# A New Method to Detect Nystagmus for Vertigo Diagnosis System by Eye Movement Velocity

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## Abstract

*As vertigo is common disease, it causes by problem with Nystagmus. It is difficult to diagnosis by observation. In this paper, we propose a method to detect nystagmus for vertigo diagnosis system using eye movement velocity. This method consists of three main steps: pupil extraction, velocity of eye movement computation, and nystagmus detection. An infrared camera is used to record eye movement in image sequence format. For first step, pupil is primary extracted by an adaptive threshold, blackest blob, and ellipse fitting technique. For second step, we measures pupil position from its center. Velocity of eye movement is then computed. For third step, involuntary eye movement is detected by comparing velocity of eye movement in each frame with a criterion. To evaluate performance of the proposed method, eye movement is recorded from six subjects. Accuracy rate of involuntary eye movement detection is 87.21%. The results show that the performance of this method is satisfactory. This is first method able to detect nystagmus from video-oculography.*

## 1. Introduction

Vertigo is a common disease and a type of dizziness. Cause of dizziness is nystagmus. Nystagmus is a condition of involuntary eye movement. It consists of three directions of involuntary eye movement: vertical, horizontal, and torsional. Doctor usually diagnoses this disease by observation without any assistant equipment. Therefore, a system for nystagmus diagnosis is necessary. In this paper, we propose a new method to detect involuntary eye movement for vertigo diagnosis system. There are several research using image processing and signal processing relating with nystagmus detection method [1, 2, 3, 4, 5].

For image processing algorithm, S. Wibirama, and at el. present a method to estimate eye-motion position and direction using initial centroid, and gradient analysis technique. They also design a camera with mask for recording eye movement. The proposed method yields 87.89%. However, this method is developed to solve problem of pupil occlusion only [1]. S. Tominaga, and at el. develop a simple method for tracking eye movement in torsional direction. This method consists of pupil detection, iris pattern extraction, and rotation angle

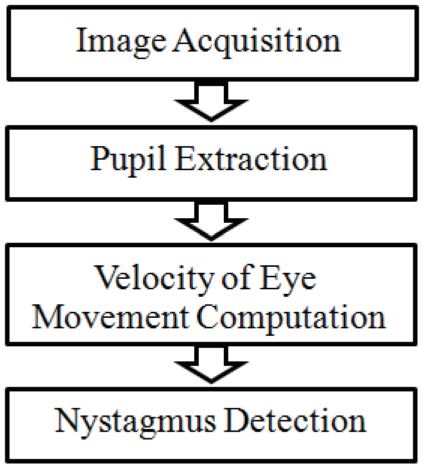
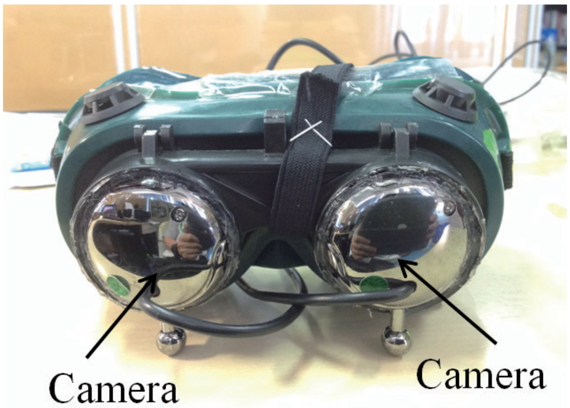



Figure 1. A diagram of nystagmus detection.

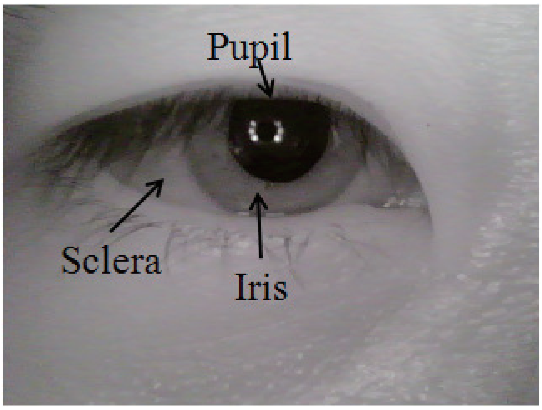
computation. However, this method is not appropriate for nystagmus detection [2]. Both of two methods are able to only track eye movement. These methods have limitation to implement for nystagmus detection.

For signal processing algorithm, I. Radinasky, and et al. proposed a method to classify slow phase and fast phase of nystagmus from electro-oculography (EOG) signal [3]. The method consists of two stages. Fist stage is to find initial estimate of the slow phase eye velocity intervals. Second stage is to identify a response phase shift and non-linearity, and compensate for their effects. The result shows that performance of the method is satisfactory. S.M.H. Jansen, and et al. proposed a method to detect fast phase of nystagmus beat [4]. Electro nystagmography signal (ENG) is used as input of system. A wavelet approach is used for fast component detection. The advantage of this method is the unsupervised automated routine. However, both of these methods only classify fast and slow phase from EOG signal. It is not able to detect involuntary eye movement.

Besed on ability of existing research, a limitation of such methods is that the existing methods cannot detect nystagmus from video-oculography. Therefore, in this paper, we propose a new method to detect nystagmus from eye movement data. Eye movement is recoded from a camera. Nystagmus can be detected by eye movement velocity.




a) Cameras mounted on the binocular.




b) Eye anatomy

Figure 2. Acquisition system and eye anatomy in input image.

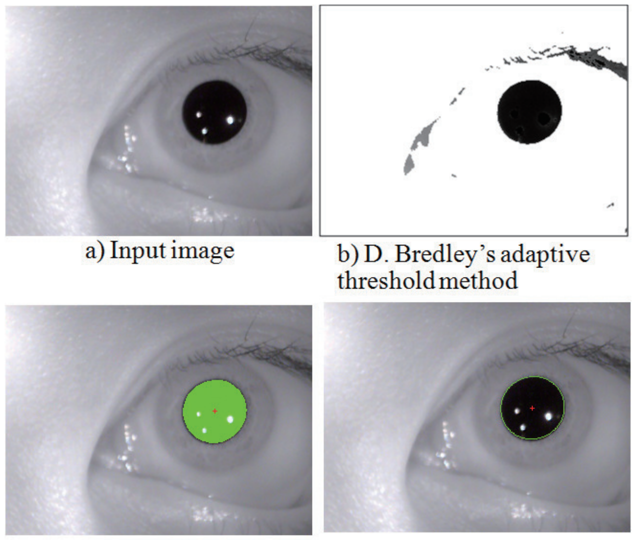
The remaining sections in this paper are organized as follows: the proposed method, experimental result, a discussion, and a conclusion in the last section.

## 2. The Proposed Method

In this section, we describe a new method for nystagmus detection for vertigo diagnosis system. This algorithm consists of three main steps: pupil extraction, velocity of eye movement computation, and nystagmus detection. A diagram of nystagmus detection is shown in figure 1.

### 2.1. Image Acquisition System

As this method proposed for nystagmus detection, it is analyzed from eye movement. Therefore, eye movement is recorded in format of image sequence. To avoid subject distracted from other light sources, an eye should be captured in dark environment. A mask with binocular is used to protect light from outside. We have mentioned to a prototype camera in our previous work [5]. In this paper, we adjust a distance from eye to camera in order to capture whole eye from different face shape. MDC-9 model from MD-Tech USB infrared camera is mounted on the binocular as shown in Figure 2.a. Image data, consisting of pupil, iris, sclera, and a part of face skin around eye, is used as input of method. A sample of input image is shown in Figure 2.b. Image size is 320x240 pixels in a frame. Frame rate is 25 frames per second. Focus range is 30 mm at least.



a) Input image
b) D. Bredley's adaptive threshold method
c) Blackest blob
d) Ellipse fitting technique

Figure 3. Pupil extraction process.

### 2.2. Pupil Extraction

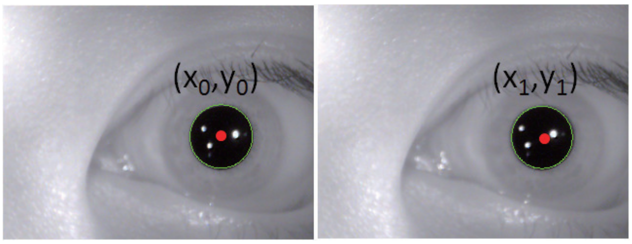
Pupil extraction is an important process to compute precise center of eye, and lead to compute velocity of eye movement correctly. Many existing methods concerning pupil extraction have been proposed [6-9]. However, such methods are not appropriate for extract pupil from eye images which are captured by infrared camera. In our previous work [5], we developed a method for extracting pupil from an infrared image using an adaptive threshold, blackest blob, and ellipse fitting technique [10, 11]. Our previous works aim to extract and estimate pupil shape more precisely although extracted pupil shape is incomplete. Based on the advantages, we use our previous work to extract pupil. Pupil extraction method is explained briefly in this subsection.

To extract pupil, three techniques are applied: adaptive threshold, blackest blob, and ellipse fitting technique as shown in Figure 3. First, image in RGB color space is converted to gray mode. We use an adaptive threshold proposed by D. Bredley [10] to segment primary pupil as shown in Figure 3.a and 3.b. There are noise occurred in primary pupil extraction. According to observation, pupil is blackest area in an image. Therefore, blackest blob is used to segment the pupil. Figure 3.c. shows result of the blackest blob technique. In some images, pupil cannot be extracted completely, its shape is incorrect. Ellipse fitting technique is used to estimate complete pupil shape [11] as shown in Figure 3.d. The estimate pupil shape will be used to compute pupil center in next subsection.

### 2.3. Velocity of Eye Movement Computation

Nystagmus is a condition involuntary eye movement. It consists of two phase of eye movement: fast and slow phase. In case eye moves involuntarily, eye movement speed is faster than general movement. Therefore, velocity of eye movement is measured. In this subsection, we will explain process for velocity computation.

Center of estimated pupil is used to compute the




a) frame i b) frame i+1

Figure 4. Coordination of pupil center.

velocity of eye movement. Ellipse equation is shown in Eq. 1. From Eq. 1, its coefficients are used to compute center of pupil as shown in Eq. 3 and 4.

$$F(x,y) = ax^2 + bxy + cy^2 + dx + ey + f = 0 \quad (1)$$

with an ellipse-specific constraint

$$b^2 - 4ac < 0 \quad (2)$$

where F(x,y) is ellipse equation, the parameter a, b, c, d, e and f are coefficients of the ellipse, (x, y) is coordinates of pair points. Finally, pupil shape is completed.

Center of ellipse is also computed.

$$x_0 = \frac{cd - bf}{b^2 - 4ac} \quad (3)$$

$$y_0 = \frac{af - bd}{b^2 - 4ac} \quad (4)$$

where $x_0$,$y_0$ are coordinate center of ellipse.

The velocity of eye movement is computed into two axis separately based on types of nystagmus direction. As using Eq. 3 and 4, center of pupil is computed as shown in Fig. 4. Distance is defined in term of number of pixel that changes from a frame to a frame. An interval of eye movement, which is used for the velocity computation, is defined from the frame rate of camera. In this method, the frame rate of camera is 25 frames per second. Equation 5 is shown velocity computation.

$$EMV_x = \frac{x_1 - x_0}{t_1 - t_0} \quad (5)$$

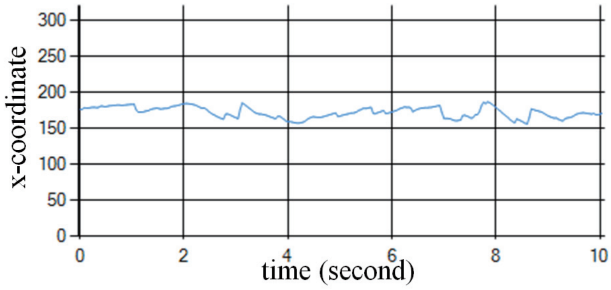
where $EMV_x$ is eye movement velocity in horizontal axis, t is time in a frame.

## 2.4. Nystagmus Detection

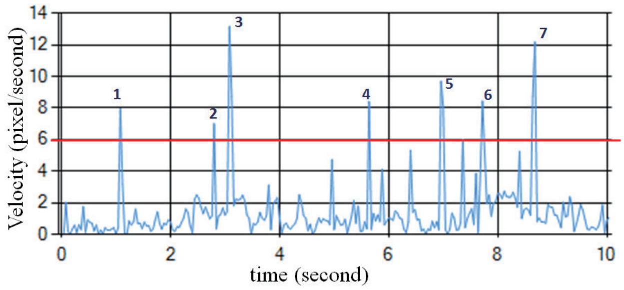
As mentioned in previous section, this method aims to detect period of involuntary eye movement. Therefore, a interval, that nystagmus is occurred, will be detected. This subsection will explain a technique to detect nystagmus.

Nystagmus consists of two phase of eye movement: fast and slow as mentioned in subsection 2.3. An interval of eye movement, which the velocity is higher than a criterion, is defined as involuntary eye movement or nystagmus. Based on empirical test, the criterion is set at six pixels per second.

Graph of eye movement is shown in Fig. 5. Fig. 5.a. shows coordinate of eye in each frame from $0^{th}$-$10^{th}$ second. Fig. 5.b. is velocity of eye movement from $0^{th}$-$10^{th}$ second. Subscript number in Fig. 5.b. show number of nystagmus occurring.




a) Eye coordinate in x-axis from $0^{th}$ -$10^{th}$ second.




b) Velocity of eye movement from $0^{th}$-$10^{th}$ second.

Figure 5. Eye coordinate changed and velocity in horizontal axis from $0^{th}$ -$10^{th}$ second.

# 3. Experimental Results and Discussion

As overall method has been explained, in this section, process to test performance of the proposed method will be described. Subjects wear binocular with dark condition. Subjects have to look directly forward during collect data process. An experimenter will rotate subject head to a side suddenly to generate involuntary eye movement in x-axis. Data is recorded from eight subjects. Frame rate is 25 frames per second. Total data are 3,260 images. Velocity criterion is six pixels per second.

## 3.1. Experimental Results

Accuracy of nystagmus detection method is tested comparing with an expert. Number of nystagmus occurring is counted manually by an expert's observation.

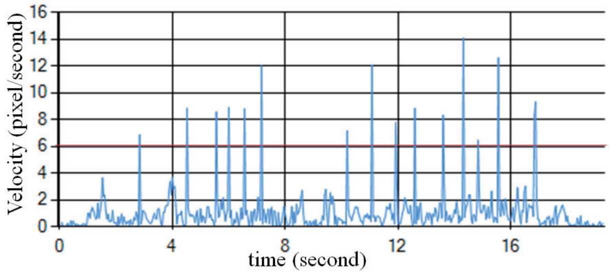
The performance of nystagmus detection method is shown in term of accuracy rates in Table 1. The average accuracy rate is 87.21 percents. Figure 6 shows velocity of eye movement in horizontal and vertical axis. As involuntary movement is occurred only in horizontal axis, Graph pattern relate with real movement. The red line in Fig. 6.a. is criterion.

## 3.2. Discussion

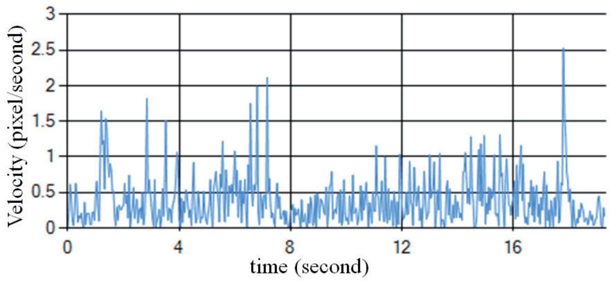
As the accuracy rate is 87.21%, causes of error occur from difficulty of counting by observation, and imprecise pupil center extraction. The difficulty of counting by observation occurs when an eye moves involuntary and frequently. Imprecise pupil center occurs when noise appears in extracted pupil result. Therefore, center is incorrect.

Table 1 Experimental results of nystagmus detection.

| **Subject ID** | **Number of frame** | **Time (second)** | **The proposed method (Time)** | **Expert (Time)** | **Accuracy Rate (%)** |
|---|---|---|---|---|---|
| 1 | 252 | 10.08 | 7 | 7 | 100 |
| 2 | 419 | 16.76 | 10 | 13 | 76.92 |
| 3 | 393 | 15.72 | 7 | 9 | 77.78 |
| 4 | 207 | 8.28 | 7 | 8 | 87.50 |
| 5 | 397 | 15.88 | 12 | 15 | 80.00 |
| 6 | 456 | 18.24 | 16 | 18 | 88.89 |
| 7 | 252 | 10.08 | 15 | 14 | 92.86 |
| 8 | 483 | 19.32 | 15 | 16 | 93.75 |
| Average Accuracy Rate | | | | | 87.21 |




a) Velocity of eye movement in horizontal axis




b) Velocity of eye movement in vertical axis

Figure 6 velocity of eye movement in horizontal axis and vertical axis.

## 4. Conclusion

In this paper, we propose a method to detect involuntary eye movement for vertigo diagnosis system using eye movement velocity. This method consists of three main steps: pupil extraction, velocity of eye movement computation, and nystagmus detection. To evaluate performance of the proposed method, eye movement is recorded from six subjects. Accuracy rate of involuntary eye movement detection is 87.21%. Causes of error occur because of difficulty of counting by observation, and imprecise pupil center extraction. The results show that the performance of this method is satisfactory. The advantage is that this is first method able to detect nystagmus from video-oculography.

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