Enhancing Panoramic Experience in Head-Mounted Displays: Multiple Optical Systems and Real-Time Display Technology

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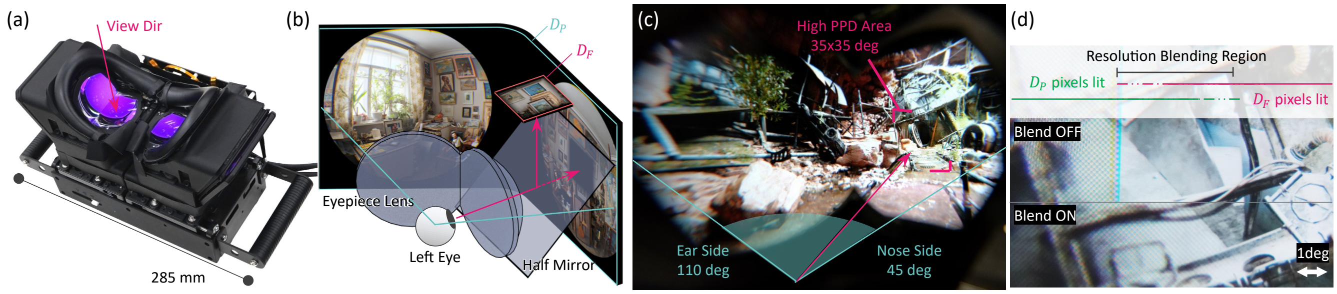

Figure 1: System schematic: (a) overall diagram of the developed headset. (b) Schematic representation of the left eye optical system. (c) Actual image captured from the left eye perspective through a wide-angle lens. (d) Close-up of blending region. Adjustments in properties such as resolution and brightness are continuously managed to minimize the visibility of boundaries.

ABSTRACT

In this study, we developed a head-mounted display (HMD) system featuring multiple displays and lenses, combined with software for calibration and real-time image correction. This HMD achieves an expansive horizontal viewing angle of 220° for both eyes and a high resolution of up to 110 pixels per degree. To utilize this enhanced viewing angle and resolution, we created an approximately 32K ultra-high resolution spherical video player and runtime software for game engines. This paper details the hardware configuration and calibration procedures and introduces a preliminary user questionnaire to assess the system performance and user experience.

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1 INTRODUCTION

The standard specifications for commercially available head-mounted displays (HMDs) typically feature a horizontal viewing angle of approximately 110° per eye and resolution of 20 pixels per degree (ppd) [Musil 2024]. When using a single conventional lens for one display, an inherent trade-off exists between viewing angle and resolution, although advancements in display technology may incrementally improve resolution. Overcoming this limitation is necessary to meet the characteristics of the human field of view and resolution and to achieve a compelling virtual reality experience.

Hypervision [Hypervision 2024] achieved a wide viewing angle by connecting two optical systems per eye, while [Ratcliff et al. 2020] and [Rakkolainen et al. 2017] achieved similar results using curved lenses and lens arrays. Varjo Technologies focused on attaining high definition by employing multiple displays for a single lens [Varjo Technologies 2024]. However, these systems have been designed to prioritize either wide viewing angles or high resolution, and from our knowledge, there have not yet been attempts to combine both features.

In this study, we developed an HMD that integrates multiple displays to achieve both high definition and wide viewing angles, supported by advanced optical design, calibration, and correction technologies. This HMD offers a horizontal viewing angle of approximately 220° for both eyes and maximum resolution of approximately 110 ppd. Additionally, we have developed software and content that utilizes these capabilities, enabling real-time display and image correction.

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2 SYSTEM

Our system employs a configuration that integrates three virtual images, two lenses, and two displays per eye (Figure 1(a) and (b)). The components are detailed as follows:

2.1 Hardware Configuration

We combined two lenses, each with a field of view (FOV) of approximately 100° , angled at 60° , to create an eyepiece that covered a 155° viewing angle per eye (Figure 1(b)). To ensure the pupil fit within the eye box of the lenses, the system was equipped with an inter-pupillary distance (IPD) adjustment mechanism ranging from 59–72 mm.

The display features a flexible OLED (6.7", 2400×1080) bent perpendicularly to the optical axis of the two lenses (Figure 1(b), D_P), displaying images for the two virtual images (front and side) on the same screen. This setup enabled a vertical FOV of 100° and horizontal FOV of 155° (Figure 1(c)), presenting at approximately 10 ppd through the lenses. Additionally, a half-mirror was positioned on the optical axis of the front lens and D_P, and a micro OLED (1.3", 3456×3840) (Figure 1(b), D_F) was superimposed optically with D_P. This arrangement achieved a high definition of 110 ppd for the central 35° horizontal and vertical area covered by D_F, displaying the third virtual image for central vision. These methods optimize the balance between the characteristics of human vision and the constraints of available hardware and software resources.

The four displays for both eyes operated at a maximum of 120 Hz. For tracking, two global shutter sensors and one inertial measurement unit for six degrees of freedom tracking were incorporated.

2.2 Calibration

To visually blend images from multiple lenses and displays into a seamless single screen, both physical and electronic corrections are essential.

First, the virtual image distances of D_P and D_F were equal. Because electronic correction is not viable for this step, mechanical alignment was adjusted using motion parallax to a precision of 0.1 mm. Additionally, discrepancies in the required image positions for the front and side views on D_P, caused by misalignment of the optical axes of the attached lenses, were addressed. The superimposition position of D_P and D_F also varied depending on assembly. These positional offsets were measured by placing a camera at the pupil position.

Differences in display characteristics between D_P and D_F, as well as the brightness variations due to the presence or absence of a half-mirror, necessitated further corrections. A color calibrator placed at the pupil position measured the appropriate color space and gamma curve for each view, ensuring consistent brightness and color perception.

2.3 Display Software

We developed software that managed display position offsets, color conversions, and additional procedures. This software uses six buffers for virtual images: two low-resolution buffers per eye for D_P and one high-resolution buffer per eye for D_F. The software performs color conversion, adjusts the display position, applies lens distortion correction, and then renders the image on each display. This process enables the user to perceive the composite virtual images as a seamless single image (Figure 1(c)).

Moreover, the area on D_P that overlaps with D_F is masked in black, and a transition zone is established to gradually modify the brightness levels of D_F and D_P (Figure 1(d)). Owing to the significant resolution disparity at the visual boundaries between displays, we incorporated a mip bias into the texture sampling of D_F within the transition area. This adjustment enabled the sampling resolution to decrease progressively toward that of D_P, effectively reducing the visibility of the seams between displays.

These corrections were performed at a frequency of 120 Hz, aligning with the refresh rate of the display.

3 EVALUATION

3.1 Applications

Two types of software stacks were developed to utilize the wide viewing angles and high definition capabilities of the system for practical content viewing.

The first software stack is a proprietary DirectX 12 application that utilizes the aforementioned display software. An example implementation is a spherical video player capable of playing back sequential still images at approximately 32K resolution (30,720×15,360 pixels) at a speed of 60 fps. This corresponds to a resolution of approximately 85 ppd.

The second software stack integrates the display software into its own runtime and provides an API compliant with OpenXR™ 1.0. We have confirmed that it is possible to render with a horizontal field of view of at least 220° and a center resolution of at least 110 ppd without customizing Unreal Engine 5.

These software stacks have the capability for IPD configuration. The inside-out tracking, rendering, and display software operate in real time on a PC equipped with an Intel Core i9-13900KF processor, NVIDIA GeForce RTX 4090 graphics card, and 32 GB of RAM.

These software stacks provide versatile environments for both video playback and real-time rendering, ensuring compatibility with advanced graphics standards and game engines.

3.2 User Study

In our demonstration, we planned to conduct a video experience using the two types of software mentioned above. Additionally, we privately invited approximately 1,500 individuals (average IPD: 62.0 mm, SD = 2.91 mm) to experience the HMD we developed, followed by a simple questionnaire survey. Some participants noted that the boundary between D_P and D_F was distinguishable, and some commented that the field of view occupied by D_F was narrow. However, there were no reports of distortions or significant video failures. Many participants provided positive feedback, highlighting that the combination of wide-field, high-definition hardware and performance-optimized content delivered in real-time offered an unprecedented sense of immersion. We are currently making improvements based on these comments and are considering head-mounted attachment options. One of the limitations of our system is that vision correction without contact lenses is difficult because the lenses are located close to the temples. Further user evaluations are necessary to understand how the wide FOV and high definition affect the overall experience with virtual-reality HMDs.

REFERENCES

Hypervision. 2024. VRDom architecture for complete human FoV in VR. https://www.hypervision.ai/copy-of-vrdom-architecture.

Richard Musil. 2024. HMD Geometry Database | Collected geometry data from some commercially available VR headsets. https://risa2000.github.io/hmdgdb/.

Ismo Rakkolainen, Roope Raisamo, Matthew Turk, Tobias Hollerer, and Karri Palovuori. 2017. Extreme field-of-view for head-mounted displays. In *2017 3DTV Conference: The True Vision - Capture, Transmission and Display of 3D Video (3DTV-CON)*. IEEE, Copenhagen, 1–4. https://doi.org/10.1109/3DTV.2017.8280417

Joshua Ratcliff, Alexey Supikov, Santiago Alfaro, and Ronald Azuma. 2020. ThinVR: VR displays with wide FOV in a compact form factor. In *ACM SIGGRAPH 2020 Emerging Technologies*. ACM, Virtual Event USA, 1–2. https://doi.org/10.1145/3388534.3407302

Varjo Technologies. 2024. Human eye resolution, Bionic Display (TM) for XR-3 and VR-3. https://developer.varjo.com/docs/get-started/human-eye-resolution.