Impact of Alignment Point Distance Distribution on SPAAM Calibration of Optical See-Through Head-Mounted Displays

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Abstract

The use of Optical See-Through Head-Mounted Displays (OST-HMDs) for presenting Augmented Reality experiences has become more common, due to the increasing availability of lower cost head-worn device options. Despite this growth, commercially available OST hardware remains devoid of the integrated eye-tracking cameras necessary for automatically calibrating user-specific view parameters, leaving manual calibration methods as the most consistently viable option across display types. The Single Point Active Alignment Method (SPAAM) is currently the most-cited manual calibration technique, due to the relaxation of user constraints with respect to allowable motion during the calibration process. This work presents the first formal study directly investigating the effects that alignment point distribution imposes on SPAAM calibration accuracy and precision. A user experiment, employing a single expert user, is presented, in which SPAAM calibrations are performed under each of five conditions. Four of the conditions cross alignment distance (arm length, room scale) with user pose (sitting, standing). The fifth condition is a control condition, in which the user is replaced with a rigidly mounted camera; the control condition removes the effect of noise from uncontrollable postural sway. The final experimental results show no significant impact on calibration due to user pose (sitting, standing). The control condition also did not differ from the user produced calibration results, suggesting that posture sway was not a significant factor. However, both the user and control conditions show significant improvement using arm's length alignment points over room scale alignments, with an order of magnitude difference in eye location estimate error between conditions.

Index Terms: Augmented reality—Optical see-through head-mounted display—Single point active alignment method (SPAAM)

1 Introduction

An important aspect of calibrating AR OST HMDs is the distribution of alignment points. This distribution, and by association, the amount of user movement required between each correspondence pair, can be typically categorized as either *user-centric* or *environment-centric*. A user-centric alignment distribution uses 3D points that fall within arms' reach, or the near visual field of the user. In contrast, environment-centric calibration uses points distributed over several meters, or the medium visual field of the user. Although they require more effort, environment-centric distributions have greater variance in position and coverage of the tracking space, which potentially aids in mitigating alignment error introduced from poor viewing angles, and reduces degenerate calibrations that arise from excessive co-planar points.

The Single Point Active Alignment Method (SPAAM), presented by Tuceryan and Navab [7], has emerged as the most commonly-cited alignment-based manual calibration method. The original SPAAM procedure utilized an environment-centric distribution of alignment points, as have many other SPAAM implementations and evaluations [1, 2, 4]. The calibration results from these environment-centric distribution schemes show that calibration quality fluctuates greatly, with user eye estimates typically varying by several centimeters across multiple calibrations.

However, other work, such as O'Laughlin [6] and Moser et al. [5], utilize alignment points distributed within arm's length of the user. The calibration results provided by Moser et al. [5] indicate that the user-centric alignment distribution strategy produces far more repeatable results, with eye estimates varying by less than a centimeter across multiple calibrations.

The experiment presented in this work is the first to systematically compare and contrast the expected accuracy and precision of SPAAM calibration results, performed using both user-centric and environment-centric alignment point distributions. The impact of postural sway on calibration results is also considered, through comparison of seated and standing calibration results. Finally, a control condition provides baseline calibration results for each alignment point distribution.

2 Experimental Design

A total of six experimental conditions were considered in the experiment (Table 1). The user completed 20 user-centric and 20 environment-centric calibrations in both a standing and sitting position, $20 \times 2 \times 2 = 80$ calibrations total. 50 alignments were used to complete each full calibration set, yielding a total of $50 \times 80 = 4000$ alignment points. The control condition utilized 20 calibrations using the user-centric and environment-centric distance ranges, for $20 \times 2 = 40$ additional calibration results, with $50 \times 40 = 2000$ alignment points.

An NVIS ST50 was used; it is a binocular display, with a resolution of 1280×1024 at each eye. At run time, an ART Trackpack dual-IR camera system was used to measure the 6DOF pose of the HMD, as well as the location of the physical alignment points. The control condition was implemented by rigidly mounting the HMD to a tripod system, equipped with a gear head assembly, allowing sub-degree rotational precision adjustment. A Microsoft Lifecam HD-600 webcam, with a resolution of 1280×720 at 30fps, was mounted behind the left optical combiner element of the display, using an optical railing system that allowed precise positioning. A standard manual SPAAM calibration procedure was employed.

All calibration data, with the exclusion of the control condition, were recorded from repeated trails by a single expert user (the first author of this paper). Because the purpose of this study was to compare the accuracy of user-centric versus environment-centric calibration schemes, restricting the calibration data to repeated measures from an expert user, knowledgeable with the procedure, removes the potential for errors resulting as an artifact of the subjective abilities of multiple participants, and allows more stable and consistent results to be obtained. This same strategy is employed in similar studies, which also employed a single expert user [2, 3, 5].

3 Experimental Results

Fig. 1 provides plots of the 3D eye locations resulting from calibrations performed in the user-centric, environment-centric, and control

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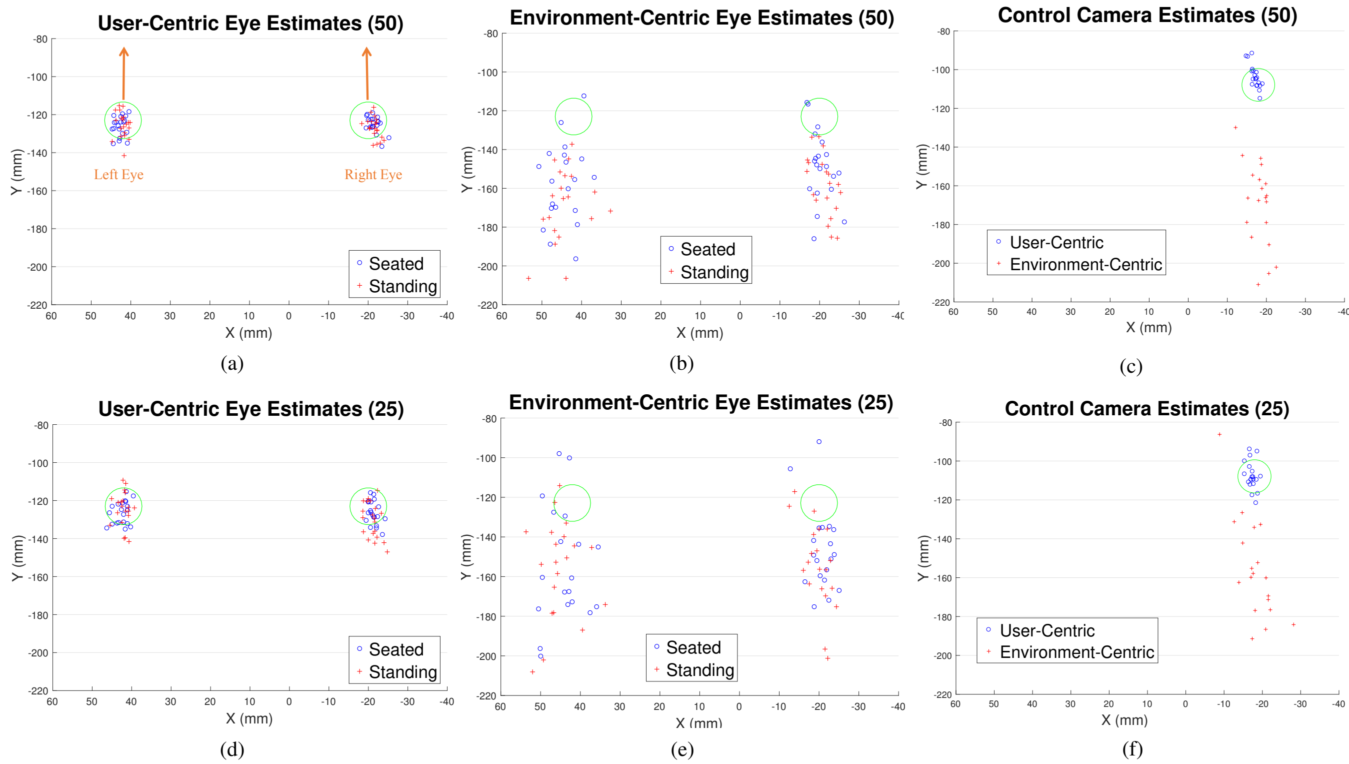

Figure 1: Estimated 2D user eye locations relative to the HMD marker constellation. (a) User-Centric, (b) Environment-Centric, and (c) Control eye estimates after 50 Alignments. (d) User-Centric, (e) Environment-Centric, and (f) Control eye estimates after 25 Alignments. In all plots, the center of the tracking constellation is at location (0, 0). Seated user calibrations are displayed in blue, standing in red. Control user-centric calibrations are displayed in blue, with control environment-centric plotted in red. Green circles indicate the expected position of the eyes or the camera.

Table 1: Experimental test conditions. **Subject** refers to whether the alignments were performed by the user wearing the HMD, or the camera control condition setup. **Posture** indicates whether the alignments were performed with the user standing or sitting. **Distribution** indicates if the condition used a user-centric or an environment-centric alignment distribution.

	Posture		Distribution (Centric)	
Subject	Seated	Standing	User	Environment
user		x		x
user	x			x
user		x	x	
user	x		x	
control				x
control			x	

alignment conditions. Two sets of plots are provided for each condition, final estimates after the full 50 alignments, and the estimated locations after the first 25 alignments. The green circles give the likely ground-truth locations of the eyes of the expert user, whose pupils were 62 mm apart. The arrows indicate the user's viewing direction.

Through visual inspection, it is clearly evident that the user-centric conditions produce eye estimate values with far less variance, compared to the environment-centric procedures. Likewise, there is a prominent deviation between the user-centric and environment-centric variants of the control condition, Figs. 1c and f. The user-centric alignment distances, in blue, are significantly more clustered and consistent compared to the eye estimates taken from the environment-centric, red, alignment results. In contrast, the seated and standing results for the expert user data sets, plotted in red and blue respectively in Figs. 1a, d, b, and e, do not exhibit much visual difference in values.

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