Continuous Automatic Calibration for Optical See-Through Displays

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ABSTRACT

The current advent of consumer level optical see-through (OST) head-mounted displays (HMD's) has greatly broadened the accessibility of Augmented Reality (AR) to not only researchers but also the general public as well. This increased user base heightens the need for robust automatic calibration mechanisms suited for non-technical users. We are developing a fully automated calibration system for two stereo OST HMD's, a consumer level and prototype model, based on the recently introduced interaction free display calibration (INDICA) method. Our current efforts are also focused on the development of an evaluation process to assess the performance of the system during use by non-expert subjects.

Index Terms: Calibration, OST HMD, Augmented Reality.

1 INTRODUCTION

The current advent of consumer level optical see-through head-mounted displays has greatly broadened the accessibility of Augmented Reality to not only researchers but also the general public as well. This increased user base heightens the need for robust automatic calibration mechanisms suited for non-technical users. The most commonly used OST HMD calibration procedures rely primarily on user feedback and interaction to estimate the values necessary for displaying on-screen geometry from the perspective of the user. The Single Point Active Alignment Method (SPAAM), introduced by Tuceryan and Navab [6], is perhaps the most common and well studied of the interaction based approaches.

In general, the SPAAM procedure tasks users with performing a number of alignments between on-screen markers, usually cross-hairs, and a single fixed point in the physical world. The pixel coordinates of each on-screen indicator, along with the location of the real world point within the head centered coordinate frame, are used to estimate the 11 parameters of the virtual camera projection matrix. Ideally, this virtual camera will closely model the real system formed by the eye and display screen, such that the computer generated geometry seen through the HMD will appear properly registered with, or located relative to, physical objects in the real environment. Since SPAAM allows the user a greater degree of mobility during calibration, over bore sighting for example, it has been popularly used in OST HMD studies and several variants have been developed. The most notable SPAAM adaptations have sought to address the limitations of the standard procedure either in terms of accessible hardware or robustness.

Stereo-SPAAM, developed by Genc et al. [2] extends the technique for use with binocular displays. Use of stereo depth cues, during the alignment steps, allow the user to perform calibration of both eyes simultaneously. Depth SPAAM, a second variant of the traditional method introduced by Tang et al. [5], improves the overall accuracy of the final result by requiring users to perform alignments at changing distance intervals from the real world point.

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(a) (b)

Figure 1: Views of the mounting rig used to measure the off-line INDICA parameters. The distance from the world tracking camera to the virtual screen, $\mathbf{t}_{WS}$, as well as the scaling factors for projecting points into screen space, $\alpha(x,y)$, are estimated using this setup per the description in [3].

These procedures are still ultimately dependent upon the abilities of the user to perform consistent and accurate alignments. In addition, each of the afore mentioned calibration mechanisms is quite cumbersome, since optimal results are only obtainable by repeating the entire procedure each time the HMD is removed and replaced onto the head. A recent development in OST HMD calibration, denoted as Interaction Free Display Calibration (INDICA), incorporates eye tracking based technology in a two phase calibration approach ideally suited for novice users.

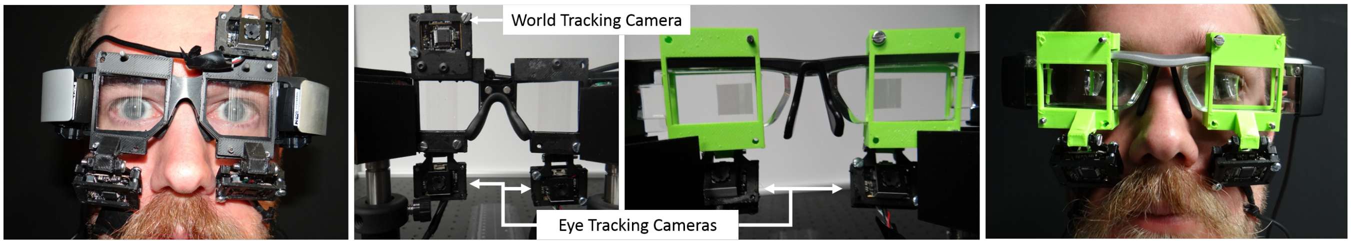
We have integrated Itoh and Klinker's INDICA [3] into a fully automated calibration system for two stereo OST HMD's, a consumer level and prototype model. Aside from the prototype display, all of the hardware employed is readily available. Our current efforts are also focused on the development of an evaluation process to assess the performance of our calibration system during a registration critical task.

2 CALIBRATION SYSTEM

Our calibration system is designed with primary focus given to three essential aspects. (1) Automation: The calibration must be able to proceed and produce acceptable results without any dependence on the user themselves. (2) Implementation Cost: All hardware components, with the exception of the HMD, are ”off the shelf” or easily acquired devices. (3) Performance: Results of the calibration must meet or exceed those produced by standard interaction dependent methods.

2.1 Hardware

We have adapted INDICA for use with two models of OST HMD. The first is the Lumus DK-32 Near to Eye Personal Display. This is a binocular display which facilitates stereo imagery at a resolution of 1280×720 per eye, with 40° diagonal field of view. As this is a prototype display, it is not available to the general market. Graphics for the display are driven by an Alienware m18 laptop, i7-4700MQ 2.4GHz processor with 16 GB RAM running Windows 7 x64, through an HDMI interface. The second OST HMD, to which we have deployed the calibration system, is the Epson Moverio BT-200 Smart Glasses. This is also a binocular display with 23° diagonal field of view and 960 × 540 resolution in each eye. The Moverio is currently available on the consumer market, and is powered by an on-board 1.2GHz TI OMAP 4460 Dual Core processor



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

Figure 2: The OST HMD and mounted cameras system. (a) User wearing the Lumus DK-32 HMD and added cameras. (b) View of the camera mountings for the Lumus DK-32 from behind the display screen. (c) View of the camera mountings for the Epson Moverio BT-200 from behind the display screen. (d) User wearing the Moverio BT-200 and added camera assembly.

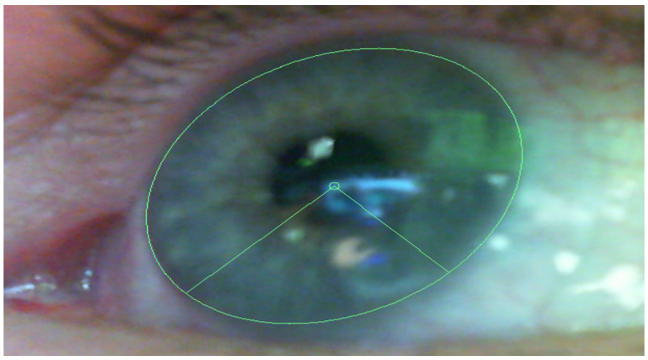


Figure 3: Image of a user's left eye taken from the camera mounted below the screen of the Lumus DK-32 display. The green circle is the fitted ellipse produced by the iris detection algorithm. The ellipse is back projected as a spheroid to obtain the eye's center location.

with 1 GB RAM running Android 4.0.4. The complete system for both displays is provided in Figure 2.

Identical hardware for eye tracking is used on both HMD configurations. Dual Microsoft LifeCam HD-6000 cameras are mounted under the eye pieces of each HMD to capture the necessary eye images required by the INDICA calibration method. These cameras provide video at a resolution of 1280×720 and 30 fps, through a USB 2.0 interface. A third camera used for head position and orientation tracking is mounted above the eye pieces on the Lumus HMD. Video capture from all three cameras, as well as execution of the related calibration software, is performed by the same Alienware m18 laptop used to drive graphics for the Lumus display.

2.2 Full INDICA

The Full INDICA setup, as described by Itoh and Klinker in [3], is implemented for use on both HMD systems. Full INDICA requires the use of a two stage method. The first stage requires that two display specific parameters be measured, and in the second stage these display specific values are combined with eye location and transformation values obtained during run time. Equation 1 expresses the desired calibration result, projection matrix from world to eye coordinate frames $\mathbf{P}_{WE}$, as a function of the eye's center position in world coordinates $\mathbf{t}_{WE}$.

$$\mathbf{P}_{WE}(\mathbf{t}_{WE}) = \mathbf{K}(\alpha, \mathbf{t}_{WE} - \mathbf{t}_{WS}) \begin{bmatrix} \mathbf{R}_{WE} & \mathbf{t}_{WE} \end{bmatrix} \quad (1)$$

Stage One: Off-Line Display Values The parameters determined during the off-line stage are: (1) Transformation from the head tracking camera to the virtual screen produced by the display, denoted $\mathbf{t}_{WS}$; (2) Pixel scaling factor, α(x, y). Both parameters are used in the projection and scaling step, $\mathbf{K}(\alpha, \mathbf{t}_{WE} - \mathbf{t}_{WS})$ of Equation 1. We determine both parameters using the setup shown in Figure 1.

Stage Two: On-Line Eye Transformation Values The transformation, translation $\mathbf{t}_{WE}$ and rotation $\mathbf{R}_{WE}$, of the user's eye relative to the HMD are determined using the mounted eye imaging cameras during run time. Images of the left and right eye are captured at constant intervals and processed using a method based on Swirski's iris detection [4] and Nitschke's algorithm [1] for 3D eye position estimation. Figure 3 shows a processed image of the left eye taken from a user wearing the Lumus DK-32 display system. The calculated eye centers are combined with the off-line parameters in Equation 1 to generate the final projection matrix.

3 Conclusion and Future Work

The calibration systems we have developed are capable of producing a calibrated projection matrix for both eyes automatically without the need for any user interaction. In addition, the calibration method itself supports continuous updating of results. The ability to update the calibration on-line allows the system to accommodate unpredictable error sources, such as movement of the display on the user's head during use. The use of readily available hardware and software components also make our systems readily reproducible.

We have yet to quantify the accuracy of the automatic calibration through a formal evaluation. Our intent is to compare the results of our Full INDICA setup against a standard interaction based method, such as SPAAM. The development of a registration critical task suited for calibration testing will be an essential aspect of our continued development.

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