Eye-movement Analysis for Measuring Visual Discomfort Caused from Watching Stereoscopic 3D Video

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Abstract: From previous researches, eye movements are related with visual discomfort caused from watching stereoscopic 3D video. In this paper, we present an analysis of eye movements to measure visual discomfort in terms of motion-in-depth and viewing time. First, we extract pupil from near-infrared eye image. Then, we detect two types of eye movements (saccadic number and blinking rate) from motion information of detected pupil. We measure eye-blinking and saccadic number per 1 minute while watching stereoscopic 3D videos. Experimental results show that the blinking rate in eye movements gradually increases but saccadic number gradually decreases oppositely.

Keywords: visual discomfort; stereoscopic; eye-movement;

I. INTRODUCTION

Recently, there has been an explosion of interest in technology for presenting stereoscopic 3D contents. Although viewers usually enjoy watching stereoscopic 3D contents, some viewers also experience adverse effects, such as eyestrain, nausea and headaches. Some visual discomfort may occur due to excessive demand on the accommodation-vergence linkage, fast local and global motion, and various stereoscopic distortions [1]-[7]. In [8], visual discomfort is measured for a wide range of distortions, including spatial distortion, asymmetries, and binocular disparities. Some eye movements are often related with visual discomfort in watching 3D video [9]-[14]. Lee et al. [14] presented that the saccade movement of the eye is decreased and the number of eye-blinking is increased when visual discomfort of viewer is accumulated. However, these eye movements are not analyzed in measuring visual discomfort in respect to various motion-in-depths and viewing time. In this paper, we present an analysis of eye moments to measure visual discomfort caused from watching stereoscopic 3D video. We measure eye-blinking and saccadic numbers using wearable eye-tracker device to analyze visual discomfort when watching stereoscopic 3D videos. Eye-blinking and saccadic movements are detected by motion information of extracted pupil area in infrared eye-image from eye-tracker devices.

II. EYE-MOVEMENT ANALYSIS FOR VISUAL DISCOMFORT WHEN WATCHING STEREOSECOPIC 3D CONTENT

A. Eye-movement detection

Psychology studies have reported that more frequent eye-blinking corresponds to greater eyestrain [15]. To

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detect eye movements, we used blinking detection method as in [11]-[12]. First, to detect an elliptical pupil area in the image, we use the following equation.

$$\max(x_0, y_0, a, b) = \left| \frac{\partial}{\partial a} \int_{x_0, y_0}^a (a, b) * \frac{I(x, y)}{L} ds \right|$$  \hspace{1cm} (1)

where \((x_0, y_0)\) is the coordinate of the center, \(I(x, y)\) is the intensity at the position \((x, y)\), \(a\) and \(b\) are the major and minor axes, respectively, \(G\) is a Gaussian filter and \(L\) is the circumference of the ellipse.

From the detected pupil location, we calculate axis ratio and motion flow of the pupil region to detect blinking and saccadic movement of eye. Eye blinking is detected by axis ratio and motion flow of the pupil region. Saccadic is detected by acceleration of pupil [14].

B. Experimental setup

The 2D and stereoscopic 3D videos were displayed on 3D display device, which use passive-row interlaced technologies with the following specifications:
- Size: 55-inch
- Aspect ratio: 16:9
- Spatial Resolution: 1920x1080
- Environmental luminance on the screen: 200 lux
- Participants: 30 subjects (13 males and 17 females, ages 21-59: medical condition checked)

When watching 2D and stereoscopic 3D videos, subjects wore polarized glasses with a mounted eye-tracking device, as shown in Fig. 1. The design of the experimental environment was in accordance with the recommendations of ITU-R BT.500-13[16]. The experimental setup is shown in Fig. 1. Lighting conditions were held constant for all participants in all sessions. All external illumination was completely blocked by a thick curtain. The temperature and humidity were held constant, and there were no vibrations or other distractions. The viewing distance was selected as 2054 mm for the 55-inch display size. These viewing distances are the standard viewing distances (three times the display height) for watching 3D videos [17].

![Figure 1. Our experimental setup](image)

C. Test videos

Because there are no publicly available stereoscopic 3D contents suitable for our purpose of measuring the viewer’s visual discomfort, we produced stereoscopic 3D video featuring diverse parallax angle variations.

In each video clip, a single salient object (butterfly) is appeared at random location in display screen which move from zero disparity to a specific, defined degree of disparity with various velocities and toward the viewer, as shown in Fig. 8. Note that the binocular disparity \(\eta\) is the difference between the converging angles of the 3D object point and the screen. This value is computed as follows:

$$\eta = \beta - \alpha$$  \hspace{1cm} (2)

Fig. 2 shows the object’s motion in depth information in our stereoscopic 3D contents. We assume that the inter-pupillary distance is 64mm. Fig. 3 shows sample frames from our stereoscopic 3D video along with

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diverse binocular disparities. The video clips at specific binocular disparity were played at 10-minute lengths.

Figure 2. Binocular disparity

Table 1: Configuration of our Stereoscopic 3D Contents

<table>
<thead>
<tr>
<th>Display size</th>
<th>(D) (mm)</th>
<th>(\Delta D) (mm)</th>
<th>(\alpha)</th>
<th>(\beta)</th>
<th>(\eta)</th>
<th>Motion Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>55 inch</td>
<td>2054</td>
<td>725</td>
<td>2.76</td>
<td>1.78</td>
<td>-1</td>
<td>Slow (105mm/s)</td>
</tr>
<tr>
<td></td>
<td>2054</td>
<td>1275</td>
<td>4.71</td>
<td>1.78</td>
<td>-3</td>
<td>Fast (257mm/s)</td>
</tr>
</tbody>
</table>

D. Test procedure

To compare visual discomfort, 30 subjects watched 2D and stereoscopic 3D video with varying viewing conditions, as shown in Table I. Before the test procedure, we obtained a random sequence of 3D videos by using a random number generator program to avoid the influence of specific sequential test ordering. The test procedure consisted of four stages, as shown in Fig. 4. Before test, the subject closed their eyes and rested to prevent eyestrain from being affected by the subject’s prior physical condition. Then, the subjects answered the following eight questions (dizzy, double vision, stimulus, blurred vision, dry, eyestrain, headache, light-headed) to check their subjective pre-stimulus eyestrain. Each question was answered using a 5-point scale where 1 and 5 represented “not at all” and “yes, very much,” respectively. After taking a rest, the eight questions (dizzy, double vision, stimulus, blurred vision, dry, eyestrain, headache, light-headed) were answered in a period of 2 minutes to check the subject’s pre-stimulus subjective eyestrain. Next, the participant watched the 10-minute stereoscopic 3D video clips. While the subject was wearing polarized glasses equipped with an eye tracking device, we detected her eye movements (blinking rate and saccadic number). After watching stereoscopic 3D video, the subject re-answered the previously mentioned eight questions in a span of 2 minutes to measure the post-stimulus subjective eyestrain.
III. EXPERIMENTAL RESULTS

We measured the blinking rates and saccadic number of viewers while the test subjects watched stereoscopic 3D video using the blinking and saccadic detection method described in Section II.

We present our subjective assessment results based on the participants’ questionnaires. A Wilcoxon sign rank test (two-tailed) was performed on the individual ratings of discomfort obtained through the questionnaires for each motion in depth. As a result, only 4 questions (Q1, Q4, Q5 and Q6) were statistically significant across the slow and fast motion in depth. Fig. 5 shows comparison result of each Q1, Q4, Q5 and Q6 rating scores for each motion in depth.

Fig. 6 shows the comparison of eye-blinking rates and saccadic number per 1-minutes in terms of viewing time with motion in depth variation. The eye-blinking rates and saccadic numbers are modeled using the linear functions: $f_{bl}(b) = \alpha_0 + \alpha_1 b$ and $f_{sc}(s) = \beta_0 + \beta_1 s$, where $b$ and $s$ denote normalized eye blink rate
and normalized saccadic number, respectively. Table 3 and Table 4 show regression coefficients with 95% confidence bounds for eye-blinking rates and saccadic numbers.

Eye blinking rate are positively correlated with binocular disparity, velocity and viewing time. Contrastingly, the saccadic number is negatively correlated with binocular disparity, velocity and viewing time. This was because that the movement of eye gradually decreased when visual discomfort increased.

**Table II. Regression Coefficients Between Eye-Blinking Rates In Terms Of Viewing Time (With 95% Confidence Bounds)**

<table>
<thead>
<tr>
<th>Motion in depth</th>
<th>$a_0$</th>
<th>$a_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blinking rates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1° S</td>
<td>0.0122</td>
<td>0.3163</td>
</tr>
<tr>
<td>-3° S</td>
<td>0.0118</td>
<td>0.4180</td>
</tr>
<tr>
<td>-1° F</td>
<td>0.0117</td>
<td>0.5687</td>
</tr>
<tr>
<td>-3° F</td>
<td>0.0147</td>
<td>0.6126</td>
</tr>
</tbody>
</table>

**Table III. Regression Coefficients Between Saccadic Numbers In Terms Of Viewing Time (With 95% Confidence Bounds)**

<table>
<thead>
<tr>
<th>Motion in depth</th>
<th>$\beta_0$</th>
<th>$\beta_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saccadic numbers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1° S</td>
<td>-0.0115</td>
<td>0.7833</td>
</tr>
<tr>
<td>-3° S</td>
<td>-0.0109</td>
<td>0.6847</td>
</tr>
<tr>
<td>-1° F</td>
<td>-0.0075</td>
<td>0.6178</td>
</tr>
<tr>
<td>-3° F</td>
<td>-0.0095</td>
<td>0.4860</td>
</tr>
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Figure 6. Subjective test result
IV. CONCLUSION

In this paper, we presented an analysis of eye moments (blinking rate and saccadic number) to measure visual discomfort caused from watching stereoscopic 3D video. We found that eye movements are related with visual discomfort. Specifically, the blinking rate in eye movements gradually increased but saccadic number gradually decreased at large binocular disparity and fast velocity of motion-in-depth. Our results show that it is possible to estimate or predict a visual fatigue of a viewer. This will be useful to improve the overall quality of experience of viewing 3D contents.

REFERENCES