JOHNS HOPKINS WHITING SCHOOL of ENGINEERING

LABORATORY FOR Computational Sensing + Robotics

Project 11: Augmented Reality Magnifying Loupe for Surgery

Seminar Presentation

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Project Summary

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

Paper

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.

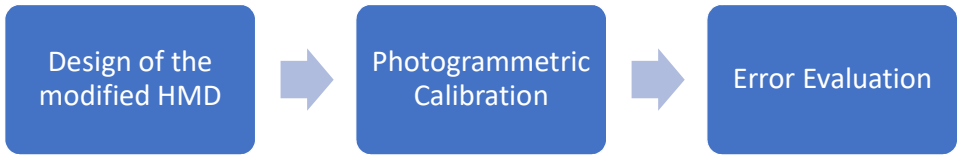
Relevance & Difference:

	W. Birkfellner et al., 2002	Augmented Reality Magnifying Loupe for Surgery
HMD prototype	Modify existing operating binocular for AR visualization	Modify existing OST- HMD for optical magnification

Significance

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

Summary



Key Results

Mean calibration error	Maximum calibration error	Overall error
1.24±0.38 pixels or 0.12±0.05 mm	3.33±1.04 pixels or 0.33±0.12 mm	< 1mm for 56% cases < 2mm for 44% cases

Background

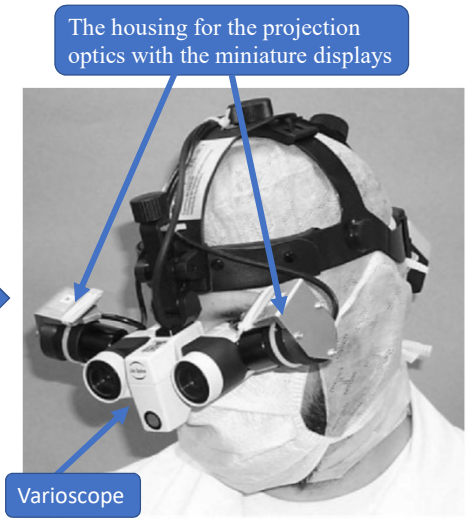
- Intra-operative use of a head-mounted microscope ("Varioscope")
  - Technical details: 300 g, magnification range: 3.6x to 7.2x, automatic focus
  - 10 cases of micro neurosurgical spinal operations[1]
- Photogrammetric calibration: relating 3D to 2D
  - 11 parameters: 6 extrinsic, 5 intrinsic
  - 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.

[1] Kuchta J et al., 2009

Method
Design

Varioscope by Life Optics, Vienna, Austria[1]

Modification



Prototype of the Varioscope AR[2].

[1] Image Source: https://www.micromo.com/applications/optics-photonic-applications/life-optics-vario
[2] W. Birkfellner et al., 2002

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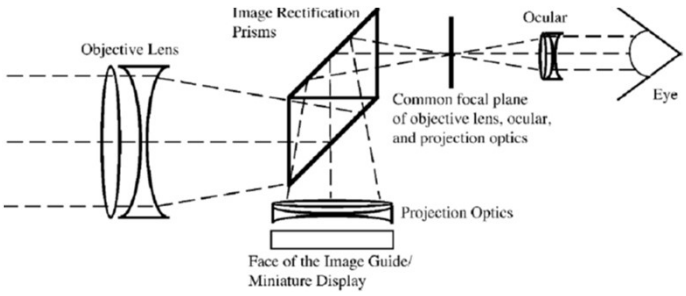
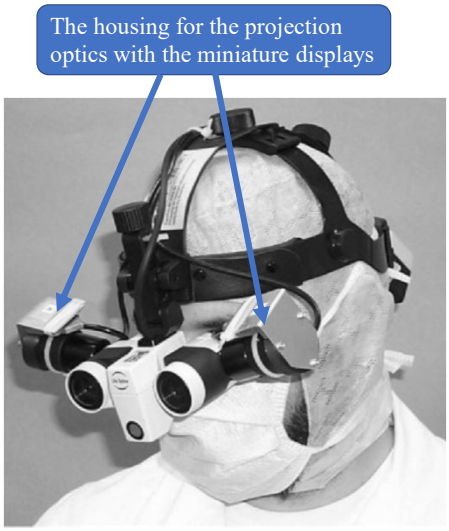
Method
Design



The principle of image overlay in the Varioscope AR[1]



Prototype of the Varioscope AR[1].

[1] W. Birkfellner et al., 2002

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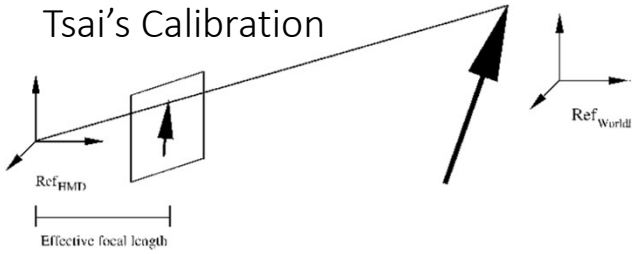
Method

Tsai's Calibration



- 6 extrinsic parameters:
  - 3 Euler angles, 3 translation parameters
- 5 intrinsic parameters:
  - f , the effective focal length.
  - k_1 , the lens distortion coefficient
  - S_x , uncertainty scale factor for x, due to TV camera scanning and acquisition timing error (not used)
  - (C_x, C_y) the coordinates of the display's center.

(X_w, Y_w, Z_w) 3D world coordinates

Step 1
Rigid body transformation from (X_w, Y_w, Z_w) to (X, Y , Z)
Parameters to be calibrated: R, T

(X, Y, Z) 3D camera coordinates

Step 2
Perspective projection with pin hole geometry
Parameters to be calibrated: f

(X_u, Y_u) Ideal undistorted image coordinate

Step 3
Radial lens distortion
Parameters to be calibrated: k_1

(X_d, Y_d) Distorted image coordinate

Step 4
TV scanning, Sampling, computer acquisition
Parameter to be calibrated: uncertainty scale factor s_x

(X_f, Y_f) Computer image coordinate in frame memory

[1] W. Birkfellner et al., 2002
[2] R. Tsai, 1987

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Method

Tsai's Calibration

[R, T, f, k1] = Tsai(2D - 3D correspondences, dx, dy, Ncx, Nfx, Cx, Cy)

Stage 1 --- Compute 3D Orientation, Position (x and y):

Stage 2 --- Compute Effective Focal Length, Distortion Coefficients, and z Position:

a) Compute an approximation of f and Tz by ignoring lens distortion

b) Compute the exactly solution for f, Tz, k1 using standard optimization scheme such as gradient descent

	Description
dx	the center to center distance between adjacent sensor elements in X (scan line) direction
dy	the center to center distance between adjacent CCD sensor in the Y direction
Ncx	the number of sensor elements in the X direction
Nfx	the number of pixels in a line as sampled by the computer
(Cx, Cy)	the coordinates of the display's center (Manually determined)

[1] R. Tsai, 1987

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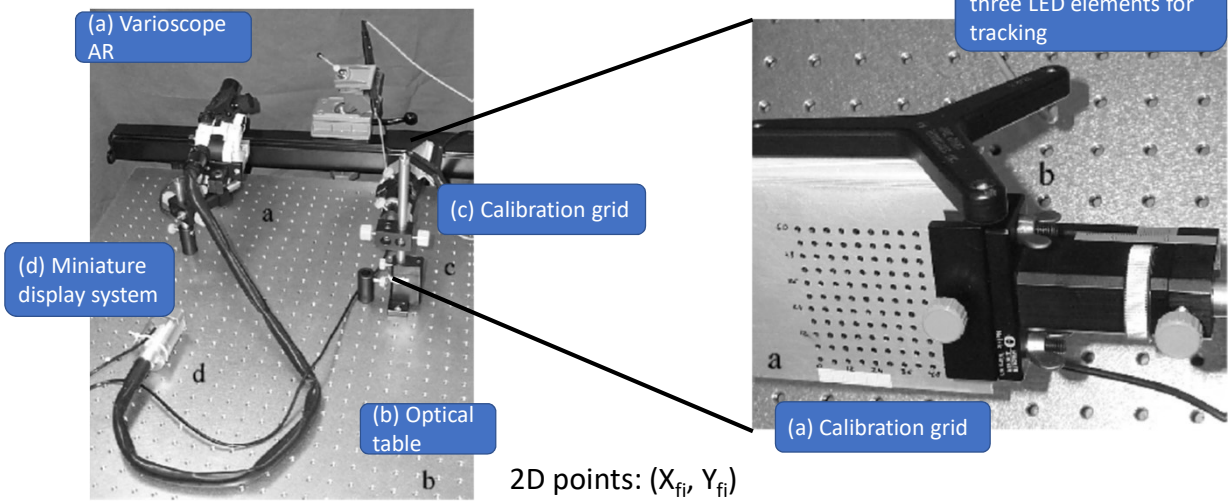
Experiment I
Calibration



2D points: (X_{fi}, Y_{fi})
3D points: $(X_i, Y_i, 0)$

[1] W. Birkfellner et al., 2002

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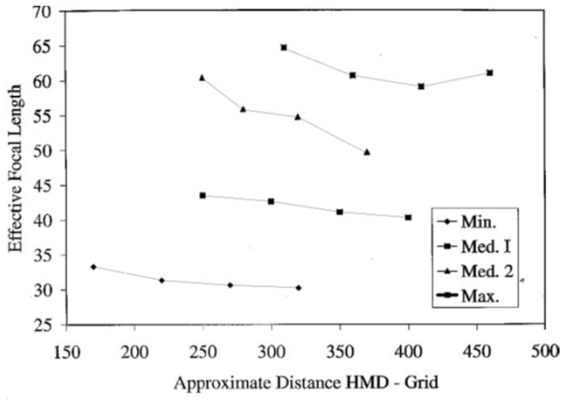
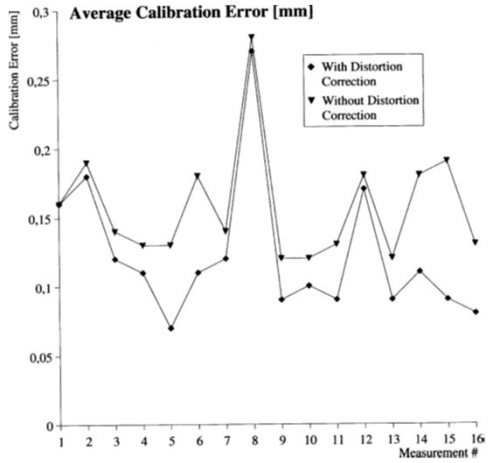
Experiment I
Calibration

16 measurement series: 4 zoom factors and different distances between optics and grid were performed.





[1] W. Birkfellner et al., 2002

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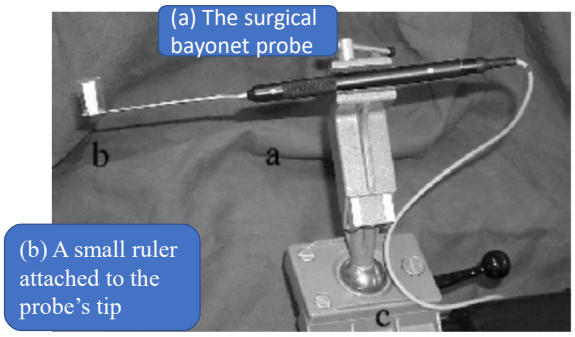
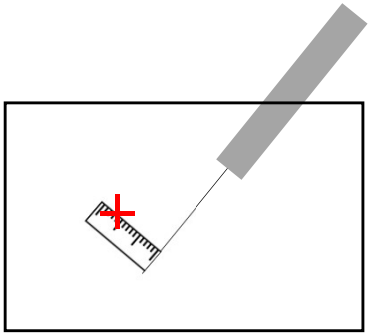
Experiment II

Overall Error

3 measurements were taken for each calibration, resulting in a total of 48 measurements for the 16 calibration procedures.





A schematic of error measurement

Overall Error

< 1mm for 56% cases
< 2mm for 44% cases

[1] W. Birkfellner et al., 2002

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Assessment

Pros

- Complete workflow from design to evaluation
- Clear description of hardware specifications and programmatic implementation
- High accuracy result

Cons

- Unclear pictures:
  - Black and white, low-resolution
- Not much description of mathematics and algorithm
- Not consider users IPD
- No user study conducted

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Conclusion

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

References

- [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.