Augmented Reality Magnifying Loupe for Surgery

Project Proposal

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Objectives: Design a surgical loupe mount for optical see-through head-mounted display (HMD) and develop a calibration method to associate the field-of-magnified-vision, the HMD screen space and the task workspace.

Background and previous works:

A magnifying loupe is often used in surgical procedures, including neurosurgery and dentistry. In this project, we focus on dental applications. There are three principal reasons for adopting magnifying loupes for operative dentistry: to enhance visualization of fine detail, to compensate for the loss of near vision (presbyopia), and to ensure maintenance of correct posture.

Augmented Reality (AR) has been used in the medical domain for treatment, education, and surgery. Useful information, measurements and assistive overlays can be provided to the clinician on a see-through display. Many dental practitioners use magnifying loupes routinely for clinical work, and dental undergraduates are increasingly wearing them when training, so AR guidance in the loupe can potentially help the practitioner in navigation and operation.

In previous work, an augmented reality magnification system, in other words, a virtual loupe, was implemented on a video see-through head-mounted display (HMD) for surgical applications. The system was evaluated by measuring the completion time of a suturing task performed by surgeons. Although it was widely accepted by surgeons as a useful functionality, surgeons were not satisfied with the video quality. Thus, this project uses physical loupes to achieve higher quality optical magnification.

Technical Approach

<u>Workflow Overview</u>

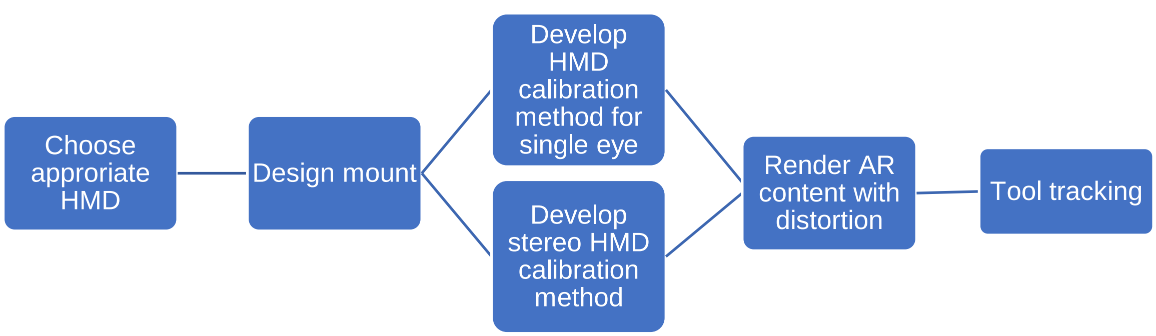

Figure 1 Technical workflow

HMD Choice

There are three common Optical See-through HMDs, Microsoft HoloLens, Magic Leap One, and Epson BT-300.

For this project, I will use Magic Leap One instead of HoloLens, because HoloLens' bulky and round-shaped design makes it hard to attach a loupe in front of the display. Magic Leap One have a light-weight design on the head. And they both have a flat surface in front of the display, making them easier to attach a loupe.

Mechanical Design

There are three criteria for the design:

The first is that users can change the lens based on different needs. In practical terms, a magnification of x2–x2.5 would enable the dental operator to see multiple quadrant areas in focus, where quadrant is the term used by dentists to split the interior of your mouth into four sections. This is the magnification normally used in general dental practice. As the magnification increases, the field that can be viewed decreases. At magnifications of x3.5 the field becomes restricted to a single quadrant, while at a magnification beyond x3.5 the view becomes increasingly restricted until only a single tooth is seen.

The second criterion is that the user is able to flip up or down the loupe, in order to switch to normal view or magnified view.

The last criterion is that each user can adjust the loupe based on their own interpupillary distance (IPD).

Distortion Correction

The magnifying loupe has large radial distortion. Lens distortion takes place during the initial projection of the world onto the image plane, so the first thing I need to do is to do a distortion correction. This correction, together with the camera calibration matrix, specifies the mapping from an image point to a ray in the camera coordinate system. The results of the distortion correction will be used later in rendering AR content.

HMD Calibration

With an optical see-through head-mounted display (OST-HMD) there is no direct access to the view of the user. Therefore, a user-dependent calibration procedure is generally required in order to correctly align the virtual content with its real counterpart. The Single Point Active Alignment Method (SPAAM) is one of the widely applied methods to perform such display calibration due to its simplicity and accuracy. In SPAAM, 2D-3D point correspondences are collected by the user, and then a mapping from the 3D point cloud to its 2D screen coordinates is calculated using Direct Linear Transform (DLT), and finally we can get a 3 by 4 matrix that maps the 3D world points to the 2D image plane. The mapping matrix is shown below:

$$s\begin{bmatrix}u\\v\\1\end{bmatrix}=\begin{bmatrix}fx & s & cx\\0 & fy & cy\\0 & 0 & 1\end{bmatrix}\begin{bmatrix}r11 & r12 & r13 & t1\\r21 & r22 & r23 & t2\\r31 & r32 & r33 & t3\end{bmatrix}\begin{bmatrix}X\\Y\\Z\\1\end{bmatrix}$$

Tracking

To enable AR, a tracking system with good accuracy is necessary. Although the HMD chosen for the project have its own visual-SLAM based tracking system works off-the-shelf, they usually have errors of a few centimeters. It is not accurate enough for surgery such as dentistry. So, I will be using marker/fiducial tracking for this project.

Rendering

Another challenge is that the effective part of the HMD screen needs to be identified. Because after the loupe is mounted, only a circular area of the screen is useful to render AR content. To find this part, basically is to find the principle point of the HMD, so that the loupe aligns with the optical axis of the HMD.

The rendered magnified AR content should also have a radial distortion behaves like the loupe. Implementing this non-linear magnification transformations based on the distortion correction results can provide a more natural visualization of the virtual content.

Deliverables:

- Minimum: A hardware prototype to integrate Magic Leap One with magnifying loupe, a calibration process for single eye
- Expected: A user-friendly stereo calibration process to associate the field-of-magnified-vision, the HMD screen space and the task workspace
- Maximum: Evaluation results of proposed system with a comparative phantom study

Schedule:

Activities	Start Date	End Date	Status
Literature review on previous work and technical solutions	2/11/2019	2/18/2019	Complete
Plan proposal and presentation	2/11/2019	2/18/2019	Complete
Written project plan	3/4/2019	3/7/2019	Complete
Design HMD mount for loupes	2/18/2019	3/5/2019	Ongoing

3D print and manufacture mount	3/4/2019	3/8/2019	Ongoing
Develop HMD calibration methods for single eye	3/5/2019	3/25/2019	Ongoing
Develop stereo HMD calibration methods	3/11/2019	4/8/2019	Not Started
Identify a practical sub-task in dental procedure	3/25/2019	4/8/2019	Not Started
Conduct a comparative phantom study	4/15/2019	5/6/2019	Not Started
Prepare for final report and poster	5/1/2019	5/9/2019	Not Started

Dependencies:

Dependencies	Solution	Alternative	Estimated Date
Access to Magic Leap One	Ask Dr. Navab for access	Ask Ehsan for Epson BT-300	**Mar 8 (Delayed)**
Access to surgical loupe	Ask Long for access		**Resolved**
Access to CAD Software (SolidWorks or PTC Creo)	Download from JHU software catalog		**Resolved**
Access to 3D printer	Access to LCSR 3D printer	Use DMC 3D printer	**Resolved**

Management Plan:

- I have weekly meetings with my project mentors to discuss our progress and obtain advice and direction on the project.
- All the source code will be stored on a GitHub private repository
- Design document, project report and additional project files will be stored on JH Box

Reading List:

[1] James, Teresa, and Alan SM Gilmour. "Magnifying loupes in modern dental practice:

an update." Dental update 37.9 (2010): 633-636.

[2] Martin-Gonzalez, Anabel, et al. “Head-Mounted Virtual Loupe with Sight-Based Activation for Surgical Applications.” 2009 8th IEEE International Symposium on Mixed and Augmented Reality, 2009.

[3] Tuceryan, Mihran, Yakup Genc, and Nassir Navab. "Single-Point active alignment method (SPAAM) for optical see-through HMD calibration for augmented reality." Presence: Teleoperators & Virtual Environments 11.3 (2002): 259-276.

[4] L. Qian, A. Winkler, B. Fuerst, P. Kazanzides and N. Navab, "Reduction of Interaction Space in Single Point Active Alignment Method for Optical See-Through Head-Mounted Display Calibration," 2016 IEEE International Symposium on Mixed and Augmented Reality (ISMAR-Adjunct), Merida, 2016, pp. 156-157.

[5] L. Qian, E. Azimi, P. Kazanzides et al., "Comprehensive tracker based display calibration for holographic optical see-through head-mounted display", 2017.

[6] C. B. Owen, Ji Zhou, A. Tang and Fan Xiao, "Display-relative calibration for optical see-through head-mounted displays," Third IEEE and ACM International Symposium on Mixed and Augmented Reality, Arlington, VA, USA, 2004, pp. 70-78.

[7] Y. Itoh and G. Klinker, "Interaction-free calibration for optical see-through head-mounted displays based on 3D Eye localization," 2014 IEEE Symposium on 3D User Interfaces (3DUI), Minneapolis, MN, 2014, pp. 75-82.

[8] E. Azimi, L. Qian, P. Kazanzides, and N. Navab. Robust optical see-through head-mounted display calibration: Taking anisotropic nature of user interaction errors into account. In Virtual Reality (VR). IEEE, 2017.

[9] Figl M., Birkfellner, W., Hummel, J., et. al. "Current Status of the Varioscope AR, a Head-Mounted Operating Microscope for Computer-Aided Surgery". Proc. of IEEE and ACM International Symposium on Augmented Reality (ISAR'01). New York. 2001.

[10] W. Birkfellner, M. Figl, K. Huber, F. Watzinger, F. Wanschitz, J. Hummel, R. Hanel, W. Greimel, P. Homolka, R. Ewers, and H. Bergmann. A Head-Mounted Operating Binocular for Augmented Reality Visualization in Medicine – Design and Initial Evaluation. IEEE Trans Med Imaging, 21(8), 2002.

[11] Figl M, Ede C, Birkfellner W, Hummel J, Seemann R, Bergmann H, “Automatic Calibration of an Optical See Through Head Mounted Display for Augmented Reality Applications in Computer Assisted Interventions,” AMI-ARCS 2004.

[12] Kuchta J, Simons P, “Spinal Neurosurgery with the Head-mounted “Varioscope” Microscope”, Technical Note, Cent Eur Neurosurg, 70:98-100, 2009.