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Construction of the Measurement System and its Experimental Study for Diagnosing Cerebral Functional Disorders Using Eye-Sensing HMD

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Abstract: Ocular information such as pupil size, eyeblink or eye gaze point can be utilized for diagnosis of cerebral function disorders. There are a lot of methods of measuring ocular information, but accuracy and simplicity are required to be applied for diagnosis of cerebral function disorders. In this paper, the relationship between ocular information and cerebral function disorders is described first, followed by the review of methods of measuring ocular information. And system configuration of Eye-Sensing HMD which can not only provide three-dimensional images but also measure ocular information is described. Then measurement system to measure ocular information by using Eye-Sensing HMD and its experimental study for diagnosing cerebral function disorders are described.

Keywords: Cerebral Functional Disorders, Eye Movement, Head Mounted Display

1. Introduction

With the development of the technology measuring human physiological and motor behaviors, a lot of new methods of evaluating and diagnosing medical disorders have been studied. The diagnosis method using ocular information can provide a non-invasive, quantitative test of medical disorders, so it is expected to be applied for the screening test which tests the general population to see if a particular disease can be picked up early. Until now, numerous studies in schizophrenia and dizziness research have been reported and the ocular information is well known to be a significant difference between patients with schizophrenia/dizziness and normals[1, 2, 3]. It is also reported that there is a significant difference between Alzheimer's patients and normals in the visual sensitivity, and this difference may be used to diagnose Alzheimer's disease[4]. And recently, some kinds of studies have been reported to examine the difference between patients with attention-deficit/hyperactivity disorder (ADHD) and normals by using the ocular information[5, 6]. Thus, the ocular information is very important index which projects various conditions and illnesses of human.

This paper focuses on measurement systems of ocular information for diagnosing cerebral function disorders. Section 2 briefly reviews the relationship between the ocular information and the cerebral functional disorders and section 3 describes the general measurement systems of the ocular information. Section 4 illustrates the configuration of the Eye-Sensing HMD which not only provides three-dimensional images but also measures the ocular information in real time. Finally, section 5 describes the result of the experiment which measured the ocular response to three kinds of optical stimuli by using the Eye-Sensing HMD, and section 6 provides conclusions and directions for future work.

2. The relationship between ocular information and cerebral functional disorders

It is well known that there is an interrelation between the cerebral functional disorders and the ocular information such as eye movement and changes of pupil diameter.

For example, concerning schizophrenia, it is known that the pupillary light reaction of a schizophrenia person is small compared with a healthy person. And it is also reported that a healthy person can pursuit a moving object smoothly, but a schizophrenia person shows eye tracking abnormalities and intersperses saccadic eye movements such as getting ahead and behind of the target[7]. Moreover, it is known that the eye movement of a schizophrenia patient is small compared with a healthy person at the time of seeing a geometric figure.

On the other hand, there are many causes of vertigo/dizziness such as otologic, neurologic, general medical, psychiatric and so on. And there are many examination methods to evaluate the cause of vertigo/dizziness. Ophthalmological examination is one of the effective examination methods to evaluate the cause of the vertigo/dizziness. If the vestibular system is damaged then the signals sent to the oculomotor system, the confusion experienced by the patient results in dizziness. Conversely, for a patient who complains of dizziness, an examination of the eye movements arising from vestibular stimuli can help identify whether, the dizziness is due to vestibular damage. For example, if a patient has a vestibular disorder, nystagmus is recognized in the absence of visual fixation but nystagmus is suppressed with any visual fixation.

And it is also reported that some ocular information is different between an autistic person and a healthy person. For example, it is known that the time an autistic child gazes a target is very short compared with a healthy child when asked to gaze a target for some time.

Moreover, it is reported that the pupillary light reaction is different between the healthy person and the SDAT (senile dementia of Alzheimer type) which becomes a serious problem with the arrival of an aging society[8, 9, 10]. And it is also reported that the eye movement of the SDAT patients seeing a geometric figure is perpendicularly larger and more distributed than the healthy persons.

In this way, there is a possibility that some kinds of cerebral function disorders can be diagnosed by analyzing ocular information.

3. Methods of Measuring ocular Information

The methods for measuring ocular information can be applied for not only diagnosing the cerebral functional disorders but also the development of the hands-free interface and the presumption of human internal states[11]. So various kinds of the measuring methods have been studied. The measuring methods of the ocular information are summarized as follows:

- Electro-Oculography method (EOG)

  Because there is a permanent potential difference between the cornea and the fundus of approximately 1mV, there is an electrical field in the front of the head. And this field changes in orientation as the eyeballs rotate. The electrical changes can be detected by electrodes placed on the skin near the eyes. Because it is affected by an electrical noise, it is not a reliable method for quantitative measurement. However, it is a cheap, easy and non-invasive method of recording large eye movements, and is still frequently used by clinicians.

- Infra-red limbus tracking technique

  Limbus tracking works by illuminating the eye of the user with an invisible near-infrared LED. A photodetector is used to pick up the intensity of reflected light. The intensity of reflected light will vary with the eye position because of the varying proportion of the light and dark regions of the eye exposed to the detector. It is better for measuring horizontal than vertical eye movements

- Cornea reflex method

  The eye is illuminated with low-intensity infrared light. As a result, the pupil appears as a black elliptical region in the camera image. The center of the pupil and the reflection of the light from the cornea are determined by image processing. There is a monotonic relationship between the vector pointing from the center of the pupil to the light reflection (eye vector) and the user's gaze direction. After individual calibration, the gaze direction can be precisely derived from the eye vector.

- Image based methods

  With the development of video and image processing technology, various methods of extracting the eye position and the pupil diameter from images of the eye have been developed. Commonly a video image is combined with computer software to calculate the pupil position and its center.

- Scleral search coils

  When a coil of wire moves in a magnetic field, the field induces a voltage in the coil. If the coil is attached to the eye, then a signal of eye position will be produced. In order to measure human eye movements, small coils of wire are embedded in a modified contact lens or anulus. The advantage of this method is that it has a very high temporal and spatial resolution. Its disadvantage is that it is an invasive method, requiring something to be placed into the eye.

As mentioned above, there are a lot of methods to measure the ocular information. But when using for diagnosis of cerebral functional disorders, the method should have the following features:

- Easy to use and need not special training.
- Non-invasive method (fast and painless).
- Accurate and reproducible in any environment.
- High temporal and spatial resolution.
- Not influenced by eyelashes and blinks.

Then, in collaboration with Matsushita Electric Works Ltd., the authors have developed a new head mounted display "Eye-Sensing HMD (ES-HMD)"[12].

4. The System Configuration of the Eye-Sensing HMD

The Eye-Sensing HMD not only provides three-dimensional images, but also monitors the eyes by infrared CCD cameras and calculates ocular information such as eye gaze point, pupil diameter and eye blinks in real time. Figure 1 and table 1 shows the appearance and the specification of the Eye-Sensing HMD respectively.

Figure 1: Appearance of Eye-Sensing HMD.

Table 1: Specification of Eye-Sensing HMD

Head unit (Including display and CCD camera)	
Mass	230g
Display	
Type	Color LCD
Field of view (H)×(V)	30deg. × 20deg.
Pixels (H)×(V)	800 × 600
Distance of virtual image	1m
CCD camera	
Pixels (H)×(V)	510 × 492
Resolution (H)×(V)	380TVline × 262.5TVline
Scan frequency (H)×(V)	15.734kHz × 59.94Hz
Lens focus	6.6mm
Eye monitoring block	
Valid area (H)×(V)	24.8mm × 18.4mm
Resolution (H)×(V)	0.0489mm × 0.0775mm

The Eye-Sensing HMD monitors both eyes and outputs the images as NTSC video signal format to the connected Realtime Image Processing Board, where binary images of pupil outline are detected by image processing. The processed binary images are send to the connected PC, where the pupil center position and the pupil diameter are calculated according to the following algorithm (Fig.2).

(1) Select 3 points from the pupil outline at random.

(2) Calculate the center position and diameter of a circle which passes through the 3 points selected in Step (1).

(3) Step (1) and (2) are repeated n times.

(4) From the center positions calculated in Step (3), remove n/5 positions in order of both large and small value of the x-coordinate system.

(5) From the center positions calculated in Step (4), remove n/5 positions in order of both large and small value of the y-coordinate system.

(6) Calculate the average of the center positions calculated in Step (5) and let the result be the pupil center position.

(7) From the diameters calculated in Step (3), remove 2n/5 diameters in order of both large and small value.

(8) Calculate the average of the diameters calculated in Step (7) and let the result be the diameter of the pupil.

The number of the appropriate repetition time n per one frame is decided by experimental investigation from the viewpoint of spatial accuracy. And in this study the repetition time was decided to be 100. In this case, the calculation time per one frame is about 27ms. And it was confirmed that the ocular information can be measured by using the above-mentioned algorithm even if the eyelash or the eyelid covers a part of the pupil.

5. Construction of the Measurement System and its Experimental Study

In this study, 3 kinds of preliminary measurements, measurement of pupillary light reaction, measurement of tracking eye movements and measurement of gaze points with visual fixation were conducted.

5.1 Measurement of Pupillary Light Reaction

As mentioned above, it is known that the pupillary light reaction of a schizophrenia person is small compared with a healthy person and the pupillary light reaction is an index important for diagnosis of cerebral functional disorders. In this study, the system was developed so that the pupillary light reaction can be measured using Eye-Sensing HMD and some measurement experiments were conducted. To make it possible to measure the pupillary light reaction by Eye-Sensing HMD, it may be considered that an optical stimulus is presented by showing the white image and the black image with the liquid crystal display embedded in the Eye-Sensing HMD. But the contrast ratio of a liquid crystal display of Eye-Sensing HMD is small, so it is difficult to present optical stimulus which makes sufficient pupillary light reaction. Then in this study, white Light Emitting Diode (LED) has been arranged to 4 locations (right, left, upper and lower sides) and these LEDs are used to present optical stimulus. In the developed optical stimulus presentation function, the presentation time of an optical stimulus can be adjusted in the range for 50ms - 200ms. And intensity of the illumination when 4 white LEDs are lighting is about 300 [lux]. The pupillary light reaction of a healthy male college student

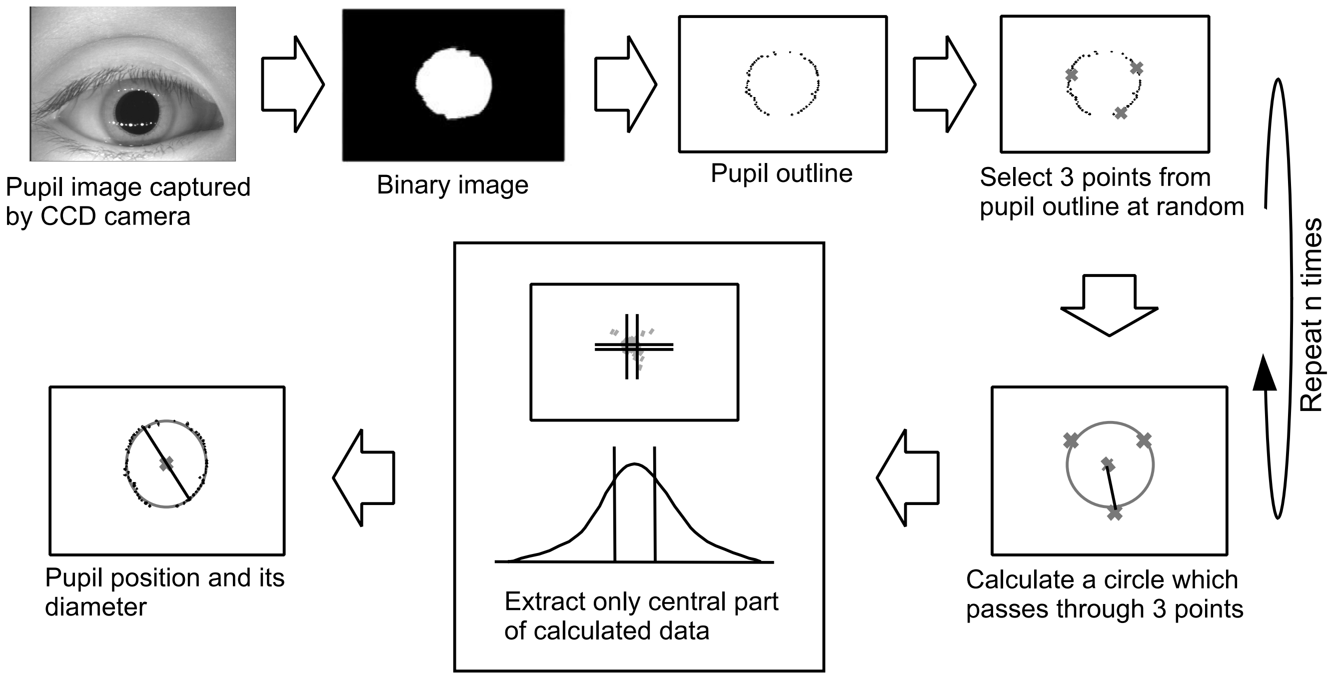

Figure 2: Calculation Method of Pupil Position and its Diameter.

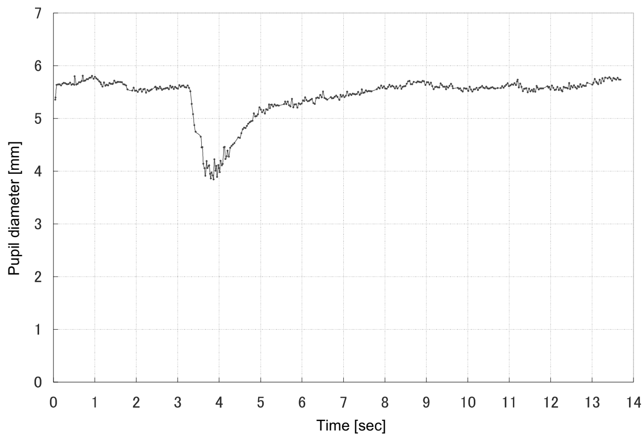

Figure 3: Measurement Result of Pupil Diameter in Pupillary Light Reaction.

in his twenties to the presentation of the flush light for 100ms is shown in Figure 3. The measurement started followed by 20 minutes quiet in the dark location without the Eye-Sensing HMD to adapt the darkness and 1 minute quiet equipped with the Eye-Sensing HMD to adapt the illumination of the LCD display. In this way, it was confirmed that the pupillary light reaction can be measured by using Eye-Sensing HMD. The authors consider that maximum contraction ratio, latency and contraction speed of the pupil diameter can be used to evaluate medical disorders.

5.2 Measurement of Tracking Eye Movements

Tracking eye movements are those which are made under visual guidance for the purpose of holding an object of regard and/or following it when it moves. Normal eye movements consist of saccades, or jumps, from one fixation to another. Typically saccades range in amplitude from 1 to 20 deg, corresponding to duration of 30 to 70 msec, and peak velocities of 70 to 600 deg/sec, respectively. When following slowly moving targets in the range of 1 to 30 deg/sec, the eye can track these movements with a smooth pursuit behavior that appears to partially stabilize the image of the target on the retina.

As mentioned above, it is known that there is a significant difference between the tracking eye movement of a schizophrenia patient and one of a healthy person. So the tracking eye movement is also an index important for diagnosis of cerebral functional disorders. Figure 4 shows the eye movement of a healthy male college student in his twenties at the time of showing the cross type target which goes back and forth for 24 degrees horizontally on a view square.

In the experiment, the target was moved slowly (3 degrees per second) at first, and the speed was gathered gradually (maximum speed was 35 degrees per second), and at last the target was moved slowly again (3 degrees per second). The measurement started followed by 20 minutes quiet in the dark location without the Eye-Sensing HMD to adapt the darkness and 1 minute quiet equipped with the Eye-Sensing HMD to adapt the illumination of the LCD display. In this way, the tracking eye movements can be measured by using Eye-Sensing HMD.

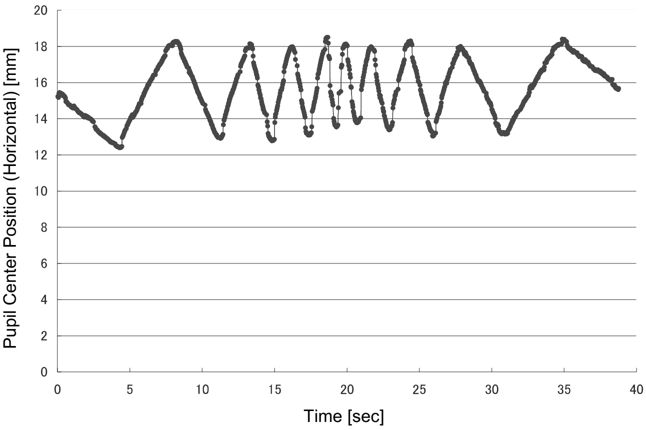

Figure 4: Measurement Result of Tracking Eye Movements.

5.3 Measurement of Gaze Points

As mentioned above, by measuring the eye movement with visual fixation, the dizziness and the autistic disorder may be evaluated. Figure 5 shows the eye movement of a healthy male college student in his twenties who was asked to gaze a cross type target for 10 seconds. The record of the eye movement shows some distribution over a small range. It seems to be small involuntary movement known as mini movements. And the difference of the distribution between vertical and horizontal coordinate system results from the resolution difference of the CCD cameras equipped with the Eye-Sensing HMD.

6. Conclusion and Future Work

Some kinds of ocular information such as pupil reaction to the light, tracking eye movements, eye gaze points can be measured by using the Eye-Sensing HMD. The measurement method using the Eye-Sensing HMD provides a non-invasive, quantitative test of medical disorders but there remain some problems. The distance of the pupil differs according to the person, so there is the case that a part of the pupil can not be measured. But it is solvable by improving the optical system. And it is also a problem that the Eye-Sensing HMD slips down during the measurement so a patient has to support the Eye-Sensing HMD by hand and it becomes a burden even if the weight of the Eye-Sensing HMD is very light. It is also important to improve the method of wearing the Eye-Sensing HMD.

As the future work, we will improve the optical system and the wearing method of the Eye-Sensing HMD. And we will conduct some experiments on the relationship between ocular information and cerebral function disorders, especially the relationship with the ADHD which is considered that an non-invasive method is needed for the early diagnosis of this disease.

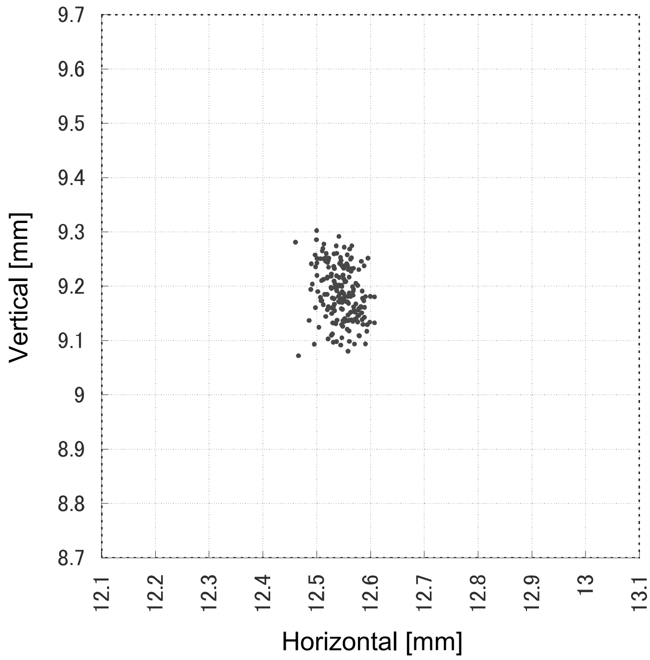

Figure 5: Measurement Result of Eye Gaze Point.

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