Automatic User Calibration for Gaze-Tracking Systems by Looking into the Distance

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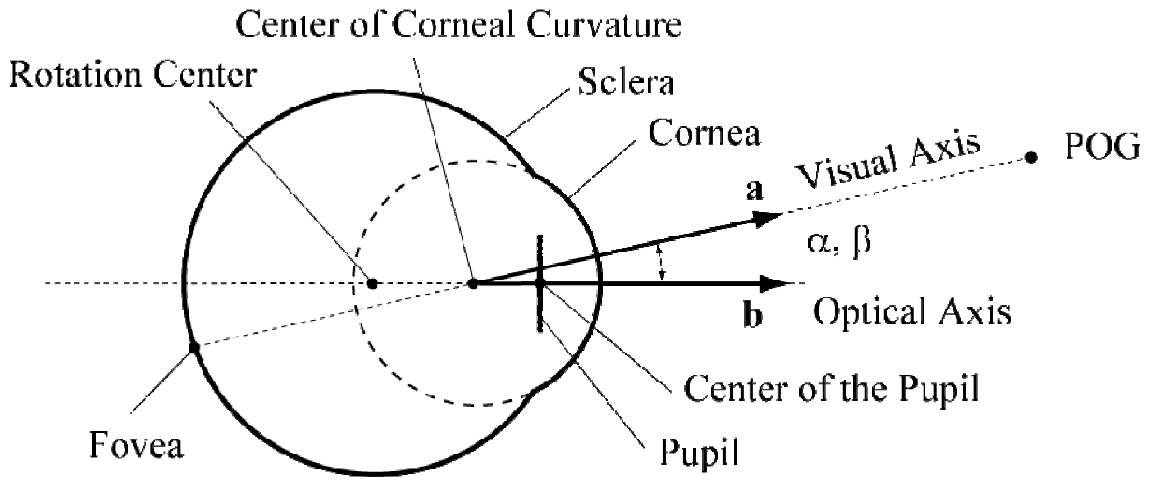
Introduction

- Gaze-tracking technology is widely used in a variety of areas,
  - Psychological experiments
    - Analysis of driver behavior, advertisements, etc.
  - User interfaces
    - Computer input, etc.
- Commercially available gaze tracking system can be used after personal calibration in which the user gazes at several points.
- Personal calibration is still a problem in the use of gaze trackers.

Estimation of the optical axis of eye (Single point personal calibration)

- Several method estimate the “optical axis” of the eye without personal calibration,
  - Using geometric eye model and calibrated cameras.

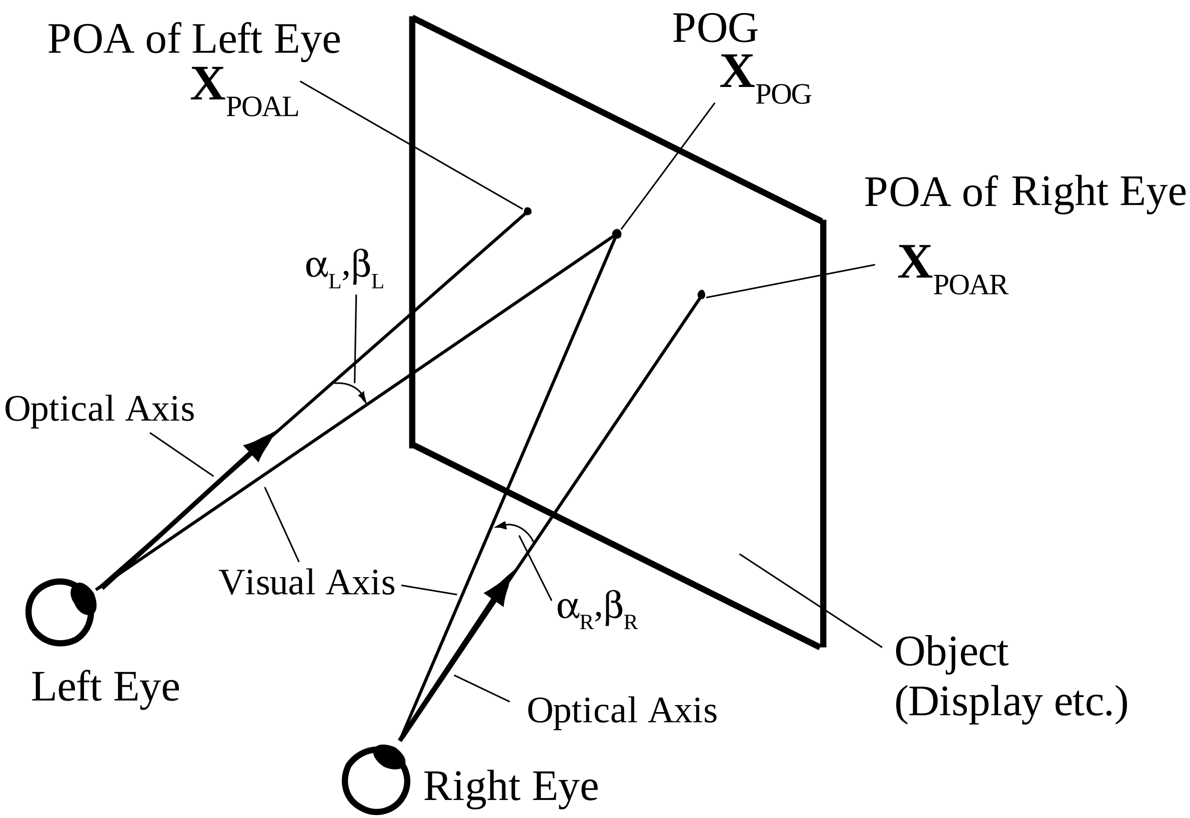


- If you want to estimate the point of gaze precisely, you must estimate the “visual axis” of the eye
- Therefore, the offset between the optical and visual axes of the eye (α, β) must be estimated.
  - → a single point personal calibration is necessary.

(Guestrin & Eizenman, 2006; Nagamatsu, Kamahara, & Tanaka, 2008; Shih & Liu, 2004; Villanueva & Cabeza, 2008)

Automatic personal calibration for gaze tracker on computer display

- Some studies propose automatic personal calibration methods where the user gazes at "a computer display" for a while.
  - (1) Estimate the optical axis of "both the eyes"
  - (2) Estimate α_L, β_L, α_R, and β_R under the condition that the visual axes of both the eyes intersect on the display.

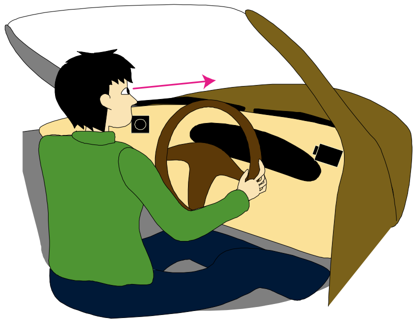


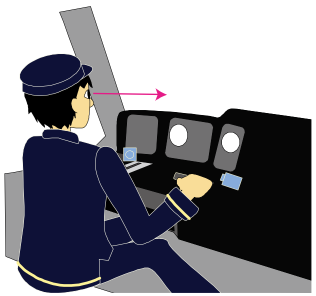
(Model & Eizenman, 2010; Ueki, Sugano, Nagamatsu, Kamahara, & Tanaka, 2012)

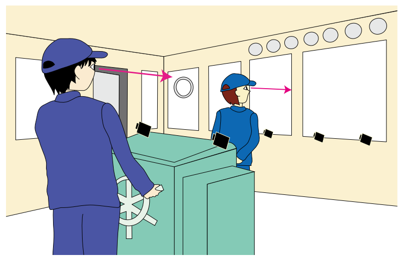
In the case of gaze tracking while driving (car, train, ship etc.)

- The driver spends most of their time looking into the distance.
- Therefore, it is more appropriate for the system to be calibrated when the user is "looking into the distance. "

- If we constantly measure the gaze of the driver, we can use the information in active safety systems, such as alarms or vehicle stopping devices.







In this study,

- We propose an automatic personal calibration method for gaze trackers that simply requires the user to look into the distance for a while.

Proposed method

Proposed method

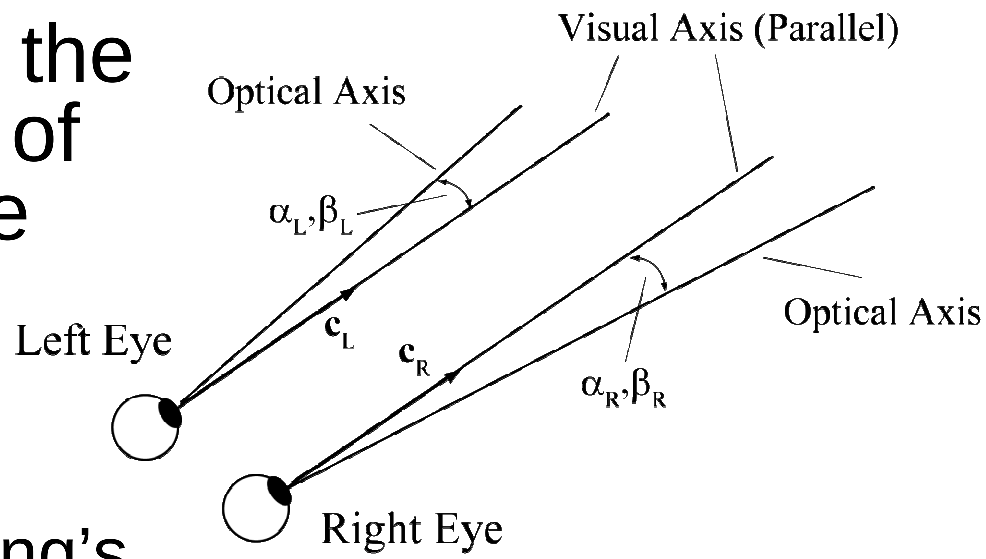
- When the user looks into the distance, the visual axes of both eyes ($\mathbf{c}_L$ and $\mathbf{c}_R$) are parallel.

$$\mathbf{c}_L \cdot \mathbf{c}_R = 1$$

$\mathbf{c}$ is calculated based on Listing's law as a function of α, β

$$\mathbf{c}_L = \mathbf{c}_L(\alpha_L, \beta_L)$$

$$\mathbf{c}_R = \mathbf{c}_R(\alpha_R, \beta_R)$$



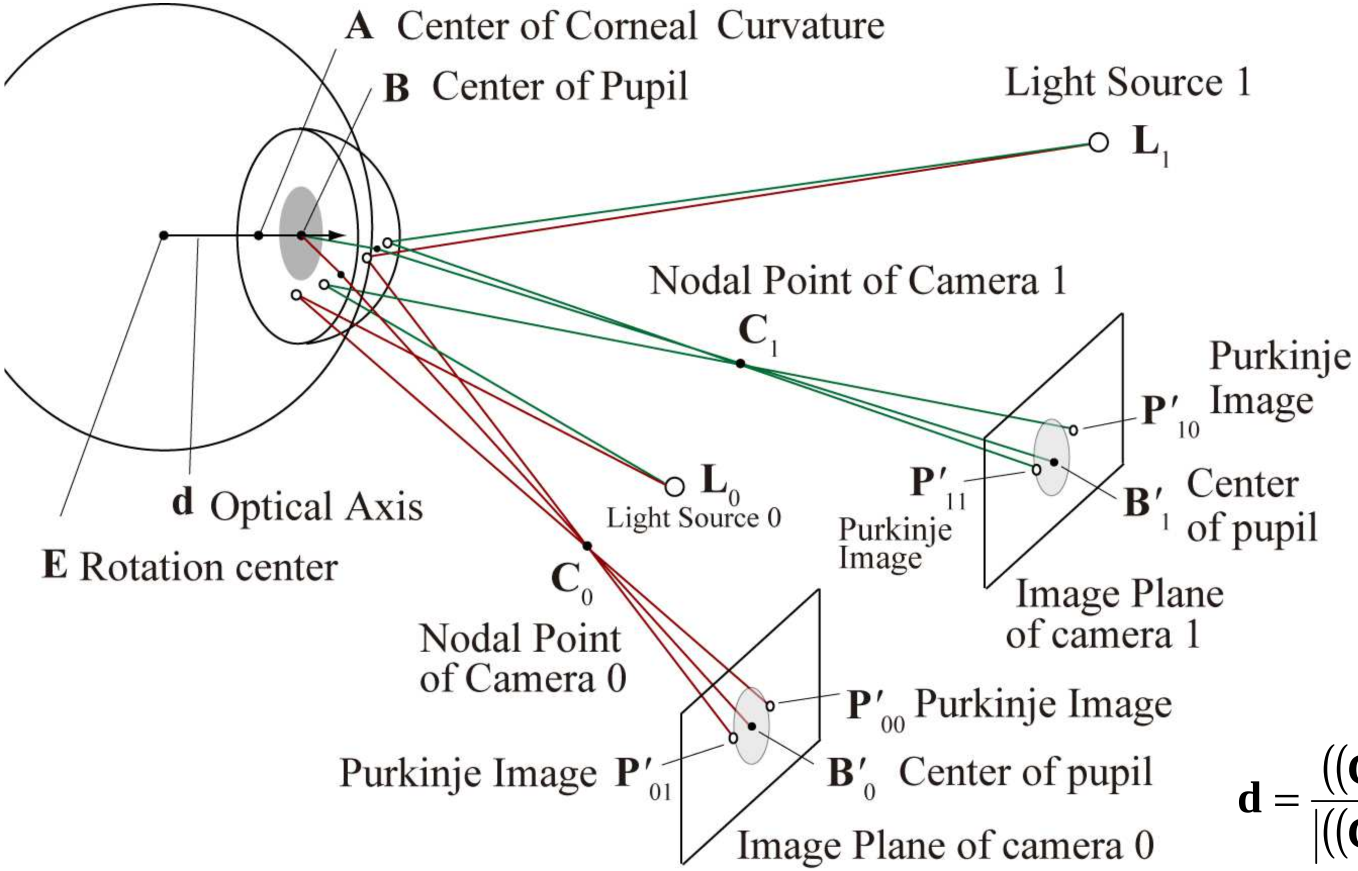
$\mathbf{c}_L$: visual axis of left eye (unit vector)
$\mathbf{c}_R$: visual axis of right eye (unit vector)

We have 4 unknown parameters (α_L, β_L, α_R, and β_R). If the user looks into four directions, we can obtain 4 equations and can calculate α_L, β_L, α_R, and β_R.

Calculation of the optical axis

Calculation of the optical axis of the eye

- Using 2 light sources and 2 calibrated cameras



$$\begin{cases} \{(\mathbf{P}'_{01}-\mathbf{C}_0)\times(\mathbf{L}_1-\mathbf{C}_0)\}\cdot(\mathbf{X}-\mathbf{C}_0)=0 \\ \{(\mathbf{P}'_{10}-\mathbf{C}_1)\times(\mathbf{L}_0-\mathbf{C}_1)\}\cdot(\mathbf{X}-\mathbf{C}_1)=0 \\ \{(\mathbf{P}'_{00}-\mathbf{C}_0)\times(\mathbf{L}_0-\mathbf{C}_0)\}\cdot(\mathbf{X}-\mathbf{C}_0)=0 \\ \{(\mathbf{P}'_{11}-\mathbf{C}_1)\times(\mathbf{L}_1-\mathbf{C}_1)\}\cdot(\mathbf{X}-\mathbf{C}_1)=0 \end{cases}$$

$\Rightarrow$ **A**

$$\mathbf{d}=\frac{((\mathbf{C}_0-\mathbf{B}'_0)\times(\mathbf{A}-\mathbf{C}_0))\times((\mathbf{C}_1-\mathbf{B}'_1)\times(\mathbf{A}-\mathbf{C}_1))}{\|((\mathbf{C}_0-\mathbf{B}'_0)\times(\mathbf{A}-\mathbf{C}_0))\times((\mathbf{C}_1-\mathbf{B}'_1)\times(\mathbf{A}-\mathbf{C}_1))\|}$$

(Nagamatsu, Kamahara, & Tanaka, CHI2009)

Eye rotation based on Listing's law

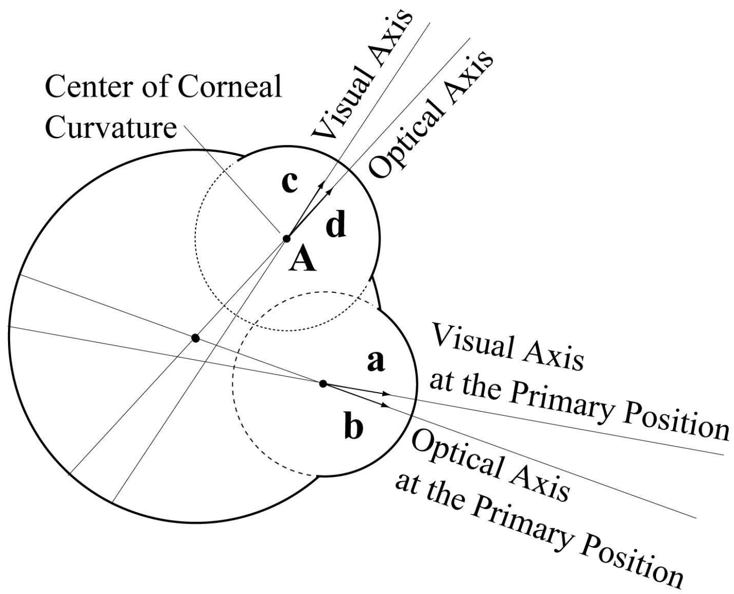
To express **c** by α and β

Eye rotation based on Listing's law

- Listing's law

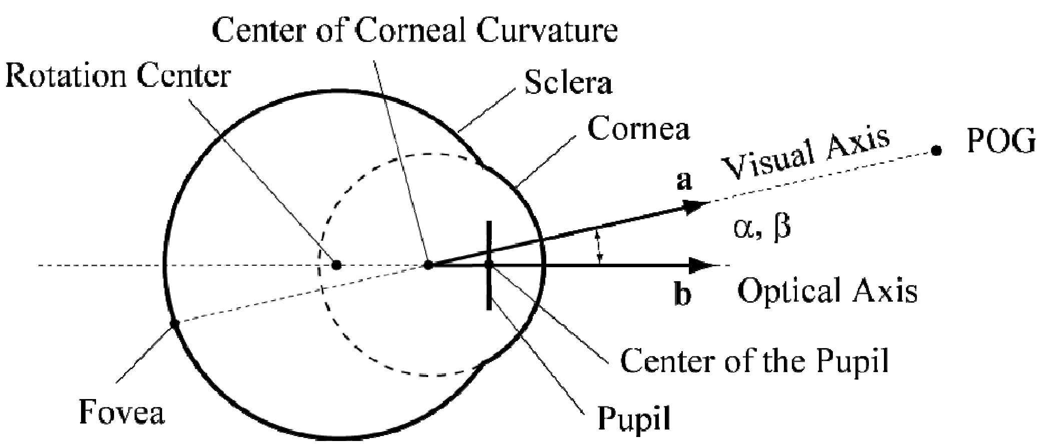
  $$\mathbf{a}\cdot\mathbf{l}=\mathbf{c}\cdot\mathbf{l}=0$$

- **a** is approximated by the direction of the face.
- **b** is written as using α and β



$$\mathbf{b}=\begin{pmatrix}1 & 0 & 0\\ 0 & \cos\beta & -\sin\alpha\\ 0 & \sin\beta & \cos\beta\end{pmatrix}\begin{pmatrix}\cos\alpha & 0 & \sin\alpha\\ 0 & 1 & 0\\ -\sin\alpha & 0 & \cos\alpha\end{pmatrix}\mathbf{a}.$$

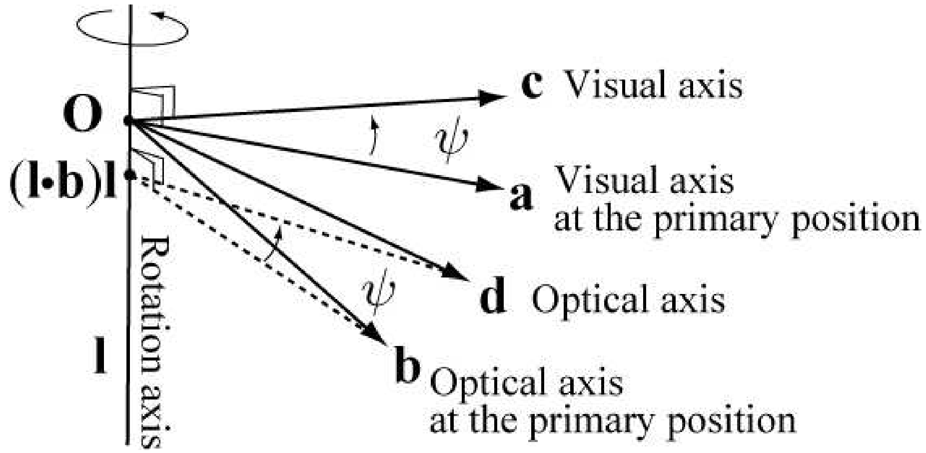
$\mathbf{l}$: axis of eye rotation



- Axis and angle of eye rotation when eye rotates from **a** to **c**

$$\mathbf{l} = \frac{\mathbf{a}\times(\mathbf{d}-\mathbf{b})}{\left\|\mathbf{a}\times(\mathbf{d}-\mathbf{b})\right\|}$$

$$\psi = \arccos\left(\frac{(\mathbf{b} - (\mathbf{l}\cdot\mathbf{b})\mathbf{l})\cdot(\mathbf{d} - (\mathbf{l}\cdot\mathbf{b})\mathbf{l})}{\left\|\mathbf{b} - (\mathbf{l}\cdot\mathbf{b})\mathbf{l}\right\|\left\|\mathbf{d} - (\mathbf{l}\cdot\mathbf{b})\mathbf{l}\right\|}\right)$$



- Visual axis of the eye

$$\mathbf{c} = \mathrm{R}(\psi, \mathbf{l})\mathbf{a}$$

a and **d** are known.
b is expressed as a function of α and β.

c is expressed as a function of α and β

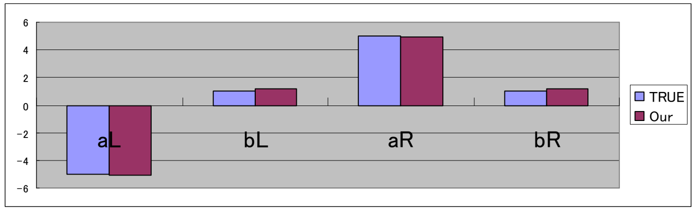
$$\mathbf{c} = \mathbf{c}(\alpha, \beta)$$

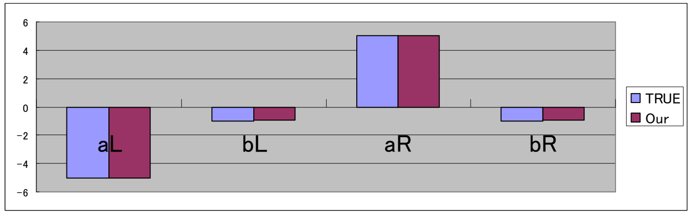
Experiments

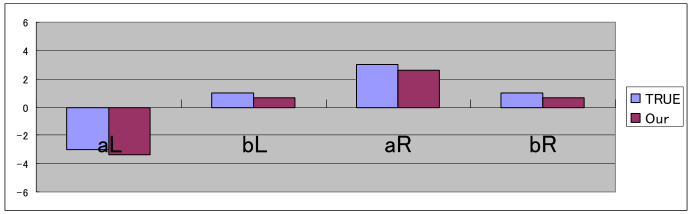
Experiment with simulated data (with noise)

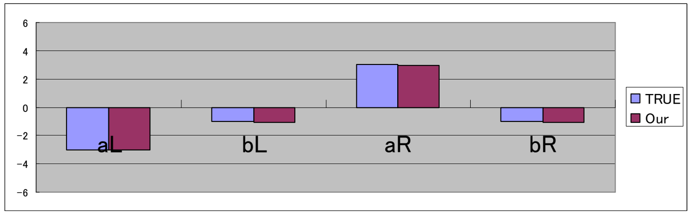
- Simulated data of optical axis of the eye
  - 6 cases of α_L, β_L, α_R, and β_R
  - 25 directions
  - Noise: $\sigma = 0.3°$
  - 60 data /each points
- Parameter estimation
  - Optimization of objective function

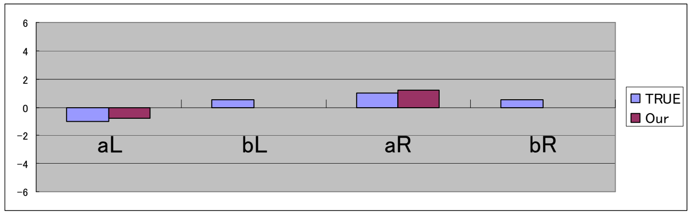
$$F(\alpha_L, \beta_L, \alpha_R, \beta_R) = \sum_i \left| \mathbf{c}_{Li}(\alpha_L, \beta_L) \cdot \mathbf{c}_{Ri}(\alpha_R, \beta_R) - 1 \right|^2$$

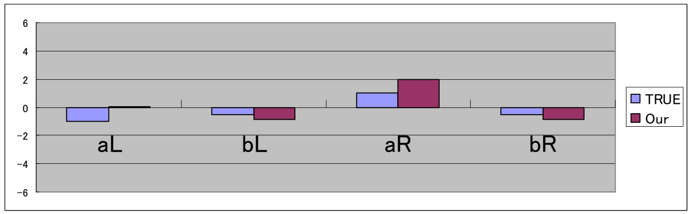






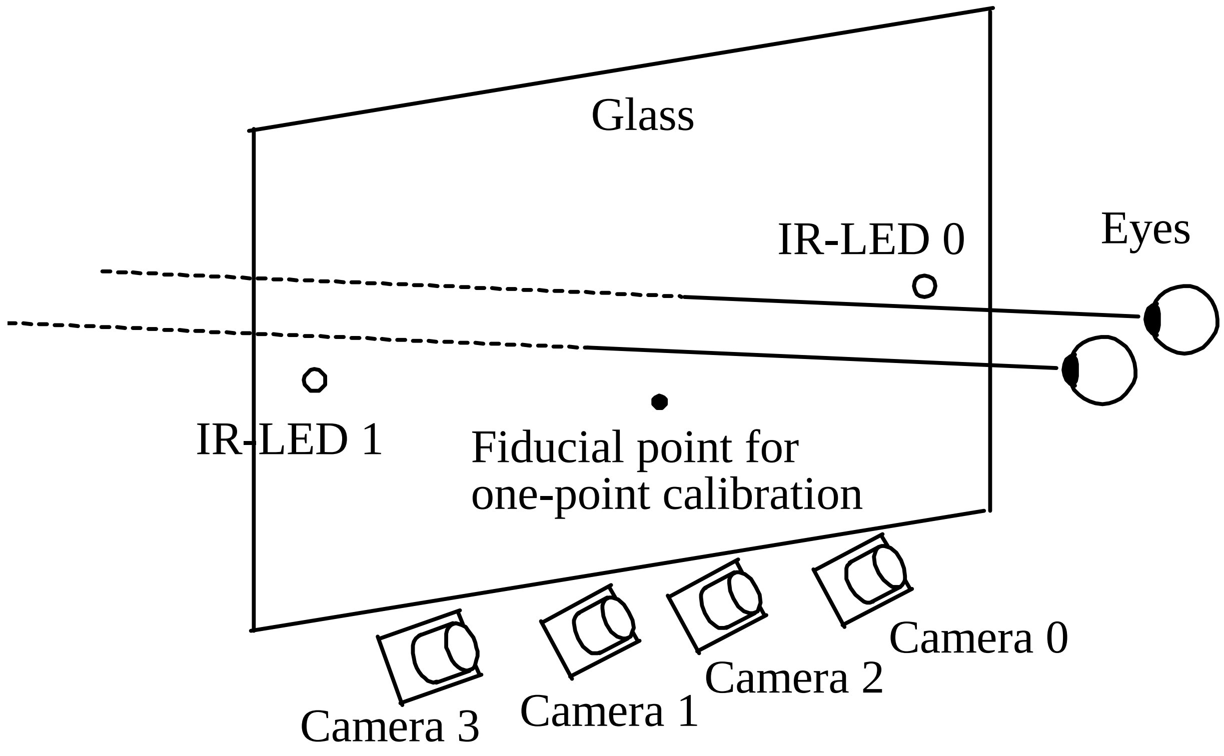






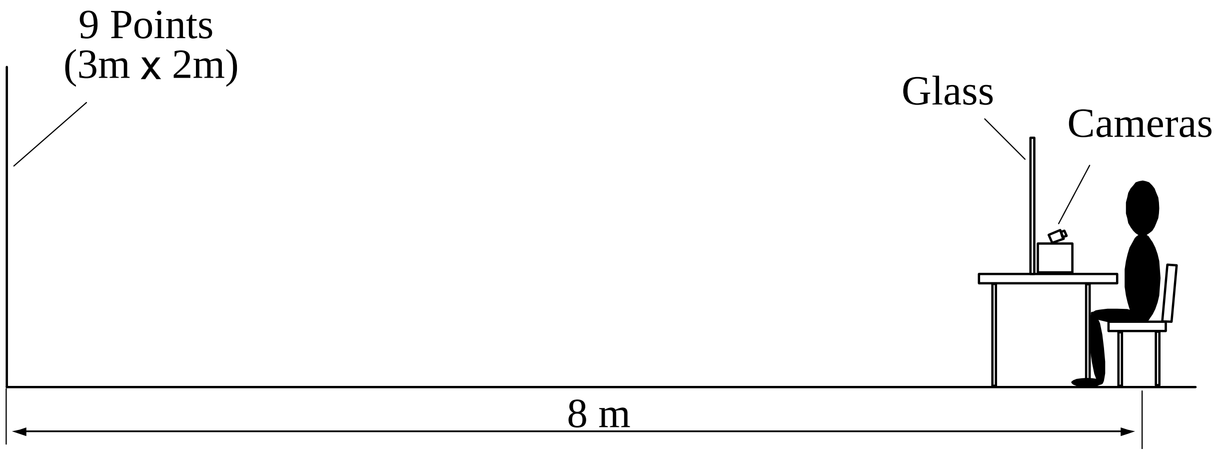
Experiment (real setup)

- Developed system
  - 4 cameras
    - 2 cameras for each eye



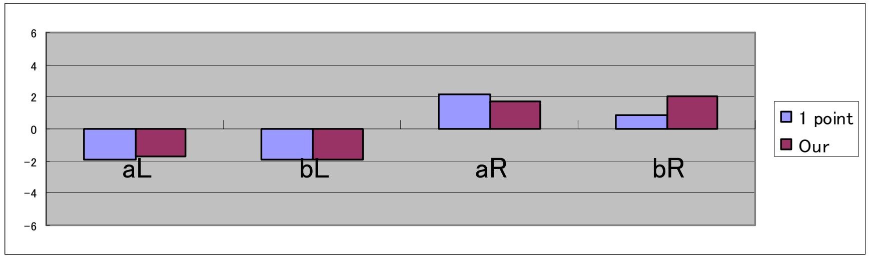
Experiment (real setup)

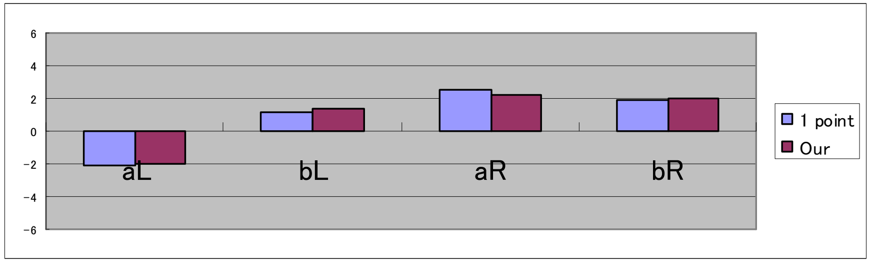
- In laboratory
  - The participants were asked to fixate on 9 points that were arranged within a 3 m (horizontally) by 2 m (vertically) area on the opposite wall of the room.
  - We recorded 30 data points when the participant gazed at each point.
  - 3 participants

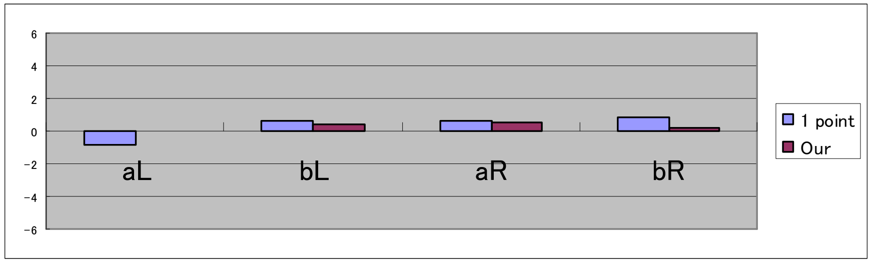


Results

- Search range
  - α_L : -7.0 ~ 0.0° , β_L :-2.0 ~ 2.0° , α_R : 0.0 ~ 7.0° , β_R : -2.0 ~ 2.0°
- Results
  - Comparing to one point calibration method





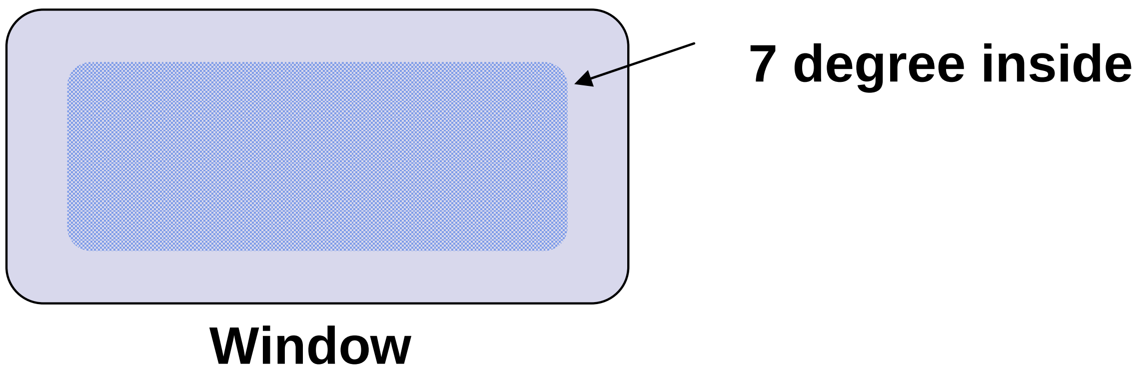


Discussion

- How to detect the user looks distant or nearby objects.

- The optical axis of the eye can be estimated without user calibration.
  - Usually, the estimated optical axis of the eye differs from the visual axis of the eye by up to 7 degrees.

- We only use the data of optical axis of the eye that are 7 degrees or more inside the window in a user calibration phase.



Conclusion

- We proposed an automatic user-calibration method for gaze trackers that operates when users look into the distance.
- This gaze tracker is suitable for drivers of cars, trains, ships, etc., who spend most of their time looking afar.
- We calculated the offset parameter values based on the fact that the visual axes of both eyes are always parallel when the user looks into the distance, irrespective of the direction of gaze.
- We evaluated the proposed method experimentally.