# Real-Time Eye Tracking System For Mouse Using a High Frame-Rate Digital Camera
# 高速撮影カメラを用いたマウス視線計測システム

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## Summary

To measure eye movements of mice at high resolution and high sampling rate, we developed a non-invasive and inexpensive eye tracking system by adopting an IEEE-1394b digital camera. Infrared light illuminates the eye and the reflected image of the iris and the black image of the pupil are captured by the camera. The center of the pupil is calculated by fitting an ellipse and tracked over time. The adoption of the WINDOWS 7 x 64 as the operation system makes this eye tracking system user-friendly. The system was originally developed for humans and monkeys, and improved for mice with consideration to the following characteristics of the mouse's eye.

1) The size of the eye is quite small (~3.4mm) compared to the human or monkey.
2) The edge of the pupil of the mouse's eye is not smooth, in contrast to the human or monkey's, which is smooth enough to allow an accurate ellipse fitting.
3) It is difficult to train a mouse to fixate on targets placed at several external positions which are used for the active calibration for the human or monkey.

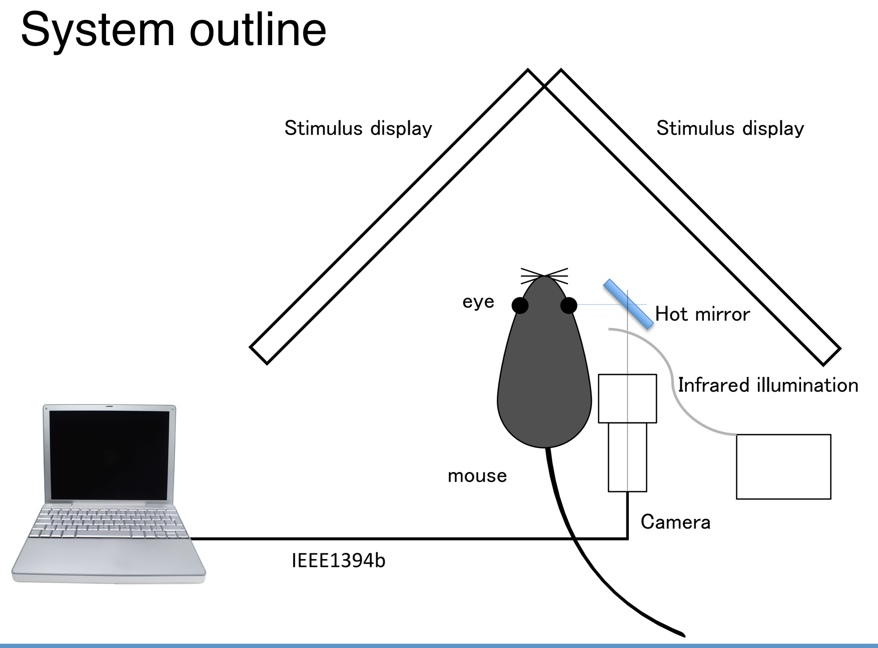
1) To overcome the small size of the mouse's eye, we illuminated the eye by an infrared light system with a halogen bulb and flexible optical fiber light-guides. The image of the eye reflected by a hot mirror was monitored by the digital camera with a size conversion adapter and a rear expansion lens attached. The hot mirror reflected infrared light but transmitted visible light, thus the mouse could see the visual stimulus behind the mirror. To keep sufficient luminance of the iris, we modulated the frame-rate of the digital video camera.

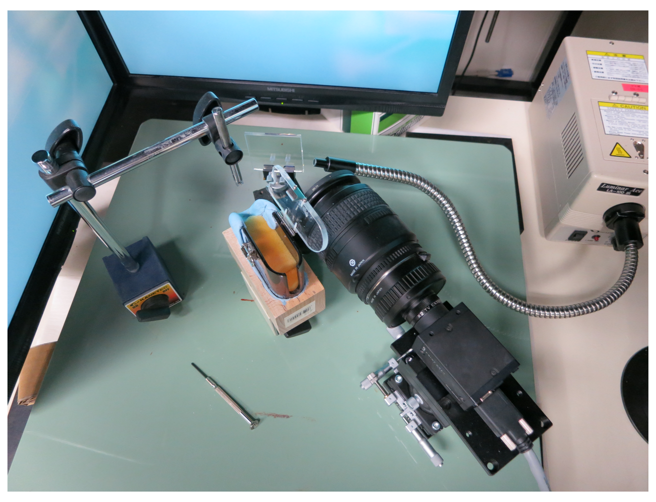
2) A noise reduction algorithm was adopted to calculate the ellipse to fit the noisy pupil edge.

3) Eye positions are passively calibrated by moving a large-field visual stimulus eliciting horizontal/vertical eye movements. By using this system, we succeeded in characterizing the short-latency ocular responses in the initial phase of the vertical optokinetic response in mice.

Supported by KAKENHI (24650105).

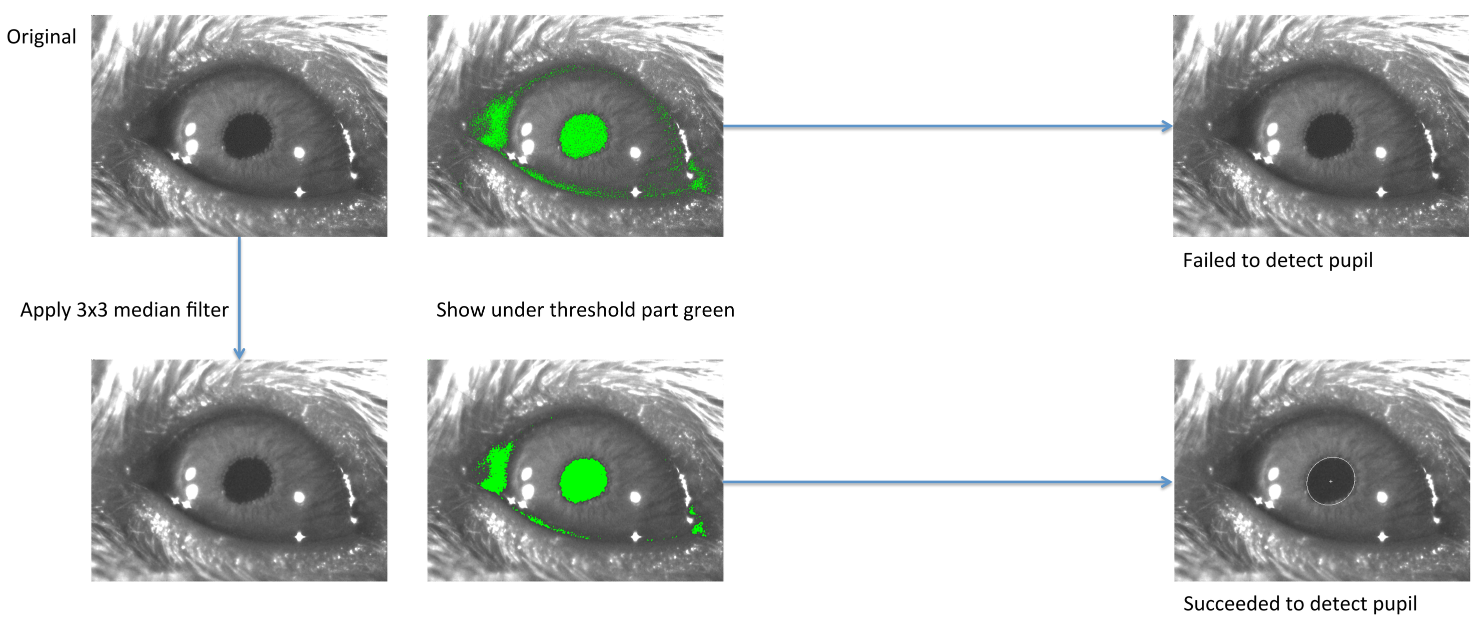
## System outline



## The noise reduction method

Taking the images at a high-frame-rate increases the noise, resulting in failure of pupil-outline detection. To reduce the noise, we adopted a median-filter. But since the median-filter takes time, by adopting it only for detecting the pupil's outline, it was possible to reduce the time to detect the pupil for real-time image processing.




## The view axis vector in the camera coordinate system

There are three ways to measure the view axis. The method [A] deals with only the pupil shape. This method can be used without calibration. The method [B] deals with only the pupil center position(Xp,Yp). This method can be used when the subject's head is fixed tightly. The method [C] deals with the pupil center position(Xp,Yp) and the center position of illumination's reflection on the cornea(Xr,Yr). This method can be used when subject's head is fairly stationary.

*Method A*

$X_p > X_o$

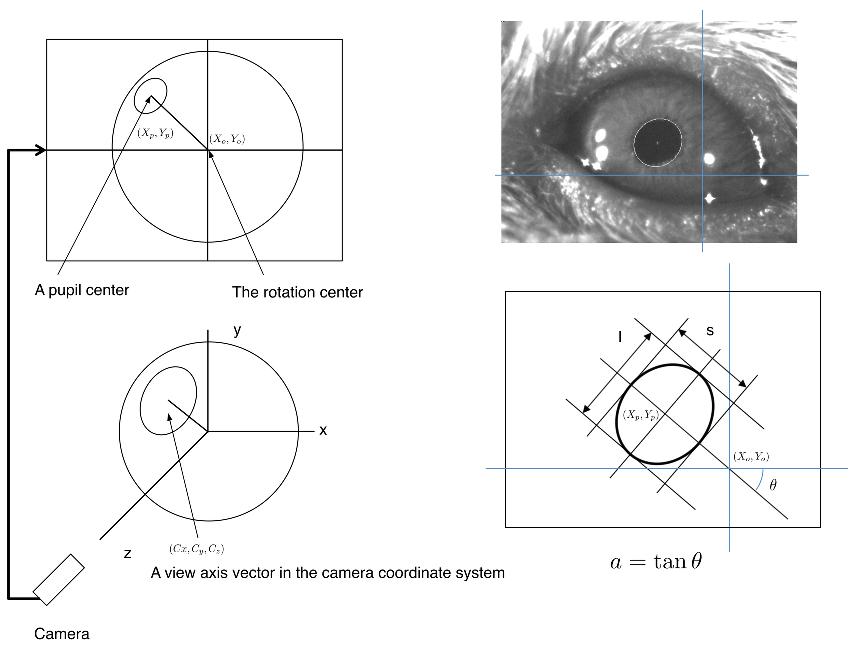
$$(C_x, C_y, C_z) = \left(\frac{1}{l}\sqrt{\frac{l^2 - s^2}{1 + a^2}}, \frac{a}{l}\sqrt{\frac{l^2 - s^2}{1 + a^2}}, \frac{s}{l}\right)$$

$X_p < X_o$

$$(C_x, C_y, C_z) = \left(-\frac{1}{l}\sqrt{\frac{l^2 - s^2}{1 + a^2}}, -\frac{a}{l}\sqrt{\frac{l^2 - s^2}{1 + a^2}}, \frac{s}{l}\right)$$

*Method B*

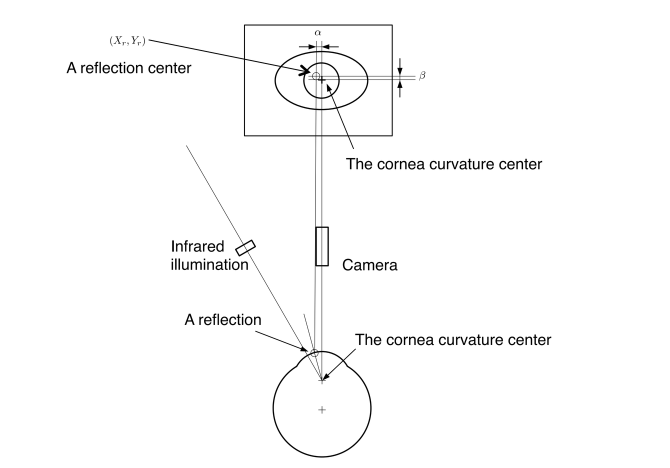
$$(C_x, C_y, C_z) = \left(\frac{X_p - X_o}{R}, \frac{Y_p - Y_o}{R}, \sqrt{1 - \frac{(X_p - X_o)^2}{R^2} - \frac{(Y_p - Y_o)^2}{R^2}}\right)$$



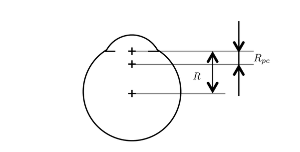

*Method C*

$$(C_x, C_y, C_z) = \left(\frac{X_p - X_r + \alpha}{R_{pc}}, \frac{Y_p - Y_r + \beta}{R_{pc}}, \sqrt{1 - \frac{(X_p - X_r + \alpha)^2}{R_{pc}^2} - \frac{(Y_p - Y_r + \beta)^2}{R_{pc}^2}}\right)$$

$$(X_{angle}, Y_{angle}) = \left(\arctan\frac{C_x}{C_z}, \arctan\frac{C_y}{C_z}\right)$$




Suppose that a cornea is a part of a sphere, we refer to the center of that sphere as a cornea curvature center. If the illumination and camera is located farther enough from the cornea curvature center shifts, the position between the cornea curvature center and the reflection is always the same. In this figure α and β are fixed.



Rpc: The length between the pupil center and the cornea curvature center
R: The rotation radius of the pupil center

## The passive calibration

When the subject spontaneously moves its eye, the system determines the rotation center of the pupil (R), the rotation radius of the pupil center(Xo,Yo), the distance between reflection center and the cornea curvature center (α,β) and the length between the pupil center and the cornea curvature center(Rpc) by using a view axis vector (Cx,Cy,Cz) measured by the method A and the least squares method.

$$X_o - C_x R + X_p = 0 \qquad Y_o - C_y R + Y_p = 0$$

Equation for method B

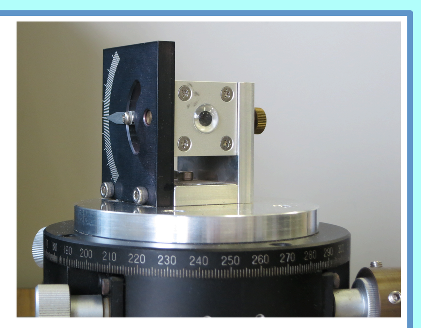
$$C_x R_{pc} + X_p - X_r + \alpha = 0 \qquad C_y R_{pc} + Y_p - Y_r + \beta = 0$$

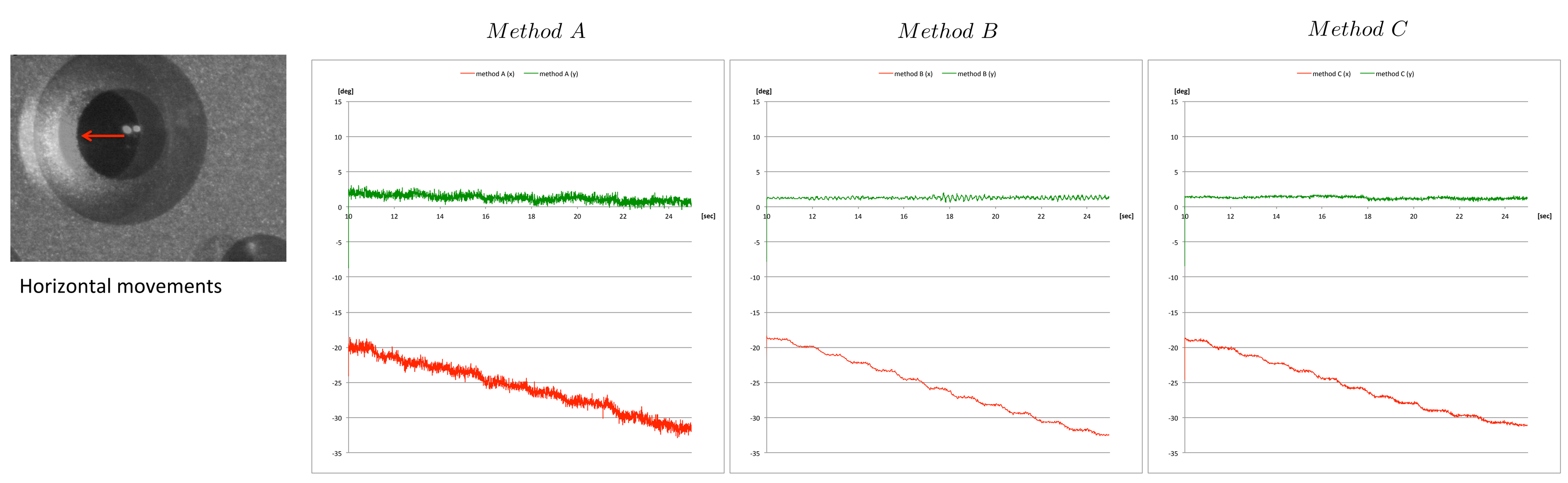
Equation for method C

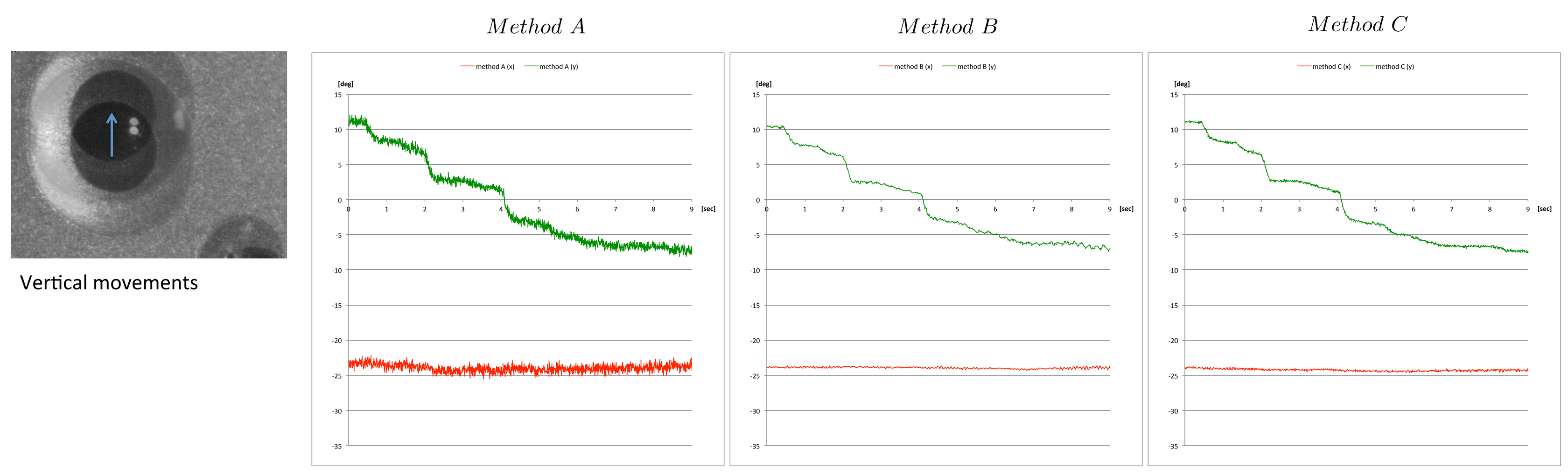
## System equipment

| | model | Company | Option/Memo |
|---|---|---|---|
| Camera | Grasshopper GRAS-03K2M-C | Point Grey Research,Inc. | DEVKIT-01-0002（IEEE1394b card,cable,etc） |
| Lens | Ai AF Micro-Nikkor 60mm f/2.8D | Nikon | |
| Lens mount converter | C-Mount ADAPTER for Nikon | Kenko | for Nikon Micro-Nikkor 60mm |
| Ir filter | 62S PRO1D R-72 | Kenko | for Nikon Micro-Nikkor 60mm |
| x2 Rear converter lens | TV rear converter x2 | | for Nikon Micro-Nikkor 60mm |
| Infrared illumination | LA-100IR（halogen lamp） | HAYASHI WATCH-WORKS CO.,,LTD | |
| Light guide | LGA1-5L500N | HAYASHI WATCH-WORKS CO.,,LTD | for LA-100IR |
| PC | Window7 x64 Ready | | |

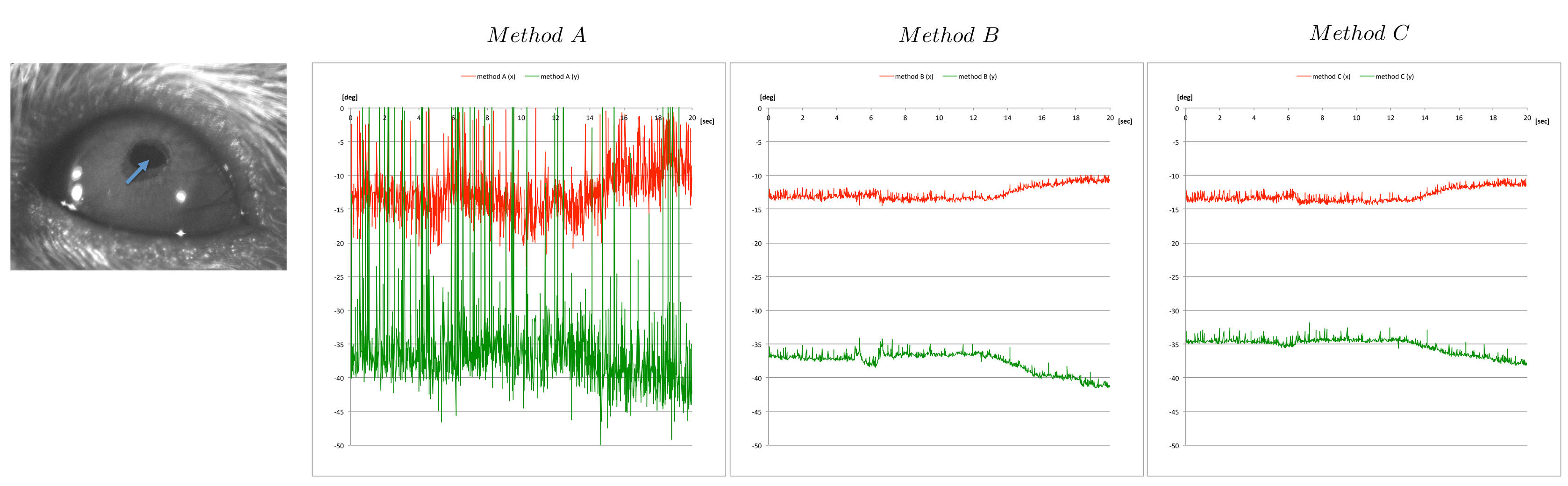
## Movements of a fake eye measured by three method






## Short-latency ocular responses in the initial phase of the vertical optokinetic responses in mice




## Horizontal optokinetic nystagmus in mice