Detection of Eye Misalignment Using an HMD with an Eye-tracking Capability

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Abstract

In this study, we implemented the Cover Test, a test method for diagnosing eye misalignment using a head-mounted display with an eye-tracking capability. Specifically, we created a virtual examination environment in a VR space. The eye-tracking technique collected eye movements immediately after the covering or uncovering of the eyes. Thus, we calculated the amount of eye deviation and developed a system to determine the presence and magnitude of strabismus and heterophoria.We assessed the system in the verification experiment by examining the consistency between the judgment results provided by this system and the clinical evaluation approach with the Maddox rod. The result was that we could verify the horizontal eye movements more accurately.

Keywords： eye position examination, cover test, strabismus/heterophoria

1. Introduction

Eye misalignment, as represented by strabismus and phoria, means abnormalities in the way we see. When one eye is out of alignment when fixating on an object, it is called strabismus, which prevents stereoscopic vision. Although stereopsis is possible, it is a condition of misaligned eyes for unknown causes. In most cases, abnormalities in the ocular muscle cause strabismus and phoria, and the abnormal location defines the treatment plan. Even if the ocular muscles are healthy, the strabismus-like symptoms may appear as a sign of a fatal disease such as cerebral infarction caused by abnormal cranial nerves. Regardless, early detection is essential, though qualified personnel are in low supply, and the practice is time-consuming[1]. Since the patient had to look at the indicator from a distance of five meters, a substantial amount of space was necessary. Therefore, in our previous study, we developed a simple and space-saving eye position testing method[2]. Specifically, we automated the conventional eye position testing method Cover-testby controlling the LCD shutter of the 3D glass with a microcontroller board Arduino. We also constructed a system that calculates the amount of eye deviation from the amount of misalignment by analyzing moving images of the eye captured by a web camera installed in the 3D glasses[2][3][4]. However, this kind of method could not completely resolve the problems of eyelid and eyelash movements as well as the reflection of fluorescent light on the surface of the eyeball, which affects the accuracy of detection. We had to ask the examinee not to blink as much as possible throughout the examination to eliminate the influence of eyelids and eyelashes. Eliminating the lighting effects was required as necessary for each examination room.

2. Purpose of Research

Our study aims to create a novel eye misalignment detection system that is unaffected by eyelid movements, eyelashes, or exam room lighting conditions. Using a head-mounted display (HMD) with an eye-tracking capability, we developed a technique to determine the existence of abnormalities. In a virtual environment, we set up an examination environment and implemented the Cover-Test to detect the amount of eye deviation from the data of eye movements retrieved from the eye tracking function during the eye covering and uncovering.

In the verification experiment, we assessed the system by comparing the results of an examination using the Ma ddox rod (hereafter abbreviated as the Maddox test) with the detected amount of eye deviation .

3. Current method

3.1 Cover-Test

Based on the movements of the eyes when covered, the CoverTest distinguishes strabismus from orthophoria. Strabismus occurs when one eye moves when the other eye is covered, and phoria occurs when the occluder is removed. There are two types of cover tests: the Alternating Cover Test (ACT) and the Cover-Uncover Test (CUT). We perform ACT by always covering one eye to detect the total deviations, manifest and latent. To distinguish between strabismus/heter ophoria and orthophoria, we perform CUT by covering one eye and observing its motions, including the activities in the other eye when exposed. These are two procedures we used in this study.

3.2 Maddox Rod Test

The Maddox test is a procedure to measure subjective total deviation in cases of binocular vision, such as strabismus and micro-angle strabismus with peripheral fusion[5]. As shown in Fig. 3, the examinee fixates one eye at a point lighted by a pen torch by a five meter distance, and the other covered with a Maddox rod. (Fig.1-(2)) If there is no ocular deviation causing binocular disparity, the point light source of the uncovered eye coincides with the red light ray perceived by the other eye. (Fig. 1-(2)). When there is an ocular deviation, such as strabismus or heterophoria, the point light source and the red light ray do not coincide. (Fig.1-(3)). If there is no match, we place a prism bar in front of the eye covered with the rod and slide it from the weakest to the highest prism degree until the point source matches the red light ray. The prismatic power at the point of coincidence is the actual ocular deflection of the examinee.

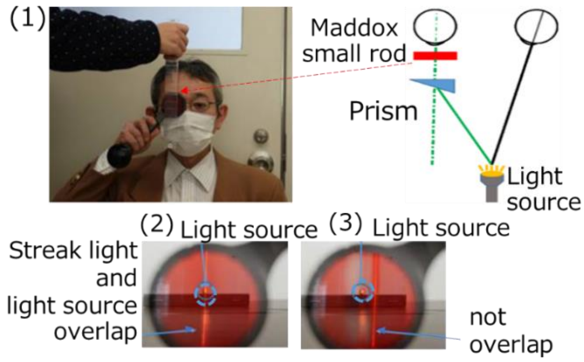

Fig.1 Inspection with the Maddox rod

4. Method Proposal

4.1 Proposed System

Fig.2 describes the hardware configuration of the system. Fig.2-A characterizes the HMD with an eye-tracking function. The camera and infrared sensor of the HMD record eye movements for data[6][7]. The examination environment comprises a test room with an optotype, a red dot displayed in he middle, and occluders. When the program functions, the HMD displays a screen shown in Fig.3 in a binocular stereoscopic form. While the examinee fixates on a target on the screen, we performed the covering and uncovering based on ACT and CUT. We used an occluder, which turns transparent and non-transparent, making the cover uncover possible.
During this procedure, we continued to collect the data to test strabismus from the degree of the eye movements: ACT calculates the total deviation of both eyes. CUT determines strabismus and heterophoria by calculating the deviation of strabismus (strabismus amount) and heterophoria (heterophoria amount).

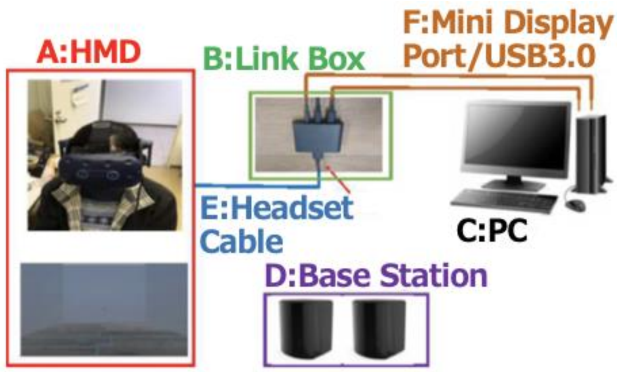

Fig.2 Configuration of the system

4.2 Functional Structure

Fig.4-(1) presents a block diagram of the system's functional structure, whereas Fig.4-(2) and Fig.4-(3) present the function composition of the "HMD" and "controller," respectively. Fig.4-(4) in the flowchart describes the overall flow of the ACT examination (Chapter 3.1), and (5) - (7) specifies each step of the procedure (4). The flow of (4), (5), and (7) for the CUT examination are the same (Chapter 3.1); The difference in procedure between ACT and CUT is the processing procedure for acquiring eye data in (6). This is because the varieties of eye movements we should observe for abnormality determination are different. Fig.4-(6) shows a flowchart for occluding and exposing the eye, effective at manifesting abnormal judgment through eye movements.

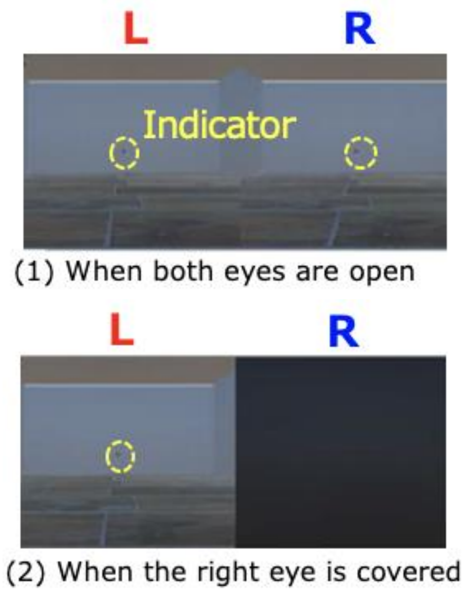

Fig.3 Image as it appears to the examinee during the Cover-Test

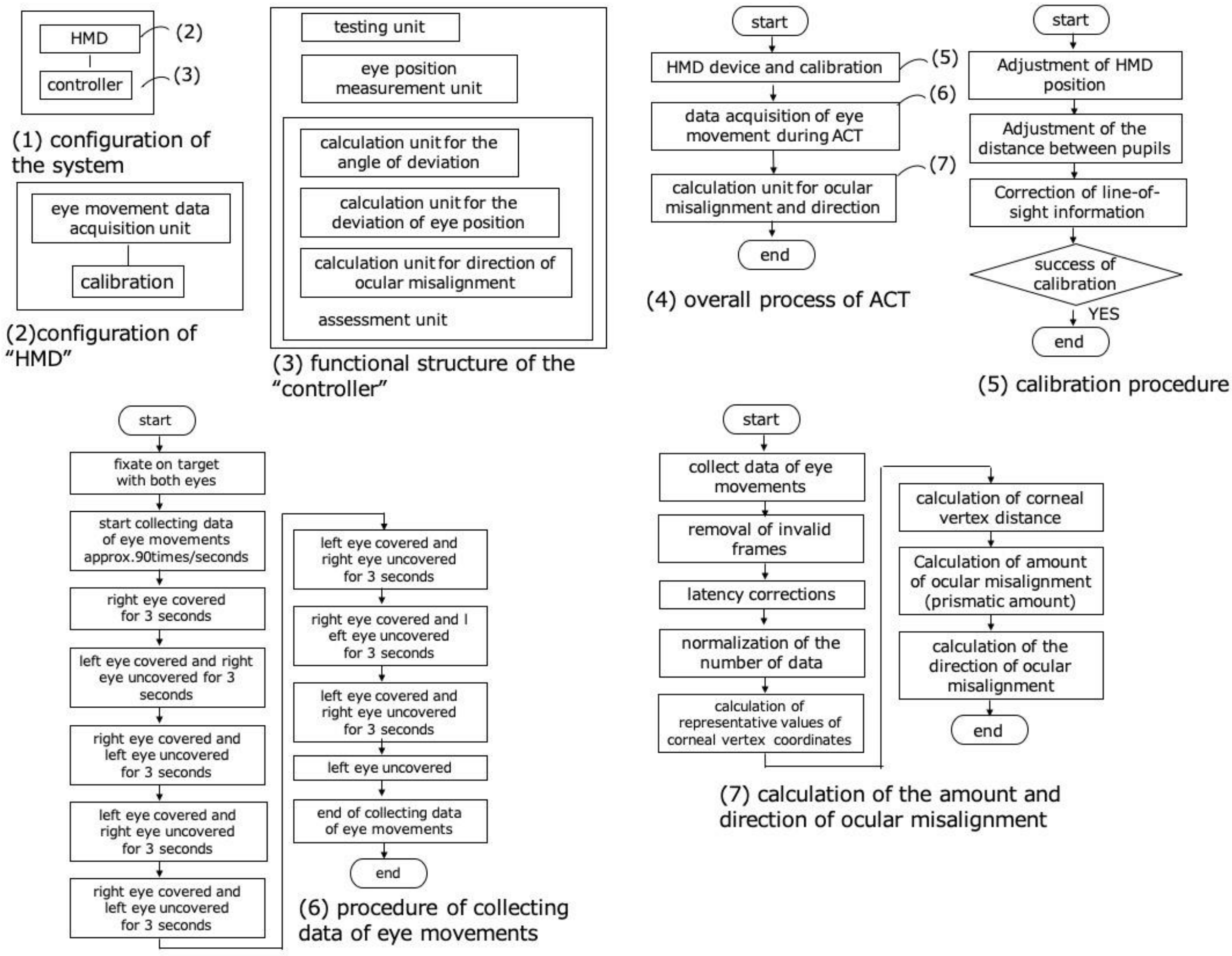

Fig.4 Functional Configuration and Operation

5. Experiment

5.1 Content of Experiment

We used the Maddox test and the system to compare the quantified results of the ACT and CUT tests in the experiment. Table.1 and Table.2 show the quantitative results. XT/XP and ET/EP represent exotropia and esotropia, respectively. Exotropia occurs when one eye moves outward when fixating on an object, while esotropia occurs when the opposite eye turns inside. Blue in the table shows the results of cases considered exotropia of 1△ or more and those in red considered esotropia of 1 △ or more.

5.2 Assessment/Discussion

Table.1 points out the total horizontal deviations for the Maddox test and ACT. The mean error for both tests was 0.61 △, less than 1 △, which is close to the correct answer.

Table.2 gives the amount of horizontal strabismus and obliqueness in the Maddox test and CUT, together with the total deviation generated by adding them up. The results show that the average error of the CUT and the Maddox test is 1.50 △, which is insufficiently accurate.

Table.1 measured value of a total amount of deviation

examinee	Maddox	proposed system
A	0-1ET/EP	0.88ET/EP
B	0	0.52XT/XP
C	0	0.36ET/EP
D	1XT/XP	1.44XT/XP
E	0	0.52XT/XP
F	4XT/XP	3.22XT/XP
G	0	1.06ET/EP
H	1XT/XP	0.88XT/XP
I	1-2ET/EP	2.27ET/EP
J	0	0.50XT/XP
K	0	0.64ET/EP
L	8ET/EP	9.51ET/EP
M	1XT/XP	0.57XT/XP
N	10-12XT/XP	12.10XT/XP
O	1XT/XP	1.49XT/XP
P	8ET/EP	7.91ET/EP

Table.2 measurements of strabismus and obliquity

		proposed system		
examinee	Maddox	strabismus amount	phoria smount	the total deviation
A	0-1ET/EP	0.56ET	0.35EP	0.91ET/EP
B	0	1.29XT	0.37XP	1.66XT/XP
C	0	0.47XT	0.58XP	1.05XT/XP
D	1XT/XP	1.09XT	0.98XP	2.07XT/XP
E	0	0.80XT	1.43XP	2.23XT/XP
F	4XT/XP	0.41XT	1.09XP	1.50XT/XP
G	0	0.30ET	0.45EP	0.75ET/EP
H	1XT/XP	0.48XT	0.20XP	0.68XT/XP
I	1-2ET/EP	0.62ET	0.62EP	1.24ET/EP
J	0	0.36XT	1.50XP	1.86XT/XP
K	0	1.38ET	0.93EP	2.31ET/EP
L	8ET/EP	0.48ET	3.43EP	3.91ET/EP
M	1XT/XP	0.87XT	1.12XP	1.99XT/XP
N	10-12XT/XP	0.51XT	9.46XP	9.97XT/XP
O	1XT/XP	0.72XT	1.68XP	2.42XT/XP
P	8ET/EP	9.26ET	0.42EP	9.68ET/EP

6. Conclusion

In this study, we automated the Cover-Test, an eye misalignment test, and used it to create a detection system. Using VR, we created a virtual testing environment. In this setting, we automated several steps, including the presentation of an optotype to the acquisition of the eye position, analysis, and test result acquisition during the cover-uncover operation. It is now possible to perform examinations in a space-saving setting. This resolves the issues from earlier studies where eyelid and eyelash movement interfered with the test's accuracy and the exam room lighting conditions. The HMD is more comfortable to wear and less burdensome than the earlier 3D glasses, making it easier to use. We assessed the system by comparing the results from ACT and the Maddox test, an actual clinical test. As a result, it provided correct outcomes in ACT but could not identify microscopic abnormalities in CUT. ACT showed a mean error of 0.61 △ (prism dioptre) and a correlation of 0.956, demonstrating excellent correlation and practicality. However, the CUT has an average error of 1.50△ and a correlation of 0.810, a significant inaccuracy. We believe that further precision is required. The following three issues are our future challenges.

The first is to improve the accuracy of CUT. The second is to make it possible to determine whether the CUT is accurate or slightly abnormal.

Despite no abnormalities, the examinee's eyes display slight tremors (fixation micro-tremors). Therefore, it is extremely difficult to tell if it is orthophoria. The goal of this system is to enable differentiation between the two. The need to differentiate orthopia, minor strabismus, and phoria is not clinically high. However, it is a critical issue for the system's development. We may use the findings gained through the development process in other systems using VR in the future.

The third is to detect vertical misalignment. The current system can monitor horizontal deflection with excellent accuracy despite the vertical measurement's low accuracy. We need a considerable amount of data to clarify how to improve the accuracy. Data on subjects with severe vertical abnormalities are rarely available, and we view data collection as a short-term issue.

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