Accuracy of a Low-Cost 3D-printed Head-Mounted Eye Tracker

removed for blind review

Abstract

This contribution presents a mobile modular low-cost open source 3D printed eye tracking prototype, equipped with two off-the-shelf webcams. We compared the accuracy with two state-of-the-art commercial remote eye trackers. In order to verify the benefit of head stabilization, the devices have been tested with and without a chin rest. Experiments have been conducted to determine the feasibility of an open source system and the field of application for this kind of eye tracking device in the low-cost price segment. This opens new use cases and possibilities for indoor and outdoor usability studies and offers new opportunities to apply eye tracking on mobile devices.

1 Introduction

Eye tracking is one of the most applied measuring techniques in usability studies and visually administered experiments. It is used in human-computer interaction, cognitive sciences, market research and psychological analytics. A commercial eye tracking system is very expensive and easily costs more than $20.000. For many applications, this is a disproportionate effort. Low-cost eye tracking devices can be a viable alternative for gaze movement recordings (Johansen et al. 2011). Existing low-cost eye tracking systems are the *openEyes* gaze tracker, presented 2005 by Li *et al.* (Li et al. 2006) and the open source system by Agustin *et al.* (Johansen et al. 2011, San Agustin 2009, San Agustin et al. 2009, 2010) in the year 2009 at the University of Copenhagen, where also the ITU Gaze Tracker (Hansen et al. n.d.) software was developed. 3D printing is an adaptive method to design stable and portable components which can be combined to meet the requirements of the respective study or application. A commercial 3D printed eye tracking system is the PUPIL-System by Kassner *et al.* (Kassner, Moritz Philipp; Patera 2012). Still unexplored is the accuracy of a low-cost eye tracking device in comparison to commercial systems. Consumer webcams have rarely a native zoom function and need to be placed very close to the eye. Therefore we developed and tested a new 3D printed open source head-mounted eye tracking system.

2 Evaluation

Four eye tracking systems were tested, two of them are remote eye trackers.

a) A monocular Logitech C310 HD webcam. Running with the free open source software ITU Gaze Tracker. Total system cost is $170.

b) A monocular Microsoft HD3000 webcam (Figure 1). Also running with the ITU Gaze Tracker. Total system cost is $160.

c) A demonstration device of a Tobii REX binocular remote eye tracker, 30 Hz. This device runs with Tobii Analytics SDK.

d) The binocular remote eye tracker SMI RED500, 60 Hz with a resolution of 752x480 pixels. System cost is $26.000.

The eye trackers a) and b) are running with 30 fps at a resolution of 1280x720 pixels. An array of 4 infrared LEDs in a) and 3 in b) illuminate the eye to determine the center of the pupil and corneal reflections. The LEDs are connected to the camera board and powered by USB. The camera and the LEDs are housed in a 3D printed shell. This is attached to a 3D printed spectacle frame with a 5 mm aluminum bar. Frame and camera shells were printed with a Dimension 1200 3D printer within 8.5 hours. A 5x7 mm sized, unified lightened photo negative was placed between the CCD and the lens to filter colored light.

Figure 1: *Prototype of a 3D printed open source gaze tracker*

3 Experiment

A total of 13 participants took part in this experiment. They were recruited randomly from our campus. Two of them have previous experiences with eye tracking. 4 participants wear glasses. For each participant, every device was calibrated according to their respective standard procedure. The eye trackers a) and b) use 12 calibration points, c) and d) use 9. During experiment the participants were presented with random visual stimuli. At each trial the subject had to look at different shapes and points. The horizontal, vertical and radial distances between gaze point on the display and the target were measured. The mouse cursor was hidden to avoid distractions. Trials with no fixations or invalid coordinates (out of the display) were dismissed. Since the performance of all visual eye tracking systems depends on the quality of the built-in image sensors, the relative length of all scan paths was measured to determine the quality of the sensors and their noise reduction capability. All tests were made with and without the chin rest.

4 Evaluation

The deviated gaze point distance in pixel was analyzed. In a first step the two webcams were compared. Without chin rest, there was no significant difference in pixel accuracy between the Microsoft HD3000 ($M = 103$, $SE = 14$) and the Logitech C310 ($M = 99$, $SE = 12$), conditions; $t(68) = 0.212$, $p = 0.833$. With chin rest there was also no significant difference between the HD3000 ($M = 56$, $SE = 43$) and the C310 ($M = 60$, $SE = 10$), conditions; $t(71) = 0.34$, $p = 0.735$. Using the HD3000, there is a significant difference between utilizing ($M = 56$, $SE = 7$), or not utilizing the chin rest ($M = 103$, $SE = 14$), conditions; $t(71) = 2.980$, $p = 0.004$. This significant difference also shows using the C310 with ($M = 60$, $SE = 10$) and without chin rest ($M = 99$, $SE = 12$), conditions $t(68) = 2.424$, $p = 0{,}018$. This shows the benefit of working with an apparatus for head stabilization, however the two commercial eye trackers show a significant lower deviation in all tests ($p < 0.05$).

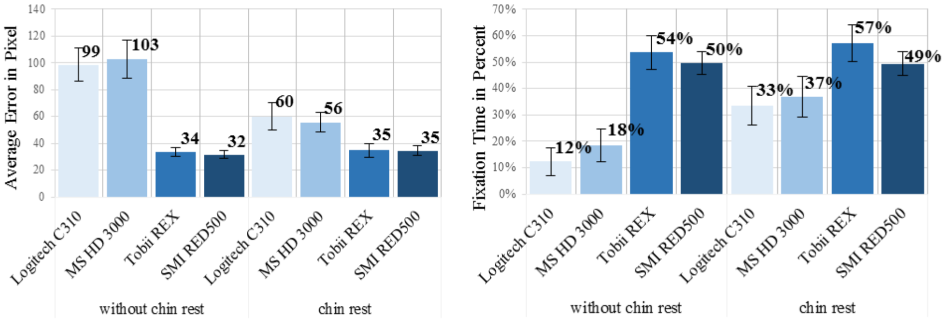

Figure 2: *(l) Horizontal, vertical and radial deviation. (r) Average Fixation Time (5 seconds = 100%) within 100 pixel sized AOIs - Error bars show standard error.*

Figure 2 (r) shows the accuracy of the eye tracker in comparison to different 100 pixel sized areas of interest (AOI). Every shape was shown for 500 ms (100%). The first fixation was dismissed. The gaze point on the screen is influenced by the noise of each image sensor. The measurement shows the duration of how long the gaze point dwells in a shape. A one-way ANOVA using all eye tracker dwell times measured with chin rest shows no significant effect between the four conditions $F(3, 100) = 2.443$, $p = 0.068$. The quality of the gaze data of the self-built solution is not significantly worse than the quality of the commercial eye trackers.

Usability experiments that need reliable statements of dwell times in AOI larger than 100 pixels can also use the head-mounted solution.

5 Discussion

The accuracy of the herein presented low-cost eye tracker do not attain the accuracy of commercial eye trackers. However, the herein presented technique to build a low-cost eye tracker is suitable for customized new user experiments and enables possibilities to customize an eye tracker for new domains and new kinds of user studies that haven't been possible before. For example, the system can easily combined with other head-mounted augmented reality systems such as Google Glass or Microsoft HoloLens. This would allow to conduct user studies on head-mounted AR displays. If an experiment requires a high temporal resolution, there is yet no way around a commercial solution. Therefore, in a further approach, the frame rate of the recording device should be improved. This could be achieved with high-speed or stereo cameras. A future version of the presented self-built eye tracker will be able to wirelessly transmit raw data to a base station. In a further step, the base station may be replaced with components integrated into the eye tracker itself for direct data storage or analysis, thus rendering the use of a laptop needless, which would have to be carried in a backpack. In addition, a camera with less noise may be incorporated, to further improve the accuracy of the system.

6 References

Hansen, J. P., Hansen, D. W., Johansen, S. A., Skovsgaard, H., San Agustin, J., & Tall, M. (n.d.). GazeGroup.org.

Johansen, S. A., Hansen, J. P., San Agustin, J., Tall, M., & Skovsgaard, H. (2011). Low Cost vs . High-End Eye Tracking for Usability Testing. In *CHI EA'11 Proceedings of the 2011 Annual Conference Extended Abstracts on Human Factors in Computing Systems*, p. 1177–1182.

Kassner, Moritz Philipp; Patera, W. R. (2012). *PUPIL: constructing the space of visual attention*. Massachusetts Institute of Technology.

Li, D., Babcock, J., & Parkhurst, D. J. (2006). openEyes : a low-cost head-mounted eye-tracking solution, *1* (March), p. 27–29.

San Agustin, J. (2009). Low-Cost Gaze Interaction : Ready to Deliver the Promises, p. 4453–4458.

San Agustin, J., Hansen, J. P., Hansen, D. W., & Skovsgaard, H. (2009). Low-cost gaze pointing and EMG clicking. In *Proceedings of the 27th International Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA '09*, p. 3247.

San Agustin, J., Skovsgaard, H., Mollenbach, E., Barret, M., Tall, M., Hansen, D. W., … Agustin, J. S. (2010). Evaluation of a low-cost open-source gaze tracker. In *Proceedings of the 2010 Symposium on Eye-Tracking Research & Applications - ETRA '10*, p. 77.