Wide Field of View Head Mounted Display for Tele-presence with An Omnidirectional Image Sensor

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Abstract

Recently, the omnidirectional image sensors have been applied to tele-presence systems, because the sensor can capture images with large field of views at video rate. On the other hand, head mount display (HMD) has been generally used as a personal display for virtual reality applications such as a tele-presence. However, almost all HMDs have a problem that the field of view (FOV), about 60 degree horizontally, of its presented image was terribly narrower than that of human. The problem makes reality and immersion lower in these applications. In this paper, we propose high-immersive visualization system that can display 180 degrees horizontal view by using a new catadioptrical HMD and an omnidirectional image sensor. The HMD consists of ellipsoidal and hyperboloidal curved mirrors, and can display 180 degrees horizontal view.

1 Introduction

Recently, many catadioptric omnidirectional image sensors consisting of convex mirror and video camera have been developed. Catadioptric omnidirectional sensors can simultaneously capture 360 degree field of view information at video rate and are usually portable. Therefore an omnidirectional movie is easily recorded while walking down a road, driving a car, taking a train, etc. In particular, the catadioptric sensors with hyperboloidal [1] and paraboloidal [2] satisfy the single center of projection constraint. The omnidirectional images captured by these sensors can be easily transformed to any designate image plane, such as perspective, panoramic, and specific screen display surface. It means that the catadioptric omnidirectional sensors are suitable for interactive media applications, because wide field of view distortionless image or interactive view-dependent perspective image can be displayed to human observer. From these reason, the catadioptric omnidirectional image sensor have been applied to tele-presence systems[3, 4, 5, 6, 7]. Some previous tele-presentation systems with omnidirectional image sensor have used an immersive projection display(IPD)[5, 6]. The IPDs display a wide field of view image surrounding to human observer. Usually, these systems need wide free space for setting up them. On the other hand, head mount display(HMD) have been also used to the tele-presence system[7]. HMD is portable and is able to display personal information accommodated to each user. It is ideal for use where space is at a premium. The system shows view-dependent images corresponding to head motion form omnidirectional images. However, reality and immersive of HMD are lower than that of IPD, because the field of view of commercial HMD is terribly narrow. It is well known that peripheral vision included wide FOV would influence postural control of human [8]. In addition, a FOV over 80 degree is required for feeling immersion and reality by human observer [9]. Therefore, HMD is also required to a wide field of view owing to improving a reality and immersion. In this paper, we propose that a wide FOV head mounted display which can cover 180 degrees horizontal and 60 degrees vertical FOV, respectively. The HMD is a suitable display for the omnidirectional video based visualization. The HMD consists of ellipsoidal and hyperboloidal mirrors, and keeps a relation of a single center of projection. Therefore, the HMD can display a distortionless image that transformed from an omnidirectional input image. Furthermore, characteristics of image resolution of an omnidirectional image sensor are similar to characteristics of display resolution of the HMD.

2 Head Mount Display

Head mounted display (HMD) is frequently used as the visual display in virtual reality, mixed reality and tele-presence applications. General characteristics of HMD are:

1) Small and lightweight.

2) Wide field of view.

3) Stereo capability.

4) Display image accommodated with head motion.

However, the field of view (FOV) of previous HMD for consumer is generally narrower (about 60 degree) than that of human. Therefore, the HMD had a problem that is low reality and immersion, because it cannot present a peripheral vision. Takahashi et al [10] measured the influence of wide FOV head mounted display to human attitude control. They compared 140 degree FOV. This research suggests that the wide FOV is one of important factor for human attitude control. Caldwell et al. [11] reported that the narrow FOV disimproved task efficiency and reality in a tele-operation, even if they compared only 30 and 60 degree FOV. Therefore, there are a lot of approaches that improve FOV of HMD. The basic idea of the HMD optics is to enlarge liquid crystal display (LCD) images in midair. There is various magnifying optics, which are roughly classified into two types:

1) The non-relay type consisting of a LCD and an eyepiece optical system to enlarge the LCD image directly.

2) The relay type equipped with a relay-optical system to form intermediate images of LCD and an eyepiece optical system to enlarge the intermediate images of LCD.

The relay type is easy for implementing the HMD with a wide FOV. Some commercial HMDs aimed for wide FOV were released. Eyephone02 (VPL inc.) was realized 80 degree FOV horizontally. Datavisor 80 (n-Vision inc.), Sim Eye XL100A (Kaiser Electro-Optics inc.) and Gemini-Eye 3 (CAE USE inc.) were realized about 100 degree FOV. Fiber-Optic HMD (CAE inc.) was realized 120h×55v degree FOV by fiber optics. In the research area, Takahashi et al.[10] constructed wide FOV HMD, which displays 100 degree with monocular and 140 degree FOV with binocular by using 4 LCD panel and fresnel lens. Inami et al.[12] construct HMD, which displays maximum 110 degree monocular by using maxwellian optics. However, the FOV of them were maximum 140 degree, which is not enough in comparison with that of human. The following Difficulties are considered on HMD optics with wide FOV:

1) Complicating of the optics according as the FOV is enlarged.

2) Increasing the weight because of the optical complication.

3) Difficulty to compensate the image distortion which come from the complex optics.

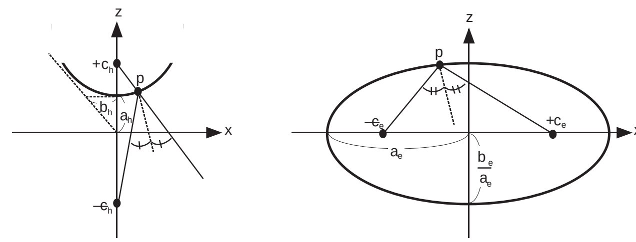


Figure 1: Characteristics of hyperboloidal and ellipsoidal

4) Restriction of the lens size if HMD has eyepiece system.

The proposed wide field of view HMD realized 120h×60v degree FOV distortionless image include a peripheral vision with simple optics. The optics consists of hyperboloidal and ellipsoidal curved mirrors. In addition, it has no eyepiece lens system, so FOV is not limited by the lens size. The distortionless image is displayed to transform the input image with the relation of the curved mirrors. The distortion can be completely compensated by the characteristics of hyperboloidal and ellipsoidal.

3. Optics of proposed HMD

Proposed wide FOV HMD consists of hyperboloidal and ellipsoidal mirror. Generally, the hyperboloidal and the ellipsoidal are described by equations 1-2 and both have two focal points ($\pm c_h$ and $\pm c_e$ in figure 1).

$$\frac{x^2+y^2}{a_h^2} - \frac{z^2}{b_h^2} = -1 \tag{1}$$

$$\frac{x^2+y^2}{a_e^2} + \frac{z^2}{b_e^2} = 1 \tag{2}$$

$$a_h^2 + b_h^2 = c_h^2, a_e^2 - c_e^2 = b_e^2$$

The normal vectors of the curves on point p aliquot the angle between the point p and the both focal points (c and $-c$), as shown in figure 1. Hence, the curved mirror reflects incident ray from a focal point to the other focal point, if the curves and the lines were displaced to mirrors and rays. The hyperboloidal and ellipsoidal mirrors enable to widely spread or gather the rays by simple optics. Moreover, the completely distortionless image can be displayed to an observer, to transform the input image in consideration of the characteristics of the curved mirrors.

Figure 2 shows the components and optics of proposed HMD. The HMD consists of planer, hyperboloidal and ellipsoidal mirror, lens and LCD. Lens is aligned on the focus of hyperboloidal mirror. The ray from LCD is reflected after through the lens. The planer mirror between the lens and

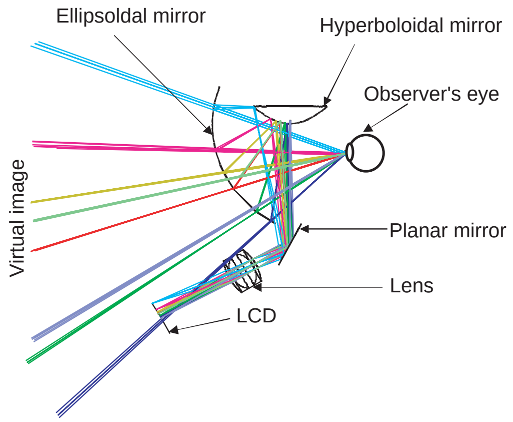


Figure 2: Optics of proposed HMD

Figure 4: Prototype HMD

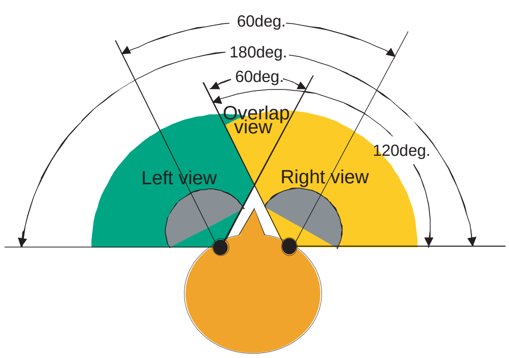


Figure 3: Binocular alignment and horizontal FOV

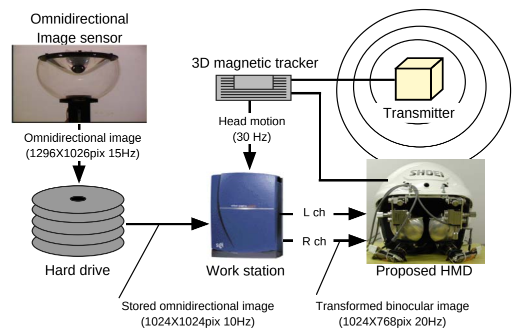


Figure 5: Experimental system

hyperboloidal mirror inclines the rays to avoid interference with observer's face. The ray reflected on hyperboloidal mirror is spread to omnidirectional directions. Then, the ray is reflected to the other focus on ellipsoidal mirror, because the focus of ellipsoidal mirror is aligned with that of hyperboloidal mirror. The axis of ellipsoidal on the focused is inclined 50 degree to avoid that hyperboloidal mirror obstruct the FOV of observer's eye. If the observer's eye position would be set on the focus of ellipsoidal mirror, the ray reflected on ellipsoidal mirror gather into observers eye. Form this property, the proposed HMD can display about 120v$times$60h degree monocular FOV virtual image to the observer by simple optics. Figure 3 shows the binocular HMD units alignment to the observer. The HMD units are aligned with 60 degree rotated to a parallel around vertical as axis shown in figure 3. The HMD can present about 180h×60v binocular FOV including 60 degree overlap area which have stereo capability.

4. Prototype HMD system

Figure 4 shows a prototype wide FOV HMD. Because the proposed HMD units should be aligned with the position corresponding to the pupil position of observer's eye, we have to adjust the positions according to the individual interpupillary difference of the observer. Therefore, the HMD units were mounted on a helmet by adjusters, which are 19[mm] adjusterable on 3 degree of freedom each. We applied LCD module (0.5 inch, 1024×768 pixels), which was disassembled from a commercial HMD (Glasstron: Sony). We attached a magnetic motion tracker (The Flock of Birds: Ascension inc.) to detect the observer's head motion.

Figure 5 shows the experimental system to estimate the HMD. The system was used the image sequence captured by omnidirectional image sensor HyperOmni Vision [1] as the input image. Figure 6 shows the sample of input image (1296×1026 pixels, 15 Hz) captured by the omnidirectional image sensor. The image sequence was stored by hard disk unit. A workstation (Octain 2: SGI) transform the input image to binocular transformed images (1024×768 pixels), then the binocular images project on the HMD. The HMD

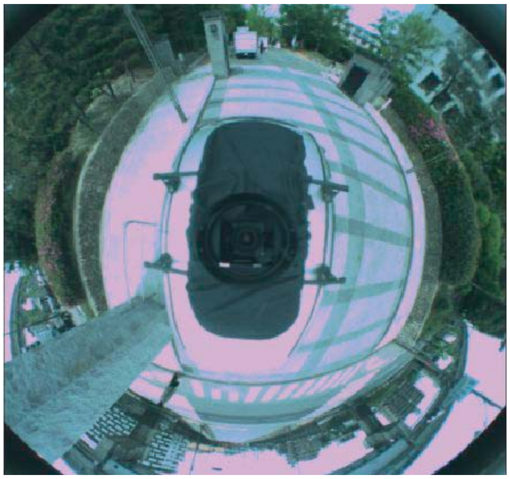


Figure 6: Omnidirectional image

can display the distortionless binocular images generated by the workstation in consideration of the optics of HMD and omnidirectional image sensor. Fugure 7 shows a sample of the binocular transformed images. Lines in figure 7 indicate a longitude and a latitude on spherical coordinate. Note that the binocular transformed images are reversed horizontally owing to reflection of the mirrors and are deformed to compensate the distortion caused by HMD optics. The angular resolution of HMD is shown in figure 9 from the resolution difference of binocular transformed image.

The system can present virtual view images corresponding to the directions of observer's sight in hemisphere of input image, because the binocular transformed images are generated depending on the head motion detected from the magnetic motion tracker. It is not only to use the wide FOV information at real-time but also to present the virtual view corresponding to the head motion without a delay of pan-tilt camera motion that the system use the omnidirectional image as the input. The system updates the image at 25 Hz by the change of head motion and at 10 Hz by the change of environment. Onoe et al.[7] also constructed the similar system. However, their system used a commercial HMD, which has normal FOV (about 60 degree horizontally).

5. Experiments

We confirmed to display image on HMD and estimate its quality. We used the three types of test charts; vertical, horizontal and Landolt circle shown in figure 10 to display on HMD. We employed 5 subjects on this experiment. We confirmed the limit size recognized by the subjects with changing the four different sizes of the chart corresponding to the angular resolutions, 1.25, 2.5, 5.0, 10 [pixel/degree]. Figure 11 shows the results that are the average resolution recognized by 5 subjects. The results include the multiple effects as resolution attribute shown in figure 9 and optical focus. The gazed area that is center of view was well focused in consideration of the resolution of binocular transformed image shown in 9. On the other hand, the recognized resolution of peripheral area is not high especially over 60 degree in figure 11-b, because of optical blur. However, human peripheral vision is insensitive of the resolution. Hence, we thought that the image quality is enough to display to the human. The prototype HMD has the vignetting problem. The position of observer's eye is severe, because the observational pupil is small on the prototype HMD. If observer's pupil would be moved when the eye is rotated, observer's pupil obstruct the rays from HMD. Therefore, we estimated the capable area without vignetting by eye rotation. We employed ten subjects on this experiment. Figure 1 shows the average and standred deviation of eye rotation angle without vignetting.

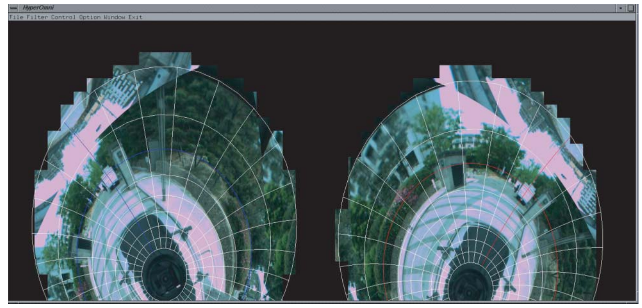


Figure 7: Binocular transformed image (180h$\times$60v degree FOV)

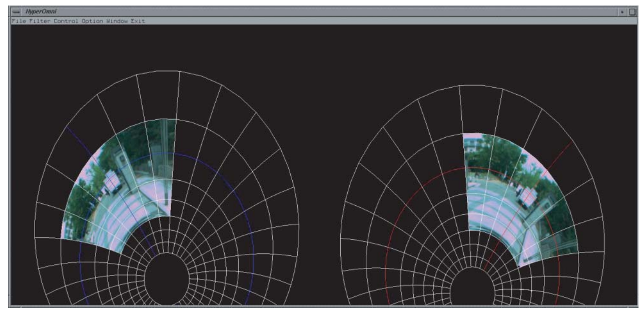
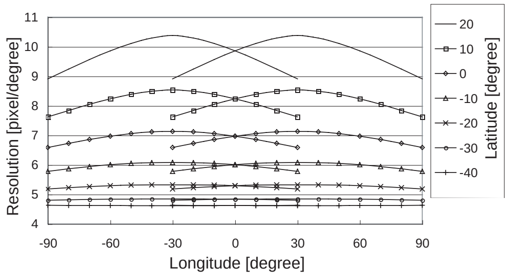
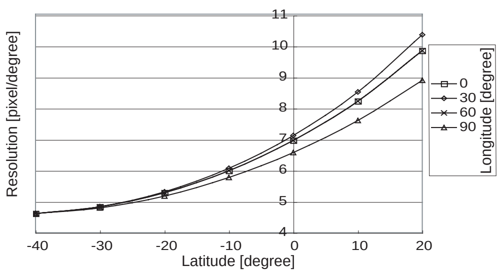


Figure 8: Binocular transformed image (60h$\times$40v degree FOV)

We compared the wide FOV (180h$\times$60h degree) and narrow FOV (60h$\times$40v degree) assumed common HMDs to estimate the effect of wide FOV. Figure 8 shows the narrow binocular FOV images limited FOV for using the experiment. We used the images captured on a moving car on this experiment. Table 2 shows the result of comparison



(a) Resolution attribute against horizontal



(b) Resolution attribute against vertical

Figure 9: Resolution of projected image on the HMD

between wide and common FOV about 10 subjects. This results shows that wide FOV indicates the advantages on the factors of reality; Extensity of FOV, immersion and moving feel.

We also estimate the influence of vignetting cased by small observational pupil. Table 3 show the result with 10 subjects in the case of constant view and accommodated view with head motion. The table indicates the number of subjects who feel the vignetting under unconscious eye motion. This result shows over half subjects clam the vigenetting in the case of constant view. However, when view accommodation with head motion was enabled, almost subjects did not care the problem. It is indicated that the prototype HMD was applicable for applications under unconscious eye motion.

We confirmed that the proposed HMD can display the 180×60h wide FOV image practically by using the experimental system. From these results, the proposed wide FOV HMD is effective to virtual reality and robotics applications, because the wide FOV including peripheral vision contributed to the reality and immersion in the virtual environment.

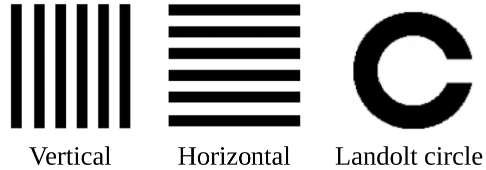
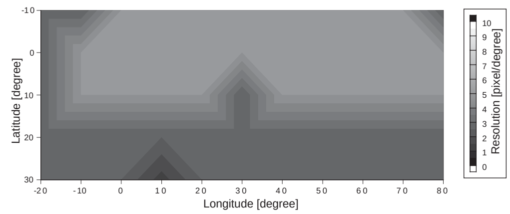
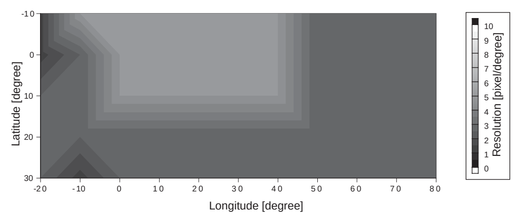


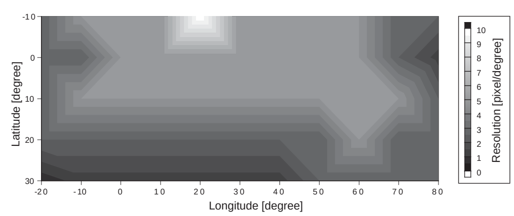
Figure 10: Test charts for confirmation of image quality



(a) Verttical Chart



(b) Horizontal Chart



(c) Verttical Chart

Figure 11: Result of image quality test by test chart

Table 1: Estimation of eye movable limit without vignetting

	Average [deg.]	standard deviation [deg.]
Horizontal	$\pm$ 16.6	5.13
Vertical	$\pm$ 15.5	4.33

Table 2: Estimation of prototype wide FOV HMD

	Advantage of wide FOV
Extensity of FOV	10/10
Immersion	10/10
Moving feel	10/10

Table 3: Influence of vignetting

Accommodation with head motion	Occurence of vignetting
Off	6/10
On	1/10

6. Conclusions

In this paper, we proposed the wide FOV HMD consisting of hyperboloidal and ellipsoidal mirrors. The proposed HMD can display 180h×60v wide FOV binocular image, and the wide FOV includes peripheral vision area. We constructed high-immersive visualization system that can display 180 degrees horizontal view by using the proposed catadioptrical HMD and an omnidirectional image sensor. We estimated the capability of HMD and confirmed the wide FOV displayed by the HMD practically. We also confirmed the advantage of wide FOV including peripheral vision.

we propose high-immersive visualization system that can display 180 degrees horizontal view by using a new catadioptrical HMD and an omnidirectional image sensor.

7. Future work

The weight of HMD is too heavy, because the mirrors and adjuster of prototype HMD were made from aluminum. We will make HMD lighter to modify the parts made from plastic. The proposed HMD has 60 degree overlapped area where can display stereo capability. However, the current system generates the binocular transformed images from monocular omnidirectional image stored by hard disk. We will modify the system to display parallax images from stereo camera and/or computer graphics, then estimate the stereo capability. Moreover, we plan to estimate the reality and task efficiency in applications such as tele-presence and virtual realty.

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