A Nonobscuring Eye Tracking Solution for Wide Field-of-View Head-mounted Displays

Michael Stengel, Steve Grogorick, Lorenz Rogge, Marcus Magnor

Institut für Computergraphik, TU Braunschweig, Germany

Figure 1: Visualizations of our HMD concept containing an integrated binocular eye tracking device.

Abstract

We present a solution for integrating a binocular eye tracker into current state-of-the-art lens-based head-mounted displays (HMDs) without affecting the available field-of-view on the display. Estimating the relative eye gaze of the user opens the door for HMDs to a much wider spectrum of virtual reality applications and games. Further, we present a concept of a low-cost head-mounted display with eye tracking and discuss applications which strongly depend on or benefit from gaze estimation.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual reality C.3 [Computer Graphics]: Special-Purpose and Application-based Systems—Real-time and embedded systems

Virtual Reality (VR) using low-cost hardware is a domain consumers have long been waiting for. Within the last two years a hype around VR has been gradually provoked in gaming industry. Advances in mobile hardware allowed manufacturers to create new head-mounted display prototypes (e.g. *Oculus Rift, Valve HMD, Sony PS4 HMD*), which are by their wider field-of-view very effective for VR and more comfortable and affordable for private customers compared to previous models. Although these HMDs are designed for VR they lack of an integrated and adeqate solution for gaze estimation. With our work we want to motivate using eye tracking to

1. extend the applicability of HMDs in a large variety of use cases for researchers and customers
2. increase immersion and presence in virtual worlds
3. integrate natural interaction in VR software.

We aim for a comfortable, drift-free eye tracking solution, which is usable within the limited space of current HMD hardware designs without field-of-view (FOV) reduction. We describe our HMD (Fig. 1) and the integrated eye tracker technically in Sec. 1 and discuss applications in Sec. 2.

1. Technical Description

HMD Assembly. The body of the HMD is comparable to consumer-grade lens-based HMDs.It contains two biconvex convergence lenses and a screen allowing a wide vertical field-of-view of about 90° which is necessary for a convincing feeling of immersion. All basic parts of the body can be printed using a 3d printer at low costs. The screen can either be a smartphone or a self-contained display panel. For

DOI: 10.2312/egp.20141063

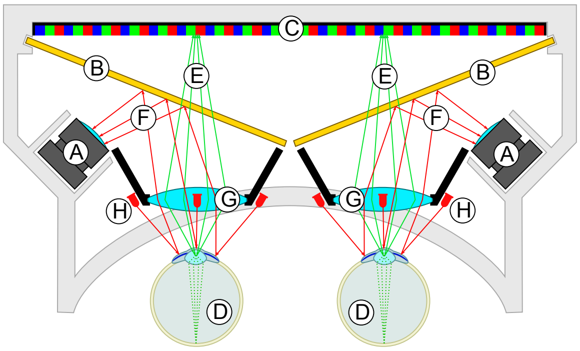

Figure 2: Assembly: eye tracking cameras (A), dichroic mirrors (B), screen (C), human eyes (D), visible light (E), infrared light (F), converging lenses (G), LED arrays (H)

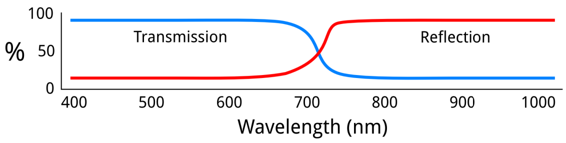

Figure 3: Dichroic mirror: Visible light for the user (blue) is transmitted, while infrared light (red) is reflected which is only visible for the eye tracking camera.

binocular eye tracking the body is extended by a tracking unit for each eye. Each unit consists of a dichroic mirror (hot mirror), a low-latency tracking camera and a circular illumination system for the iris area using infrared light (Fig. 2).

Eye Tracker. As the user must not be distracted by the eye tracking system, it must be invisible to the user. Therefore, we exploit the property of a dichroic mirror to seperate the visible light for the user from the infrared light used for eye tracking. The surface of such a mirror transmits the visible spectrum of light and reflects in the infrared part (Fig. 3). The infrared light is generated by LEDs, reflected on the surface of the eye, then reflected on the mirror and finally received by the eye tracking camera sensor (Fig. 2, red lines). The user only perceives the visible light generated by the display and transmitted through the mirror and the lens to the eye (Fig. 2, green lines).

For accurate and robust gaze estimation we adapt the STARBURST feature tracking algorithm [BJ11]. In Fig. 4 frames of the eye tracking camera are shown for a first non-optimized version of the illumination setup. The eye tracking cameras work at a resolution of 640×480 pixels with 75 frames per second. The weight overhead caused by the eye tracker is about 126 g in the current prototype (both mirrors 100 g, cameras 20 g, illumination 6 g), which is appropriate for preserving wearing comfort. However, the weight of the system could be reduced by using thinner but more fragile mirrors. Our array of five infrared LEDs in the current setup

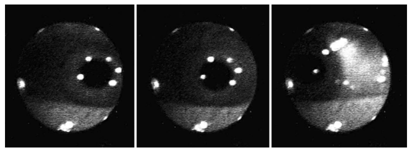

Figure 4: Recorded eye illuminated by 5 infrared LEDs.

for each eye fullfills recently recommended irradiance limits to guarantee a safe long-term usage [MVS*08].

2. Applications

Providing eye tracking data in games and other virtual reality (VR) and augmented reality (AR) software enables new use cases and may largely improve existing applications.
Interpupillary distance (IPC) is a person-dependend value. An accurate estimation is important to enable a correct perception of the virtual world and to avoid motion sickness. Our binocular head-mounted eye tracker could remove or automate the intricate task of calibration.
Gaze-directed rendering is a novel application field in computer graphics and requires knowledge about the current foveal region in real-time. Our solution would allow for realistic depth-of-field rendering, adaptive rendering quality, HDR effects, glare and blooming effects. Knowing the pupil diameter may improve the accuracy of the latter.
Enhanced immersion and presence in virtual worlds are possible since the personality of virtual avatars can be represented much stronger in case their eyes move naturally.
Other fields of application could benefit of an integrated eye tracker as well, for example cognitive applications, assistive technologies, user studies or medical uses.

3. Conclusion

We presented a novel idea for integrating dichroic mirrors into HMDs to create a low-cost eye tracking solution which facilitates a rich variety of applications. The next steps of our project are to improve the lighting of the eye by a different layout of the circular LED array and to conduct first tests of the eye tracker in the 3d printed HMD prototype with respect to robustness and accuracy of gaze estimation. We are convinced that the described applications in Sec. 2 just scratch the surface of possible applications and use cases enabled by accurate eye tracking in HMDs.

References

[BJ11] Bazanov P., Järvenpää T.: Gaze estimation for near-eye display based on fusion of starburst algorithm and fern natural features. *Proceedings of the 10th Conference of Open Innovations Association FRUCT* (2011), 16–23. 2

[MVS*08] Mulvey F., Villanueva A., Sliney D., Lange R., Cotmore S., Donegan M.: D5. 4 exploration of safety issues in eyetracking. *Communication by Gaze Interaction (COGAIN)* (2008). 2