LETTER

Simplified Relative Model to Measure Visual Fatigue in a Stereoscopy

Jae Gon Kim, Nonmember *and* Jun-Dong Cho [a)], Member

SUMMARY In this paper, we propose a quantitative metric of measuring the degree of the visual fatigue in a stereoscopy. To the best of our knowledge, this is the first simplified relative quantitative approach describing visual fatigue value of a stereoscopy. Our experimental result shows that the correlation index of more than 98% is obtained between our Simplified Relative Visual Fatigue (SRVF) model and Mean Opinion Score (MOS).
key words: *visual fatigue, simplified relative visual fatigue model, stereoscopy, stereo vision systems.*

1. Introduction

When an observer watch a stereo image on the screen, the observer focuses to match the left and right images with converging eye movement, permitting each image to appear as stereoscopy by spatial perception of human nature. In this process, *visual fatigue* is occurred by various reasons; binocular disparity, motion parallax, texture gradients, occlusion, blur, etc. [1]. Resolving the problem of visual fatigue or discomfort after watching 3D displays, even for a short period, has been considerably researched in relation to stereoscopic displays [1, 2, 3]. Hoffman et al. [1] noted that conventional 3D displays create unnatural conflicts between accommodation and vergence. Lambooij et al. [2] also mentioned that the human eye experiences conflict between accommodation and vergence that mostly affects visual fatigue.

In this paper, we propose a so-called *Simplified Relative Visual Fatigue* (*SRVF*) model to evaluate the degree of the visual fatigue in a stereoscopy. Ukaia et al. [3] used a modified simulator sickness questionnaire (SSQ) evaluation commonly experienced by users of virtual reality systems. However, SSQ always need participants to obtain the result. Therefore, existing model evaluating visual fatigue is unsuited for measuring visual fatigue in run-time. Whereas, our model considers only the "accommodation and vergence" factors that can be calculated by disparities in a stereoscopy. Therefore, we suggest a new quantitative visual fatigue model, which can preprocess when capturing or displaying stereo images in real-time.

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The authors are with Department of Mobile Systems Engineering, Sungkyunkwan University, Korea.
a) Corresponding author; E-mail: jdcho@skku.edu

2. Experiments and Results to Derive Simplified Relative Visual Fatigue Model

We motivated by Ohzawa et al. [4] who classified the disparity as the positive disparity and the negative disparity. The negative disparity provides a pop-out effect to the viewer. In this case, large-sized objects are uncomfortable to the viewer.

From [4], five sets of four different stereoscopic instances were provided to evaluate visual fatigue in our experiments. The first and second in a set are a large object; the third and fourth are small objects in the negative disparity zone and in the positive disparity zone. A large object implies an object that exceeds 30 % of a complete image size. A small object is less than 5% of the image size. We used the MOS method for evaluation.

We used bad/good parallax pairwise comparison in a stereoscopy for a fair evaluation. Good parallax refers as a stereoscopy which contains convergence point (typically shows as zero parallax) clearly, whereas bad parallax is not. Fig. 1 shows partial test images.

(*D: Avg. converged objects disparity)

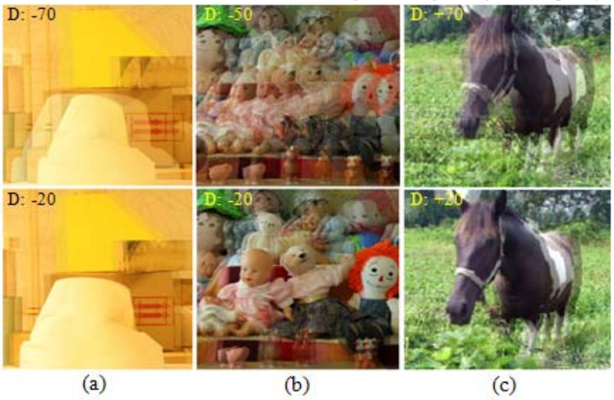

Fig. 1 Test images to evaluate visual fatigue. The top are bad parallax images and the bottom are good parallax images.

Table 1 MOS results (selected)

Stereoscopy	Avg. MOS result with bad parallax image	Avg. MOS result with good parallax image
Fig.1.(a),Case 1	4.8	1.6
Fig.1.(b),Case 2	2.6	1.4
Fig.1.(c),Case 3	1.9	1.2
Case 4	1.2	1.1

* Note) The evaluation is based on the five grades (1 to 5); 1:very comfortable, 2:comfortable, 3:a little uncomfortable, 4:uncomfortable, 5:very uncomfortable.

Table 1 shows selected MOS results of a set. We drew the MOS results (depicted as bars) in Fig. 2 from the total results with various average of converged objects disparity. Bar indicates the deviation from converged object size at same disparity. We obtained relatively accurate visual fatigue from the MOS evaluation. However, we need extra surveys whenever we evaluate new stereo images. Therefore, we decided to fit a curve from our MOS result database. In Fig. 2, we drew the curve fitted from a regression analysis of MOS. When we fit a curve, we discovered that the SRVF curve shape is changed at the zero parallax point.

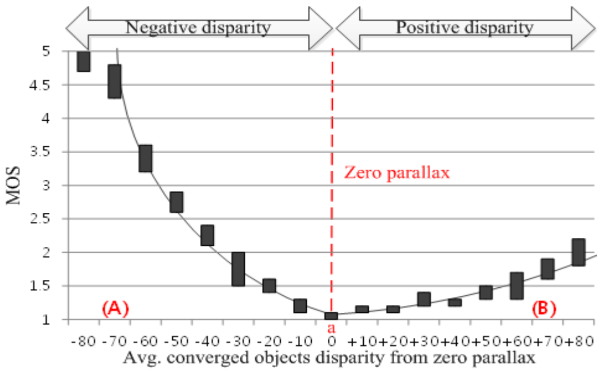

Fig. 2 The graph of MOS results with various Avg. converged objects disparity and curve fitted from a regression analysis of MOS.

We divided the curve to two parts to make the best fit. As shown in Fig. 2, **(A)** is the negative disparity part and **(B)** is the positive disparity part. The negative disparity usually occur bigger visual fatigue than the positive disparity. When we used separated models of each part, we obtained accurate curve fitting.

The simplified relative visual fatigue value in the positive disparity part (denoted as VF_p) is modeled as

$$VF_p = \left(\frac{x-a}{a}\right)^2 \tag{1}$$

where x is the distance from the stereo camera to the object and **a** is the zero parallax distance. The simplified relative visual fatigue value in the negative disparity part (denoted as VF_n) is modeled as

$$VF_n = (x-a)\cdot\ln\left(\frac{x}{a}\right) \tag{2}$$

From (1) and (2), we finally derive the simplified relative visual fatigue value in a stereoscopy (*SRVF*) as follows:

$$SRVF = \int_0^a \frac{P_x}{TP}(x-a)\cdot\ln\left(\frac{x}{a}\right) + \int_a^\infty \frac{P_x}{TP}\left(\frac{x-a}{a}\right)^2 \tag{3}$$

where ***TP*** is total number of pixels in stereoscopy and $\boldsymbol{P_x}$ is the number of pixels at x. We tested our SRVF through same stereoscopic instances which are used in MOS evaluation. Table 2 shows the result.

Table 2 SRVF results (selected)

Stereoscopy	SRVF with bad parallax image	SRVF with good parallax image
Fig.1.(a),Case 1	98	4
Fig.1.(b),Case 2	19	3
Fig.1.(c),Case 3	4	2
Case 4	2	1

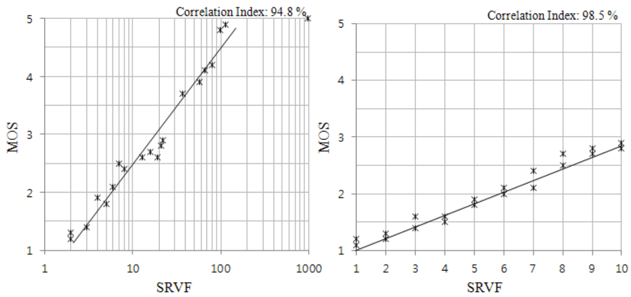

Fig. 3 The correlation between MOS and SRVF; bad parallax results(left), good parallax results(right).

*Note: In bad parallax results, some SRVF results show very high points due to a limitation of the regression model.

As shown in Fig. 3, we obtained the 98.5% (resp. 94.8%) of correlation index between our SRVF model and MOS for good (resp. bad) parallax results. In addition, we determined that when SRVF is less than 10 points, the stereoscopy is comfortable to watch. However, when SRVF exceeds 50 points, the stereoscopy is very uncomfortable to watch.

3. Conclusion

In this paper, we demonstrated that our proposed SRVF model is sufficiently to be used to measure the quantitative visual fatigue value. The advantages of SRVF are 1) we can use in run-time to minimize visual fatigue 2) SRVF is of practical use due to monotonic formula 3) we can obtain optimal stereo images even though they are unfamiliar 3D contents. Accordingly, we suggest SRVF as a standard to measure quantitative visual fatigue.

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