Reduction of Interaction Space in Single Point Active Alignment Method for Optical See-Through Head-Mounted Display Calibration

Long Qian* Alexander Winkler† Bernhard Fuerst‡ Peter Kazanzides§ Nassir Navab¶

Johns Hopkins University, Baltimore, MD, United States
Technische Universität München, Munich, Germany

Abstract

With users always involved in the calibration of optical see-through head-mounted displays, the accuracy of calibration is subject to human-related errors, for example, postural sway, an unstable input medium, and fatigue. In this paper we propose a new calibration approach: Fixed-head 2 degree-of-freedom (DOF) interaction for Single Point Active Alignment Method (SPAAM) reduces the interaction space from a typical 6 DOF head motion to a 2 DOF cursor position on the semi-transparent screen. It uses a mouse as input medium, which is more intuitive and stable, and reduces user fatigue by simplifying and speeding up the calibration procedure.

A multi-user study confirmed the significant reduction of human-related error by comparing our novel fixed-head 2 DOF interaction to the traditional interaction methods for SPAAM.

Index Terms: Augmented Reality, SPAAM, OST-HMD Calibration and Human Factors

1 Introduction

The immersion in augmented reality (AR) highly depends on how well virtual objects are integrated into the real world. With optical see-through head mounted displays (OST-HMD), computer generated images can be presented to the users while they are also able to see the real world through a semi-transparent display. To achieve a good alignment between virtual objects and the user's perception of the real world, optical see-through systems require a user specific calibration. To make the calibration procedure acceptable to an undiscerning user, it needs to be simple and efficient to perform.

Single Point Active Alignment Method (SPAAM) [7] is widely used for the calibration of optical see-through devices due to its simplicity and accuracy. The user is extensively involved in the calibration process and is required to move around to make alignments of virtual and real world targets. The stylus-marker method [2] was proposed independently of SPAAM, but it can still be thought of as a special case of SPAAM where 3D-2D point correspondences are collected and analyzed. In this method, the 3D point is the tracked location of the user's finger.

Another category of OST-HMD calibration methods is two-phase calibration, where user-independent parameters are measured in the first phase, and users are involved only in the second phase to calibrate the rest of the unknowns for the OST system. Although the number of free parameters is reduced, the interaction is still complex and error-prone. Interaction-free calibration proposed by [4] is very user-friendly since no interaction is required, but at the current stage, it does not outperform SPAAM in terms of accuracy.

*e-mail: long.qian@jhu.edu
†e-mail: alexander.winkler@tum.de
‡e-mail: be.fuerst@jhu.edu
§e-mail: pkaz@jhu.edu
¶e-mail: nassir.navab@tum.de

2 Actuating Factor and Interaction Space

The *actuating factor* of the calibration process is defined as the *mandatory difference* between sequential alignments, which is usually predefined in the system. For SPAAM and stylus-marker method [2], the actuating factor is defined to be the displacement of the crosshair on the foreground. The position of the crosshair is fixed, and it drives the user to react.

The *interaction space* is defined as the set of possible conditions of the input that the user can actively manipulate with respect to the actuating factor in order to collect 3D-2D correspondences. For each alignment, the input of the user is a configuration in interaction space. The interaction space for SPAAM is the 6-DOF head position and orientation, and for the stylus-marker method it is the position of the user's finger (3 DOF) in tracking coordinates [3].

Each 3D-2D alignment in the process of OST-HMD calibration is the combination of one condition of the actuating factor and one sample of the interaction space.

3 Fixed-Head 2 DOF Interaction for SPAAM

Following the concept of interaction space and actuating factor, a new approach for performing SPAAM calibration is proposed: *fixed-head 2 DOF interaction for SPAAM (fh-SPAAM)*, in which the user's head is fixed on a chin rest, 3D targets at different 3D poses are simulated and visualized on a screen, and the alignment of virtual and simulated real world targets is performed by manipulating a cursor instead of controlling the head pose.

The interaction space for fh-SPAAM is the cursor position on the foreground, which is a two dimensional space.

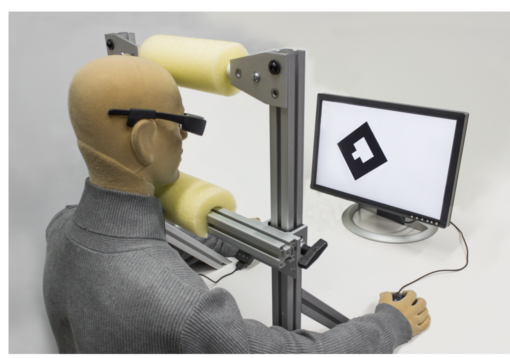


Figure 1: The setup of the novel fh-SPAAM: The user can position the head on a chin rest for additional stability, a screen is used to display marker images, and alignments are acquired using a computer mouse.

4 Experiment and System Setup

A comparative study with 16 participants was conducted to evaluate the users' alignment behavior for SPAAM and fh-SPAAM. The subjects were required to make 20 alignments in both methods under video see-through configuration, where the video captured by

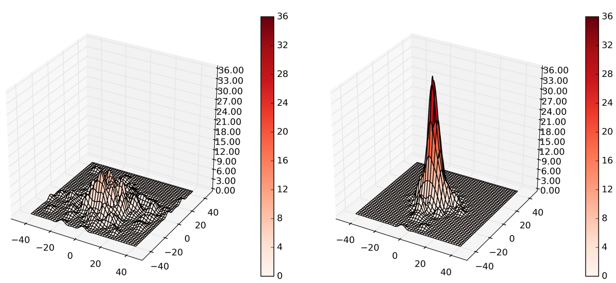
Method	Actuating factor	Interaction space	DOF	Input medium
SPAAM	2D screen cursor	Head position and orientation	6	Head
Stylus-Marker	2D screen cursor	Finger position	3	Hand
fh-SPAAM	Background screen target	Cursor position	2	Mouse

Table 1: Actuating factor and interaction space for different OST-HMD calibration methods

the HMD camera is displayed to the user to simulate OST-HMD calibration. For fh-SPAAM, the user controls the mouse and thus maintains a fixed head alignment. The user's clicked point is compared to the ground truth (the location of the marker in the video). Subjective feedback about the system usability [1] was acquired from the user after the experiment. One participant reported that the OST-HMD was not stable on top of prescription glasses, which led to inconsistent performance in the alignment exercise. Thus, the data of this participant was excluded from the study.

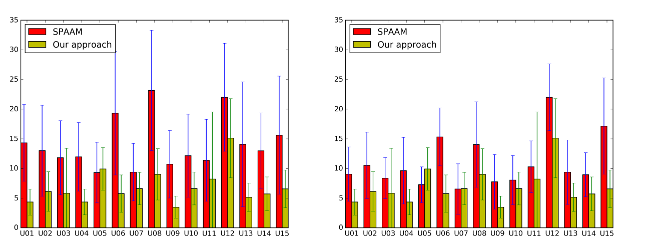
An Epson Moverio BT-200 is used as the OST-HMD for the experiment. The vision-based tracking functionality is provided by ARToolKit [5]. A Python script displays fiducial marker images sequentially on the background screen, captures mouse movement, and handles socket communication to the HMD.

5 Results and Discussion



(a) SPAAM (b) fh-SPAAM

Figure 2: Confirmation displacement in screen pixels of all alignments from the user study. The target is at (0,0) for both setups. Both accuracy and precision are improved by our approach.



(a) SPAAM vs. fh-SPAAM. (b) SPAAM with averaging vs. fh-SPAAM.

Figure 3: Mean alignment error in screen pixels for SPAAM and fh-SPAAM for each participant. Whiskers show standard deviation. fh-SPAAM outperforms SPAAM, without and with software based error reduction (averaging), in terms of accuracy and precision.

Alignment error can be described as the Euclidean distance between the confirmed location and ground truth. To statistically compare the two experimental conditions, the users' mean value and standard deviation of the alignment errors are calculated and analyzed. The data is illustrated in Fig. 3a, in which the means and standard deviations are plotted as bars and whiskers, respectively.

To test whether there is a statistically significant difference, we deploy the Kolmogorov-Smirnov (KS) test for the set of means to test normal distribution, which is a precondition to perform a t-test. The KS test results in a p-value greater than 0.05, indicating that the data is of normal distribution. A paired t-test comparing the mean alignment error of SPAAM and fh-SPAAM shows a p-value less than 0.05 ($8.1 \cdot 10^{-6}$), revealing that the alignment error of our approach is significantly smaller compared to the alignments obtained with traditional SPAAM.

The comparison between fh-SPAAM and traditional SPAAM with averaging technique [6] is shown in Fig. 3b. Due to the constrained interaction space and less error-prone input medium, user alignment error with fh-SPAAM is reduced significantly and consequently the OST-HMD calibration achieves higher accuracy.

The fh-SPAAM method also reduced the time required for calibration by 40% when compared to the traditional SPAAM calibration (67.3 s compared to 112.4 s). With a mean System Usability Score of 72.3, the users assign our approach a "good" usability [1].

6 Conclusion

This poster categorized existing OST-HMD calibrations that are based on SPAAM using two core concepts: *actuating factor* and *interaction space*. The proposed fixed-head 2 DOF interaction for SPAAM (fh-SPAAM) method has a reduced interaction space of 2 DOF, rather than requiring 6 DOF user head motion (for SPAAM) or 3 DOF user hand motion (for stylus-marker). 16 subjects with different familiarity with augmented reality applications were recruited to perform a comparison experiment between SPAAM and fh-SPAAM. The alignment error analysis confirmed that the reduction of the interaction space yielded reduced user interaction error and therefore higher calibration accuracy.

References

[1] A. Bangor, P. Kortum, and J. Miller. Determining What Individual SUS Scores Mean: Adding an Adjective Rating Scale. *J. Usability Studies*, 4(3):114–123, May 2009.

[2] A. Fuhrmann, D. Schmalstieg, and W. Purgathofer. Fast calibration for augmented reality. In *ACM Symp. on Virtual Reality Software and Technology*, pages 166–167, 1999.

[3] A. Fuhrmann, D. Schmalstieg, and W. Purgathofer. *Practical calibration procedures for augmented reality*. Springer, 2000.

[4] Y. Itoh and G. Klinker. Interaction-free calibration for optical see-through head-mounted displays based on 3d eye localization. In *IEEE Symp. on 3D User Interfaces (3DUI)*, pages 75–82, 2014.

[5] H. Kato and M. Billinghurst. Marker tracking and HMD calibration for a video-based augmented reality conferencing system. In *IEEE/ACM Intl. Workshop on Augmented Reality (IWAR)*, pages 85–94, 1999.

[6] P. Maier, A. Dey, C. A. Waechter, C. Sandor, M. Tönnis, and G. Klinker. An empiric evaluation of confirmation methods for optical see-through head-mounted display calibration. In *IEEE Intl. Symp. on Mixed and Augmented Reality (ISMAR)*, pages 267–268, 2011.

[7] M. Tuceryan and N. Navab. Single point active alignment method (SPAAM) for optical see-through HMD calibration for AR. In *IEEE/ACM Intl. Symp. on Augmented Reality (ISAR)*, pages 149–158, 2000.