Seminar Paper Summary

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Project Overview

The objectives of this project are to 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.

Paper Selection

The paper "A Head-Mounted Operating Binocular for Augmented Reality Visualization in Medicine – Design and Initial Evaluation" [1] is chosen because it presents a complete workflow from modifying the existing HMD to the assessment of the accuracy achievable with a standard photogrammetric calibration method for various zoom factors and working distances of the HMD. The end goal of this work is also to develop an HMD prototype that provides AR visualization in the optical magnified view. Reading this paper can help me understand the common challenges, the calibration method that can be used for my project.

Significance

The paper provides a creative solution to integrate AR-display system into a well-accepted operating microscope. The accuracy achieved in the experiments is sufficient for a wide range of computer-aided surgery applications. It serves as a baseline and good reference for my project.

Background

<u>Intra-operative use of a head-mounted microscope:</u> Two neuro surgeon reports that between December 2006 and March 2008, 10 cases of micro neurosurgical spinal operations were performed using a head mounted microscope called "Varioscope" [2]. There were no technical failures and no intra-operative adverse events that could be attributed to the optical system, therefore recommended by these two surgeons.

<u>Augmented reality:</u> Augmented reality (AR) refers to the overlay of computer-generated graphics over a real-world scene. Typically, a device such as a head-mounted display (HMD) is used for AR. The clinical benefit is the fact that the surgeon can concentrate on the operating field rather than looking at a monitor.

<u>Photogrammetric calibration:</u> The basic problem in AR is to determine a transformation from 3D world coordinates to HMD's 2D screen coordinates. This can be solved by photogrammetric calibration. The calibration results are 11 parameters which are:

- 6 extrinsic parameters describing the global rigid-body transformation relating the world coordinate system to the HMD's coordinate system:

  - 3 Euler angles, 3 translation parameters
- 5 intrinsic parameters describing the projective properties of the display:
  - f, the effective focal length of the optical system
  - k_1, the lens distortion coefficient
  - S_x, uncertainty scale factor for x, due to TV camera scanning and acquisition timing error
  - (C_x, C_y) the coordinates of the display's center

Methods

- **Design**
  This commercially available device Varioscope is a head-mounted, lightweight operating binocular developed and produced by Life Optics, Vienna, Austria. This device was modified for AR visualization. An additional image from a miniature computer display is being projected into the focal plane of the Varioscope's objective lens. The merged image can be viewed through the ocular of the Varioscope. The computer-generated images are displayed on two miniature LCD displays with VGA resolution.

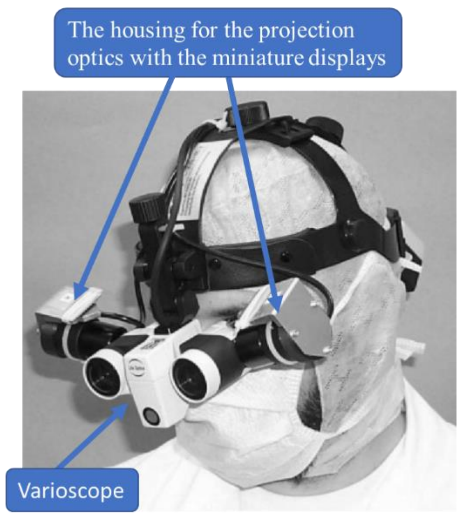

Figure 1 Design of Varioscope AR

- **Calibration**
  The paper employed Tsai's camera calibration method [3] to solve the problem of relating 3D position information to the 2D coordinate system of the HMD's display. Tsai's method requires the input of 2D and 3D correspondences, during the measurements, a crosshair at a defined 2D screen position is displayed on the HMD by the miniature display system. The crosshair was aimed at the center of a grid point on the calibration grid, and the 3D coordinate of the grid point is recorded.

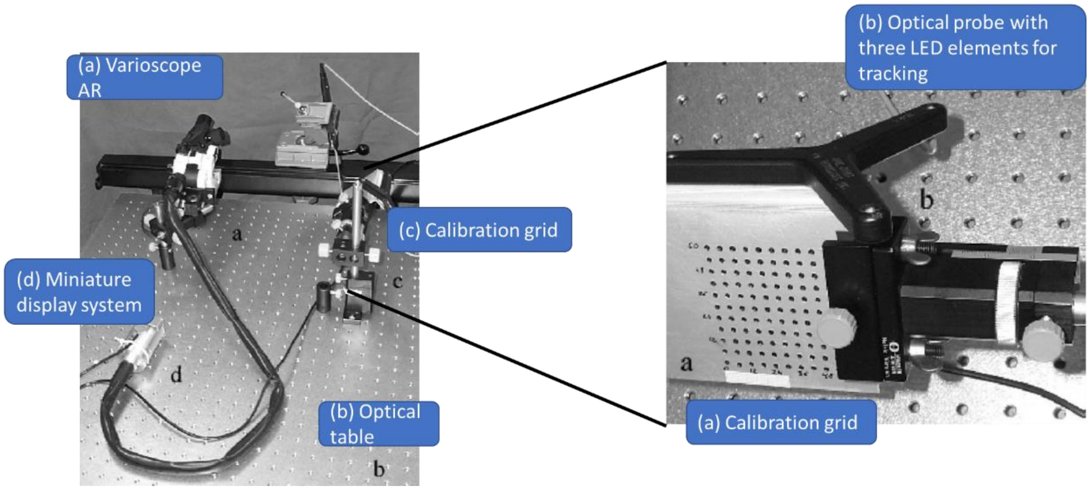

Figure 2 Calibration setup

After calibration, 6 extrinsic parameters and 5 intrinsic parameters can be determined.

- **Evaluation**
  In addition to calibration error, the paper also evaluated the overall error with the setup shown below:

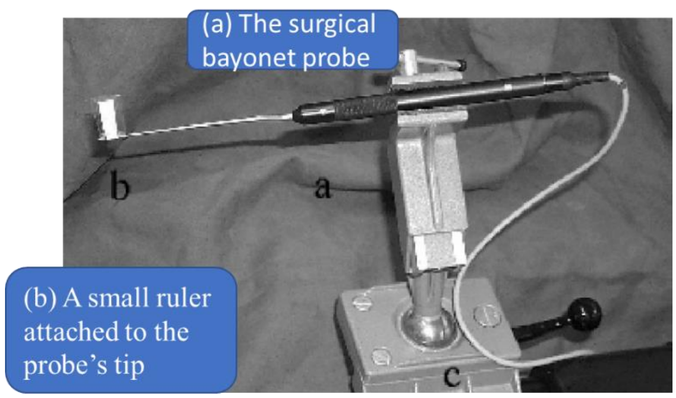

Figure 3 The surgical bayonet probe

Attached to the probe's tip is a small ruler which allows for measuring the difference between the visual position of the probe's tip and its position after transformation to the HMD's display in millimeters.

Results

In a series of 16 calibrations with varying zoom factors and object distances, a steady relationship between the distance of the viewed object (the grid) and the effective focal length can be seen. Therefore, accurate measurement of the Varioscope's current zoom factor in real time, can be used to assign and use the correct calibration dataset.

The mean calibration error was found to be 1.24 ± 0.38 pixels or 0.12 ± 0.05 mm for a 640 x 480 display. Maximum error accounted for 3.33 ±1.04 pixels or 0.33 ± 0.12 mm.

The overall error is less than 1 mm in 56% of all cases. For the remaining cases, error was below 2 mm.

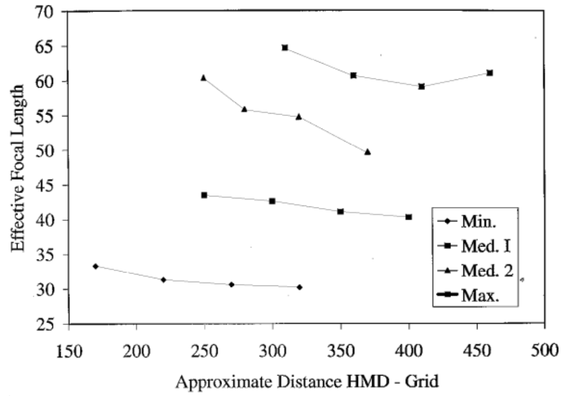

Figure 4 The effective focal length for 4 zoom factors vs approximate distance between HMD and the grid

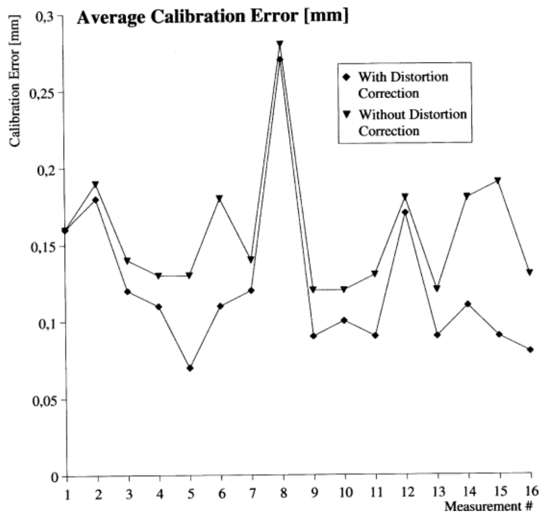

Figure 5 Average calibration error

Overall Assessment

Pros: The paper outlines a complete workflow from design to evaluation of the modified HMD. It provides a clear and detailed description of the hardware specifications and programmatic implementation. The high-accuracy result they achieved is sufficient for a wide range of surgery applications.

Cons: However, the graphics in the paper are hard to read: they are black and white and low-resolution. Although the paper did provide references for the calibration algorithm they used and the error they evaluated, there is not much description of mathematics, which damages the credibility of the paper. Finally, the paper did not mention the effect of users' interpupillary distance (IPD), and no user study is conducted.

Conclusion and Relevance

In conclusion, this paper presented an HMD prototype by modifying the existing operating binocular for AR visualization. It provides the complete workflow from modification, calibration to evaluation. The high-accuracy result it achieves is suitable for a wide range of computer-aided surgery.

I will adopt part of the calibration method for my project with user-in-the-loop design, since each user have different IPD.

Reference

[1] 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.

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

[3] R. Tsai, "A versatile camera calibration technique for high-accuracy 3D machine vision metrology using off-the-shelf TV cameras and lenses," in IEEE Journal on Robotics and Automation, vol. 3, no. 4, pp. 323-344, August 1987.