Estimating Focused Object using Corneal Surface Image for Eye-based Interaction

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Motivation

- ☐ Everyone will wear a information system in the near future

Google glass

⇩

Questions

- How to realize intuitive interfaces ?
- How to control these systems ?

There are several hints in human factors

- Speech
- Blink
- Eye movements(Point-of-regard, focused object)
- Hand and Finger etc.

Eye tracker has to be developed as a daily-use device

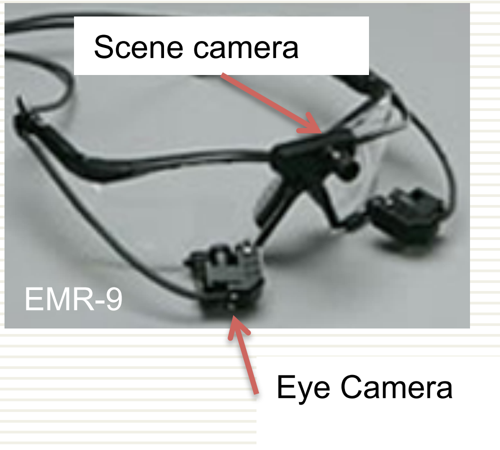
Objective

- Requirements as a daily-use device
  - Heavy → Lightweight
  - Calibration → Calibration free
  - Estimating PoR → Estimating focused objects

Solve these problems toward daily-use device

Approach

- How to solve these problems toward daily-use device
  - Lightweight
  - Calibration free
  - Estimating focused objects



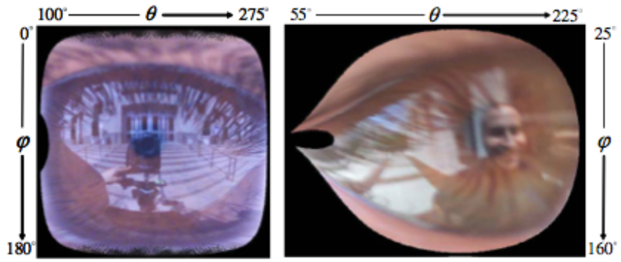
Retrieve the focused object from corneal surface image

Relative Works

Some research groups are also interested in using corneal surface image

- ☐ The World in An Eyes(Nishino et al., 2004)

  Extracting visual information
  within a image of an eye



- ☐ Super-Resolution from Corneal Reflections (Nitschke et al.,2012)

  Extracting high-resolution image by super-resolution

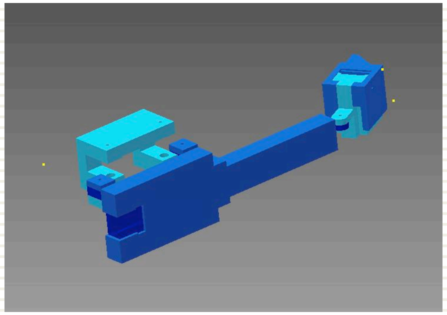
Their works showed the promising results for employing corneal surface image

- Developing a wearable system toward a daily-use device
- Retrieving the focused objects using corneal surface image

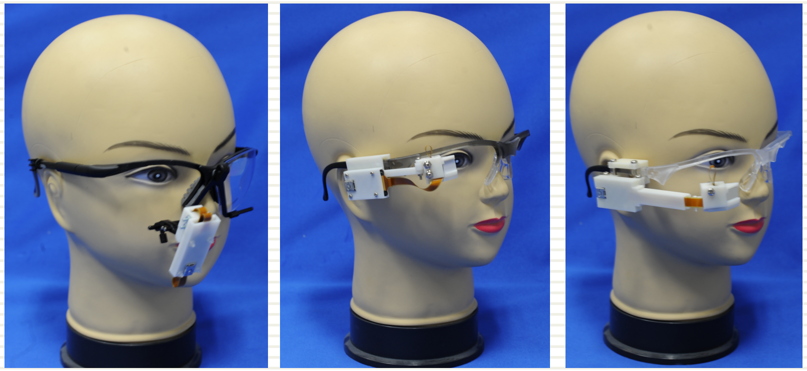
Wearable device for capturing corneal surface image

□ System Configuration

The device consists of an eye camera and prism,
so we achieved lightweight and calibration free.

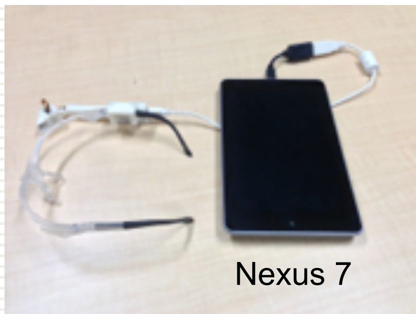


NCM13-J + NCM-USB-C



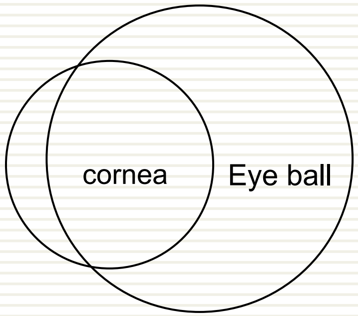
1st 2nd 3rd[current]

	NUM13-J
pickup device	¼inch, CMOS
resolution	SXGA
frame rate	15[fps]

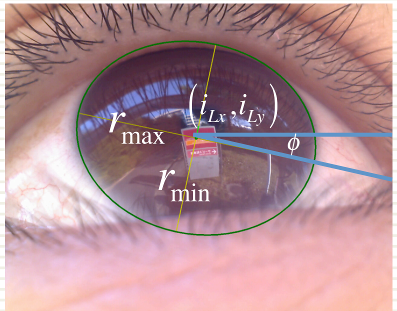


Estimating 3D Corneal Surface

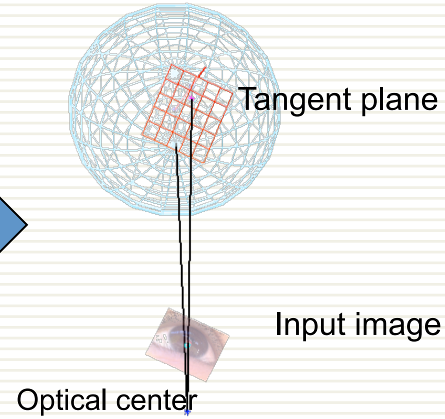
- Assumption: Corneal surface is a part of sphere
- Detecting iris area with elliptical approximation



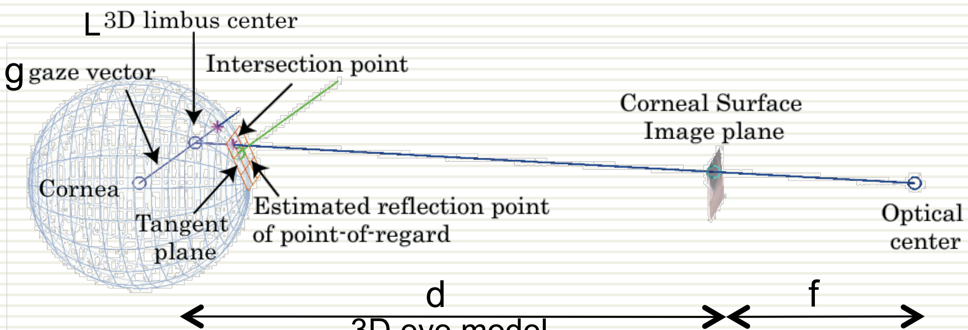
Geometric model
of eye ball



Corneal reflection image



Estimated 3D position



3D eye model

[Nakazawa 2011]

$$d = 5.6 f / r_{\max}$$

$$g = \begin{bmatrix} \sin\tau \sin\phi & -\sin\tau \cos\phi & -\cos\tau \end{bmatrix}^T$$

$$\tau = \pm arc\cos\left(r_{\min} / r_{\max}\right)$$

$$L = \begin{bmatrix} (d+f)\dfrac{i_{Lx} - C_x}{f} & (d+f)\dfrac{i_{Ly} - C_y}{f} & (d+f) \end{bmatrix}^T$$

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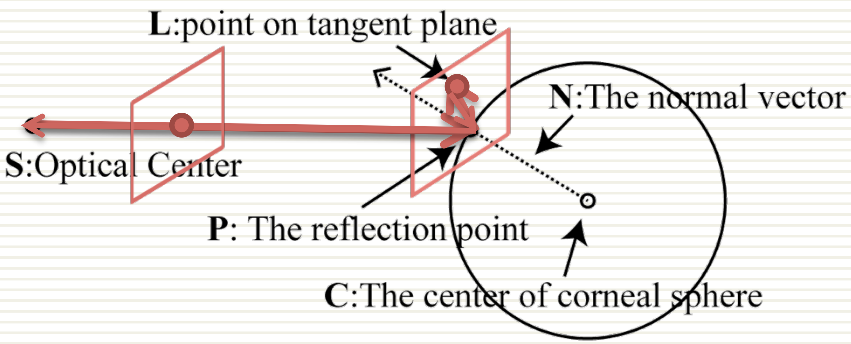
Generating unwarped image using inverse ray tracing

1. Ray is reflected on corneal surface with the perfect specular reflection model.
2. Generating a image of tangent plane as an unwarped image
3. The color of each pixel on the plane is computed using inverse ray tracing.
4. The intersection between the input image and the ray is calculated.



Geometry model of reflection on corneal surface

Constraint

$$4cdy^4 - 4dy^3 + (a + 2b + c - 4ac)y^2 + 2(a - b)y + a - 1 = 0$$

where

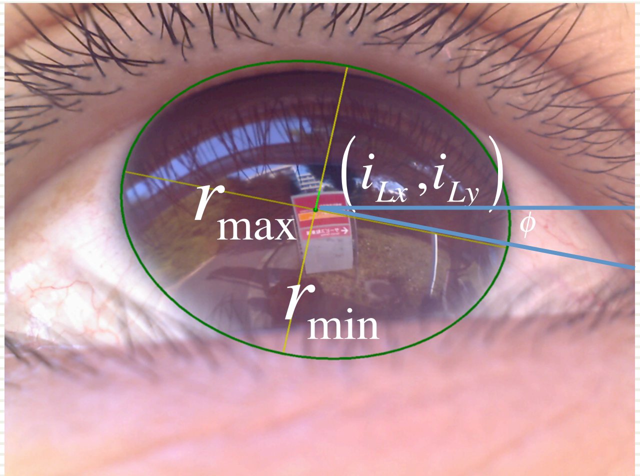
$$a = \mathbf{S}\cdot\mathbf{S}, b = \mathbf{S}\cdot\mathbf{L}, c = \mathbf{L}\cdot\mathbf{L}, d = |\mathbf{S}\times\mathbf{L}|^2$$

Normal Vector and reflection point

$$\mathbf{N} = x\mathbf{S} + y\mathbf{L}$$

$$\mathbf{P} = r_c\mathbf{N} / \|\mathbf{N}\|$$

Result of the generated unwarped image



Corneal surface image

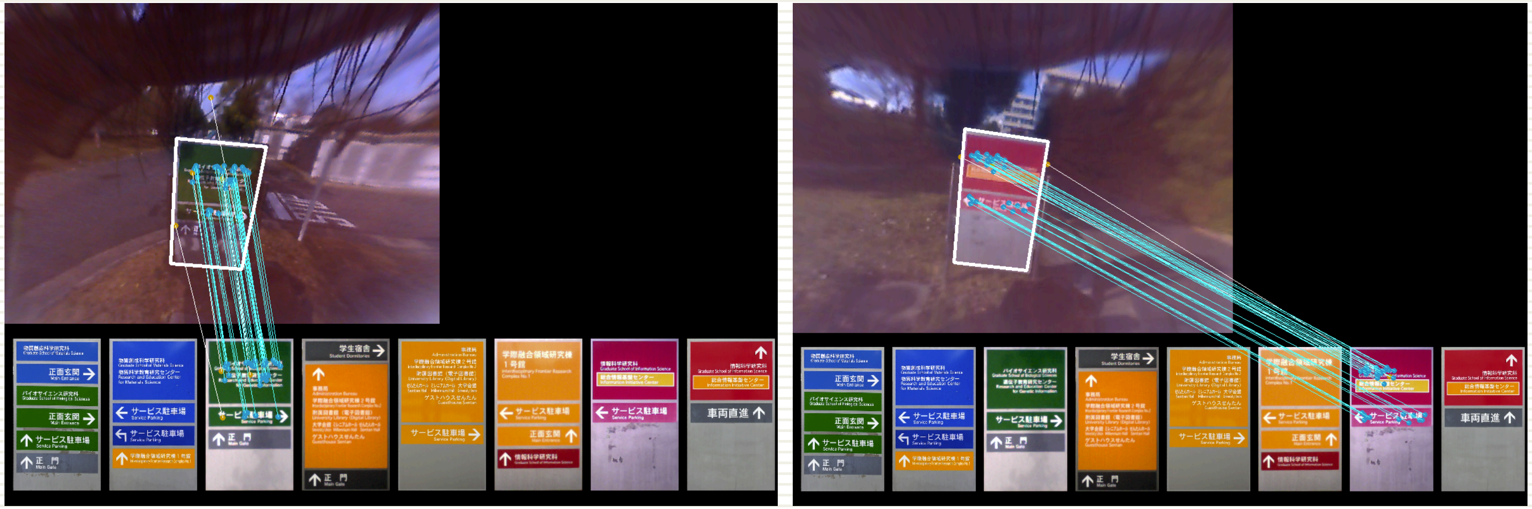
Unwarped image

- Resolution of unwarped image: 640 x 640
- Processing time : About 80 [sec] in MATLAB

We need the improving the processing time
using optimization and parallelization

Estimating focused object

- It’s possible to apply general image processing to the unwarp image
  - Feature: Scale-Invariant Feature Transform
  - Outliers are removed using RANSAC



Specific object recognition using unwarped corneal image

Focused object could be recognized

Evaluation experiment for object recognition

- Eight direction boards located around the university were used

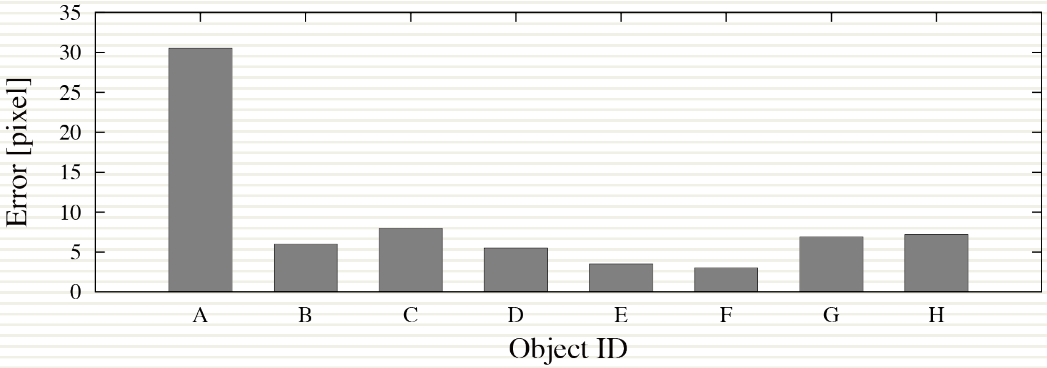
Eight direction boards

Average of correspondence errors

$$\bar{E} = \frac{1}{n}\sum_{i=1}^{n}\left\|\mathbf{HP}_i - \mathbf{P}'_i\right\|$$

feature position in registered template

feature position in unwarped image



Average of correspondence errors between registered templates and unwarped corneal surface images.

Which objects are you looking at ?

- If there are some objects in eye,
  we cannot detect the focused object.

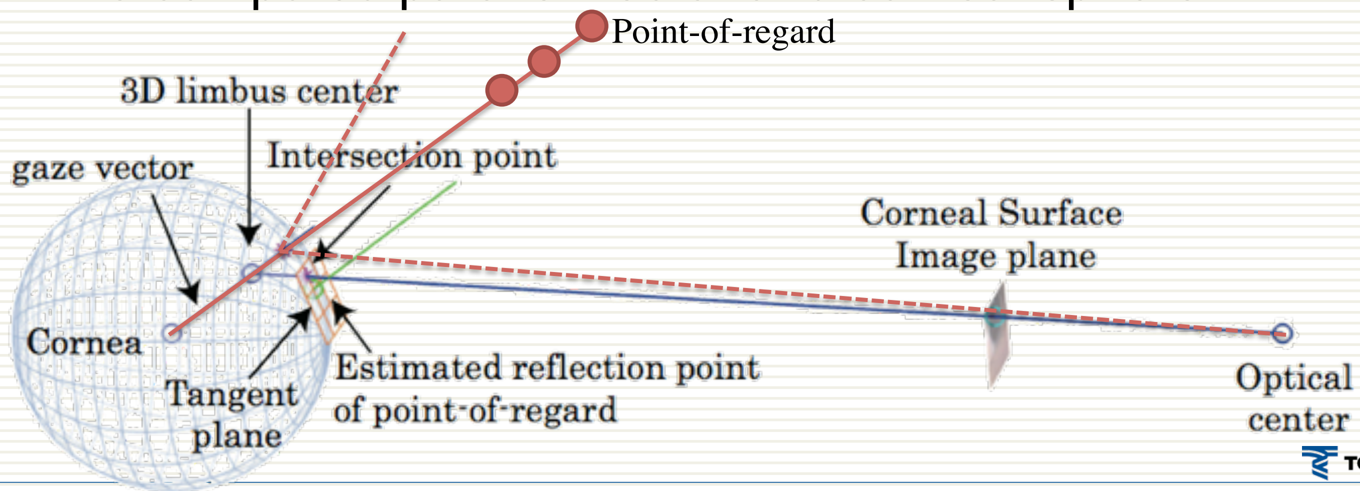
The image is an unwarped image,
when the user looking at book shelf.

It's important to estimate the PoR

Estimating Point-of-Regard

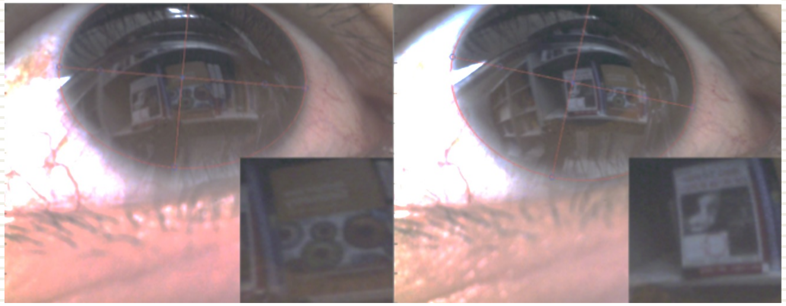
- The gaze vector is known.
- The distance to the PoR is not known.

- Assumption: The distance of PoR is at infinity
  - A vector, which is parallel to the gaze vector, is computed as the reflected ray.
  - The unwarped image is generated around the intersection of the computed parallel vector and corneal sphere.



The results of unwarped images based on Point-of-Regard

- The focused object can be extracted based on PoR



Looking at bookshelf

Looking at human

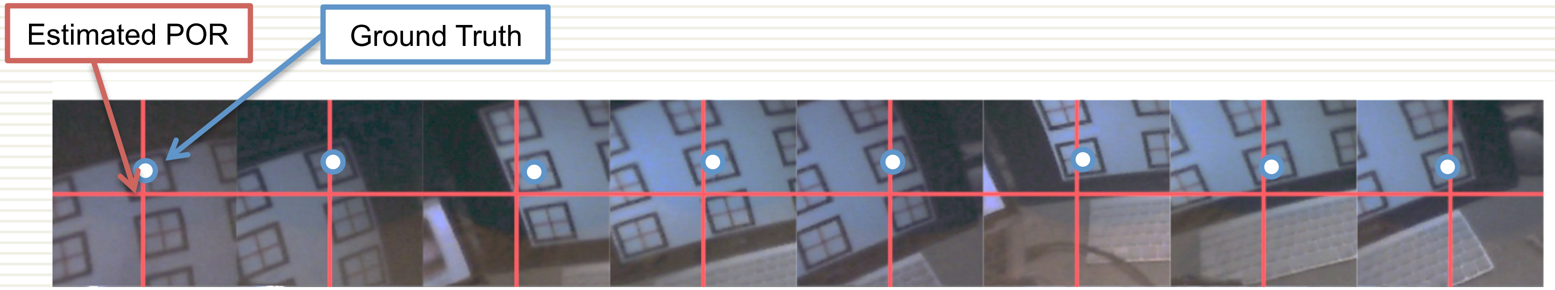
Driving situation

Dependence on illumination condition

The far distance to the focused object → Low resolution

Evaluation experiment for PoR

- We compared between ground truth and the estimated PoR.



The results of estimating point-of-regard using reflection point of vector parallel to a gaze vector.

- The relationship between a user and focused object
  - The angle of error: r< 8[deg]
  - The distance: d < 2.5[m]
  - The error: e < 350[mm]

Our proposed method has sufficient accuracy for application such as a guidance systems

Conclusion

- Wearable device as daily-used device is proposed.
- Unwarped image is generated based on PoR using inverse ray tracing.
- Extracting the focused object.

Future works

- Solving problems
  - Dependence on illumination condition
  - The far distance to POR
- Extracting life event as a daily-use device.

THANK YOU
FOR YOUR ATTENTION