Optimized HMD System for Underwater VR Experience

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Figure 1: We have optically designed the HMD so that it has a sufficient field of view even when the internal structure is filled with water. This reduced the buoyancy, and so the user can swim comfortably while experiencing VR.

CCS CONCEPTS

•**Human-centered computing** →**Virtual reality;**

KEYWORDS

Head-mounted display. Virtual reality. Visuohaptic interaction.

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1 INTRODUCTION

Many people exercise in water. However, when they swim in the pool, they may get bored. Therefore, studies on virtural reality (VR) and augmented reality (AR) in water have been made. Aquacave[Yamashita et al. 2016] allows you to experience VR in an aquarium. The payload is low but the cost of setting up the environment is high. We cannot swim, over a wide area, and so it cannot be used by many people. Zhang, Tan, and Chen (2016) have created a head-mounted display (HMD)[Zhang et al. 2016] that can be used underwater, but in this structure, air enters the device, which greatly increases the buoyancy, making swimming uncomfortable. In Quarles (2015)[Quarles 2015], water was present in the internal structure of the HMD, but its optical impact was not discussed, the viewing angle is unknown. Therefore, we designed an optimal HMD for swimming. Because there was no air layer in the HMD, it was expected that buoyancy would not be an issue and that the HMD could easily be worn while swimming. Our study is the first to evaluate underwater VR by subject experiments.

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	Environmental cost	
	Low	High
User-friendly	This study John[6]	Shogo[10] Torsten[3]
Not user-friendly	Abdelkader[1]	

Figure 2: A map of related work (underwater VR/AR).

2 DESIGNING UNDERWATER HMD

In this section, we explain our HMD configuration, which uses smartphones, planoconvex lenses and underwater goggles designed for this study. First, as a prototype, we attached the lens of the Google Cardboard to underwater goggles and watched a video of Google Cardboard content for two eyes underwater. However, the image was located at the center of the field of view, and three images were formed. Therefore, we developed an optical design, using Zemax OpticStudio, that enabled the screen to be seen underwater with almost the same viewing field as that provided by Google Cardboard out of the water. Because the focus and the image are symmetrical, we only needed to consider the optical design for one eye. First, as shown in figure 3, the optical system of Google Cardboard, when used in air, was reproduced in OpticStudio. We used an iPhone 7 as the display unit. The vertical width of the

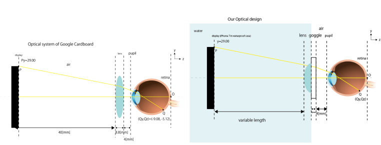

Figure 3: Left: Optical design of Google Cardboard. Right: Our designed HMD.

Table 1: Lens data.

Diameter	Focal length	Variable length	Qy	Qz
Google Cardboard	-	-	-9.08	-5.11
20	20	45.8	-10.13	-8.00
22.5	22.5	51.7	-9.77	-6.42
25	25	65.8	-8.38	-4.13
30	30	69.9	-8.02	-3.73

system was 58.00mm when it was laid sideways, so we set one ray from a height of 29.0 mm and another ray from the center, 0 mm. The wavelength of the ray was set to 590 nm, which is a general wavelength that defines the focal length of the lens. The eye model downloaded and used on the official site of Zemax was used. The center of the retina of the eyeball model was set as the origin of the coordinate system. When reproducing the optical system using Google Cardboard in the air, the coordinates of a ray coming from a height of y = 29.0 mm reached the retina as shown in figure 3. This figure also shows the optical system for a ray with y = 0 mm. It is designed so that the coordinates of the image formed by the retina are almost the same as when the Google Cardboard is used in air. We tried each of the plano-convex lenses sold by Edmund Optics one by one, and repeated the optimization calculations for the image on the retina with the distance between the display and the lens as a variable. For each lens, the coordinates for a ray with y = 29 mm reaching the retina were examined as shown in table 1. Therefore, we used a lens with a diameter of 25 mm and a focal length of 25 mm, whose coordinates were closest to the coordinates when using Google Cardboard. The HMD was designed by laser cutting acrylic material. Because vision is different for each person, a mechanism was provided that allows adjustment of the focus by varying the distance between the display and the lens. Specifically, a vertical hole was made in the upper part and side of the HMD and screws were passed through it. We designed a 3D model of the

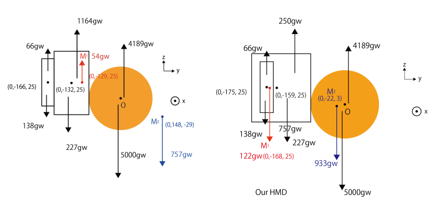

Figure 4: Left: Watertight HMD. Right: Our designed HMD. M_1 is the centroid of the enclosure. M_2 is the overall centroid.

enclosure using Rhinoceros. For the sake of simplicity, the head was a ball with a diameter of 20 mm and a weight of 5 kg, and its center was set as the origin of the coordinates. For other objects, the weight was measured and the volume was calculated from the model. The volumes of the tape and adhesive were ignored. The relationship between the center of gravity, weight, volume and so on is shown in the figure. The coordinates in each HMD are set as shown in figure 4. These figures show that when a person puts on a watertight HMD, the head floats in the water, but when the person puts on our designed HMD, the head sinks in the water.

3 EVALUATION

Five volunteers (ages 18-21, 0 female) were recruited. Their average height and weight were 171.6 cm (SD=3.2, range 169-175) and 62.4 kg (SD=9.3, range 50-79). All participants had normal or corrected vision. Two types of HMD were prepared in the experiment. The first was a water-tightened off-the-shelf HMD with adhesive and vinyl tape. It was fixed in a position that was in focus for one of the authors. The second was an HMD with a structure that allowed water to fill inside. Subjects swam freely while looking at a 360 movie delivered as content for Google Cardboard from Youtube using an iPhone 7. The movie movie screen moves according to the movement of the head by using the motion detection capabilities of the accelerometer and gyro sensor of the iPhone 7. When the subjects swam, they wore a snorkel, nose plugs, and earplugs depending on their choice. Visibility in a wide field of view was evaluated by the subjects using a seven-level scoring system (0 = unsatisfied, 6 = satisfied). For the watertight HMD, the average was 3.0 (SD = 2.2). For our HMD we made, the average was 3.8 (SD = 1.47). This result proved that there was sufficient field of vision. We asked each subject to compare the ease of moving their head underwater (0 = unsatisfied, 6 = satisfied), both for the watertight HMD with large buoyancy and for the HMD with low buoyancy designed by us. For the watertight HMD, the average was 3.2 (SD = 0.9). For our HMD, the average was 3.6 (SD = 1.7). This result proved that players can swim comfortably by wearing an HMD with less buoyant force. We used factor analysis of an iGroup Presence Questionnaire (iPQ) [igroup org 2010] to evaluate the immersion feeling. In a watertight HMD, the overall presence of all reported participants was reported as 2.78 / 6 (SD = 1.72). Spatial Presence was reported as M = 2.92, (SD = 1.83), Involvement as M = 2.70 (SD = 1.22), and Realness as M = 2.70 (SD = 1.55). In the HMD, the overall presence of all reported participants was 3.31 (SD = 1.72). Spatial Presence was reported as M = 3.15 (SD = 0.96) for, Involvement as M = 3.52, (SD = 1.70), , Realness as M = 3.40 (SD = 0.47). From this result, we can infer that though the participants were engaged with and were present in the virtual underwater world, they behaved as if they were actualy scuba diving. In other words, our HMD made it possible to experience the virtual world more naturally.

REFERENCES

igroup org. 2010. igroup Presence Questionnaire (IPQ) overview. http://igroup.org/pq/ipq/index.php. (2010).

John Quarles. 2015. Shark punch: A virtual reality game for aquatic rehabilitation. In *2015 IEEE Virtual Reality (VR)*. IEEE, 375–375.

Shogo Yamashita, Xinlei Zhang, and Jun Rekimoto. 2016. AquaCAVE: Augmented Swimming Environment with Immersive Surround-Screen Virtual Reality. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology*. ACM, 183–184.

Wenlong Zhang, Chek Tien Tan, and Tim Chen. 2016. A safe low-cost HMD for underwater VR experiences. In *SIGGRAPH ASIA 2016 Mobile Graphics and Interactive Applications*. ACM, 12.