Virtual Reality-based Eye Gaze Calibration for Early Diagnosis of Neurological Disorders

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NeurOpthalmoscope (NEOS) is a virtual reality-based system *aiming to provide fully automated eye examination to support early diagnosis and monitoring of neurological disorders, such as brain tumors and multiple sclerosis. CSEM has developed a specialized eye gaze calibration algorithm for accurate gaze tracking (< 2° accuracy), which holds utmost importance for ensuring reliable and effective diagnosis in clinical settings, especially in patients without perfect binocular vision.*

In the context of eye gaze tracking applications, a personal calibration step is needed to achieve a reliable and accurate eye gaze estimation by effectively accommodating the inherent anatomical disparities observed in patients' eyes. This is done by calculating the offset between the optical axis, which passes through the corneal and pupil centers, and the visual axis, which is directed towards where the person is actually looking at. The foveal offset and other invisible personal variations such as size of the sclera, the curvature of the cornea and the position of pupil inside the eye make the personal calibration necessary for an accurate tracking. In the Innsouisse project NEOS, along with our partner machineMD, we aimed at applying this calibration technology to improve the diagnosis and monitoring of neurological disorders. The primary objective of the work was to develop a set of algorithms tailored to enhance the accuracy and reliability of the eye tracking information provided by a head-mounted display (HMD) device for extracting medical features.

The study started with a data collection campaign involving a total of 25 subjects. While 21 subjects had a visual acuity within ±2 diopters of nominal sight, 4 subjects were out of this range, requiring a compensation with refractive correction lenses placed in the HMD. To develop and compare our method with the HMD's optional default calibration approach, we conducted two separate sessions: one without (any) calibration for capturing raw eye gaze data and the other with (only) HMD's default 5-point calibration. Both sessions involved viewing an 11x11 calibration grid in a 20° horizontal and vertical Field of View (FoV).

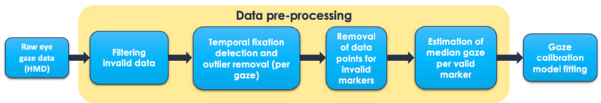

Figure 1: Eye gaze calibration algorithm pipeline.

To ensure high-quality input data for the gaze calibration algorithm, we performed various pre-processing steps as shown in Figure 1. Initially, we extracted stationary stimulus marker fixation data, discarding transitional and blink-related sections and filtering out invalid points flagged by the HMD. To remove outliers caused by saccadic eye movements, we developed a novel RANSAC-based algorithm that can robustly filter out user-or session-specific temporal saccadic data sections (patent filed). We also detect and remove the gaze data for markers that a patient fails to look at. These steps collectively enhanced the eye gaze calibration quality, addressing challenges linked to blink events, saccades and incorrect gazing. The preprocessed data is used to find the parameters of an eye gaze calibration model (polynomial or homography-based) that can estimate the ground-truth marker locations from the raw eye gaze coordinates provided by the HMD. Figure 2 shows that using the homography model, 9-point calibration performs equally well or better than the 13-point calibration in the central region (i.e., for the FoV of ±5°, ±10°, ±15°). However, on the periphery of the FoV (i.e., ±20°), 13-point calibration shows a marginal improvement over 9-point.

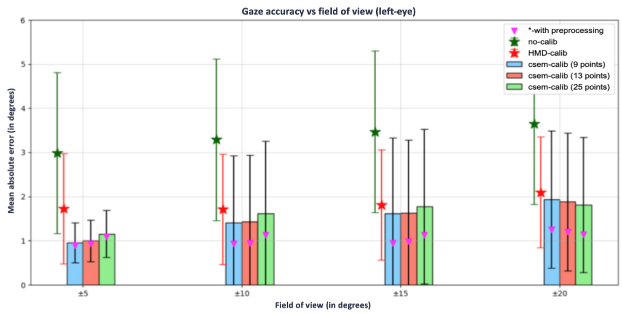

Figure 2: Comparison of eye gaze accuracy (mean absolute error) of homography-based gaze calibration model, trained on 9, 13, and 25 calibration points (blue, red, and green bars respectively), using different FoVs for validation markers.

The homography-based 13-point calibration method improved eye gaze accuracy by 52.4% compared to using raw eye gaze data and by 16.2% compared to using the default calibration of the HMD in the FoV of ±20°. Similarly, the 13-point polynomial calibration method leads to a 51.5% improvement in the eye gaze accuracy compared to using raw eye gaze data and a 14.8% improvement compared to using the HMD's default calibration in the same FoV. As shown in Figure 3, our approach significantly reduces the angular error between the calibrated eye gaze and the ground-truth stimulus markers.

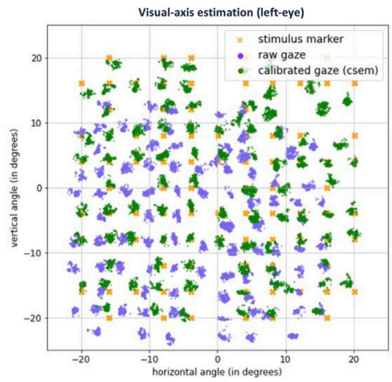

Figure 3: Calibration results for the left eye of a participant in the 2D angular space using the homography-based calibration model.

Based on this analysis, we opted for a 13-point calibration procedure using the homography-based model. On a single i9 processor core, while model fitting takes around 30 msec, inference on a raw gaze input takes less than 100 µsec, enabling real-time performance on the HMD operating at 200 Hz. Our system significantly augments the eye gaze tracking capabilities of the commercial HMD device while aligning it with the specifications of a medical diagnostic instrument. This robust and highly efficient eye gaze calibration process can be seamlessly integrated across various applications in the VR and augmented reality landscape.