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Head Mounted Display for Mixed Reality using Holographic Optical Elements

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Synopsis

We propose the stereoscopic Head Mounted Display(HMD) using Holographic Optical Elements(HOE). This display uses HOE as the holographic combiner instead of half mirror that is used by conventional HMD. A single HOE can record the multiple optical images by the characteristic in itself, that is angular selectivity and wavelength selectivity. Therefore, the HOE as the combiner has the feature which can separate the stereoscopic images onto the left and right eyes and it has high efficiency both transparency for outside world and reflectance of virtual images shown by electrical display like as small LCD or CRT and so on.

In this paper we proved that the HMD using Lippmann hologram has the potentiality of miniaturization, lightening, wide field of vision for outside world. In addition, we have developed the Mixed Reality system by using our new HMD. This HMD can be suitable to the Virtual Reality field, especially Mixed Reality we have to observe both the real outside world and the virtual world at the same time.

KEYWORDS: HMD, HOE, HUD, Virtual Reality, Mixed Reality, Augmented Reality

Introduction

Recently, the Mixed-Reality (MR) is remarkable in many fields, such as medical and game fields, multimedia, and attractions for the various events. MR technique is the concept that includes Augmented Reality (AR) and Augmented Virtuality(AV)[1][2]. AR is to augment the real world by electrical virtual information, and AV is to augment the virtual world by real information. But the boundary between AR and AV is not defined accurately. In other words, the Mixed Reality is to combine the real world and virtual world by using the electrical visual display system. Therefore the display we can see the real and virtual world is necessary for MR technique. Recently the Mixed Reality technique is researched by many other Virtual Reality researchers who want to apply this technology to practical usage like as the consumer electronics because only Virtual Reality technology which has been investigated over a decade can't realize the satisfied application. Although we can use the various type of display for MR, see through Head Mounted Display (HMD) is considered as the main device for MR now.

But conventional HMD, that is made by optical lenses magnifying the small LCD, has varies defects. For example it has a narrow field of vision for outside world and a tradeoff between transparency for outside world and reflectance of LCD images. And it has a limitation of miniaturization, lightening for practical industrial application because two pieces of optical components(lens and combiner) are needed.[3] Therefore we have to overcome these defects and develop the new see through HMD for Mixed Reality in order to observe the clear and wide outside world as well as bright virtual stereoscopic images.

We propose that Holographic Optical Elements(HOE) can be used instead of half mirror of conventional HMD. By using the HOE as the combiner on our new HMD, the function of lens and

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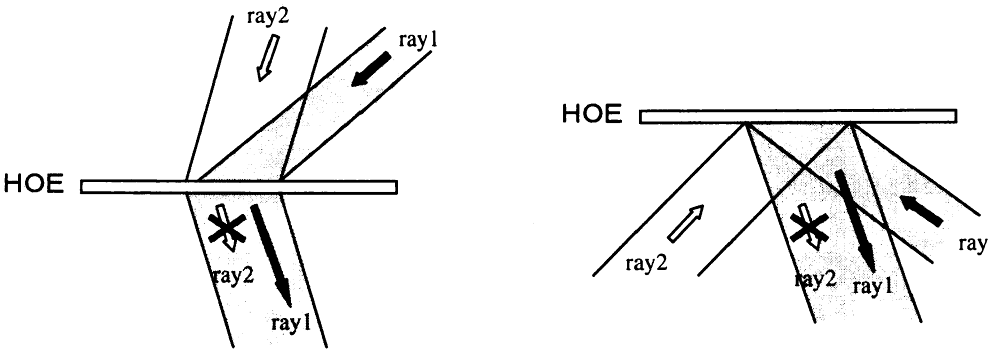
combiner and binocular stereoscopy can be integrated into one piece of HOE, therefore it can provide us the wide field of vision of real outside world as well as both high transparency for real world and intensity for virtual images.

Principle of HOE for see-through HMD

Angular Selectivity of HOE

The HOE is diffraction grating and has the characteristic of angular selectivity and wavelength selectivity. The angular selectivity is that the diffractive intensity of HOE in reconstruction depends on the incident angle of illuminating beam which is equivalent to reference beam used in recording. In a word, the diffraction light can not be seen if the view point is slipped off slightly. HOE can be exposed by multiple beams and diffract many illuminating lights to the specific directions. Fig.1 shows the basic principle of the angular selectivity of HOE concerning about transmission type and Lippmann type.



wavelength of ray1 = wavelength of ray2

(a) Transmission type of HOE (b) Lippmann type of HOE

Fig.1 Basic principle of angular selectivity of HOE

Wavelength Selectivity of HOE

The wavelength selectivity of HOE is that the diffractive intensity of HOE in reconstruction depends on the wavelength of illuminating beam in case the incident angle of illuminating beam is equivalent to reference beam used in recording. In other words, HOE can diffract the slight width of wavelength in the illuminating beam. The characteristic of Lippmann type of HOE is very remarkable. It is possible to transmit the visible rays and to reflect the narrow band of specific wavelength of rays (for example red).

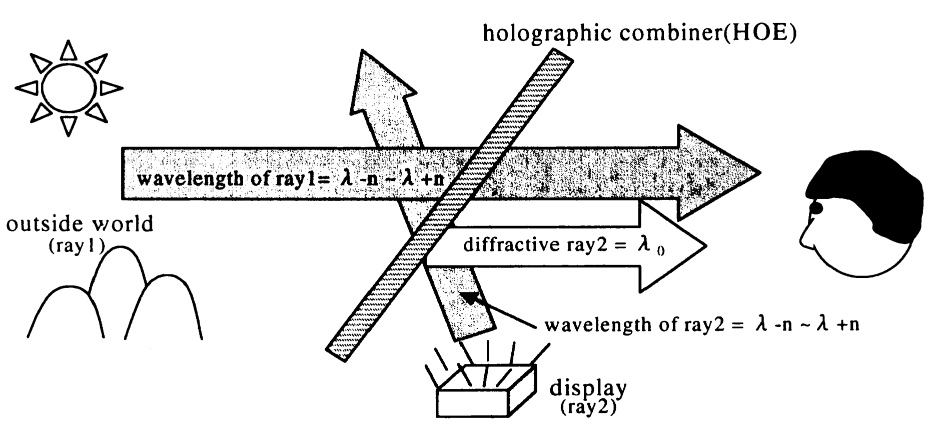
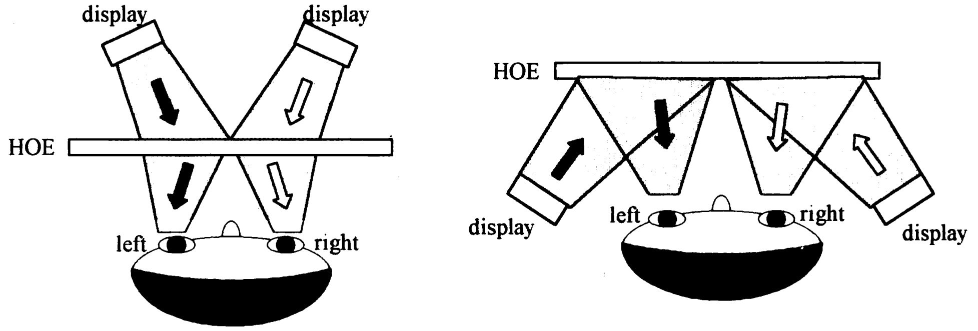


Fig.2 Principle of holographic combine

Therefore, we can make the holographic combiner we can see both the outside world and the specific wavelength image shown by display. Fig.2 shows the principle of holographic combiner. Its principal is the same as the Head Up Display(HUD). In case of HUD, we can not see the stereoscopic images on the display like as the LCD and so on. Normally, the viewing distance of HUD is long(focal distance is 60cm~2m) and the screen size is not so large(about 10cm square), therefore we have to observe small images of HUD on both eyes. Furthermore if we move our head slightly, we can not see the images because the exit angle of HUD is very narrow.

Binocular Stereoscopy of HOE

According to the angular selectivity and wavelength selectivity, single HOE exposed by multiple recording beams can display the binocular images diffracted from two illuminating beams on each left and right eye separately. It is very easy for us to understand that single HOE has the function providing the binocular parallax images like as parallax barrier display or lenticular display without special glasses. And we propose that we can see the binocular stereoscopic images through the HOE like as HUD if it is located close to our eyes and two rays including the parallax information are illuminated from different direction. Fig.3 shows the principle of binocular parallax display of HOE.

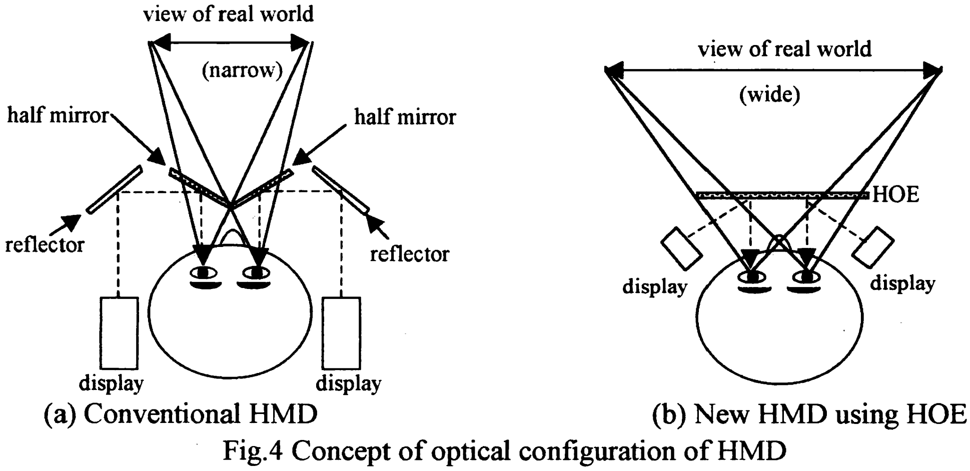


(a) Transmission type (b) Lippmann type

Fig.3 Principle of binocular parallax display of HOE

Feature of HMD using HOE

We propose the HMD using HOE as the combiner instead of the conventional HMD by using the feature of HOE shown in fig.1 and 2. The HOE is most suitable to realize the see-through HMD for MR because it has the function both the combiner and the optical lens. Fig.4(a) shows the optical configuration of conventional HMD and Fig.4(b) shows the optical configuration of HMD using HOE.



(a) Conventional HMD (b) New HMD using HOE

Fig.4 Concept of optical configuration of HMD

The HMD using HOE is more useful than the HMD using a half mirror as the combiner, especially at the Mixed Reality environment. The conventional HMD has the optical system close to the eyes and it is limited the field of view for the real world. Fig.4(a) shows the field of view for the real world about the conventional HMD. Meanwhile the HMD using HOE has only one grating in front of the face and its field of view for the real world is very wide. Fig.4(b) shows the field of view for the real world about the HMD using HOE. Furthermore all wavelength rays of the real world can be transparent and only specific wavelength rays illuminated by a display can be diffracted to a certain direction. Therefore, this HOE can provide the binocular stereoscopic images.

Optical characteristics of HOE

A prototype of HOE is 4 inches long by 5 inches wide. The distance between eye and HOE is 4 inches. The pupil distance is 65 mm. Fig.5 shows the optical characteristic of HOE. In recording, an object beam and a reference beam are diverging rays, the angle between them is 120 degree. This angle can put the small LCD display on both side of head and can prevent the reflection light on HOE from being incident upon the human eyes. We can see the binocular images modulated by illuminating light for reconstruction

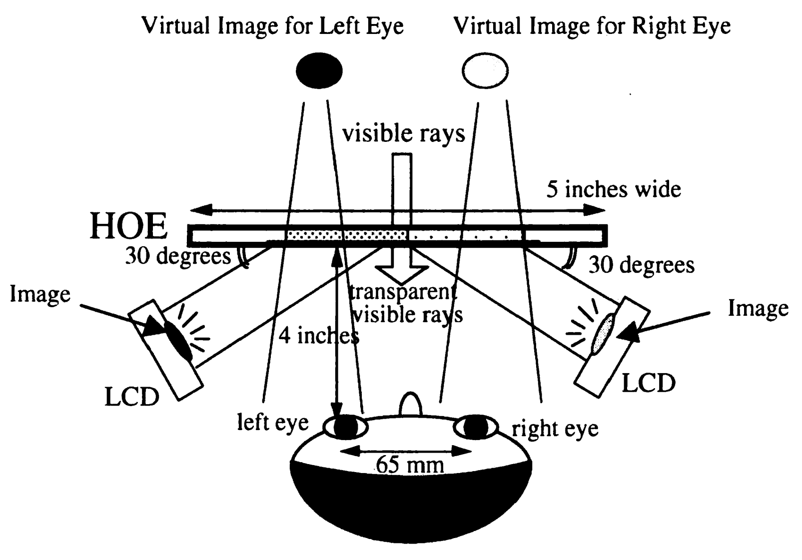
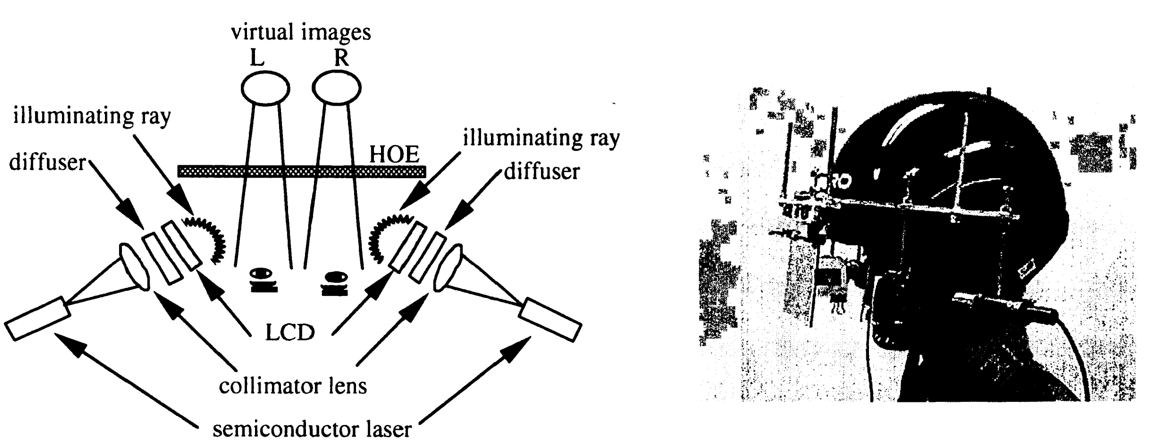


Fig.5 Optical Specification of HOE



(a) Optical system for reconstruction (b) Appearance of HMD using HOE

Fig.6 Prototype of optical system

at the viewing point. The rays from left is diffracted by HOE and can be seen on the left eye, the rays from right is diffracted and can be seen on the right eye, therefore only one HOE can separate the stereoscopic images to left and right eye. In addition, we can see the rays both the real world and the diffracted images at the same time because HOE can diffract only specific wavelength rays without reducing the intensity of the visible rays. We made the prototype of HOE shown in fig.5 by way of the two-beam interference method and we made the experimental optical system for reconstruction by using the semi-conductor laser as the illuminated light. Fig.6(a) shows the experimental optical system for reconstruction. It uses the He-Ne laser (wavelength:632.5nm) in recording and semiconductor laser (wavelength:635nm) in reconstructing. The reconstructed image was red color only.

This optical system uses 1.3 inches LCD display as the spatial modulation devices. Fig.6(b) shows the appearance of HOE mounted on the helmet. Fig.7 shows the diffracted images displayed by this optical system. Fig.7(a) shows the diffractive image for left eye and Fig.7(b) shows the diffractive image for right eye. Both the diffractive images and the outside world through HOE can be seen in the ordinary office room which illuminating intensity was about 900lux. According to Fig.7, we can distinguish the left and right parallax about a triangle and a ellipse on reconstructed diffracted light.

(a) Image for left eye (b)Image for right eye

Fig.7 Diffracted images for binocular parallax recognition

Interactive MR System

Structure of MR System

We have developed the interactive MR system by using this HMD. In this MR system, we can observe the virtual stereoscopic images among the real world and we can feel the virtual objects floating in the real environment through HMD using HOE because the view of real world behind the virtual hologram images is very wide. Fig.8 shows the structure of MR system. It uses graphic workstation for generating the stereoscopic images and the magnetic sensor for head tracking. Graphic workstation creates a pair of VGA resolution images for each left and right parallax and those images are transmitted to the LCD attached on the helmet. The images on LCD can be diffracted by HOE and holographic images are reconstructed and we can see virtual images through HOE. If the observer looks around in the real world by moving his head, he can see the virtual objects according to his heading by magnetic head tracking sensor. In order to create the high definition images for interaction of walk though and to grasp the objects, SGI Indigo2 Maximum IMPACT as the hardware and Division dVISE which is a virtual reality application package software are used.

Concept of Floating Image Media

We propose the Floating Image Media as the new expression. Floating Image Media means to express the virtual images among the real environment, namely, new media expression by Mixed Reality technology. Our ultimate end for Mixed Reality is to display the electro-holography among the real world because we can see the real world naturally as well as the natural electronic stereoscopic image with full parallax . But it is very difficult to complete the electro-holography because there is no device and calculator which can display the plenty of interference fringes. We can managed to use the optical see-through HMD now for this purpose, but the HMD we can use now is not so good for combine both the real world and the virtual images. Therefore we developed new HMD using HOE which is very effective for viewing the natural real environment. By using our new HMD, we can complete the Floating Image Media system without the electro-holography. The software contents of the Floating Image Media is molecular simulation at this first prototype although it is possible to express the any shape and motion. Fig.9 shows the example of Floating Image as the molecular simulation. We can look around the various molecular model according to the observer's heading of his head.

We demonstrated the HMD using HOE on the interactive MR system at SIGGRAPH99[4]. Total number of 656 subjects tried it and all except 3 subjects who are originally stereo blind could observe the binocular stereoscopic images among the real world through HOE.

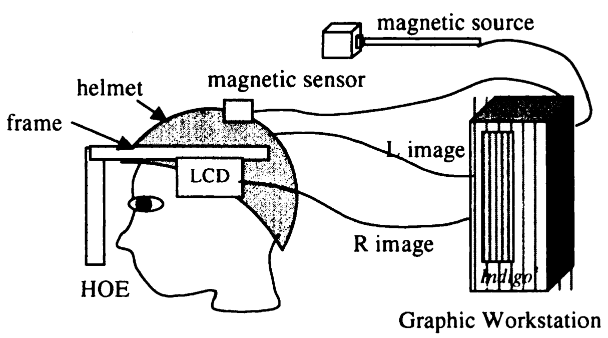


Fig.8 Interactive MR System

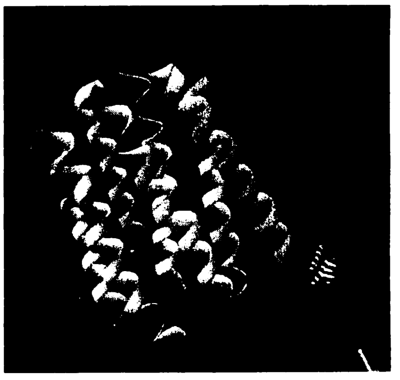


Fig.9 Example of Floating Images

Conclusion

We have completed the prototype of HMD using HOE for the purpose of usage of MR environment. And we proved that only one piece of HOE can separate the binocular parallax images onto left and right eye. Furthermore we showed that the HOE as the combiner can improve the defects of half mirror which is the tradeoff between transparency and reflectance. This time prototype is a little heavy and is not miniaturized because it was made by our own hands. In addition, the field of view of virtual image is a little narrow because angle of view is about 20 degrees. And the virtual image is only one color because we used just red semiconductor laser. In future, we have to improve these factors.

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