[POSTER] Improved SPAAM Robustness Through Stereo Calibration

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ABSTRACT

We are investigating methods for improving the robustness and consistency of the Single Point Active Alignment Method (SPAAM) optical see-through (OST) head-mounted display (HMD) calibration procedure. Our investigation focuses on two variants of SPAAM. The first utilizes a standard monocular alignment strategy to calibrate the left and right eye separately, while the second leverages stereoscopic cues available from binocular HMDs to calibrate both eyes simultaneously. We compare results from repeated calibrations between methods using eye location estimates and inter pupillary distance (IPD) measures. Our findings indicate that the stereo SPAAM method produces more accurate and consistent results during calibration compared to the monocular variant.

Keywords: Augmented reality, calibration, OST HMD, SPAAM.

Index Terms: I.3.6 [Computing Methodologies]: Computer Graphics—Methodology and Techniques

1 INTRODUCTION

The objective of OST HMD calibration is to determine the properties of the "camera" system produced by the user's eye and the display screen. A number of methods designed to estimate these necessary viewing parameters have been developed. The most commonly deployed of these approaches is the Single Point Active Alignment Method, introduced by Tuceryan and Navab [5]. SPAAM is a hardware independent technique which allows the user a large range of movement during calibration. The ease of implementation and relatively simple user requirements have made SPAAM the focus of numerous investigations aiming to improve robustness to errors and extend the applicability of the method to a broader range of OST AR systems.

Tang et al. [4] improved SPAAM accuracy by varying the distances at which users acquire calibration measurements. Genc et al. [2] extends SPAAM to stereo OST HMDs, allowing calibration of both the left and right views simultaneously. Despite these improvements though, SPAAM, in general, remains susceptible to user errors which negatively impact both accuracy and reliability.

A recent user study evaluation of OST HMD calibration methods by Moser et al. [3] shows that SPAAM registration accuracy is lowest in depth, compared to horizontal or vertical registration. These findings correspond to those reported by Axholt et al. [1], in which SPAAM's insensitivity to depth error manifests in widely varying eye position estimates, particularly in relation to the display screen. These varying eye position estimates reveal that repeated calibrations, even by the same user, often produce inconsistent results.

Our aim is to extend this body of work by developing methods to diminish the impact of user errors and improve not only the accuracy but also the consistency of a SPAAM calibration. This work presents the results of a preliminary study examining the consistency of a standard monocular and a stereo SPAAM implementation. Using eye position and IPD estimates as evaluation metrics, we compare the performance of each method during calibration. We believe the added stereo cues from a binocular calibration aid the user in performing the necessary alignments increasing the precision and consistency of the result.

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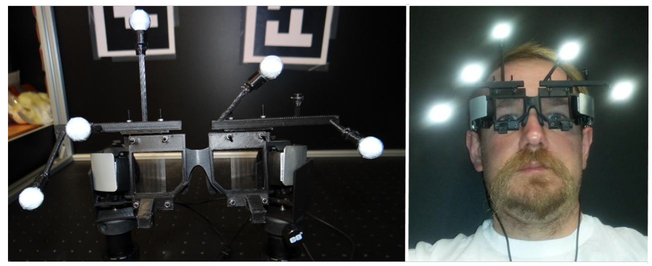
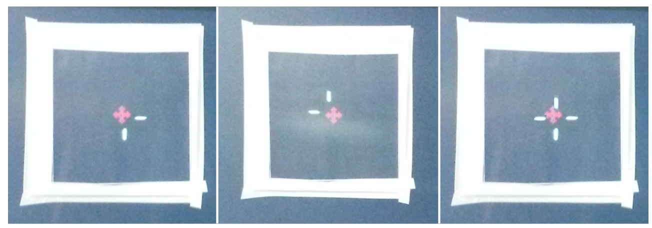


(a) (b)

Figure 1: Components of the calibration system. (a) The Lumus DK-32 head mounted display with tracking constellation. (b) User wearing the Lumus DK-32 with illuminated constellation.



(a) (b) (c)

Figure 2: Views through the HMD of the alignment marker and cross-hair. (a) Left eye nonius cross-hair half. (b) Right eye nonius cross-hair half. (c) Full cross-hair.

2 CALIBRATION SYSTEM

2.1 Hardware

We used a Lumus DK-32 HMD for this study. This is a binocular OST HMD with a resolution of 1280×720 per eye and 40° diagonal field of view. Graphics are produced by an Alienware m18 laptop, i7-4700MQ 2.4GHz processor running Windows 7 x64, through an HDMI interface. A passive IR marker constellation is rigidly attached to the Lumus HMD (Figure 1). The constellation's position and orientation are tracked using a pair of ART TrackPack cameras, with a resolution of .7 MPix and a 90Hz update rate.

2.2 Calibration Procedures

We focus this investigation on two SPAAM variants, both of which were conducted in an identical manner with only the display style of the on-screen cross-hair differing between methods. 20 screen-world alignments were made for each calibration. During alignment, the user was instructed to line up the center of the on-screen cross-hair with the center of a physical marker. As recommended by [4, 1], the user was instructed to take steps forward or backward between alignments to vary the distance of each measurement. Alignment measures were recorded using a game controller.

Monocular SPAAM: All 20 alignments were made with only a single eye, right or left, and then the calibration was repeated for the remaining eye. The unused eye was covered to avoid binocular rivalry during alignments. Figure 2(c) provides a view of the on-screen cross-hair shown to the user during alignments.

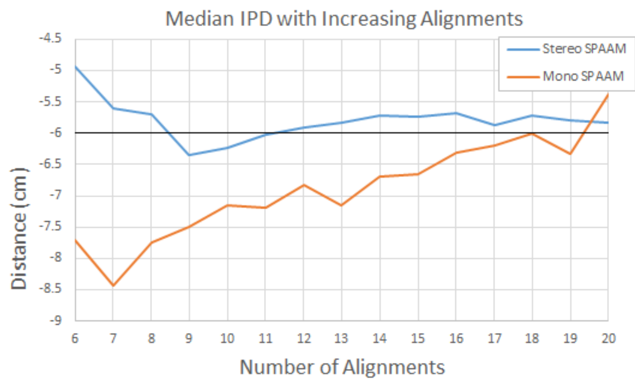


Figure 3: Plot of the median IPD for Stereo (blue) and Mono (orange) SPAAM over the 20 alignments made during a calibration.

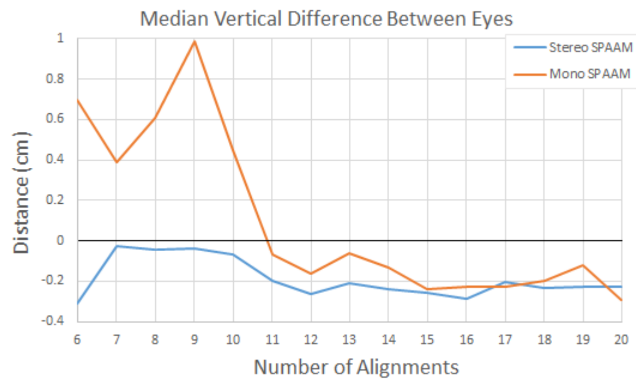


Figure 4: Plot of the median vertical eye position difference between the left and right eye for Stereo (blue) and Mono (orange) SPAAM over the 20 alignments made during a calibration.

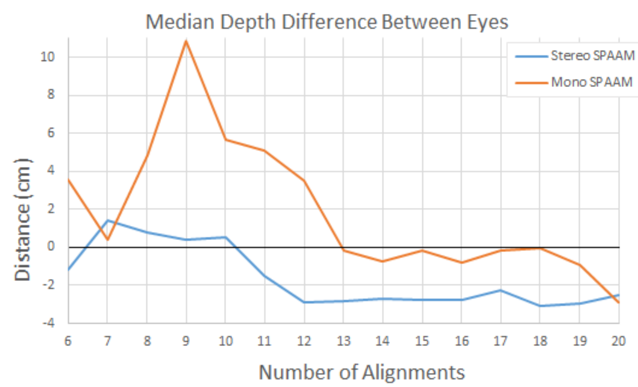


Figure 5: Plot of the median depth eye position difference between the left and right eye for Stereo (blue) and Mono (orange) SPAAM over the 20 alignments made during a calibration.

Stereo SPAAM: While [2] used concentric circles, our approach was based on nonius lines. We display half of a cross-hair to each eye, Figures 2(a) and (b). The user's optical system fused the two halves into a single image. During calibration, the user was instructed to focus on the center of the physical marker. Using the controller, the user independently adjusted the on-screen location of each cross-hair half until the vertical and horizontal portions aligned to form the single cross-hair in Figure 2(c), and then the alignment measurement was recorded.

3 Calibration Consistency

A single user performed a total of 5 stereo and 10 monocular (5 for each eye) SPAAM calibrations. For each calibration, the user performed 20 alignments. SPAAM requires at least 6 alignments to produce a result. Each stereo SPAAM calibration simultaneously gave both left and right eye locations, while each pair of monocular SPAAM calibrations separately gave both locations. Our evaluation metric is the difference between the left and right eye location estimate along each major direction: horizontal (IPD), vertical, and in depth. Figures 3, 4, and 5 show the median eye position differences after each alignment during calibration. Negative values indicate the right eye position estimate is greater in the indicated direction.

In each direction, stereo SPAAM, plotted in blue, not only achieves a steady state value sooner than mono SPAAM, but also exhibits significantly less deviation between the first and last estimates. The change in IPD during calibration for stereo SPAAM is only .89cm compared to 2.34cm for mono SPAAM. Stereo SPAAM varies by only 0.09cm and 1.34cm compared to 0.99cm and 6.47cm for mono SPAAM in the vertical and depth directions respectively.

Accuracy of the calibration can be evaluated using the IPD as an indicator. Mean IPD estimates for calibration are approximately 5.8cm and 6.8cm for stereo and mono SPAAM respectively. The stereo SPAAM estimate is closer to the user's real IPD value of 6cm and also maintains this value through nearly the entire calibration, where as mono SPAAM estimates slowly improve and only approach the correct value near the calibration end.

4 Conclusion

Our objective for this study was to identify if the binocular cues provided by stereo SPAAM provide improvement in calibration stability over a standard monocular implementation. Our preliminary results indicate that the stereo SPAAM method produces more consistent results compared to the monocular variant. The IPD, horizontal distance between eyes, is also more accurately approximated by stereo SPAAM , which we find converges on a steady result in far fewer alignments.

We believe these findings indicate that the calibration burden of a user may be substantially decreased if a binocular system is fully utilized. Our future goals include replication of this experiment with multiple users, including those with less familiarity with HMDs. In addition, we also plan to develop a prediction model for identifying convergence of a SPAAM result, in order to more appropriately guide the number of alignments required by the user.

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