doi:10.3772/j.issn.1006-6748.2019.01.006

Effects of disparity distribution on visual comfort for multiple objects of stereoscopic images①

Su Zhibin (苏志斌)②, Li Dongrui, Zou Fangju, Ren Hui
(Key Laboratory of Acoustic Visual Technology and Intelligent Control System & China Beijing Key Laboratory of Modern Entertainment Technology, Communication University of China, Beijing 100024, P. R. China)

Abstract

With the development of stereoscopic technology, more attention is attracted on the stereoscopic three-dimensional (S3D) content and service, and researches on images and videos have emerged in large numbers. This paper focuses mainly on visual comfort affected by characteristics of disparity for multiple objects. To find the relationship between disparity distribution and visual comfort perception, several subject evaluation experiments are done. The study contains two spatial distribution types of disparity: 1) only one of the foreground objects has zero disparity; 2) one of the foreground objects has positive disparity, while the other one has negative disparity. The experimental results and relative regression analysis provide appropriate relationship between disparity distribution and visual comfort for both conditions, which is significant to meet the applicant field in S3D content acquisition, display adjustment and quality evaluation.

Key words: disparity distribution, disparity magnitude, stereoscopic images, visual comfort, regression analyses

0 Introduction

In recent years, more attention has been paid to 3D content and service than ever, especially for the videos production and image processing and analysis, which can bring people strong sense of immersion and reality. This kind of visual experience can also be transplanted to some mobile terminals, with the 3D screen of same display principle but smaller size. To enlarge the application field and improve the viewer's perception, researchers have begun to focus on the quality and experience level of stereoscopic three-dimensional (S3D) images and videos in the past thirty years. The quality indicators include image resolution, visual comfort, depth perception, naturalness, immersion feeling, and so on. Moreover, some evaluation methods for viewers' experience and visual stimulation based on experimental psychology are used to quantify the subjective perception and search the visual regular patterns. As the increasing requirements for long time watching and better experience for visual health, main concern of this paper is visual comfort under different disparity distribution conditions. The following are some existing researches about visual comfort of the S3D images or videos. Choi et al.[1] selected four kinds of visual fatigue (some reports also called it visual discomfort) factors as the perception features of the visual comfort, and they finally got the prediction method for the stereoscopic videos based on linear combination of these factors. Zhang et al.[2] extracted four kinds of visual features of S3D images having potential correlations with visual comfort, including disparity distribution features, disparity jump features, object distribution features as well as object width features on multiple salient objects. Wang et al.[3] did a research on the effects of the luminance on the visual comfort of 3D images. And they gave a conclusion on what relationship is between the extracted feature and the visual comfort. Ref. [4] viewed the content dependent factors as a prediction of the visual fatigue, mainly for the images with excessive disparity range. Through experiments, they got a conclusion about the relationship between these factors and the visual comfort. These studies have shown that either the image content features or the disparity features is used to represent the influence for visual comfort effectively.

Of all kinds of features extracted from the S3D im-

① Supported by the National Science and Technology Planning Project (No. 2012BAH38F00) and the Engineering Research Project of Communication University of China (No. 3132016XN1622).
② To whom correspondence should be addressed. E-mail: suben@cuc.edu.cn
Received on Mar. 21, 2018

ages, factors of disparity are the main concern of viewing perception. Ref. [5] exploited an attention model-based visual comfort metric, considering perceptually significant regions of stereoscopic images. And they also developed a model to describe the relationship between visual comfort and depth perception based on psychophysical experiments with diverse amount of binocular disparities. Jiang et al. [6] extracted the disparity mean, disparity variance, disparity range and disparity gradient based on the visual important regions. They defined the variable disparity range as the difference between the mean value of maximum disparity and the minimum disparity. Zhu et al. [7] did a research to find the relationship between different vertical disparity magnitude and the visual comfort. And the results showed that the best performance of vertical disparity angle should be controlled between $-0.14°$ and $0.375°$. Ref. [8] proposed an index model to predict the visual comfort, and the feature which they extracted is negative disparity in the vertical direction. Above all, these researches showed that the disparity features are one kind of the most important factors as the prediction features of the degree of the visual comfort. However, there are few researches taking both the negative and positive disparity into account. And the relationship between them is still not clear.

In this study, the effects on the visual comfort are considered mainly when there are both negative disparity and positive disparity with two same objects in a stereoscopic image. In addition, two kinds of experiments are designed to find what effects the disparity features have on the visual comfort of stereoscopic images. The contribution of the work is three fold.

(1) multiple contents are chosen as the main foreground objects, while most of other researches consider only one main object for visual comfort;

(2) two types of disparity distribution are studied separately, especially the type with both positive and negative disparities, which is more similar to the natural image of S3D content;

(3) the relative regression linear models are contributed through subject evaluation results, which will help to predict the visual comfort for different application fields.

The remaining parts of this paper are arranged as follows. In Section 1, the steps of the experiments are listed. Section 2 shows the experimental results and analyses. Finally, conclusions are drawn in Section 3.

1 Experimental design

To simulate the real scene of multiple objects for S3D image and videos, a computer generated image with two simple shapes of Maltese cross is designed. The left cross is object A and the right cross is object B. For different space position type of the subjective experiment, there are forty-eight combinations for disparity type (negative or positive) and disparity magnitude of the two Maltese crosses. To reduce the impact on visual comfort of the contrast between main body and background, details about the local contrast can be found in Ref. [9], the region contrast of images in the proposed experiment is set to 0.5. In addition, to avoid the influence of spatial frequency on visual comfort, the Maltese cross, which is considered to have both high-frequency components and low-frequency components, is also a better choice than other simple objects[10,11]. An improved single-stimulus method is used for evaluation (observers were demanded to watch twice of the whole sequences without duplicate orders) and a five-point scale table is given to the observers, as shown in Table 1.

Table 1 Evaluation scales of visual comfort

Description of evaluation scales	Scale
Very comfortable	5
Comfortable	4
Perceptibly uncomfortable but acceptable	3
Clearly uncomfortable and unacceptable	2
Extremely uncomfortable and extremely unacceptable	1

The final test sequences are generated by the format of 19 201 080, side-by-side (half) after postproduction and sent to the professional LCD 3D monitor of SONY 2451TD through a 3G-SDI line. Observers watch the 24 inches screen at a view distance of 1.8 m with polarized glasses. There are totally 23 observers participating in the proposed experiment with an average age of 22. All of the observers are proved to have normal stereo vision functions after testing of stereoscopic acuity, perception level of different layers and so on. According to the standard of subjective evaluation method for image quality, the observers of this experiment will be informed of the experimental motivation and possible negative influence of experimental stimulation before the experiment starts. In order to exclude the error caused by the experimental results, due to the different educational backgrounds and knowledge levels of the research, none of them is familiar with S3D video technologies.

The video playing mode of each test image contained 6 s for viewing the stereoscopic images (T2) and another 6 s for rating (T3), which is shown in Fig. 1.

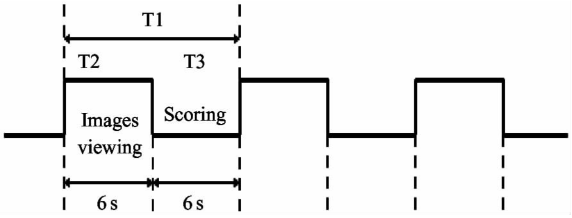


Fig. 1 The video playing mode

Of the forty-eight image sequences, the disparity distribution of the two objects is divided into two types. Type1: only one of the foreground objects had zero disparity; Type2: one of the foreground objects had positive disparity, while the other one had only negative disparity. These two distribution types are both the common scene for S3D productions.

For type1, the absolute value of disparity magnitude include six levels: 20, 30, 40, 50, 60 and 70 (arcmin) respectively. These values of the disparity magnitude also represent the disparity distribution range. And the experimental variables are designed as shown in Table 2, with a total number of 26 sequences. As for the two kinds of disparity spatial distribution, one of them is called type1_N, which represents that one subject is on the screen (zero disparity), and the other one is outside the screen (negative disparity), called type1_P, which means one of the two objects is inside the screen (positive disparity), and the other is on the screen (zero disparity).

Table 2 Experimental variables of type1

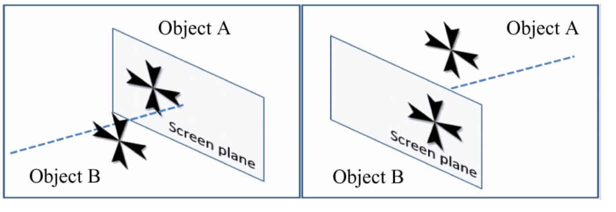
Variables (arcmin)	Descriptions
Disparity types	type1_N: Object A (zero disparity), Object B (negative disparity) type1_P: Object A (positive disparity), Object B (zero disparity)
Disparity magnitude	20, 30, 40, 50, 60, 70
Disparity distribution	Object A: 0 – 70 arcmin Object B: – 70 – 0 arcmin

For type2, the absolute value of disparity magnitude is the same as type1 yet with a total number of 66 sequences. In this experiment, by combining the disparity magnitudes of these two objects, the analyses form is more than one way. Table 3 shows the variable settings about type2, of which none of the objects is on the screen. So the range of the disparity spatial distribution is double of type1. It can be got from Table 3, and the disparity range is from 40 to 140, with the interval of 10 levels.

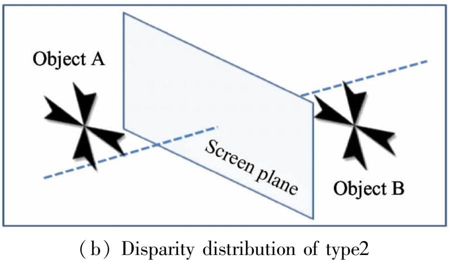
Table 3 Experimental variables of type2

Variables (arcmin)	Descriptions
Disparity types	Object A (negative disparity) Object B (positive disparity)
Disparity magnitude	20, 30, 40, 50, 60, 70
Disparity distribution	Object A: – 20 – – 70 arcmin Object B: 20 – 70 arcmin

Fig. 2 shows the details of the experiments. Fig. 2(a) represents the disparity distribution of type1_N (the left part) and type1_P (the right part). For type1_N, object A is on the screen plane, and the disparity magnitude of object B varies from – 20 arcmin to – 70 arcmin; for type1_P, the object B is on the screen plane, and the disparity magnitude of object A varies from 20arcmin to 70arcmin. Fig. 2(b) represents the disparity distribution of type2, in which the disparity magnitude of object A varies from – 70 arcmin to – 20 arcmin, and the disparity magnitude of object B varies from 20 arcmin to 70 arcmin.



(a) Disparity distribution of type1_N&type1_P



(b) Disparity distribution of type2

Fig. 2 The sketch map for the experiment material

2 Experimental result and analyses

2.1 Experiment of type1: with zero disparity

The disparity distribution include two forms: type1_N and type1_P. For the disparity distribution pattern of type1_N, the left Maltese of object A is on the screen, and the right Maltese of object B is out of the screen. For the disparity distribution pattern of type1_P, the left Maltese of object A is inside the screen, and the right Maltese of object B is just on the screen. The ANOVA analysis has shown that both the disparity distribution range of type1 ($F(1,17) = 11.786$, $p < 0.01$) and the disparity magnitude ($F(5, 85) = 27.898$, $p < 0.01$) have obvious effects on the visual comfort of the stereoscopic images.

With the increasing of disparity magnitude of two distribution pattern for type1, the scores of visual comfort is decreased, as shown in Fig. 3. Because of the negative disparity, the comfort level of type1_N is lower than that of type1_P in each case of same disparity magnitude.

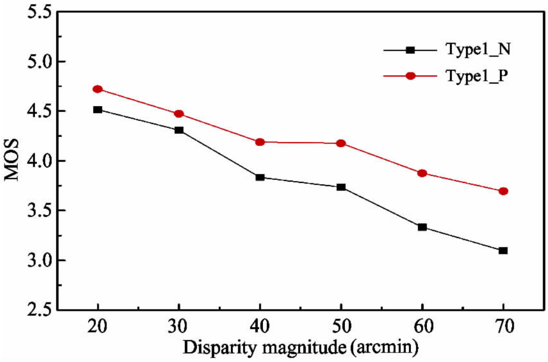


Fig. 3 The MOS of two kinds of disparity distribution for type1

For different types of disparity distribution, some simple linear regression analyse between the max disparity magnitude and the mean opinion score (MOS) of visual comfort are shown in Table 4. The variable of DISP represents the disparity magnitude under different disparity distribution conditions, and R^2 of type1_N is 0.982, R^2 of type1_P is 0.972. R^2 represents the goodness of fitting. The value is closer to 1 and the fitting performance is better. Therefore, both the two kinds of regression models are effective and significant.

Table 4 The formulations of regression analyses

Disparity distribution	The regression model of visual comfort	R^2
Type1_N	MOS = $-0.288DISP + 4.814$	0.982
Type1_P	MOS = $-0.198DISP + 4.881$	0.972

2.2 Experiment of type2: with both positive disparity and negative disparity

For type_2, the Maltese cross of object A is arranged to 6 kinds of disparity magnitude with negative disparity, and object B is arranged to 6 kinds of disparity magnitude with positive disparity. Therefore, there are totally 36 different combinations. Considering two factors of disparity magnitude of object A and object B, for the disparity magnitude of object A, $F(5, 85) = 36.024$, $p < 0.01$, so it has significant influence on the visual comfort. For object B, $F(5, 85) = 74.952$, $p < 0.01$, it is also proved to be a significant affecting factor. Besides, the interaction of these two disparity magnitude is not significant, $p > 0.05$.

When the two objects are distributed inside and outside the screen respectively, they have different levels of disparity and their position combinations in space are also different. Fig. 4 shows the evaluation results about the distribution of the two objects. When object A's disparity magnitude (x-axis) is fixed, the degree of visual comfort decreased as the object B's disparity magnitude (the comment line) increases. It is easy to understand that with the increasing of disparity magnitude, the distribution distance between the two objects is getting larger. When the observers' sight is changing for staring at the two cross separately, they have to adjust the adaption of negative and positive disparity. From Fig. 4, a fitting formula is found to represent the relationship for the disparity distribution of type 2.

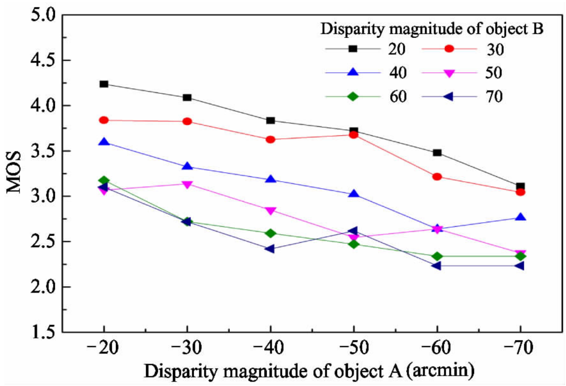


Fig. 4 MOS of the disparity distribution of type2

After the comparison of several statistical methods, the multivariate regression analysis is chosen for fitting the trend lines. It is usually expressed as follows:

$$y = \alpha 1 \times x1 + \alpha 2 \times x2 + \cdots + \propto k \times xk + \beta \quad (1)$$

Here, k represents all of the variables in total, and represents the constant term; $\alpha 1$, $\alpha 2$, $\cdots$, αk are called as the regression coefficient. In this experiment, there are two independent variables which show the disparity distribution of the two objects away from the screen plane respectively. So k equals to 2. The relative regression analyses between the disparity distribution of these two objects and their significant valuesare are shown in Table 5.

Table 5 The results of regression analyses

Model	Unstandardized coefficients		Significance
	B	Standard Error	
(Constant)	4.986	0.059	0.000
*DISP*1	−0.171	0.001	0.000
*DISP*2	0.259	0.001	0.000

Row B includes 3 coefficients: the first value represents the constant term, and the followed two variables mean different regression coefficients of *DISP*1 and *DISP*2. The row of Sig value shows the degree of the significance on the dependent variable. If the value of Sig is less than 0.05, the situation shows that the chosen factors have significance on the visual comfort of the stereoscopic images. In view of these cases, a comprehensive regression model of visual comfort for S3D images is proposed. The relationship between the disparity distribution of these two main objects and the visual comfort are as

$$\text{MOS} = -0.171 DISP1 + 0.259 DISP2 + 4.986 \tag{2}$$

Here, *DISP*1 represents the disparity magnitude of object A, *DISP*2 represents the disparity magnitude of object B, and the complex correlation coefficient is 0.96, which shows highly consistency with the objective assessment score.

Through Eq. (2), the relationship between the disparity magnitude of each object and the evaluation result could be got; however, for the disparity distribution, finding a new variable to represent space position of both the two objects is needed, which would extend the scope of application situation. Therefore, the rate of two types of disparity magnitude and the max absolute disparity magnitude as the new influencing factors are set and the calculation is shown as follows:

$$\begin{aligned} DISP\_Max &= Max(abs(DISP_N, DISP_P) \\ DISP\_Ratio &= DISP_N / DISP_P \end{aligned} \tag{3}$$

here, $DISP_N$ represents the negative disparity, and $DISP_P$ represents positive disparity respectively. *DISP_Max* means the max disparity magnitude between the two types of disparity distribution. *DISP_Ratio* means the ratio of the two factors. Table 6 shows the regression analyses of the two new factors for type2. The significance values prove the availability of *DISP_Ratio* and *DISP_Max* ($p < 0.01$).

Table 6 The regression analyses of new factors for type2

Model	Unstandardized coefficients		Significance
	B	Standard Error	
(Constant)	4.558	0.201	0.000
DISP_Ratio	-0.245	0.065	0.001
DISP_Max	-0.033	0.003	0.000

Through the linear regression analyses, the model between these two factors and the visual comfort assessment is got finally. Here R^2 is 0.967, which means the model is effective. The new regression formula is shown as follows.

$$\text{MOS} = -0.245 DISP\_Ratio - 0.033 DISP\_Max + 4.558 \tag{4}$$

In addition, the experimental results give a contrast between the two kinds of disparity distribution (type1 and type2) on the mean degree of the visual comfort. A conclusion is got that the mean score of visual comfort for type1 is 3.996, higher than the mean score for type2, which is 3.05. This means that the same subject with different disparity distribution will produce different visual perception. Especially when there are multi-objects existing in the images, the negative disparity distribution will reduce the degree of the visual comfort.

3 Conclusion

This work investigates the visual comfort perception and the linear models for different spatial distributions of disparity for multiple objects. The conclusions are drawn as follows.

When there are two objects located inside and outside the screen plane, the overall evaluation scores of S3D image is lower than that when only one of them is on the screen plane. It indicates the addictive effect of disparity distribution. Compared with the situation that there is only positive disparity, negative disparity will decrease the visual comfort. For this disparity spatial distribution type (type1_N&type1_P), as the disparity magnitude increases, the distribution distance also increases. It also emphasizes the significant affection of negative disparity for S3D image. The trend analysis of experimental scores confirms that as the disparity distribution distance between the two objects increases, the visual comfort decreases. For all of the distribution combinations in the experiment of type2, the ratio of negative and positive disparity can be extracted as an important factor affecting the visual comfort. In addition, the disparity related features of maximum disparity magnitude and disparity ratio are both used to establish the linear model, which is easily to guide the safety control for S3D image and videos.

Over the past twenty years, there are already lots of studies and assessment experiments designed for visual comfort. It is known much of the features can be extracted from the S3D images through the tests for single object with simple shapes. But in real application for 3D display, such as the natural images captured through stereo cameras, with not only one main subject, the relationship between the features might be much more complicated. Therefore, it is necessary to find the interactive relationship of these features and choose the ones with greatest contribution. Furthermore, it is also believed that, for different kinds of images such as grey image, color image or image sequences, the features and their weights will be different from one another. On the other side, the relevant S3D image database should be established for model test and subjective evaluation. The work will help peoples to optimize the study and make it acceptable generally.

References

[1] Choi J, Kim J, Sohn K. Visual fatigue modeling and analysisfor stereoscopic video[J]. *Optical Engineering*, 2010, 51(1):117-123

[2] Zhang X, Zhou J, Chen J, et al. Visual comfort assessment of stereoscopic images with multiple salient objects [C]. In: Proceedings of the 2015 IEEE International Symposium Broadband Multimedia Systems and Broadcasting (BMSB), 2015(6):1-6

[3] Wang X N, Wang S G. Optimize evaluation of stereo video comfort based on luminance[J]. *Chinese Optics*, 2015, 8(3):394-399

[4] So G J, Kim S H, Kim J Y. Evaluation model of the visual fatigue on the 3D stereoscopic video[J]. *International Journal of Computer Theory and Engineering*, 2016, 8(4):325-327

[5] Sohn H, Yong J J, Lee S I, et al. Attention model-based visual comfort assessment for stereoscopic depth perception[C]. In: Proceedings of the IEEE International Conference on Digital Signal Processing, Corfu, Greece, 2011. 1-6

[6] Jiang Q P, Feng S, Jiang G Y, et al. An objective stereoscopic image visual comfort assessment metric based on visual important regions[J]. *Journal of Electronics & Information Technology*, 2014, 36(4):875-881

[7] Zhu D. Research of the Parallax Influencing the Visual Comfort of Stereoscopics Images[D]. Tianjin: Tianjin University, 2014. 20-28 (In Chinese)

[8] Hu A, Meng F, Zheng Y J. Assessment algorithm on visual comfort of stereoscopic image based on visual attention [J]. *Video Engineering*, 2016, 40(1): 141-144

[9] Ren H, Su Z, Lv C, et al. Effect of region contrast on visual comfort of stereoscopic images[J]. *Electronics Letters*, 2015, 51(13):983-985

[10] Chang B. Objective Metrics for Predicting Visual Comfort on Stereoscopic Videos[D]. Xi'an: Xi'an Electronic University, 2014. 1-59 (In Chinese)

[11] Sohn H, Yong J J, LeeS I, et al. Predicting visual discomfort using object size and disparity information in stereoscopic images[J]. *IEEE Transactions on Broadcasting*, 2013, 59(1): 28-32

Su Zhibin, born in 1987. She received her Ph. D degree in communication and information systems from Communication University of China in 2015. She also received her B. S. and M. S. degrees from Communication University of China in 2009 and 2011 respectively. Her main research interests are visual information processing and perception, image understanding and analysis.