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D5 REALTER-X

A feasibility study for a gaze-contingent binocular rendering of altered reality in XR mode

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Table of Contents

Executive summary

REALTER (IO5) system was originally conceived as a virtual reality (VR) simulator for learning by experience visual disabilities. Hence, it had been a device for simulating in VR environment, in real time, visual impairment in low vision conditions, to be used as a training tool for operators specialized in the rehabilitation of partially sighted subjects.

The description of the system, its components and functionality are reported in **DK10 Designers' KIT "REALTER".**

At the time of drafting the project proposal, we had prudently indicated an "extended reality (XR)" version (REALTER-X solution) only as a feasibility study, since commercial headsets with an integrated eye-tracker and external binocular cameras for the "pass-through" mode were not yet so perfected. Though, actually the sudden technological progress has enabled us to adopt gaze-contingent XR functionalities *already* in the REALTER-1.0 system, by adapting a commercial system (HTC - Vive Pro Eye) for our purposes.

Therefore, here we present an analysis of the limitations of the current XR solution by examining in depth the indeterminateness related to proprietary design solutions, and by advancing (1) possible solutions to retrieve geometrical parameters necessary to improve rendering, and (2) a calibration refinement procedure to cope with intrinsic inaccuracies of the integrated eye-tracking system.

Figure 1: The REALTER system.

Ex-post functional assessment

In recent years, the development of head-mounted displays (HMDs) has created opportunities to conduct vision studies in virtual and augmented reality [1]. Among them, the HTC VIVE Pro Eye with its embedded eye tracker [2] stands out as a valuable tool for simulating low-vision conditions of different kinds and with different degrees of progression of the pathology. Specifically, the VIVE Pro Eye has been proved effective in providing a realistic experience of vision impairments, including conditions such as cataracts, glaucoma, and colour-blindness. Additionally, its ability of measuring user's gaze and of performing eye tracking offer valuable insights into the impact of vision disorders on daily life. Overall, by providing a safe and controlled environment, the REALTER system, based on VIVE Pro Eye can be used to study how vision disorders affect a person's ability to interact with their environment and understand the implications of these impairments on their overall quality of life.

Main issues

The REALTER system based on HTC VIVE Pro Eye is not without its drawbacks. Despite its useful capabilities, the device has two main issues that require attention: (1) the accuracy of the gaze position measures and (2) the impossibility of a direct setting of the real-world position of the user's eyes. The accuracy of the eye-tracking feature may be not optimal, leading to inaccuracies in the measured gaze position with respect to the actual position (resulting in an offset error). Additionally, the device does not consider the information available from the eye tracker when rendering the images, instead relying on fixed eye positions that are built-in the plug-in software provided with the device. This can lead to inaccuracies in the rendered images, as well as discomfort for the user.

From a user’s perspective, the inaccuracies of the HTC VIVE Pro Eye might have a significant impact on the realism of simulations of vision pathologies. The device's fixed setting of eyes positions can indeed lead to errors in the rendered images. Moreover, the inaccuracies of the embedded eye tracking can lead to erroneous gaze-contingent effects of vision impairments, i.e. to an inconsistency between the real position of the gaze and the position of the simulated pathology, which eventually lead to an altered experience of the discomfort associated with low-vision impairments.

Considering these two main problems we conducted a set of experiments in order to (1) estimate the actual eye positions and (2) to assess the accuracy of the HTC VIVE Pro Eye eye-tracking feature and its ability to accurately capture the user's gaze, with the final aim of mitigating these problems.

Estimate of the actual eye positions

We set up a virtual reality environment using the Unity engine and asked the subjects to look at visual targets, located at different eccentricities and directions with respect to the straight-ahead direction. We then used the eye-tracking feature of the device to measure the subject's gaze position twice within 10 different subjects. For each measurement, we used the eye-tracking data to calculate the positions of the left and right eye by intersecting the gaze lines (i.e., the gaze vector provided by the eye tracker) backwards. The LMS intersection of those lines is takes as the estimate of the eye’s positions (See Fig. 2).

This allowed us to calculate for each subject the 3D position of the eyes with respect to the system’s eye tracking origin (see Fig. 2 (Right)). The boxplots in Fig. 3 (Left) show the overall mean and standard deviation across all subjects.

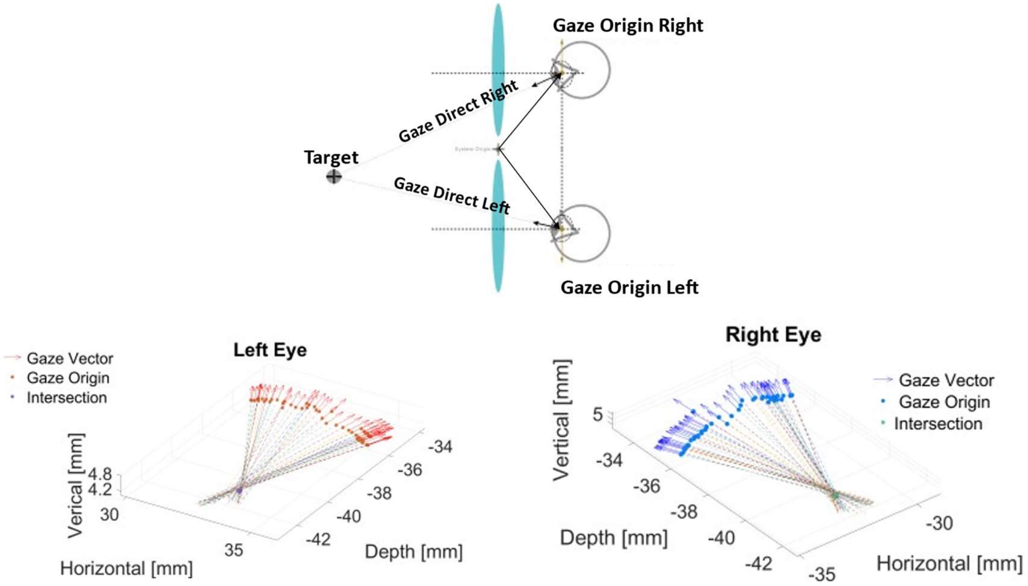


Figure 2 (Top) Geometric description of HTC Vive Pro Eye Tracker System, adapted from [4]. (Bottom) Results of the measure system with gaze origin and gaze directions (vectors).

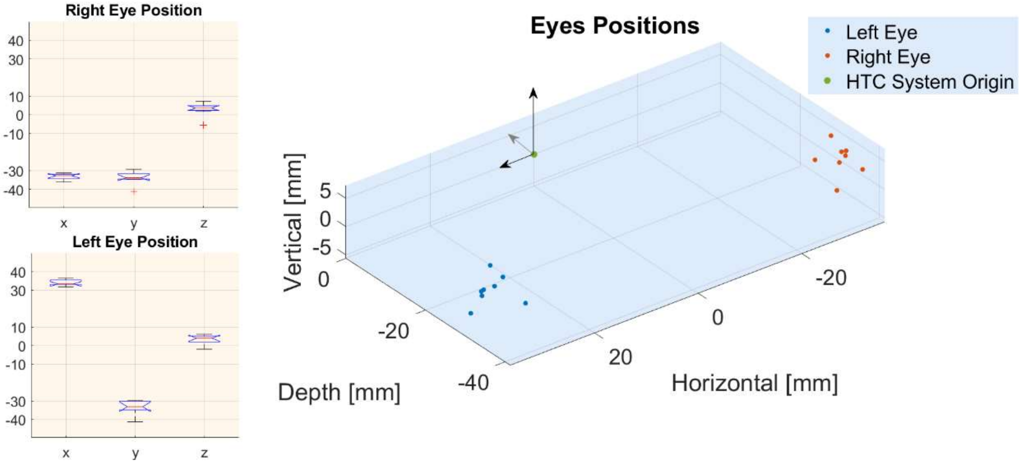


Figure 3 (Right) A 3D plot of estimated eye positions of all subjects. (Left) The mean and variance of the estimated eye positions for each eye across all subjects.

These results (summarized in Table 1) can be exploited to replace the built-in eye positions with more realistic ones, thus giving the opportunity to design a more realistic experience of a visual pathology.

Mean - Variance	**Left Eye**	**Right Eye**
μ_x [mm]	33.4105	-32.8639
μ_y [mm]	2.6168	2.3737
μ_z [mm]	-32.7024	-33.1680
σ_x [mm^2]	3.7231	2.6888
σ_y [mm^2]	7.3461	13.1488
σ_z [mm^2]	16.3819	13.1562

Table 1 Mean and variance values (across all subjects) estimated for each eye.

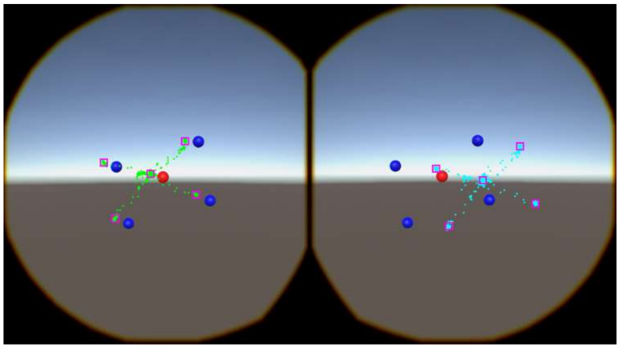
Compensation of eye tracking offset errors

We conducted a second experiment to assess the accuracy of the HTC VIVE Pro Eye eye-tracking feature. We set up a virtual reality environment using the Unity engine and asked the subjects to look at five different visual targets. Targets are displayed at at different degrees of eccentricity in order to obtain different fixation points. We then used the eye-tracking feature of the device to get the subject's gaze position and we extract from the device the images of the two displays.

Even though the device is able to capture the user's gaze, results show that the eye-tracking data are not perfectly aligned with the visual targets and turn up to have a measure offset (see Fig. 4 (Left)). To address this issue, we used the Kabsch co-registration algorithm [3] to calculate a roto-translation matrix that would move the data points to the desired position.

The results (see Fig. 4 (Right)) show that the algorithm can be successfully used to mitigate the offset measure problem. Accordingly, a corrective calibration function has been integrated in the REALTER gaze-contingent rendering pipeline in order to compensate the eye-tracking offset measurements and accurately display the simulated visual alteration in the correct position.

Before corrective calibration



After corrective calibration

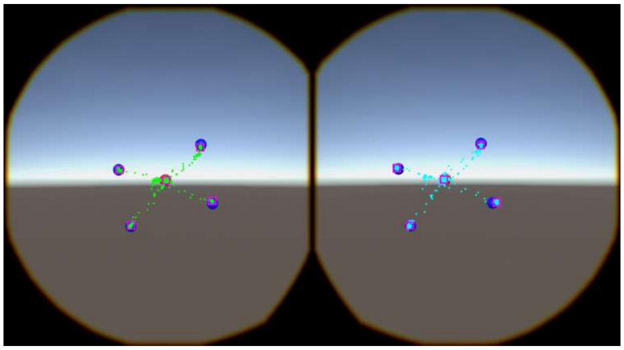


Figure 4 Results of the calibration procedure for one subject. Green dots represent subject’s saccades to the targets (blue spheres). Magenta squares represent the fixation points estimated from the eye tracker data. (Top) Raw data of gaze positions before calibration. (Bottom) Corrected gaze positions after calibration.

References

[1] Feng Zhou, H. B. -L. Duh and M. Billinghurst, Trends in augmented reality tracking, interaction and display: *A review of ten years of ISMAR, 2008 7th IEEE/ACM International Symposium on Mixed and Augmented Reality*, Cambridge, 2008, pp. 193-202, doi: 10.1109/ISMAR.2008.4637362.

[2] Sipatchin A, Wahl S, Rifai K. Eye-Tracking for Clinical Ophthalmology with Virtual Reality (VR): A Case Study of the HTC Vive Pro Eye's Usability. Healthcare (Basel). 2021 Feb 9;9(2):180. doi: 10.3390/healthcare9020180. PMID: 33572072; PMCID: PMC7914806.

[3] Kabsch W. A solution for the best rotation to relate two sets of vectors. *Acta Cryst A* 1976; 32:9223.

[4] Image retrieved from HTC Vive website: https://www.vive.com/us/vive-pro-eye/.