Liquid Lens Used for the Virtual Reality System

Yu-Lin Chen[1], Tsung-Hsien Wu[2], Jui-Wen Pan[1*]

[1] Institute of Photonic System, National Chiao Tung University, Taiwan
[2] Institute of Imaging and Biomedical Photonics, National Chiao Tung University, Taiwan
*Corresponding author: juiwenpan@gmail.com
Keywords: Liquid Lens, Penta Prism, Head-Mounted Display, Virtual Reality System

ABSTRACT

This design combines the liquid lens with a VR system to improve the image quality for myopic and hyperopic users. A penta-prism is also incorporated and used to change the direction of the optical path to improve any optical aberration caused by the gravity effect.

1 INTRODUCTION

Recently, Virtual Reality System (VR) have been widely used in different fields, and in optical designs for military, commercial, biomedical, and entertainment applications [1,2].

However, there are many weaknesses of the VR system, which need to be solved. One of them is to make devices accessible to users with myopia and hyperopia. Such users of the VR system devices may see only a blurred virtual image. In general, there is a mechanism that can be incorporated to help users see a clearer virtual image, the liquid lens. The liquid lens allows for autofocus and zooming by changing the shape of the surface of the lens. However, the liquid lens[3,4] has a large clear aperture, rendering the gravity effect more obvious, serious enough to cause optical aberrations, such as spherical aberrations, coma, astigmatism, field curvature and distortion [5]. In order to deal with this problem, we present a new optical design for a VR system.

2 RESULTS

2.1 Optical layout for the VR system with liquid lens

When users with myopia and hyperopia use a VR system, they may not be able to see the virtual image clearly. In our design we use a liquid lens to solve this problem. The curvature of the liquid lens can be changed to obtain different optical paths to improve the image quality. In the VR system, the liquid lens is set perpendicular to the ground. The liquid inside the lens may be affected by gravity and gather at the bottom. This phenomenon may cause severe aberration. To alleviate the gravity effect, the arrangement of the VR system and the liquid lens is important. In this new optical design, a prism is used to change the direction of the optical path to deal with the gravity effect and to improve the image quality [6]. There are two kinds of prism that can be used, a right-angle prism or a penta-prism. The penta-prism is commonly used in the traditional camera system for the purpose of producing a normal image [7]. This novel VR system design is comprised of an eyepiece lens, penta-prism, and liquid lens. Moreover, in order to minimize the volume of the system, the eyepiece is designed with two lenses near the penta-prism. The novel design is shown in Fig. 1. The microdisplay is a self-emissive Organic Light Emitting Diode (OLED) [8].

2.2 Analysis of penta-prism size

To find the most suitable size for the penta-prism used in this VR system, the clear aperture of the liquid lens needs to be considered. If the rays pass through the exit port of the penta-prism, they may be blocked by the liquid lens. In order to prevent the obscuration effect, the ray height must be controlled well. Fig. 2 shows the arrangement of the penta-prism, liquid lens and micro display, where e is the distance between the penta-prism and the liquid lens; g is the distance between the liquid lens and the display; f is the thickness of the liquid lens; h is the diagonal half-length of the display; k is the half clear aperture of the liquid lens; and y is the upper marginal ray height.

Cost-reduction is also an important factor for mass production. The selection of commercially available products is a good way to reduce tooling costs and to facilitate quick evaluation of the optical performance. A 20 mm penta-prism from Edmund is selected for this design. The total track and entrance port of the penta-prism are 67.728 mm and 20 mm, respectively. The size of the penta-prism is large enough that the imaging rays will not be blocked by the mechanism of the penta-prism and liquid lens.

2.3 Paraxial eyepiece design and analysis

In any optical design, paraxial analysis is an important step in the beginning. In this design, to ensure compact size and low cost the eyepiece is composed of two lenses, located at the entrance and exit of the penta-prism, respectively. The boundary conditions for the eyepiece's focal length are set based on the penta-prism's size and the clear aperture of the liquid lens. Suppose that the paraxial lenses are very close to the penta-prism. Fig. 3 shows the VR system optical layout with a tunnel diagram of the penta-prism and liquid lens. Parameter a is half of the pupil diameter of the human eye; b is the eye relief; c and m are the thicknesses of the penta-prism and liquid lens, respectively; d and h are the length of the penta-prism's entrance port and half the diagonal length of the micro display. Parameters e and g are the distances between the penta-prism and liquid lens and the liquid lens and micro display, respectively; n is the refractive index of the penta-prism; and θ is the FOV of the VR system. Parameters f1, f2 indicate the focal lengths of the first and second lens groups while R1, R2, R3 are the two off-axis marginal rays, and on-axis marginal ray. R4 is the off-axis chief ray. The parameters y1, y2 are the heights of rays R1 and R2 at the exit port of the penta-prism.

2.4 The relation of the focal length of VR system to the field of view

The values of the parameters b, e and g are 15 mm, 8 mm and 8 mm, respectively, for the compact VR system. Table 1 shows the specifications of the micro display for use in the VR system. Fig. 4 shows the relation between f1, f2, F and the FOV. Moreover, the penta-prism is used to deal with the gravity effect on the liquid lens. In order to ensure that all rays pass through the penta-prism without a vignette effect, the focal length of the first lens group is limited by the boundary condition. The boundary condition of f1 is from 44.65 mm to 120 mm. In order to get a large FOV, as indicated in Fig. 4(a) and 4(b), the maximum value of the FOV is 14.83 degrees under boundary condition f1. Fig. 4(a) indicates that the FOV is 14.83 degrees when f1 is 120 mm. Fig. 4(b) indicates that f2 is 49.84 mm when f1 is 120 mm. Fig. 4(c) indicates that the focal length F is 53.84 mm when f1 is 120 mm. The paraxial design is satisfactory. The optical specifications of the whole system are shown in Table 2.

After the paraxial lens design is satisfactorily completed, designing the real lens is the next step. An Edmund lens is used in the real design and cemented doublet lenses are used for the second lens group to correct for chromatic aberration. All lenses are spherical. The lens design data for the VR system is shown in Table 3. The ray path of the VR system with a penta-prism tunnel diagram is shown in Fig. 5.

2.5 Experiment verification

In order to verify the system, we use the camera system to check the function for VR system The Fig. 6 shows the structure and verify the liquid lens function under the myopia situation. The camera with stander lens is pretended to be an eye to capture the image that is from the micro display. Fig. 6(a) shows that the result of the virtual image without myopia situation. The myopia situation means that the parallel rays passing through an eye may focus at the front of the retina. However, in order to simulate the myopia situation, a positive lens is put in front of the camera to let the rays that can be focused at the front of the CCD as shown in Fig. 6(b). Fig. 6(b) shows that the image is not clear. Next, in order to improve the image quality, optical power of the liquid lens is changed to be negative as shown in Fig. 6(c). Fig. 6(c) shows that the image quality is as good as the result of Fig. 6(a). Consequently, the results indicate that the image quality can be obviously improved by changing the optical power of the liquid lens. In this way, this VR system with the liquid lens can be used without glasses for the myopia users.

3 CONCLUSIONS

An optical design for a VR system with a liquid lens is presented. This design incorporates a liquid lens into a VR system to improve the image quality for users with myopia and hyperopia and also to overcome the effects of gravity by the use of a penta-prism to adjust the direction of the liquid lens. The optical aberration of the whole VR system can be minimized by using this method. The two-lens group in the eyepiece is arranged close to the penta-prism to attain a more compact size and the lens of the eyepiece is close to the liquid lens. A cemented double lens is used to correct for the chromatic aberration. In this novel design, commercially available products are used for the two lenses of the eyepiece, the penta-prism and the liquid lens. The specifications of this VR system are as follows: exit pupil 8 mm, eye relief 15 mm, and FOV 14.83 degrees. The MTF has a value above 0.9 at 3.3 lp/mm and the tolerance analysis results indicate that the value of MTF is greater than 0.3 at 3.3 lp/mm.

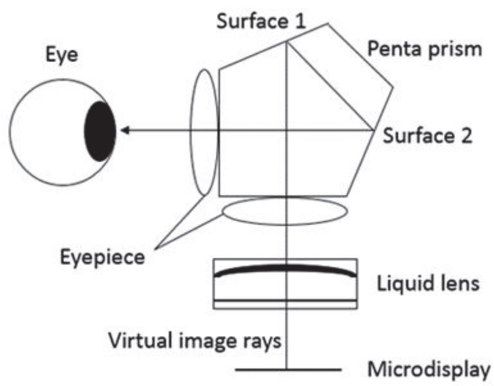

Fig. 1. Layout of the VR system with liquid lens

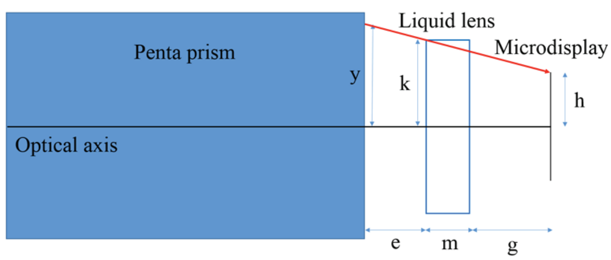

Fig. 2. Layout of the penta-prism, liquid lens and micro display

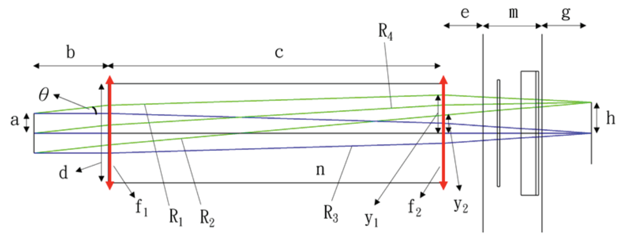

Fig. 3. VR system optical layout with tunnel diagram of the penta-prism and liquid lens

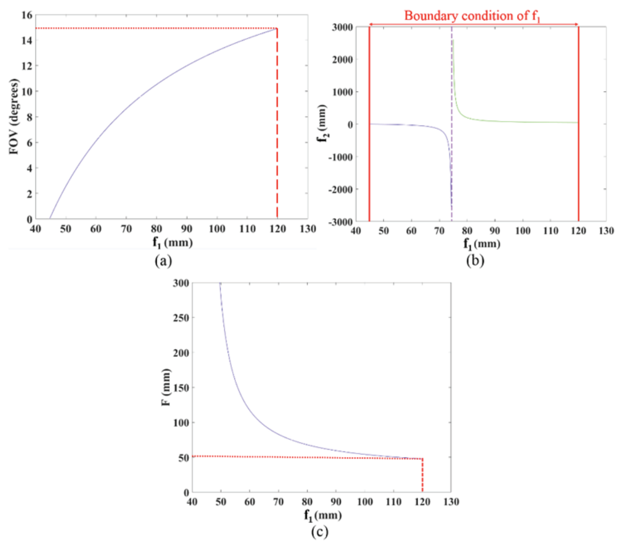

Fig. 4. (a) The relation of f_1 to the FOV; (b) relation of f_1 to f_2; (c) relation of f_1 to F

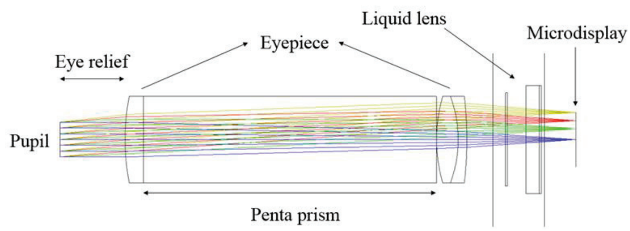

Fig. 5. Ray path of the VR system with penta-prism tunnel diagram

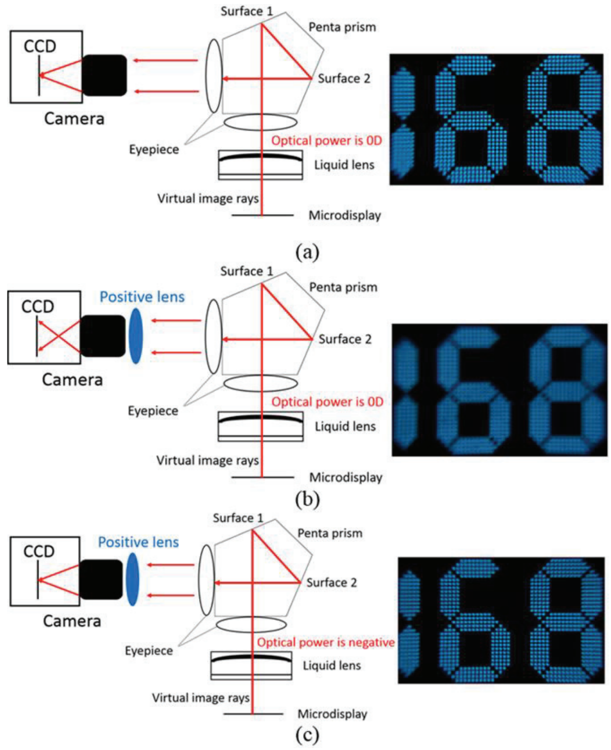

Fig. 6. The structure of experiment (a) without myopia (b) with myopia (c) of improvement

Table 1. Specifications of the micro display for the VR system

	Parameters	Specifications
Image source	Microdisplay	WEO006432A
	Active area	11.18 mm×5.58 mm
	Resolution	64 × 32 pixels
	Pixel size	153 μm/pixel

Table 2. Parameters and specifications of the VR system

	Parameters	Specifications
VR system	Effective focal length	53.84 mm
	Exit pupil diameter	8 mm
	F-number	6.73
	Field of view	14.83 degrees
	Eye relief	15 mm
	Liquid lens	Optotune EL-16-40-TC-VIS-5D-C

Table 3. The lens design data for VR system

Surface number	Radius (mm)	Thickness (mm)	Glass
OBJ	Infinity	Infinity	
1(Stop)	Infinity	15	
2	51.68	4.3	N-BK7
3	Infinity	0	
4	Infinity	67.728	N-BK7
5	Infinity	0	
6	35.92	5	N-BK7
7	-28.12	2	N-SF5
8	-83.79	8	
9	Infinity	2.88	
10	Infinity	0.5	D263T
11	Infinity	4.32	
12	Infinity	3.01	OL1224 _VIS
13	Infinity	0.5	D263T
14	Infinity	0.7	
15	Infinity	7.308	
16	Infinity	-	

REFERENCES

[1] J. Rolland and O. Cakmakci, "Head-Worn Displays: The Future Through New Eyes," Opt. Photonics News **20**(4), 20 (2009).

[2] Google glasses, website https://vr.google.com/.

[3] Liquid lens of Optotune, website https://www.optotune.com/products/focus-tunable-lenses/electrical-lens-el-16-40-tc

[4] D. Ke and C. Xuemin, "Current trends of liquid lenses," Opt. Dev. and Integ. #paper OF3A.3 (2014).

[5] W. J. Smith, *Modern Optical Engineering* (McGraw Hill, 2008)

[6] Gravity effect of liquid lens, website https://www.optotune.com/images/products/Optotune%20EL-16-40-TC.pdf

[7] S. F. Ray, *Applied Photographic Optics: Lenses and Optical Systems for Photography, Film, Video, Electronic and Digital Imaging* (Focal Press, 2002)

[8] G. Rajeswaran, M. Iton, M. Boroson, S. Barry, T. K. Hatwar, K. B. Kahen, K. Yoneda, R. Yokoyama, T. Yamada, N. Komiya, H. Kanno, and H. Takahashi, "Active metric low temperature poly-Si TFT/OLED full color displays: development status," SID Digest **31**, 974–977 (2000).