Non-Obscuring Binocular Eye Tracking for Wide Field-of-View Head-mounted-Displays

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Abstract

We present a complete hardware and software solution for integrating binocular eye tracking into current state-of-the-art lens-based Head-mounted Displays (HMDs) without affecting the user's wide field-of-view off the display. The system uses robust and efficient new algorithms for calibration and pupil tracking and allows real-time eye tracking and gaze estimation. Estimating the relative gaze direction of the user opens the door to a much wider spectrum of virtual reality applications and games when using HMDs. We show a 3d-printed prototype of a low-cost HMD with eye tracking that is simple to fabricate and discuss a variety of VR applications utilizing gaze estimation.

1 Introduction

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.

In our demo we show our novel drift-free, low-cost, low-weight eye tracking solution, which is usable within the limited space of current HMD hardware designs without field-of-view reduction for immersive VR applications.

2 Technical Description

Our HMD is modular and each component can be easily replaced, therefore, providing a very flexible trade-off with regard to costs, input and output quality, physical dimension and weight.

General Our setup resembles a classic HMD including converging lenses to focus the view on the display. The important difference to a standard HMD lies in the inclusion of infrared cameras hidden from the user's view at the outer boundary of the body case. For each eye, a circular array of infrared LED lights along the adjustable lense holders provides the required illumination. The reflected light passes the converging lens and gets reflected towards the camera using a tilted hot mirror while light from the display passes unhindered towards the lenses and the eye. Markers at the outside of the body case provide information for a practical positional tracking using an additional external camera. Orientation is measured by an integrated Inertial Measurement Unit. The wiring for all the electronic components are combined within a single cable connected to an external box containing the display controller, an Arduino for orientation tracking and an adjustable power supply for the illumination units.

Converging Lenses Converging lenses increase the perceived Field-of-View by distributing the display information over a wider angle into the eye. With the lenses used in our prototype the HMD offers a horizontal Field-of-View of 86°. We provide dedicated controllers to adjust the position of the lenses in three dimensions, being horizontal and vertical direction and lense-to-screen distance for optimal lens placement. This is important to avoid motion sicknes and especially important for precise eye tracking, while for traditional HMD a coarse adjustment is sufficient.

Infrared Illumination Array To avoid distraction of the user we opted for infrared light outside the visible spectrum to illuminate the eye. This can be captured by our eye tracking cameras and allows us to use the hot mirrors described earlier. Additionally, the illumination units result in visible glints on the user's eyes that are used for our simplified user calibration.

Eye Tracking Algorithm We developed a novel pupil tracking algorithm which is optimized for our eye-tracking scenario. Additionally, we created a model for system calibration and world-to-screen mapping of the pupil position using a simulation of the physical properties of the converging lenses.

User Calibration User calibration can be a tedious task for many eye tracking solutions. Our calibration is derived automatically from a precalibration of the HMD and automatic estimation of the adjusted lense position. The position of the eye is the only free calibration parameter, which we derive from a specific gaze direction based on the reflected glints of the LEDs.

3 Applications and Benefits

Providing eye tracking data in games and other virtual reality (VR) software enables new use cases and improves several existing applications.

Gaze-directed rendering is a novel application field in computer graphics and requires knowledge about the current foveal region in real-time. We implemented demo applications for realistic depth-of-field rendering and adaptive rendering quality.

Enhanced immersion and presence in conversations with virtual avatars becomes available due to natural eye movement. In our demo we show a mapping of the gaze and head movements of a user onto a virtual avatar.

Interpupillary distance (IPC) is a person-dependent value. Accurate estimation is important to enable a correct perception of the virtual world and to avoid motion sickness. Our binocular head-mounted eye tracker simplifies the intricate task of calibration.

Other fields of application could benefit from an integrated eye tracker as well, for example cognitive applications, assisting technologies, user studies or medical uses.

4 Conclusion

We have presented a novel design for integrating eye-tracking into HMDs which facilitates a rich variety of applications. The next steps of our project are to improve the tracking performance and to create new gaze-based VR applications. We are convinced that the applications described in Sec. 3 just scratch the surface of possible applications and use cases enabled by accurate eye tracking in HMDs.