Expanding the Field-of-View of Head-Mounted Displays with Peripheral Blurred Images

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ABSTRACT
Head-mounted displays are rapidly becoming popular. Field-of-view is one of the key parameters of head-mounted displays, because a wider field-of-view gives higher presence and immersion in the virtual environment. However, wider field-of-view often increase device cost and weight because it needs complicated optics or expensive modules such as multi high-resolution displays or complex lenses. This paper proposes a method that expands the field-of-view by using two kinds of lenses with different levels of magnification. The principle of the proposed method is that Fresnel lenses with high magnification surround convex lenses to fill the peripheral vision with a blurred image. The proposed method doesn't need complicated optics, and is advantageous in terms of device cost and weight, because only two additional Fresnel lenses are necessary. We implement a prototype and confirm that the Fresnel lenses fill the peripheral with a blurred image, and effectively expand the field-of-view.

Author Keywords
Head-mounted display; Virtual reality; Field-of-view;

ACM Classification Keywords
H.5.2. Information Interfaces and Presentation (e.g. HCI): User Interfaces

INTRODUCTION
Technological improvements such as better displays, greater processing power and higher mobility have made it possible for head-mounted display (HMD) with high immersion to become popular consumer products. Many HMD products for Augmented and Virtual Reality (AR and VR) have been released, and many applications are being created.

There are mainly two types in HMDs. One is a HMD having processing units, displays and lenses like STAR VR[1]. The HMD having two high-resolution displays and processing units are especially popular in the type. For example, STAR VR has 210° horizontal field-of-view(FOV) which covers more than 75% of the entire human vision using two high-resolution displays (2560 x 1440 pixels) and complex Fresnel lenses. The other type uses smartphones like Google Cardboard[2]. The type consists of lenses and a case, and user's smartphone is attached as display and processing units . The biggest advantage of this type is greater reduced cost, because only lenses and a case are needed in addition to the smartphone.

Unfortunately, the type using a smartphone is inferior to the other in performances. In particular, it is difficult to emulate the type having modules more than two high-resolution displays in the FOV, because the type using smartphone has only single display.

Although HMD having a wide FOV induces simulator sickness more easily than narrow one, wide FOV also gives higher presence and immersion[1]. Thus, number of researches had tried to make FOV wider to enhance user experience in VR environments; however, technical difficulties in producing commercial devices with wide FOV (e.g., complicated optics, increased weight etc.) often limit the available FOV[2]. Robert et al[2] focused on the fact that peripheral vision has much lower resolution than foveal vision. In order to expand FOV, they proposed to fill the periphery of the HMD with a low-resolution, high-contrast array of diffused, colored LED lights, whose driving signals are tightly coupled to the content presented on the device. Their approach can expand FOV without complicated optics; however, it is still difficult to apply it to smartphone HMDs because of the additional costs; it needs various devices such as a lot of colored LED lights, processing units, battery and diffuser panel.

Our solution is to expand the FOV by using two kinds of lenses having different focal lengths. The proposed method combines a convex lens with normal focal length with a Fresnel lens with shorter focal length for each eye. The convex lens fit into a hole at the center of the Fresnel lens. The convex lens shows high-resolution image in foveal vision. Moreover, the Fresnel lens around convex lens fills the peripheral vision with blurred image. The result is analogous to wearing glasses for near-sighted eyes. The glasses yield a clear image across the glass lens but beyond the frame the image is blurred.

[1]InfinitEye. StarVR Tech Specs, http://www.starvr.com/

[2]Google Cardboard, https://vr.google.com/cardboard/

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The proposed method has the advantages low weight and cost and high versatility. The weight penalty is basically insignificant. This is a critical advance to encourage rapid adoption. The cost penalty is also small, because the proposed method only needs two additional Fresnel lenses. Thus, the proposed method supports both types of HMDs. Moreover, our approach doesn't need any new software programs. Existing contents and applications can be used directly.

IMPLEMENTATION AND EVALUATION

Fig.1 shows the prototype that we implemented based Google Cardboard. The prototype has two 30mm diameter convex lenses with 40mm focal length and two Fresnel lenses (70 x 68 x 2 mm) with 25mm focal length. All lens centers lie on the same plane. An Apple iPhone 6 was set 37mm from the lens plane. The other arrangements basically followed the Google Cardboard approach.

A screen size of iPhone 6 (104 x 59 mm) is smaller than the entire size of two Fresnel lenses. Fig.1 shows that the image of the screen reaches the edges of Fresnel lenses. The images of Fresnel lenses are grossly distorted as Fig.1 shows, because the Fresnel lenses have much short focal length and the images are captured away from them. Users in wearing the prototye doesn't see images grossly distorted like Fig.1

We captured two close-up images to confirm the view of the proposed method. Fig.2(a) is a close-up of the prototype. Fig.2(b) is a close-up of the prototype where the Fresnel lenses were replaced with black opaque boards. Both images are taken focused on the screen, though the convex lenses.

The screen is clearly visible through the convex lens in both images. The periphery is filled with black in Fig.2(b). In contrast, the Fresnel lens filled the periphery a blurred image of the screen in Fig.2(a), which effectively widened the entire FOV. Note that the focal length of the Fresnel lens is much shorter than normal.

The periphery image in Fig.2(a) is strongly blurred because of the large focal length difference between the Fresnel lens and the convex lens. A user sees both clear and blurred images in actual use, because it is impossible to focus simultaneously on both images. The result is natural because the blurred images are lie in the field of peripheral vision.

Incidentally, characteristics of peripheral vision and blurred images benefit in some cases. A focal length of the Fresnel lens is much shorter than lenses normally used for HMD. It causes two kinds of visual effect. One is that an overlapping and discontinuous areas germinate in a user's view. The other is that lattice patterns of the screen can outstand, especially in low-resolution display. The characteristics of peripheral vison and blurred images contribute to obscure an overlapping area and lattice patterns. As a result, it reduces the unnaturalness of the HMD.

We confirmed that the proposed method expand FOV of HMD through the observation of the prototype, altough the prototype was designed and fabricated without precise optics and custom-made parts.

Figure 1. Overall image of our prototype. The prototype has two pairs of Fresnels lens and convex lens. Grossly distorted images of the screen are shown by the Fresnels lenses.

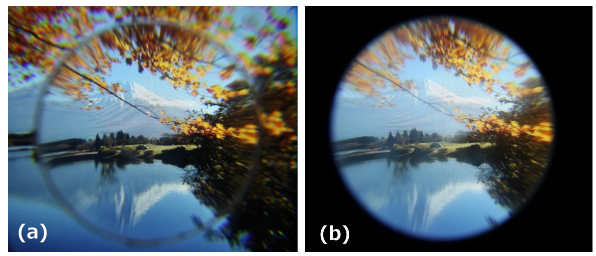

Figure 2. Close-up images from the inside of prototype. (a) the prototype having convex lenses and Fresnel lenses. (b) the prototype having only convex lense and black opaque boards instead of Fresnel lense. Both images were captured focusing on the screen through the convex lenses. The Fresnel lenses fill the peripheral area with blurred images.

CONCLUSION

A method that places convex lenses in the center of Fresnel lenses with shorter focal length was proposed to widen the FOV of HMDs. The Fresnel lenses fill the areas peripheral to the clear center image with blurred images. This is possible due to the different characteristics of our foveal vision and peripheral vision. We implemented a prototype to confirm the characteristics of the proposed method. Both clear image and blurred image were simultaneously observed in close-up images produced by the prototype. Total image area is wider than that of the images produced using only convex lens, confirming that the FOV was widened. We also confirmed that the blurred image of the Fresnel lens contributed to obscuring the overlapping and discontinuous area and lattice patterns of the screen. We intend to redesign the architecture of the prototype to suit the use of precise optics. Moreover, we will evaluate how well the proposal is accepted by users and its effect on simulator sickness.

REFERENCES

1. James Jeng-Weei Lin, Henry B.L. Duh, D. E. P. H. A.-R., and Furness, T. A. Effects of field of view on presence, enjoyment, memory, and simulator sickness in a virtual environment. In *Proceedings of IEEE Virtual Reality 2002* (2002), 164–171.

2. Robert Xiao, H. B. Augmenting the field-of-view of head-mounted displays with sparse peripheral displays. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (2016), 1221–1232.