Detecting Impaired Vision Caused by AMD from Gaze Data

Huiying Liu, Yanwu Xu, Damon Wong, Ai Ping Yow, Augustinus Laude, and Tock Han Lim

Abstract—Age Related Macular Degeneration (AMD) is the third leading cause of blindness and the first one in the elderly. AMD usually causes central blindness due to loss of photoreceptor cell. In this paper, we propose to detect AMD caused vision impairment from gaze data. Compared with the current methods, e.g., Amsler grid, Microperimetry and Preferential Hyperacuity Perimetry, to detect vision impairments, the proposed method has several advantages. 1) It does not require the patient to stare at a fixed position throughout the test. 2) It does not require the patient to orally or manually report / mark out the vision impairment. 3) It is easy to operate thus a trained nurse is capable of operating the test. We collect gaze data while the patient is performing fixation and smooth pursuit. Features describing the gaze properties are extracted and SVM with linear kernel is trained to detect AMD impaired vision. To implement the proposed method, we collected gaze data of 74 eyes of 57 patients, who are diagnosed as AMD patient by clinicians. Nidek Microperimetry is adopted as gold standard. 57 eyes with normal vision and 17 eyes with impaired vision (blind at more than half test points in Nidek test) are used for test. The result verifies the effectiveness of detecting vision impairment from gaze data.

I. INTRODUCTION

Age-related macular degeneration (AMD) is the third leading cause of blindness, and the first one in the elderly. The first line of defense for AMD is awareness. A simple vision assessment will alert a person to any changes that may indicate a problem with AMD or a worsening of the condition. There are presently a number of devices for monitoring of visual function for AMD.

1) Amsler grid chart: The Amsler grid is the mainstay for screening and monitoring of the eye to detect the onset of AMD [8]. In this test, the patient is required to stare at the central dot and to report the missing or distortion of the lines. However, there are problems associated with performing the paper Amsler Grid test correctly, e.g., compliance with the testing, and recording or reporting the test findings. Furthermore, many elderly patients find it difficult to maintain fixation, thus affecting the accuracy of the test.

2) Microperimetry is now widely used by ophthalmologists to do vision field assessment [10]. In this test, the patient fixes his/her chin on the chin-rest and stares at a cross at the center. A dot is displayed at different position and at brightness. The patient is required to press a button if he/she notices the appearance of a dot. The output of this test is the vision attenuation at the tested positions.

3) Preferential Hyperacuity Perimetry (PHP) [7], based on Vernier acuity or the ability to judge whether a pair of target features is aligned, requires a subject to fixate on a central point and indicating on a screen at the perceived location of a misaligned dot. This has been shown to be more sensitive than the Amsler grid in detecting visual changes associated with AMD, although this may be at a cost of less specificity. This technology is costly and the current device is bulky and not portable. More recently, a home monitoring device (ForeseeHome device (Notal Vision Ltd, Tel Aviv) based on PHP testing has been developed and was shown to be beneficial in picking up AMD patients with high risk for choroidal neovascularisation development and was able to achieve better visual outcome with timely intervention [3].

4) Entopic perimetry (EP). Noise field campimetry helps subjects perceive scotomas because of perceptual filling in. This can be done for example, by staring at a display that visual noise patterns, such as black and white spots flickering randomly or the static produced by a conventional television, tuned to a non-transmitting station. The region of scotoma is perceived as a motionless or dark/grey area, different from the rest [2].

The above methods of vision assessment require forced fixation, rely on oral report or manual response, and necessitate the presence of a doctor. To address the drawbacks of the current methods, we propose a method to detect AMD caused vision impairment from gaze data. This method is an objective, and automatic method for vision assessment. The basis of this method is that due to the deflection at the central vision field, the AMD patient may suffer from difficulties in

Fig. 1. Illustration of detecting impaired vision by using eye tracker.
eye movements, e.g. fixation [5], [13], [12], [1] and smooth pursuit [11]. In this paper, we investigate the properties of fixation pattern and smooth pursuit to detect AMD caused vision impairments. Fig. 1 shows the scenario of record gaze data for analysis.

Some diseases may cause the change of eye movement patterns. There are already works to investigate to detect disease from the change of eye movement patterns, for example, cerebellar dysfunction[14], Autism Spectrum Disorders [9]. Vision impairment also changes the pattern of eye movement and these information can be used to detect eye disease. In [4], the researchers find that the gaze pattern of glaucoma patients are different with the group of normal vision. In [6], gaze data is recorded while the participant is watching TV. Then it is found that the saccades of glaucoma patients are of shorter length due the narrowed vision field caused by glaucoma.

The contribution of this paper is that we propose a vision assessment solution using gaze analysis. The advantages of this solution are 1) it does not require the patient to stare at a fixed position thus causes less fatigue. 2) it does not need patients’ manual response or oral report thus is more objective. 3) It is simple and easy to be operated.

The rest of the paper is organized as follow. In section II, we will detail the proposed method of detecting impaired vision from gaze data. In section III, we introduce the system setting. The experimental results will be shown in section IV. Finally, we will conclude our work in section V.

II. IMPAIRED VISION DETECTION FROM GAZE DATA

There are several types of eye movement, fixation, saccade, smooth pursuit, and vergence shifts. In this paper, we investigate to detect AMD impaired vision from gaze data while the patient is doing fixation and smooth pursuit.

A. Impaired Vision Detection from Fixation

AMD involves the progressive dysfunction and death of the macula’s photoreceptors that may eventually lead to loss of acuity and other visual functions [5]. After the fovea is damaged by disease, the ocular motor system needs to acquire a new reference area in a part of the retina where vision remains intact. In patients with central vision loss, the damaged fovea cannot generate the input for proper eye movement control and fixation stability, resulting in unstable fixation, especially shortly after the onset of the disease. As part of the adaptation to the loss of central vision, patients learn to use a part of their eccentric retina for fixation, a location referred to as a pseudofovea or preferred retinal locus (PRL). These characteristics of the vision of AMD patients cause the changes of fixation pattern. These changes are described through accuracy and precision, which are used to describe the deviation from gaze to the target, and the stability of gaze.

\[
\text{accuracy} = \frac{1}{n} \sum_{i=1}^{n} || g_i - t ||
\]

\[
\text{precision} = \frac{1}{n} \sum_{i=1}^{n} || g_i - \bar{g} ||, \quad \bar{g} = \frac{1}{n} \sum_{i=1}^{n} g_i
\]

Here \( n \) is the number of gaze, \( g_i \) is the \( i \)th gaze point, \( t \) is target. While calculating these parameters, the unit of pixel is used.

Examples are shown in Fig. 2. In the fixation result of the first row, the dot at the center gets both low accuracy and low precision. The dot at left-top gets low precision and high accuracy. While comparing the result of un-impaired vision and impaired vision, we can see that the impaired vision has poor fixation performance, meaning that high accuracy and precision.

Five points, with positions \((0.1,0.1), (0.1,0.9), (0.5, 0.5), (0.9, 0.1), (0.9, 0.9)\) (in normalized image coordinate) are displayed on the screen to record gaze data. Each point is displayed for 4 seconds. The gaze data during the last 3 seconds are used in our paper for the consideration that during the first second, the patient is shifting gaze from the previous dot to the current one. Examples of gaze data from un-impaired and impaired eyes are displayed in Fig. 2.

For each dot position, the accuracy, precision, and tracking rate are calculated to describe the quality of fixation. Then the maximum, minimum, and average of accuracy, precision, and tracking rate of the five points are calculated and catenated as a 9-dimension feature. Here tracking rate is the hit rate of the eye tracker.

SVM with linear kernel is utilized to train a classifier to detect impaired vision.

B. Impaired Vision Detection from Smooth Pursuit

Due to vision impairment at the central vision field, AMD patients may have difficulty in smooth pursuit. Investigations on this topic verified that AMD patients are capable of smooth pursuit eye movements, but are limited by target trajectory and scotoma characteristics.

To test the patients’ performance in smooth pursuit, a dot moves along a sine wave is displayed on the screen. The function of the sine wave is as

\[
y = \sin(x \times 0.01) \times 0.25 \times h + 0.5 \times h
\]

Here \( h \) is the height of the screen in pixel, \( x \) and \( y \) are in the ‘x-y’ coordinate with unit of pixel. The values of \( x \) are \( x = 1, 3, 5, ..., 1919 \) because the resolution of the screen is \( 1920*1080 \) in our setting. The dot stays at each position for 0.01 seconds.

The histogram of the distance to target is used as feature. In our setting of 300 FPS of the eye tracker, we get about 3 gaze points for each position. For each position, the distance to target is calculated as the average of all the valid gaze points. SVM with linear kernel is used to train the classifier.

III. SYSTEM SETTING

Tobii TX300 is adopted for data collection. A system developed on the basis of Tobii SDK is used to display the test patterns and record gaze data. Our objective is to do vision assessment for each eye separately. For this purpose, we utilize the one eye occluder to cover one eye and track gaze while the participant is watching the test image with one eye, as shown in Fig. 1. This occluder is opaque to
Fig. 2. Examples of gaze data of fixation. The first row and second row show an example of un-impaired and impaired vision, respectively. From the first to the third column show the result of Nidek microperimetry, the gaze points of the fixation test, the gaze points of the smooth pursuit test. In the image of microperimetry, a solid square means the dot is noticed by the patient, a empty square indicates a not-noticed dot. a triangle means the dot is not projected. The number below the square is the attenuate scale. The color changes with the value, from red to green when the value changes from 0 to 20. In the images of fixation, the black star is the position of the target and the dots are the gaze points. The colors of the dots are red, green, blue, mega, and cyan in sequence. The five dots are displayed in a random sequence. At the left top of each rectangle the display sequence (Seq.), tracking rate (T), precision (P), accuracy (A) of each dot are displayed. In the third column are the smooth pursuit results, with the trajectories shown by black curves and the gaze points shown by green dots.

visible light but transparent to ultra-red ray. Therefore the eye tracker, which detects human eye through intra-red ray, is able to detect the two eyes but in fact the participant is watching with only one eye. The system is installed at the eye center of a hospital. Patients who are diagnosed by clinicians as having AMD are referred to attend the test.

The patient sits in a chair before the screen. The operator adjusts the chair to make sure that when the patient looks forward directly, the patient’s eyes locate at about 60cm distant to the screen, and the gaze locates at the center of the screen. At the beginning, one eye calibration is done by using the one eye calibration tool provided by Tobii. The setting with 5 points are used. The ‘white dot on black background’ display scheme is adopted in both calibration stage and data collection stage.

Nidek Microperimetry is used to assess the patients’ vision impairment and is used as ground truth. The setting with 33 test points is used. Among the eyes, the ones with all the 33 test points seen are labeled as normal vision. The ones with at least half (17) of the test points not seen are labeled as with impaired vision. The ones with less than 17 dots seen are not used in this paper. 74 eyes of 57 patients are used for this work. Among the 74 eyes, 57 eyes are of un-impaired vision and 17 ones are of impaired vision. Examples of Nidek Microperimetry are shown in the first column of Fig. 2.

<table>
<thead>
<tr>
<th>Table I</th>
<th>The Result of Impaired Vision Detection.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixation</td>
<td>Pursuit</td>
</tr>
<tr>
<td>accuracy</td>
<td>0.91</td>
</tr>
</tbody>
</table>
sensitivity | 0.76 | 0.82 |
specificity | 0.95 | 0.95 |

IV. RESULT

Leave-one-out scheme is used to test the performance. At each time, 73 samples are used to train a classifier and the left one is used as test sample. The performance, evaluated through accuracy, sensitivity, and specificity, is shown in Table I. Using fixation data, the accuracy is 0.91, the sensitivity and specificity are 0.76 and 0.95, respectively. Using smooth pursuit, the accuracy is 0.92, the sensitivity and specificity are 0.82 and 0.95, respectively. From the result, we can see that both fixation and smooth pursuit are capable of discriminating impaired and un-impaired vision and smooth pursuit is better in sensitivity.

In the above results, we detect impaired vision from fixation data and smooth pursuit data separately. We tried to catenate the features to train a classifier but the performance is not better than the separate ones. We tried to merge the output of the two methods. The result is shown in Table II. Among all the eyes, 12 out of 17 (71%) impaired ones are classified as impaired by the two sets of data. 52 out of 57 (91%) un-impaired ones are consistently classified as un-impaired. 7 out of 74 (9%) eyes get conflict outputs from the two sets of data. 64 out of 74 eyes get consistent output from the two sets of data. The three samples wrongly detected are shown in Fig. 3.

V. CONCLUSION

In this paper, we propose to detect AMD impaired vision by using gaze data. Two eye movement types, fixation and
smooth pursuit, are investigated. Experiments performed on gaze data of AMD patients verified the effectiveness of the proposed method. In our future work, we will extend our work to detect AMD caused scotoma, coving the position and size of the scotoma.

**REFERENCES**


