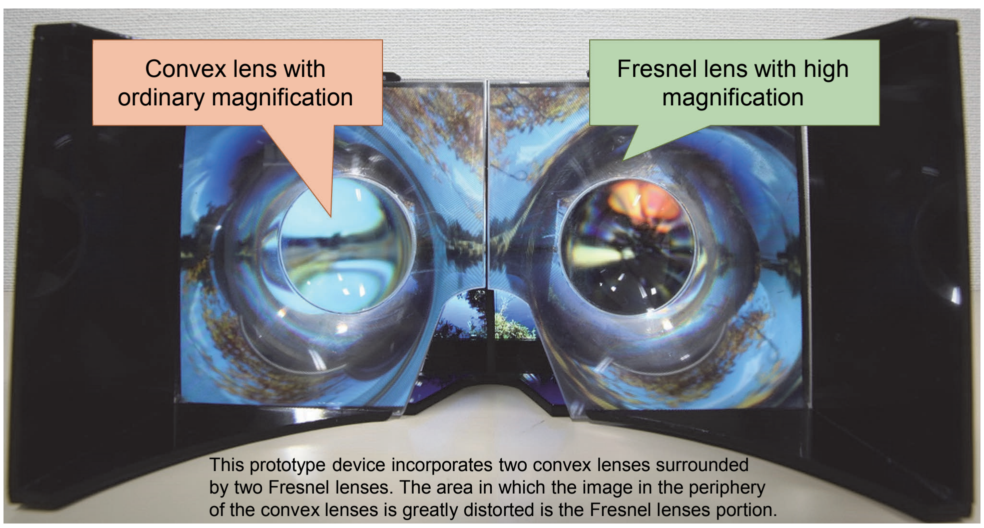

Figure 2 Prototype device

*5 **Focal length**: For a convex lens, parallel light incident along the optical axis of the lens will focus at a certain point called the focal point. The distance from this point to the lens center is the focal length.

the outer side of the glasses. We note here that the photo in the figure was taken at a distance from the prototype, so while the image in the Fresnel lens portion is greatly distorted, it will not appear as such when actually wearing the device.

A close-up photo of the prototype device equipped with both convex lenses and Fresnel lenses is shown in **Figure 3** (a) and that with the Fresnel lens portion replaced by an opaque black panel is shown in Fig. 3 (b). In either case, the photo was taken with the focal point lying on the display seen through a convex lens. Although the image seen through the convex lens in either photo appears clear, a blurred image can be seen through the Fresnel lens in Fig. 3 (a), but in Fig. 3 (b), the area surrounding the convex lens is black. In this way, a user wearing a prototype device based on the proposed technique will be presented with a blurred image in peripheral vision resulting in a wider viewing angle as shown in Fig. 3 (a).

A blurred image presented in peripheral vision has several characteristics. For example, the Fresnel lenses through which the user sees an image in peripheral vision have a shorter focal length than the convex lenses, so a portion of the image appears to be duplicated and discontinuous across the convex and Fresnel lenses (Fig. 3 (a)). Moreover, the image seen through the Fresnel lenses is expanded at high magnification with the result that the boundaries of individual pixels on the display would normally become noticeable. In actuality, though, the blurred appearance of the image seen through the Fresnel lenses tends to conceal those boundaries making them barely visible for the most part.

As described above, the proposed technique can widen the viewing angle in an ordinary add-on HMD by adding high-magnification Fresnel lenses

(a) Prototype device equipped with both convex and Fresnel lenses

(b) Prototype device replacing the Fresnel lens with an opaque black panel

Figure 3　Close-up photo of convex lens in prototype device

and filling peripheral vision with a blurred image. The main feature of this technique is that only two types of lenses with different levels of magnification are needed with no need for complicated optics or electronic parts. It is therefore a superior approach from the viewpoint of cost and weight. There is also no need for specialized image-reproduction software, which means that existing content can be appropriated as-is. This is another strong point of the proposed technique from the viewpoint of practical use.

3. Conclusion

In this article, we described a technique for expanding viewing angle of an HMD at low cost with a lightweight configuration by using lenses with two different levels of magnification. In future research, we plan to research and develop a more detailed design for the optical system and to study the commercialization of this technique toward new VR services while promoting advancements in this technology.

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