Visual fatigue detection using binocular disparity and PPG in stereoscopy

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Abstract: In this paper, the amount of visual fatigue caused by stereoscopic videos and its corresponding physiological changes are analyzed. We analyze visual fatigue using binocular disparity which is the most fundamental cause of such fatigue. The previous researches used a methods of comparing data obtained before and after watching 3D videos; however, the comparative data analysis from such method is hard to find. This research aims to achieve relevant results that can be gathered by determining the VFL (Visual Fatigue Level) of 3D videos and analyzing the changes in body signals while watching the videos.

1. Introduction

With the development in 3D technology, 3D displays and image processing techniques are improving too. However, occurrence of visual fatigue from using stereo-type display devices has been reported in [1]. Moreover, phenomenon such as headache, motion sickness, and dizziness can occur due to visual fatigue caused by watching the 3D videos. There are various methods of representing the VFL (Visual Fatigue Level): modeling VFL using histograms [2]; SRVF (Simplified Relative Visual Fatigue), which involves curve fitting of two divided regions where each represent disparity of sound and volume obtained from MOS test [3]; and VVF (Variance based on Visual Fatigue), which uses dispersion collected by partitioning the disparity map into multiple areas [4].

Recently, there has been an active progression of research involving the changes in body signals caused from the 3D visual fatigue. Such researches include the use of EEG (Electroencephalogram) for assessing fatigue levels by watching 3D TV [5], the influence of 3D visual fatigue levels on autonomic nervous system [6], and canonical correlation of 3D visual fatigue between subjective and physiological measures [7]. These existing researches analyze the change in body signals associated with the visual fatigue by comparing data obtained before and after watching 2D and 3D videos. In this work, PPG (Photo plethysmography) is used which measures body signals of viewers while watching 3D videos to achieve the comparative analysis with VFL [2]. The effects of 3D visual fatigue on autonomic nervous system are observed by checking the heart rate variability and activity of both parasympathetic and sympathetic nervous systems.

2. Method

2. 1 Human Visual System & 3D systems

Human visual system uses two eyes to cognize objects and their depth using difference of field of view in each eye. Figure 1 shows general human visual system.

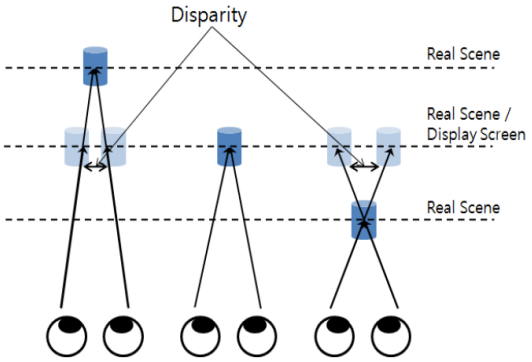


Figure 1. Human Visual System

Stereoscopic is difference from human visual system because it is an artificial display device. The basic requirement is to display offset images that are filtered separately to the left and right eye. There are four systems to watch 3D display [9]: 1) Anaglyph 3D with passive color filters, 2) Polarized 3D system with passive polarization filters, 3) Active shutter 3D system with active shutters, 4) Head-mounted display with a separate display positioned in front of each eye. As observers watch artificial scene, visual fatigue is occurred different with human visual system.

2. 1 Visual fatigue Level acquisition

In order to calculate the VFL, obtaining the disparity map of stereoscopic images is necessary; hence, SSD (Sum of Squared Difference) is used to obtain the disparity map. The SSD finds matching points by comparing the difference of squared values between a target pixel in the left image and pixels on the search range in the right image. The equation for SSD is given in (1).

$$SSD(i,j,d) = \sum_{r=-w}^{w}\sum_{c=-w}^{w}(P_R(i+r,j+c) - P_L(i+r,j+c+d))^2 \quad (1)$$

In equation (1), i and j represents the current position of the pixel while d and w represents the range and size of the mask, respectively.

Figure 2. Disparity-map Image

With the obtained disparity map shown in Figure2, VFL is calculated [2]. The X-axis and Y-axis in the histogram represent disparity value and number of pixels at the disparity respectively. Figure3 shows an example of obtained hostogram. This method sets a threshold at the zero disparity to 60% of area and calculates VFL with weight at each area. Each area is divided into positive and negative area, which is close and far from the zero-disparity, respectively. The VFL is found by applying the weights on each area and the averaged over 60 seconds intervals for all frames of VFL.

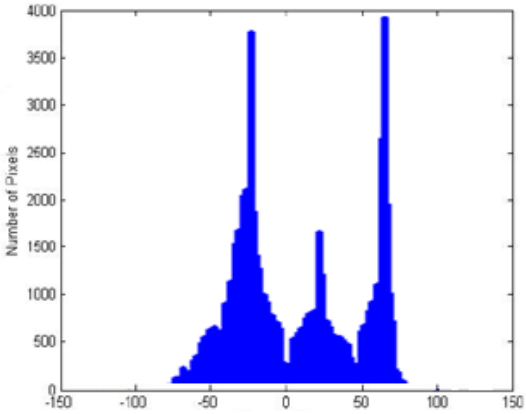


Figure 3. Example of Histogram

2. 2 Photo plethysmography

The heart rate per hour can vary depending on the physical activities. PPG is used in order to measure it. To determine the actual clinical significance, HRV (Heart rate variability), which represents the fine difference between the two consecutive heart beats was used.

The autonomic nervous system affected HRV which is related with interaction between sympathetic and parasympathetic nerves. The parameters used to analyze HRV are mean HRV, SDNN, RMS-SD of Time-domain analysis and frequency area dependent VFL, LF, HF, LF/HF ratio of frequency-domain analysis. In the proposed method, Mean HRV, SDNN, RMS-SD, LF/HF ratio are used. Table1 shows HRV analysis lists.

Table 1. HRV analysis list

Variable Range	Units	Description	Domain
Mean HRV	ms	Mean of HRV	Time
SDNN	ms	Standard deviation of the NN interval	Time
RMS-SD	ms	Root mean square of successive difference of the NN interval	Time
LF	ms^2	Power in the low frequency range	Frequency (0.04 - 0.15Hz)
HF	ms^2	Power in the high frequency range	Frequency (0.15 -0.4Hz)
LF/HF ratio	-	Ratio of LF to HF	Frequency

2. 3 Experiment design

In this experiment, 12 people were asked to sit on fairly comfortable chairs and were made to watch two 6-minutes videos on a 3D TV. The 47-inch 3D TV and PPG devices were given to the people with an average age of 29.3 years, and they were seated about 1.5 meters away from the TV. The PPG device collected a signal of 200 Hz by attaching p400 sensor on left hand index finger. The 3D contents used in this experiment were 6-minutes extraction of highly detailed 3D movies, Avengers and Frozen.

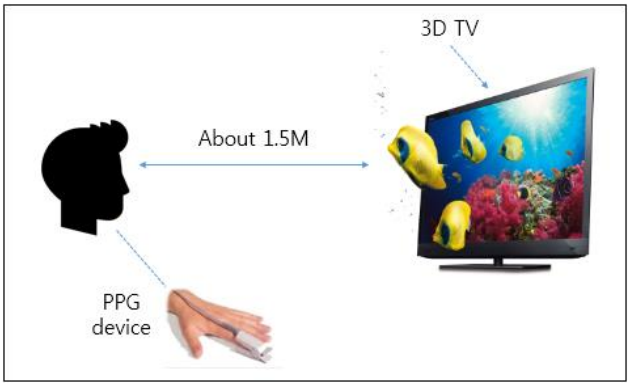


Figure 4. Experiment system for measuring PPG on 3D display

3. Result

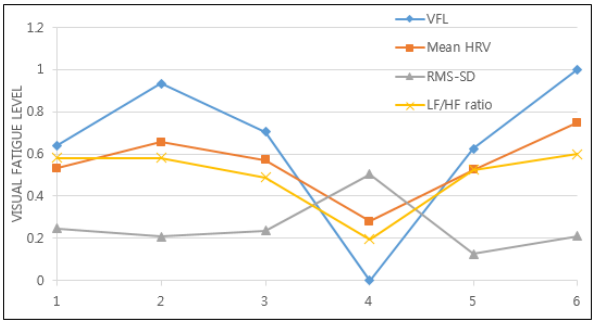
Using the method from section 2.1, the average VFL of 3D movie per minute was calculated. Table 2 lists the average VFL for the two videos arranged with 1-minute interval. The high VFL is achieved at 2 and 6 minute in the video of Avengers and at 3, 4, and 5 minute in the video of Frozen.

Table 2. Average VFL in time

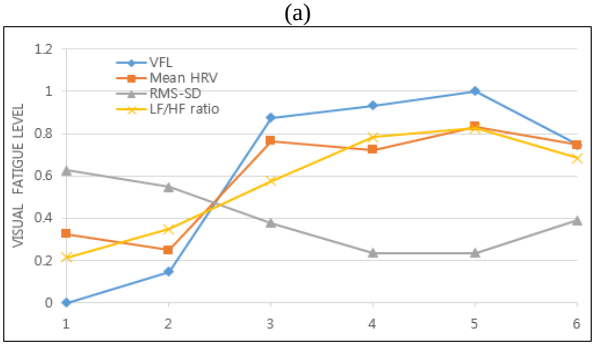
Time	Avengers	Frozen
1	57.44	43.58
2	64.89	50.47
3	59.08	84.50
4	41.06	87.21
5	57.01	90.28
6	66.62	78.41

The hourly VFL and measured PPG parameters were found and analyzed through comparison, and it was observed that when VFL is high, the value of Mean HRV and RMS-SD decrease and LF/HF ratio value increases. The Mean HRV is

increased with respect to VFL. RMS-SD represents the control ability of parasympathetic nerves of the heart, and hence the decrease of RMS-SD indicates weakened activity of the parasympathetic nerves. Figure5 shows VFL and PPG parameters.



(a)



(b)

Figure 5. VFL PPG parameter analysis; Mean HRV; RMS-SD; LF/HF ratio (a) Avengers (b) Frozen

On other hand, the LF/HF ratio indicates the degree of activity balance of sympathetic and parasympathetic nerves of LF and HF. When VFL is high, the increase of LF/HF ratio means that the sympathetic system is activated. In other words, if VFL is significant, the visual fatigue creates stress and activates the sympathetic nervous system by autonomic nervous system.

These existing researches analyze the changes in body signals associated with the visual fatigue by comparing data obtained before and after watching 2D and 3D videos[6][7]. There is research showing that the sympathetic nerves are activated after viewing 3D images. In this paper, we quantitatively quantify the visual fatigue due to images is analyzed by measuring the body signal using ppg while watching 3D images. In general, when viewer is subjected to mental fatigue and stress, the central parasympathetic nerve activity is suppressed and reduced the variation and heart rate that occurs relatively quick by activating the sympathetic nervous heartbeat. The sympathetic nervous system is activated by quantified visual fatigue that also suppresses parasympathetic nervous system when its level increases during experiment.

4. Conclusion

In this paper, we determined the VFL from stereoscopic images and performed comparative analysis of the calculated VFL with measured body signal using PPG. Through this experiment, the 3D VFLs and their corresponding meaningful analysis results can be obtained. This research will be useful in improving the user's inconvenience associated with visual fatigue. We will also be able to introduce new devices such as those featuring VR (Virtual Reality) technology in the display market.

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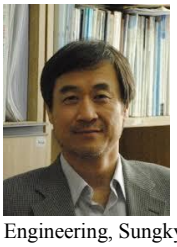

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