Asymmetric Field-of-View Angle for Virtual-Reality Optical System

Huanli Yang, Hao Sun, Rui He, Rui Yang, Fei Ai, Qiang Gong, Jingfeng Xue, Bin Zhao

TCL China Star Optoelectronics Technology Co., LTD, Wuhan, China

Abstract

In order to further increase the horizontal temporal FOV of the VR lens without sacrifice the distance between the eyes and the lens or increasing the lens aperture, we proposed a asymmetric design of FOV by offset the optical center, while cutting the lens and display accordingly to minimize lens size and maximize display utilization. Compared to conventional solutions, the utilization rate of the display has increased by about 14.2%, and the coverage rate of the human perspective has increased by about 10.5%.

Author Keywords

Virtual Reality; Optical Center; Asymmetric FOV; Utilization Rate;

1. Introduction

With the continuous improvement of people's requirements for the display of consumer electronic products, virtual/augmented reality display technology has attracted more and more attention. Virtual reality has a good immersive experience and is increasingly favored by consumers. It can be seen that the core significance of virtual reality lies in immersion, and the key to achieving immersion is panoramic view. FOV[1-5] represents the panoramic angle you see and is an iconic parameter reflecting the core optical technology.

As shown in Figure 1, the maximum horizontal field of view of the human eye is 155 °(90 ° on the temporal side>65 ° on the nasal side); The maximum vertical field of view angle of the human eye is 130 °(70 ° on the lower side>60 ° on the upper side); The FOV is the smallest at the location where the nose is obstructed (about 45 °); The horizontal overlap range of the two eyes is about 120 °; Stereoscopic vision (fusion of left and right monocular vision that provides 3D depth clues) is approximately+/-40 °. Therefore, a too low FOV cannot bring us immersion, and the images presented by VR devices need to be more consistent with human eye structure and behavioral habits to ensure the realization of immersion. For currently available VR products, a 100 ° FOV has become the industry's minimum standard. Below this degree, the range you can see is not only limited, but even the black edges of the screen in front of you can be seen. Therefore, only angles greater than 100-120 ° can create a good virtual experience. The factor that limits the VR field of view is the lens. In order to obtain a larger field of view , there are generally two ways: sacrifice the distance L between the eyes and the lens, and increasing the size D of the lens. The first option of sacrifice the space is limited, and excessively reducing the distance between the eyes and the lens will affect the comfort of wearing; The second option will result in an increase in the weight and volume of product, as well as an increase in the difficulty of correcting geometric distortions and chromatic aberration. Therefore, when designing the optical solution, in order to provide users with the best visual experience, it is necessary to maintain a distance L between the eyes and the lens of ⩾ 16mm, and maximize the FOV without making the lens too large or heavy.

As shown in Figure 2, the approximate calculation method for lens aperture is: D=2L * Tan (w/2) (where L is the eye relief and w is the field of view). As the lens aperture increases rapidly with the increase of the field of view, for example, D (120 °)=2L * Tan 60 °=2L * 1.732=55.4mm, considering that the pupil size is generally 4mm and the eye box is generally 4 ± 3mm, the lens aperture reaches 65.4mm. Such a large aperture is not allowed in VR headset products and will greatly limit the adjustable range of pupil distance (58-72mm).

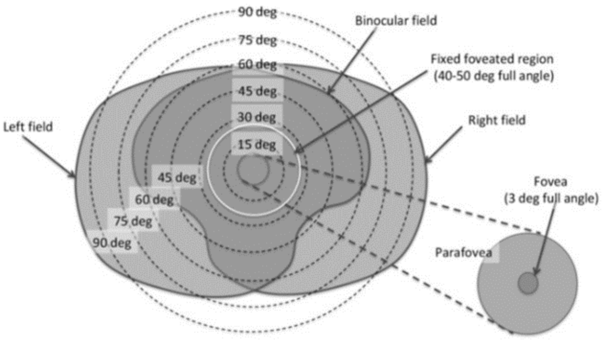

Figure 1. Field of the human eye

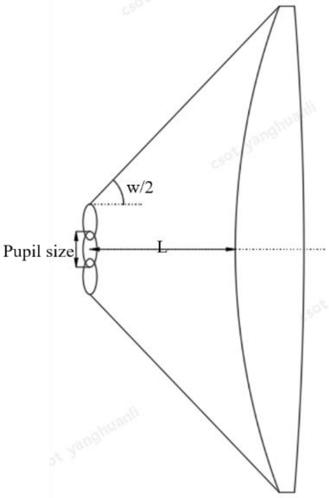

Figure 2. The calculation of lens aperture

2. Optical Design of Asymmetric FOV

Therefore, this paper proposes a solution to the problem of excessive lens aperture caused by a large field of view (⩾ 120 °) in NED[5-10]:

Figure 3 (a) shows a conventional optics design, where the optical center of the lens coincides with the center of the display, the temporal FOV is equal to the nasal FOV (or can be equal to the vertical FOV), and there is no distinction between left and right eyes. The overlapping FOV of the two eyes (such as the nasal FOV) is basically equal to the monocular FOV. The limitation of this design is that the FOV is determined by the distance between

ISSN 0097-996X/25/5603-1569-$1.00 © 2025

the eyes and the lens and the lens's aperture, and cannot achieve a large FOV, such as ⩾ 120 ° . Figure 4 (a) and (b) achieve an asymmetric design of temporal FOV>nasal FOV. At the same time, the lens/display is cut into corresponding irregular shapes to minimize lens size and maximize display utilization. The schematic diagram of the right eye is shown in Figure 4 (a)(the right edge of the lens is not cut), and the design principle of the left eye is the same. Figure 4 (b) shows the prototype of the left and right VR lenses under this design method.

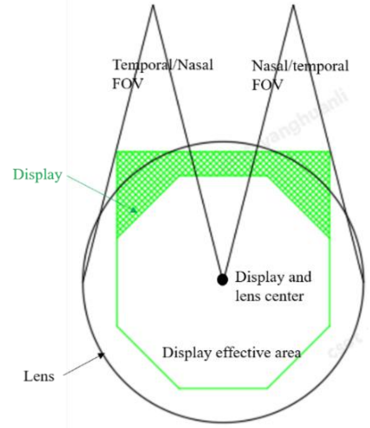

Figure 3 (a). Conventional optics design

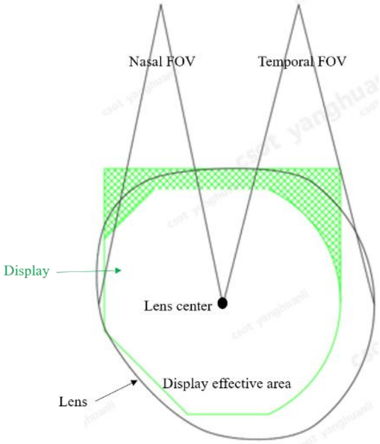

Figure 4 (a). Optical design of asymmetric FOV

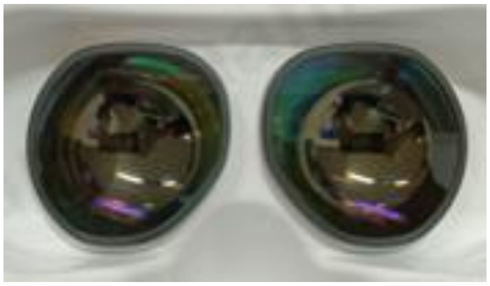

Figure 4 (b). The asymmetric prototype of VR lens

The principle of above design explains that the optical center of the lens coincides with the initial geometric center of the display (the center of the image circle designed by the optical system), and at this time, the FOV size in all directions is the same (for example, all directions have a half field of 60 °, corresponding to a half aperture of approximately 32.7mm@eye relief 16mm for the lens). In order to reduce the aperture of the lens and consider the requirements of the field of view in all directions and the design of the external ID, the edge cutting methods of the lens/display is determined. For example, the monocular horizontal nasal side FOV meets the requirement of ⩾+/-40 ° (which is the requirement for binocular overlapping stereoscopic vision area), and the nasal side of the lens can be appropriately cut off. The cutting curve should be smooth and excessive, and the final shape needs to be comprehensively considered in the ID design of the whole machine. When the nasal side of the lens is cut into irregular shapes, the required size of the corresponding display also decreases, that is, the nasal side boundary of the display moves towards the temporal side, and the movement value is determined by the cutting curve of the nasal side of the lens mentioned above, because the position of the same light reaching the lens and the display corresponds one-to-one. However, considering that the boundary of the display AA area is generally not made into a curve like the cutting edge of the lens mentioned above, so the boundary of the display can meet the corresponding field requirements of the human eye (as shown in Figure 4a, the nasal side of the left display is a straight edge of the AA area) . The best solution to improve the utilization rate of the display is to generate the boundary of the AA area on the nasal side of the display according to the cutting curve of the nasal lens. In addition, to ensure the horizontal lateral FOV, the temporal side of the lens is not removed, and the corresponding boundary of display AA area also needs to meet the requirements of the horizontal lateral field of view (as shown in Figure 4a, the temporal side of the right display is designed with an arc-shaped boundary, and the outline of display can also be made into an arc). The design of vertical cutting for lenses/display is determined by the corresponding requirements of the field of view and the design of external ID, and generally requires a vertical FOV of ⩾ 90 ° .

The corresponding optical path of the lens in Figure 4 (b) is shown in Figure 5, with a display size of 2.56 inches. The field of view and the effective aperture of the lens are the same as those in Figure 6 and Table 1. The horizontal temporal FOV of 60 ° is greater than the nasal FOV of 50 °, the FOV at the nasal occlusion is about 45 °, and the vertically symmetrical FOV is 105 °.

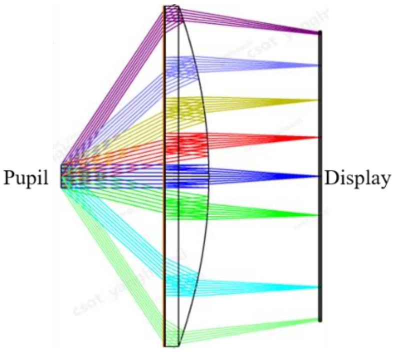

Figure 5. Optical path of the lens

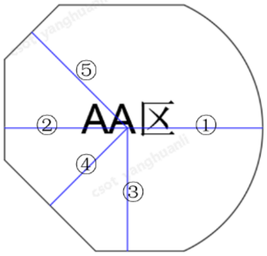

Figure 6. Display of asymmetric VR lens

position	Display height (mm)	Lens size (mm)	FOV (°)
①	26	29	60
②	20	24	50
③	22	23	52.5
④	19	18	45
⑤	23	26	56

Table 1. Effective aperture of the asymmetric VR lens

3. Advantage

Compared with the technical specifications of VR optical module on the market, the compatibility between lens's FOV and human visual characteristics is relatively low, and the compatibility between the display and lens's FOV is also relatively low. The optical scheme of the asymmetric FOV mentioned above adopts matching design of lens and display, providing a binocular 120 ° FOV that surpasses similar products. Users will not feel the presence of image edges, thus bringing better immersion.

Figure 7 (a) shows the comparison between the left VR lens's field of view for the asymmetric design mentioned above and the left eye's field of view. The blue area represents the field of view of the left VR lens, corresponding to 60 °field of view on the left side; The orange area represents the field of view of the left eye. Figure 7 (b) shows the comparison between the actual usage area of VR lens in the display and the display AA area. The black area represents the display AA area, and the green area represents the actual usage area of VR lens in the display. The coverage rate of human visual is 60.2%, and the utilization rate of display is 98.3%. At this time, the horizontal dimension of the lens is 53mm, and the vertical dimension is 46mm.

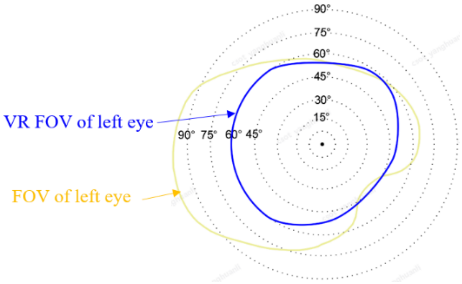

Figure 7(a). The left VR lens and left eye's field of view

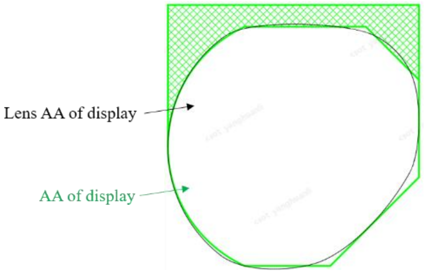

Figure 7(b). The actual usage area of VR lens in the display and the display AA area

Figure 8 (a) shows the comparison between the VR lens's field of view (half-field angle is 52.5 °) for the normal symmetric design and the left eye's field of view. Figure 8 (b) shows the comparison between the actual usage area of VR lens in the display and the display AA area. The coverage rate of human visual is 53.3%, and the utilization rate of display is 94.8%. At this time, the horizontal dimension of the lens is 51.5mm, and the vertical dimension is 51.5mm. Most products generally do not choose this design, but will make certain cutting and avoidance treatments on the nose side.

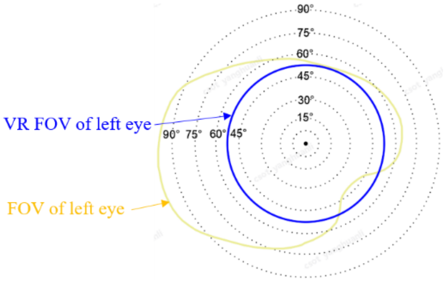

Figure 8(a). The normal VR lens and left eye's field of view

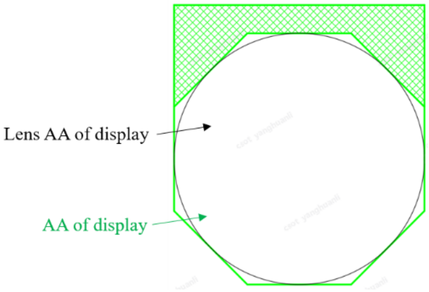

Figure 8(b). The actual usage area of VR lens in the display and the display AA area

Figure 9 (a) shows the comparison between the left VR lens's field of view for the other design (corresponding to 52.5 °field of view on the left side) and the left eye's field of view. Figure 9 (b) shows the comparison between the actual usage area of VR lens in the display and the display AA area. The coverage rate of human visual is 49.7%, and the utilization rate of display is 84.1%. At this time, the horizontal dimension of the lens is 47mm, and the vertical dimension is 50.5mm. Most products will choose this scheme with certain avoidance treatment on the nose side.

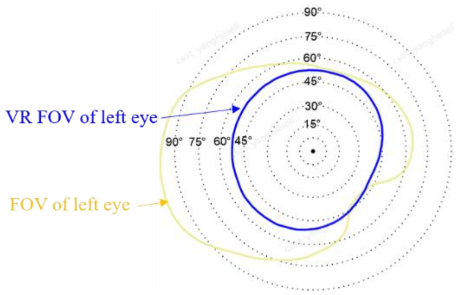

Figure 9(a). The other left VR lens and left eye's field of view

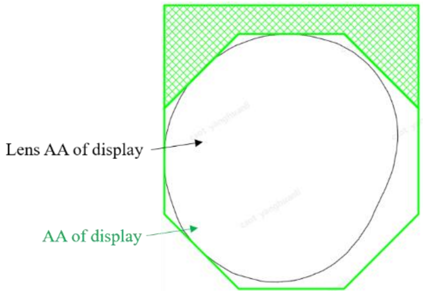

Figure 9(b). The actual usage area of VR lens in the display and the display AA area

In summary, the VR optical module with asymmetric FOV mentioned above has an approximately 14.2% increase in display utilization and a 10.5% increase in human visual field coverage compared to conventional designs. At the same time, compared to the same FOV, the volume and weight of VR optical module is reduced by approximately 14%.

4. Conclusion

In a asymmetric VR design of FOV , the lens is cut into corresponding irregular shapes to minimize lens size and maximize display utilization. It can achieve horizontal FOV ⩾ vertical FOV and horizontal temporal FOV ⩾ 60° for providing users with the best visual experience. Compared to conventional solutions, the utilization rate of the display has increased by about 14.2%, and the coverage rate of the human perspective has increased by about 10.5%.

5. References

[1] Yasutaka Maeda, Hayato Watanabe, Daiichi Koide, Hisayuki Sasaki, Takuya Handa, Kensuke Hisatomi, Jun Arai, "Wide field-of-view light-field head-mounted display for virtual reality applications", Optics Continuum, vol.3, no.4, pp.574, 2024.

[2] Bang K , Jo Y , Chae M ,et al.Lenslet VR: Thin, Flat and Wide-FOV Virtual Reality Display Using Fresnel Lens and Lenslet Array[J].IEEE Transactions on Visualization and Computer Graphics, 2021, PP(99):1-1.DOI:10.1109/TVCG.2021.3067758.

[3] Zhan T , Yin K , Xiong J ,et al.Augmented Reality and Virtual Reality Displays: Perspectives and Challenges[J].iScience, 2020, 23(8):101397.DOI:10.1016/j.isci.2020.101397.

[4] Tsurutani K , Naruse K , Oshima K ,et al.65‐2: Optical Attachment to Measure Both Eye‐Box/FOV Characteristics for AR/VR Eyewear Displays[J].Sid Symposium Digest of Technical Papers, 2017, 48(1):954-957.DOI:10.1002/sdtp.11805.

[5] Sauer Y , Sipatchin A , Wahl S ,et al.Assessment of consumer VR-headsets' objective and subjective field of view (FoV) and its feasibility for visual field testing[J].Virtual Reality, 2022.DOI:10.1007/s10055-021-00619-x.

[6] Li Y , Cheng D , Shi X ,et al.Optical design of a wide-angle pinhole lens for VR and AR inspection[J]. 2022.DOI:10.1117/12.2641854.

[7] Liu P , Lee T , Luo C ,et al.Volume holographic grating for wavelength multiplexed field-of-view expansion[J]. 2022.DOI:10.1117/12.2615083.

[8] Marougkas A , Troussas C , Krouska A ,et al.Virtual Reality in Education: Reviewing Different Technological Approaches and Their Implementations[J].Springer, Cham, 2023.DOI:10.1007/978-3-031-17601-2_8.

[9] Shiraga S .Advanced technologies for large FOV waveguide and compact projector[J].SPIE AR, VR, MR Industry Talks 2022, 2022.DOI:10.1117/12.2632530.

[10]Measurement and Standardization of Field of View in See-through Near-Eye Display[J]. 2023.