Evaluation of Hand and Stylus Based Calibration for Optical See-Through Head-Mounted Displays Using Leap Motion

Kenneth R. Moser*
Mississippi State University

J. Edward Swan II†
Mississippi State University

Abstract

Next generation OST HMDs promise the inclusion of a variety of integrated and on-board sensors. In particular, hand tracking cameras, such as the Leap Motion, show potential for facilitating intuitive OST calibration procedures accessible to researchers, developers, and novice users alike. In this work, we evaluate hand and stylus based OST calibration utilizing tracking data from a Leap Motion. Our findings show that performance of both methods is comparable to results from prior studies using standard environment-centric methods. Also, while our hand based calibration improved through the use of more contextual reticle designs, calibrations performed with a stylus yielded the most accurate and precise results over all.

Index Terms: H.5.1 [[Information Interfaces and Presentation]: Multimedia Information Systems]: Artificial, augmented, and virtual realities—

1 Introduction

Growing availability of consumer level Optical See-Through (OST) Head-Mounted Displays (HMDs) is producing a burgeoning market for new and innovative Augmented Reality (AR) applications for general use. This new domain is also producing an ever growing need for intuitive and easily implemented calibration procedures accessible to researchers, developers, and novice users alike. Fortunately, next generation devices, such as the Microsoft HoloLens and Epson Moverio Pro BT-2000, promise the inclusion of a variety of integrated and on-board sensors. The presence of hand and gesture tracking cameras, in particular, offers great potential for the creation of calibration methodologies standardized across devices.

The goal of OST calibration is to properly model the user's viewpoint through the display screen. Unlike Video See-Through (VST) AR, where the world is seen through an externally mounted camera, OST AR provides a direct overlay of virtual content onto the world from the user's own natural perspective. Automatic calibration techniques, including Itoh and Klinker's Interaction Free Display Calibration (INDICA) [2] and Plopski et al.'s Corneal Imaging Calibration (CIC) [5], have been proposed but require additional cameras mounted within the HMD to directly measure the position of the eye relative to the screen. Since current commercial HMD offerings do not natively include this extra hardware, applicability of such approaches is limited. As a result, calibration techniques for OST displays have traditionally relied on manual interaction methods, such as the Single Point Active Alignment Method (SPAAM) introduced by Tuceryan and Navab [6], which require the user to align points on-screen to target points in the world. Typically, target points are static locations or markers within the environment. While effective, the use of external objects or patterns inherently forces a restriction on the tracking environment itself and requires the user to obtain or print portable alignment targets themselves. For the vision of ubiquitous OST AR to be possible, environment agnostic calibration standards must be implemented. The incorporation of hand tracking devices into HMDs would allow the replacement of environment dependent target points with the user's own fingers.

*e-mail: moserk@acm.org
†e-mail:swan@acm.org

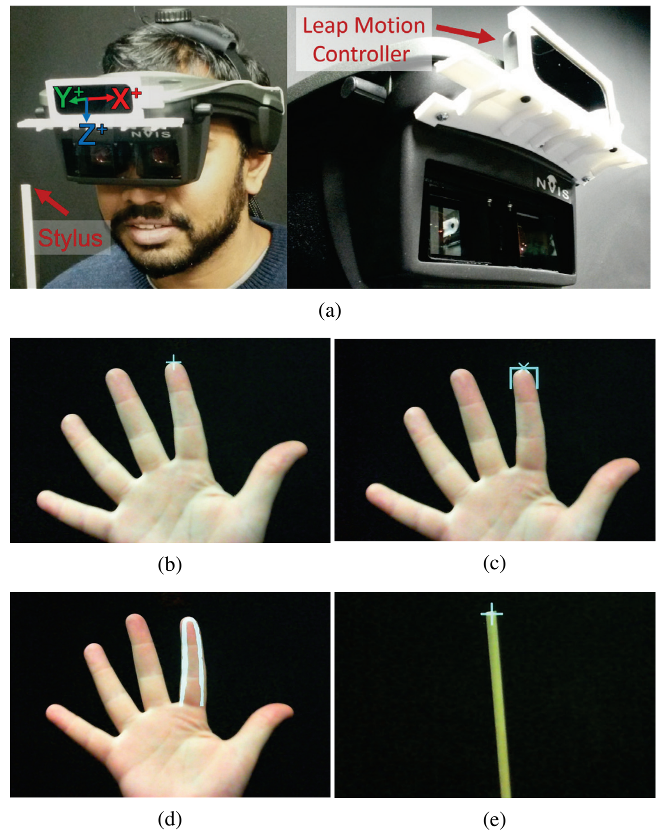
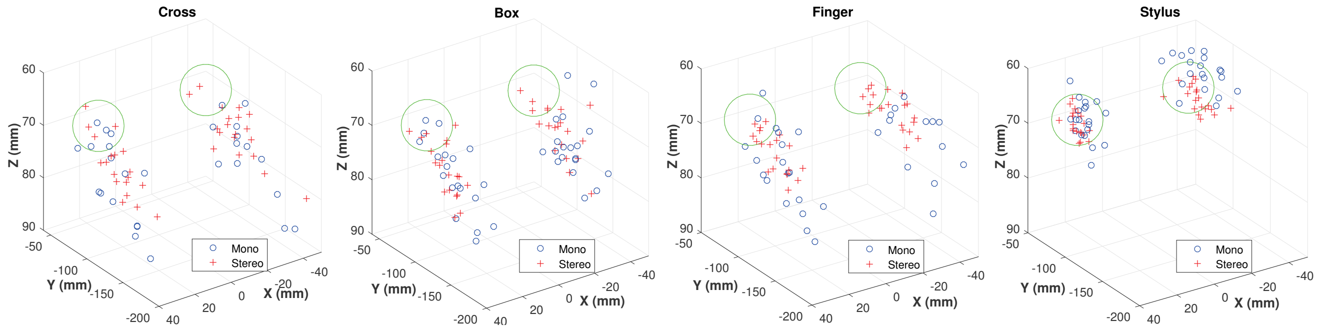


Figure 1: Views through the (a) HMD system of calibration alignments performed using a stylus or hand. Hand calibration using the (b) cross, (c) box, and (d) finger reticle. (e) Stylus calibration.

In this work, we investigate the efficacy of the Leap Motion controller as an interface for facilitating hand and stylus based calibration of OST HMD systems. Our study includes an examination of both accuracy and precision for both methods including an exploration of the impact of on-screen reticle design in providing proper context for screen to hand alignments.

2 Leap Motion OST HMD Calibration

Our calibration system is comprised of an NVIS ST50 OST binocular display, with a resolution of 1280×1024 and 40° horizontal and 32° vertical field of view, and a Leap Motion controller rigidly attached to the front of the ST50 using a custom 3D printed mount, Figure 1 (a). Since the Leap Motion is able to perform both hand and tool tracking, we utilize each in a SPAAM based procedure, requiring multiple alignments between on-screen reticles and either a finger or stylus. Additionally, we utilize several on-screen reticle designs in order to provide varying degrees of context for finger tip alignments.



(a) (b) (c) (d)

Figure 2: User eye locations derived from the calibration results of the (a) cross reticle, (b) box reticle, (c) finger reticle, and (d) stylus alignment conditions. Estimates from monocular sets are displayed in blue with binocular values shown in red. Values along X , Y and Z correspond to locations relative to the X, Y, and Z axis of the Leap Motion coordinate frame, respectively. Green circles denote plausible eye points.

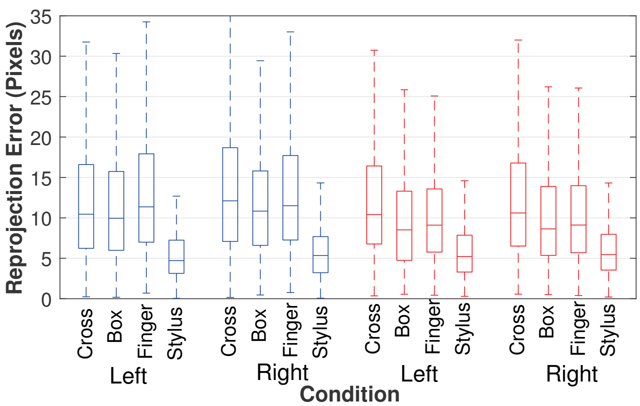


Figure 3: Reprojection error for monocular (blue) and binocular (red) calibrations performed with each alignment method.

2.1 Alignment Methods

Hand Alignments: The center tip of the right index finger is used as the alignment point for hand calibrations. Since calibration accuracy depends heavily on alignment precision, we employ three reticle designs to provide varying degrees of context to aid in finger positioning. *Cross*: a horizontal and vertical line 64×64 pixels with target alignment point located at the center of the intersection point. *Box*: a 3 sided rectangle 128×128 pixels with an 'X' placed on the upper edge at the target alignment point. *Finger*: a finger outline 128×364 pixels with the target alignment point located at the center tip of the outline. Figure 1 (b), (c), and (d) provide views through the HMD of cross, box, and finger reticle alignments respectively.

Stylus Alignments: The stylus is made from a 5mm diameter wooden dowel rod, approximately 20cm in length, held with sufficient length extending beyond the user's hand. The cross reticle, as described previously, is used for stylus calibrations, and proper alignment occurs when the center of the cross coincides with the center of the stylus tip. A stylus alignment is shown in Figure 1 (e).

2.2 Calibration Procedure

Monocular and stereo calibrations are performed using each alignment method, with 25 alignments completing a single calibration set. During each of these alignments, the 3D finger or stylus tip location, relative to the Leap Motion, is measured and recorded along with the X, Y, on-screen pixel location of the reticle. The combined data across all alignments is used to produce the calibration result.

3 Analysis and Discussion of Results

Our primary objective is to verify the efficacy of a Leap Motion controller for calibrating OST displays and not the inherent usability or intuitiveness of our design. In this regard, repeated measures from an expert user, as employed by [2, 3], provide more stable results, void of subjective affects. 20 monocular and 20 stereo sets for each alignment method, $20 \times 8 = 160$ calibrations, were completed.

3D eye positions, relative to the Leap Motion coordinate frame, are calculated by decomposing the extrinsic component from calibration results, Figure 2. Visual inspection of the 3D estimates shows that stylus calibration yields more consistent and accurate extrinsic estimates, in relation to plausible ground truth positions. All three hand alignment methods produce noticeably less uniform results, though with very similar patterns and distributions to those seen in Axholt [1] and Moser et al. [4] for standard environment-centric implementations. Analysis of reprojection error, Figure 3, confirms that stylus alignment is the most optimal strategy for OST calibration using the Leap Motion, producing significantly less reprojection error than any of the hand calibration variants.

We believe this work confirms the utility of the Leap Motion as a viable option for user-centric calibration of consumer OST HMDs. However, unpredictable accuracy of hand tracking makes stylus based calibration the most optimal method for the device.

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