

Visual Fatigue Measurement Model Based on Multi-Area Variance in a Stereoscopy

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Abstract— In this paper, we propose a visual fatigue measurement model which based on multi-area variance. Existing visual fatigue measurement model focused at negative area which largely occurred visual fatigue. To make up for previous research, our method uses characteristic of depth-map image that can consider negative area and positive area. Then, we calculate variance ratio and average ratio that located at maximum variance area and minimum variance area in a depth-map image. We obtained correlation index of 87.3% from experimental results which is between Variance based on Visual Fatigue (VVF) model and Mean Opinion Score (MOS).

Keywords— visual fatigue, depth map, stereoscopic, multi-area variance, MOS

I. INTRODUCTION

Development of 3D display technology has revolutionized in new display market. However, 3D display market scale was rapidly reduced due to visual fatigue [1]. When observers watched a 3D image on screen, they felt eyestrain and video motion sickness. Video motion sickness caused nausea in human body when observers are watching video that includes shake and dizziness. Eyestrain is caused by mismatching of human visual system that includes accommodation and vergence. Accommodation is to focus on objects and vergence is an angle formed of focusing on objects. Ohzawa et al. [2] classified the disparity as the positive disparity and the negative disparity. The negative disparity is located closely and provide pop-out effect to the observers. When observers watch objects in the negative area, accommodation and vergence will be congested. Due to this reason, several visual fatigue researches are focused at close objects [3, 4]. Kim et al. [3] proposed VFL (Visual Fatigue Level) model based on histogram. This method sets a threshold at the zero disparity to 60% area and calculate VFL with weight at each area. Another method is SRVF (Simplified Relative Visual Fatigue) model [4] which drew the curve using MOS test. Then, they divided the curve into two parts, the negative disparity and the positive disparity in order to make the best fit. They derived the equation using the curve and an exponential in the negative area which observer felt large visual fatigue.

In this paper, we propose a new visual fatigue measurement model which considers the positive disparity, observers felt less visual fatigue. Therefore, we consider positive disparity for

visual fatigue measurement using depth map. Depth map is a distance between left and right images which is an easy way to measure the visual fatigue. Then, we divide a depth map of image to calculate variance and average. Finally we derive a so called *Variance based on Visual Fatigue (VVF)* model to measure a visual fatigue.

The remainder of this paper is organized as follow. Section 2 discusses human visual system, 3D display systems and depth map acquisition algorithm. In Section 3, we explain how to derive our VVF model. Experiment result is shown in Section 4. Finally, we draw a conclusion in Section 5.

II. RELATED WORK

A. 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 [3]. Figure 1 shows general human visual system.

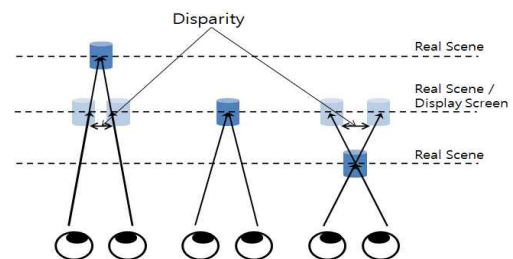


Figure 1. Human Visual System [3]

Stereoscopic is different 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 [7]: 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.

B. Depth map Acquisition

To measure a visual fatigue, firstly we obtain disparity map. Generally, disparity map acquisition uses left and right image in stereoscopic [5]. Then, we calculate similarity using MSWO

(Multi-Sliding-Window-Operation) [6]. To find similar point, we adapt an SSD algorithm. The SSD (Sum of Squared Difference) algorithm calculates difference of value in the block and values in the mask are added and squared. The equation of SSD is shown in (1). Here, i and j are location of current pixel, d is search range and w is mask size respectively.

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

We obtained a disparity map, however, disparity map has many noises. To remove these noises, we use morphological operation and median filter. Morphological operations are based on erosion and dilation. Erosion operation is removing a pixel if any pixel value in an n by n window is not valid, and dilation operation is opposite, which is filling a pixel if any value in an n by n window is valid [7]. Finally, we use the median filter to remove noises which has strength of salt-pepper noises. Figure 2 shows a result of depth map.



Figure 2. Result of depth map

III. DERIVE VARIANCE BASED ON VISUAL FATIGUE MODEL

In this paper, our main goal is to measure a visual fatigue using depth map. To achieve our method, we use the variance to find a positive disparity and a negative disparity. The variance has the characteristic that indicates the degree of scattering in the average. Therefore, we divide several areas and find maximum variance area and minimum variance area. The equation of variance shown in (2). Figure 3 shows an example of our proposed method.

$$S^2 = \frac{1}{N} \sum_{i=1}^N (x_i - \bar{x})^2 \quad (2)$$

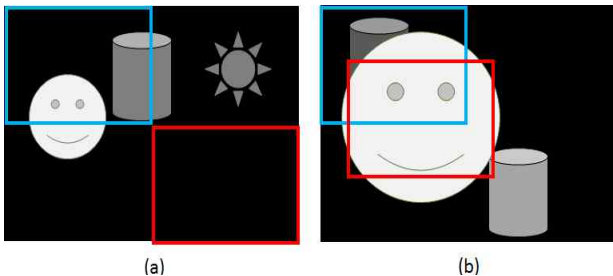


Figure 3. Example of proposed method

In figure 3, the bright object indicates the closest object that can classify negative area and positive area. And red rectangle indicates minimum variance area and blue rectangle indicates maximum variance area. Compare with (a) and (b), minimum variance area locates different. In this case, we do not know whether positive area or negative area. To solve this problem, we set 4 steps to measure a visual fatigue.

Step 1. (Create an optimized depth map)

This process already explained in section 2.

Step 2. (Set an area to one of fourth of an image)

To classify positive area and negative area, we set an area to one fourth of a depth map of image. Then, we search the overlapping multi-area of the image. Actually we move one quarter of an image width through the complete image and we get nine searching areas.

Step 3. (Find maximum variance area and minimum variance)

In step 2, we set the nine searching area. We calculate the variance and average pixel value at each area. And find the maximum variance area and the minimum variance area. Up to this time, we find average at minimum variance area and maximum variance area. The average can classify the positive area and negative area.

Step 4. (Measure a visual fatigue)

It is difficult to classify variance difference between positive area and negative area. Therefore, we calculate the variance based on visual fatigue (VVF) model as shown in equation (3).

$$VVF = \frac{V(j) * A(j)}{V(i) * A(i)} \times \max_disp \quad (3)$$

In the equation (3), V means the variance and A means average pixel value, i means maximum variance area and j means minimum variance area. $\max_disp$ indicates maximum value in depth map. If minimum variance area is a positive area, the average pixel value is lower than maximum variance area. Conversely, if the minimum variance area is a negative area, the average pixel value is higher than maximum variance area. Therefore, we multiply the variance and average at each area and divide the value. Finally we multiply $\max_disp$ and obtain the variance based on visual fatigue (VVF) model.

IV. EXPERIMENT RESULT

The main purpose of this measuring model is closeness to MOS test. To verify our VVF model, firstly, we compare with MOS test. Secondly, we compare with SRVF [4] and MOS test. We use six images using middle-berry stereo data set [9] and obtained depth map of image. We set the ratio of the negative disparity search range to the positive search range to be 3:1. Therefore we adapt 54 negative pixel and 18 positive pixel [10]. Our experiment environment is shown in table 1 and figure 4 shows original images and depth map images.

Table 1. Experiment environment

Viewing distance	1.5 M
Display device	LG d2743P
Image size	720 x 480
Depth map search range	-54 to 18

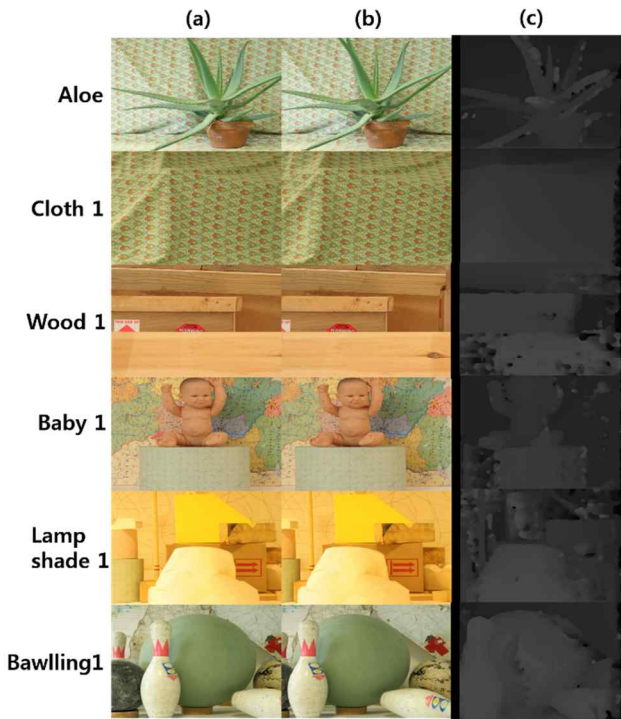


Figure 4. Depth map image for experiment, ((a): left image, (b): right image, (c): depth map image)

Firstly, we calculate the VVF result. Table 2 shows the result of VVF model and MOS test. Each observers mark grads for each images from 1 to 5 depend on degree of visual fatigue they felt and calculate the averages.

Table 2. Result of VVF

Image	Maximum variance (average)	Minimum variance (average)	VVF	MOS score
Aloe	235.67 (40.36)	49.98 (47.13)	17.83	4.3
Cloth	499.80 (52.53)	3.85 (52.59)	0.92	2.1
Wood	451.82 (52.158)	42.72 (52.06)	6.79	3.1
Baby	298.09 (44.25)	36.00 (53.39)	10.49	3.8
Lampshade	424.30 (56.70)	49.36 (64.05)	9.46	3.5
Bowling	437.43 (51.48)	31.62 (60.97)	6.16	1.9

In the table 2, an aloe and a baby depth map image shows complicated and contain many negative areas. On the other hand, a bowling and a cloth depth image shows monotonous. Therefore, observer felt larger visual fatigue at an aloe image and felt less visual fatigue image at bowling image. In addition, the result of VVF is similar to MOS test.

Secondly, we compared with VVF and SRVF. Table 3 shows the result of SRVF [4]. SRVF model is shown as equation (4). In equation (4), where TP is total number of pixel in stereoscopy and P_x is the number of pixel at x.

$$SRVF = \int_0^a \frac{P_x}{TP} (x - a) \cdot \ln \left(\frac{x}{a} \right) + \int_a^\infty \frac{P_x}{TP} \left(\frac{x-a}{a} \right)^2 \quad (4)$$

Table 3. Result of SRVF

Image	SRVF
Aloe	71.88
Cloth 1	51.24
Wood 1	45.40
Baby 1	65.50
Lampshade 1	49.85
Bowling 1	39.42

Then, we obtained the correlation index to compare with our VVF model. Table 4 shows the result of correlation index between SRVF model and MOS test, VVF model and MOS test.

Table 4. The correlation between VVF, SRVF and MOS (%)

	VVF	SRVF
MOS	87.3 %	81.2 %

As shown in Table 4, our VVF model obtained the 87.3% of correlation index. However, SRVF model obtained the 81.2% of correlation index. SRVF model sets a weight at negative area using exponential and obtained large value at negative area. Although SRVF consider the positive area yet its value is minimum. Comparing with SRVF, our proposed VVF model improves by the difference of 6% of correlation index.

V. CONCLUSIONS

In this paper, we proposed new visual fatigue measurement model using multi-area variance. We only use the variance ratio and average ratio in the image, we derive a visual fatigue model. Compared with existing visual fatigue model, our model improves by the difference of 6% correlation index. Our research will be useful for user discomfort improvement. In addition, we can assist new display market such as VR (Virtual Reality) or HMD (head-mounted-display). In our future research, we will measure a visual fatigue using biomedical signal such as EEG (Electroencephalogram) and PPG.

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REFERENCES

- [1] Kwai Dakashi, Morikawa Hiroyuki, Ota Gage and Abe Nobuyaki, *Based on the 3D stereoscopic image*, Paju, Korea: BM Sungandang, 2011.
- [2] Ohzawa, Izumi, Gregory C. DeAngelis, and Ralph D. Freeman. "Stereoscopic depth discrimination in the visual cortex: neurons ideally suited as disparity detectors." *Science* 249.4972 (1990): 1037-1041.
- [3] Jong-hak Kim, Jeong-hun Kim, Hun-ho Ham, jun-dong Cho, "Measurement of Level of Stereoscopic Visual Fatigue for User Discomfort Improvement" *IEIE SoC Conference*, 2011, pp. 234-238.
- [4] Jea-geon Kim, Jun-dong Cho, "Simplified relative model to measure visual fatigue in a stereoscopy." *IEICE TRANSACTIONS on Fundamentals of Electronics, Communications and Computer Sciences* 94.12 (2011): 2830-2831.

- [5] Cho, Hyeong-jun, Shim, Sang-kwon, Kim, Seung-ho, Kim, Jong-hak and Cho, Jun-dong, "On High-Computational Disparity Acquisition of HD Image Using CUDA Implementation for Stereo Matching", SoC Design Conference (ISODC), 2015 International. IEEE, 2015.
- [6] Kim, Jong Hak, et al. "A real-time 3D disparity-map acquisition hardware architecture for a multi-sliding-window-operation." *Signal Processing Algorithms, Architectures, Arrangements, and Applications Conference Proceedings (SPA), 2011*. IEEE, 2011.
- [7] Kim, Jong-hak, and Jun-dong Cho. "A real-time 3D image refinement using two-line buffers." *Advanced Communication Technology (ICACT), 2011 13th International Conference on*. IEEE, 2011.
- [8] "3D TV". *3D Wise*. Retrieved 28 March 2013.
- [9] www.middleberry.com
- [10] Kim, Jae Gon, and Cho, Jun-Dong. "Optimizing a virtual re-convergence system to reduce visual fatigue in stereoscopic camera." *IEICE TRANSACTIONS on Information and Systems* 95.5 (2012): 1238-1247.



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