Journal of information and communication convergence engineering
http://jicce.org

J. Inf. Commun. Converg. Eng. 12(4): 246-251, Dec. 2014 Regular paper

Convergence Point Adjustment Methods for Minimizing Visual Discomfort Due to a Stereoscopic Camera

Jong-Soo Ha[1], Dae-Woong Kim[2], and Dong Hyun Kim[3*], *Member, KIICE*

[1]Subdivision of High-Tech Broadcasting & Imaging, Kyungnam College of Information & Technology, Busan 612-020, Korea
[2]Faculty of Design, Kyushu University, Fukuoka 815-8540, Japan
[3]Division of Computer & Information Engineering, Dongseo University, Busan 617-716, Korea

Abstract

The recent rise of the three-dimensional television (3DTV) industry has led to a wide exploitation of the dual-lens stereoscopic camera. However, when the zoom-in function is used, it is possible that a camera object is magnified only with a fixed convergence point, thereby leading to visual discomfort. In this paper, we propose several methods based on which a convergence point can be adjusted to prevent visual discomfort during zoom-in for a dual-lens stereoscopic camera. Further, we produce 3D contents by applying the proposed methods to certain cases and at certain distances and conduct a subjective evaluation. On the subjective evaluation, 48 subjects watch the 3D contents created by the proposed methods and score the stages of the visual comfort. The result of the subjective evaluation shows that some of the proposed methods are more efficient than the others. We hope that these proposed high-efficiency methods can be applied to produce a dual-lens stereoscopic camera that allows convenient stereoscopic photography.

Index Terms: Auto focus, Binocular disparity, Convergence point, Dual-lens stereoscopic camera, Visual discomfort, Zoom

I. INTRODUCTION

The recent rise of three-dimensional television (3DTV) and the commercialization of a dual-lens stereoscopic camera provide opportunities to easily create 3D image contents. For a user to comfortably view these images, the dual-lens stereoscopic camera automatically controls the convergence point in order to adjust the 3D effects. However, when the zoom-in function is used, it is possible that a camera object is magnified only with a fixed convergence point, i.e., the convergence point is not adjusted. If people view 3D images created using the zoom-in function, they may feel dizzy and experience visual discomfort. Further, it is possible that the zoom-in function or the movement of the convergence point makes the depth of the objects be changed.

In this study, we attempt to ease the visual discomfort arising from the zoom-in function of a dual-lens stereoscopic camera. A relational model is suggested depending on the locations of the focus, object, and convergence point before the zoom-in. In the proposed model, nine possible occurrences are defined and classified according to the position of the convergence point. For these nine types of occurrences, we propose methods to minimize the visual discomfort by adjusting the convergence point. We also conduct a subjective evaluation by using 108 3D images, considering the position and the distance of the convergence point, the focus, and the object. The result shows that one of the proposed methods outperforms the others.

The rest of this paper is organized as follows: Section II provides an overview of the current research trends. We

Received 12 May 2014, **Revised** 27 May 2014, **Accepted** 19 June 2014
***Corresponding Author**: Dong Hyun Kim (E-mail:pusrover@dongseo.ac.kr. Tel: +82-51-320-1801)
Division of Computer & Information Engineering, Dongseo University, 47 Jurye-ro, Sasang-gu, Busan 617-716, Korea.

Open Access http://dx.doi.org/10.6109/jicce.2014.12.4.246 print ISSN: 2234-8255 online ISSN: 2234-8883

define a relational model for the focus and the convergence point in Section III. In Section IV, methods to adjust the convergence point are suggested to prevent visual discomfort and the change in the visual distance; we also present a comparison of the suggested methods in this section. In Section V, the results of the subjective evaluation are presented and the performance of the proposed methods is compared. Finally, the conclusion is drawn and the future research direction is suggested in Section VI.

II. RELATED RESEARCH

In [1-4], 'Binocular Disparity' is defined as the difference in the image location of an object seen by both the left and the right eye. Further, this disparity is used for determining the depth perception. People get dizzy and experience visual discomfort with increased depth perception. This visual discomfort is due to the fact that the main view point and the accommodation do not correspond.

In [5], a binocular disparity of 1° is recommended as the condition for the visual comfort zone to content producers. However, further research is required since there is no analysis of the parallax value when an image changes because of the altered accommodation, as in the case of a zoom action.

In [6], visual tiredness was measured for each camera movement (pan, tilt, roll, and zoom) that causes visually induced motion sickness. On the basis of these measurements, a correlation was suggested between motion speed and visual discomfort. However, the experiment was based on a single-lens image, which made it difficult to infer the direct impact of the motion in the case of a dual-lens image. Further, it is far more difficult to figure out the impact in the case of zooming, which is considerably influenced by the convergence point.

As shown by the related studies, to realize comfortable stereoscopic vision, a method to adjust the excessive binocular disparity that occurs in the case of zooming needs to be studied. We suggest an adjustment method of the convergence point so that a comfortable parallax region can be maintained when the zoom function is used.

III. RELATIONAL MODEL FOR FOCUS AND CONVERGENCE POINT

A dual-lens stereoscopic camera is convenient for even an ordinary user to use the zoom function, since the easy and convenient zoom function is precisely synchronized on two lenses, just like in a 2D camera. However, in a currently used dual-lens stereoscopic camera, the convergence point that determines the stereoscopic area is not coupled with the zoom. Therefore, if we use the zoom-in function with a fixed convergence point, only the object gets enlarged in high magnification, resulting in an excessive binocular disparity.

The focus has been classified into three types depending on the location of focus before zoom-in (Fb) from zoom-in object (ZO). Fig. 1 shows the concept of the Fb, ZO and Cb. The first case is where Fb is located closer to the camera than ZO. In the second case, Fb overlaps ZO, and in the third case, Fb is farther from the camera than ZO. Here, as presented in Table 1, the relation between the focus and the convergence point is defined through a further classification into nine types of occurrences depending on the location of convergence before zoom-in (Cb).

IV. CONVERGENCE POINT ADJUSTMENT METHODS

In this study, we attempt to minimize the visual discomfort and semantic stereoscopic distortion caused by the zoom-in function and suggest various methods: fixed convergence point (FCP) method, focus-convergence correspondence (FCC) method, coupled focus-convergence point (CFC) method, and convergence point comfort threshold

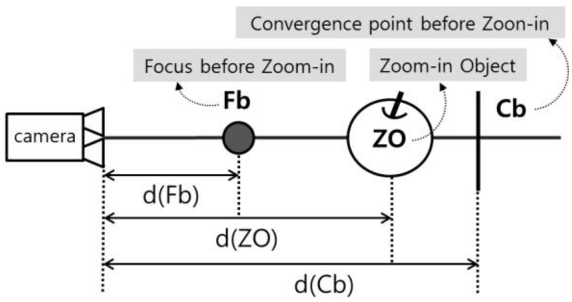

Fig. 1. Distances among camera, Fb, ZO, and Cb.

Table 1. Relational model based on the location of the convergence point depending on the focus position

Position of Fb	Position of Cb
d(Fb) < d(ZO)	d(Cb) < d(Fb) d(Fb) ≤ d(Cb) ≤ d(ZO) d(ZO) < d(Cb)
d(Fb) = d(ZO)	d(Cb) < d(Fb) (or d(Cb) < d(ZO)) d(Cb) = d(Fb) (or d(Cb) = d(ZO)) d(Fb) < d(Cb) (or d(ZO) < d(Cb))
d(ZO) < d(Fb)	d(Cb) < d(ZO) d(ZO)≤ d(Cb) ≤ d(Fb) d(Fb) < d(Cb)

ZO: zoom-in object, Fb: focus before zoom-in, Cb: convergence before zoom-in.

(CCT) method that is based on the stereoscopic comfort threshold.

In the FCP method, Cb does not move after the zoom-in. It is based on the principles of a currently used dual-lens stereoscopic camera and can be expressed by the following equation:

$$d(\mathrm{Ca}) = d(\mathrm{Cb}). \quad (1)$$

In the FCC method, Cb moves to ZO upon zoom-in. This can be expressed in terms of the distance value as follows:

$$\mathrm{d(Ca)} = \mathrm{d(ZO)}. \quad (2)$$

In the CFC method, Cb, upon zoom-in, moves towards the focus by a distance equal to the movement distance of the focus. To minimize the change in the visual distance that can occur in the FCC method, the convergence point is moved in the movement direction of the focus, by a distance equal to the movement distance of the focus. This distance value can be expressed as follows:

$$\mathrm{d(ZO)} - \mathrm{d(Fb)} = \mathrm{d(Ca)} - \mathrm{d(Cb)} \quad (3)$$
$$\therefore d(\mathrm{Ca}) = d(\mathrm{Cb}) + (d(\mathrm{ZO}) - d(\mathrm{Fb})).$$

In the CCT method, Cb, when zoom-in starts, moves towards the focus by a distance equal to the movement distance of the focus but within the range of the threshold value. This method is designed to prevent the change in the visual distance that can occur in the CFC method. The movement distance is determined by separating the two cases: one in which visual discomfort does not occur and the other in which it does. In Eq. (4), $d(\theta)$ denotes the maximum distance where visual discomfort is not caused.

$$\boldsymbol{If}\ \mathrm{d(Cb)} + \big(\mathrm{d(ZO)} - \mathrm{d(Fb)}\big) \le |\mathrm{d}(\theta)| \quad (4)$$
$$\boldsymbol{then}\ d(Ca) = d(Cb) + \big(d(ZO) - d(Fb)\big),$$
$$\boldsymbol{If}\ d(\mathrm{Cb}) + \big(d(\mathrm{ZO}) - d(\mathrm{Fb})\big) > |d(\theta)|$$
$$\boldsymbol{then}\ d(Ca) = d(\theta).$$

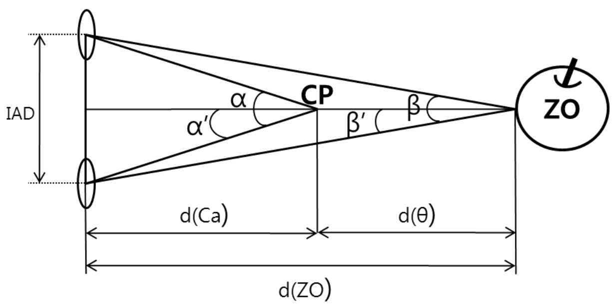

Fig. 2. Interangle distance (IAD).

In [5], a binocular disparity of 1°, which is a parallax angle, is recommended for the visual comfort zone. The parallax angle is $|\boldsymbol{\alpha} - \boldsymbol{\beta}|$, as shown in Fig. 2. The distance between two lens is called the interangle distance (IAD), and $\boldsymbol{\alpha}, \boldsymbol{\beta}$ denotes the convergence angle.

By using the convergence angle and IAD, we can define $d(\theta)$ as follows:

$$|\alpha - \beta| = 1°, \quad (5\text{-}1)$$
$$|\alpha' - \beta'| = 0.5°, \quad (5\text{-}2)$$
$$\tan\beta' = \frac{\mathrm{IAD}}{2}/\mathrm{d(ZO)}, \quad (5\text{-}3)$$
$$\beta' = \tan^{-1}\left(\frac{\mathrm{IAD}}{2\mathrm{d(ZO)}}\right)\mathrm{rad}, \quad (5\text{-}4)$$
$$0.5° = 0.008722\ \mathrm{rad}, \quad (5\text{-}5)$$
$$\alpha' = \tan^{-1}\left(\frac{\mathrm{IAD}}{2\mathrm{d(ZO)}}\right) + 0.008722\ \mathrm{rad}, \quad (5\text{-}6)$$
$$\tan\alpha' = \frac{\mathrm{IAD}}{2}/\mathrm{d(Ca)}, \quad (5\text{-}7)$$
$$\mathrm{d(Ca)} = \frac{\mathrm{IAD}}{2}/\tan\alpha' = \frac{\mathrm{IAD}}{2\left(\tan\left(\tan^{-1}\left(\frac{\mathrm{IAD}}{2\mathrm{d(ZO)}}\right)+0.008722\right)\right)}, \quad (5\text{-}8)$$
$$\mathrm{d}(\theta) = |\mathrm{d(ZO)} - \mathrm{d(Ca)}| = \left|\mathrm{d(ZO)} - \frac{\mathrm{IAD}}{2\times\tan\left(\tan^{-1}\left(\frac{\mathrm{IAD}}{2\times\mathrm{d(ZO)}}\right)\right)+0.008722}\right|. \quad (5\text{-}9)$$

V. EXPERIMENTS

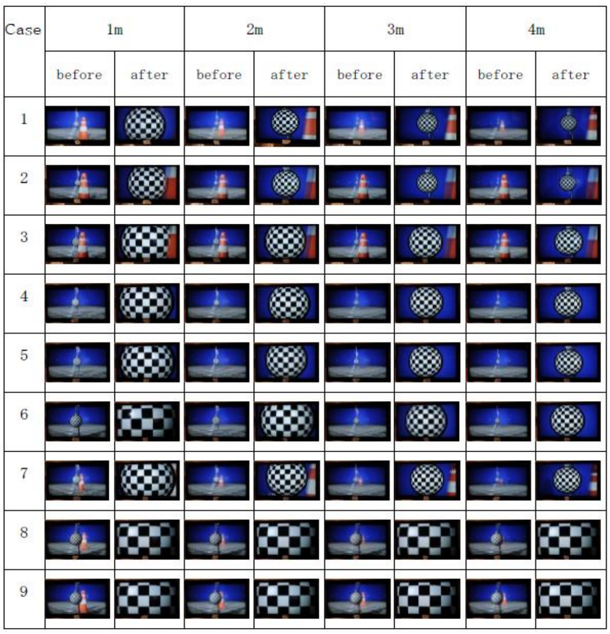

Fig. 3. Example of sample images.

For the experiments, we created 3D sample images by using the proposed methods as shown in Fig. 3. Further, 48 subjects viewed the sample images and participated in the subjective test conducted to check the visual comfort.

A. Test Environment

To create 3D sample images, we applied the nine cases listed in Table 2, four different distances, and three of the proposed methods. As a result, 108 sample images were taken and evaluated.

Table 2. Result of the variance analysis

	F-value	p-value	Method pair		p-value (b)
Case 1	20.355	0.000	CCT	FCC	0.001**
				FCP	0.000**
			FCC	CCT	0.001**
				FCP	0.068
			FCP	CCT	0.000**
				FCP	0.068
Case 2	21.800	0.000	CCT	FCC	0.001**
				FCP	0.000**
			FCC	CCT	0.001**
				FCP	1.000
			FCP	CCT	0.000**
				FCP	1.000
Case 3	22.664	0.000	CCT	FCC	0.000**
				FCP	0.000**
			FCC	CCT	0.000**
				FCP	1.000
			FCP	CCT	0.000**
				FCP	1.000
Case 4	18.878	0.000	CCT	FCC	0.000**
				FCP	0.001**
			FCC	CCT	0.000**
				FCP	0.068
			FCP	CCT	0.001**
				FCP	0.068
Case 6	30.580	0.000	CCT	FCC	0.000**
				FCP	0.000**
			FCC	CCT	0.000**
				FCP	0.573
			FCP	CCT	0.000**
				FCP	0.573
Case 7	3.226	0.059	CCT	FCC	0.009
				FCP	0.002
			FCC	CCT	0.009
				FCP	1.000
			FCP	CCT	0.002
				FCP	1.000
Case 8	20.429	0.000	CCT	FCC	0.000**
				FCP	0.001**
			FCC	CCT	0.000**
				FCP	1.000
			FCP	CCT	0.001**
				FCP	1.000
Case 9	12.320	0.000	CCT	FCC	0.000**
				FCP	0.009**
			FCC	CCT	0.000**
				FCP	1.000
			FCP	CCT	0.009**
				FCP	1.000

*p < 0.05, **p < 0.01.

The CFC method was excluded because it was impossible to be applied to a real film. The subjects were 48 male and female participants in the age group of 20–40 years (average, 23.2 years); 64.6% of these participants were male and 35.4%, female. All participants had prior experience of watching 3D movies. However, none of them had viewed 3DTV images before.

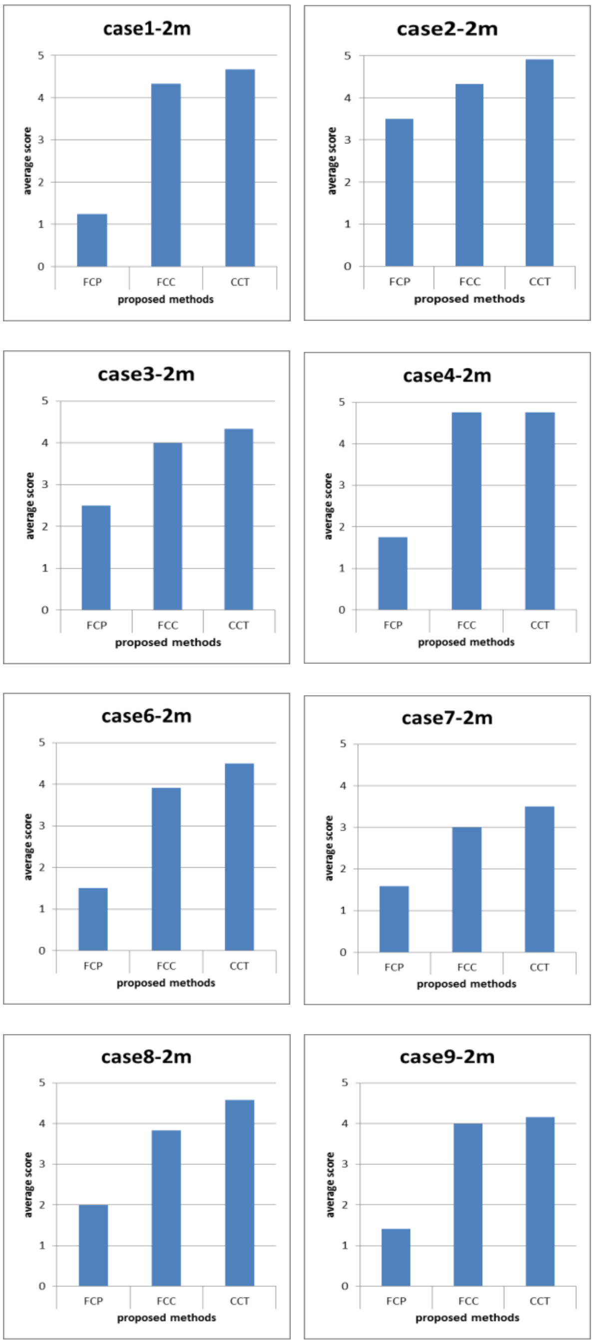

Fig. 4. Average scores of FCP, FCC, and CCT in each case. FCP: fixed convergence point, FCC: focus-convergence correspondence, CCT: convergence point comfort threshold.

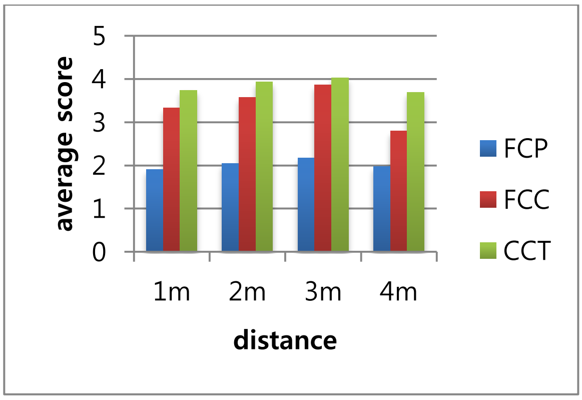

Fig. 5. Average scores for visual comfort. FCP: fixed convergence point, FCC: focus-convergence correspondence, CCT: convergence point comfort threshold.

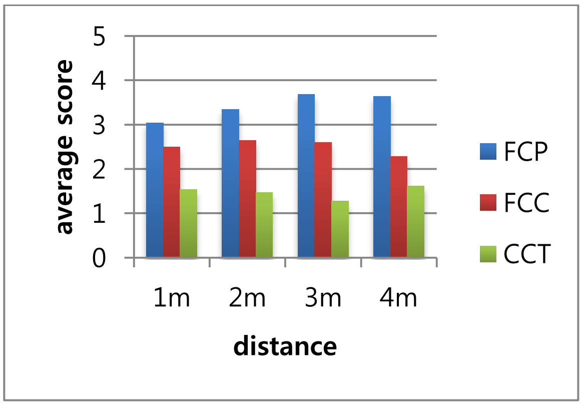

Fig. 6. Average scores for the change in visual distance. FCP: fixed convergence point, FCC: focus-convergence correspondence, CCT: convergence point comfort threshold.

To display the test 3D images, 55' 3DTV was exploited, and all participants were asked to wear polarized glasses. The viewing distance for these images was 205.5 cm, which was three times the height of the TV display (68.5 cm). For the subjective test, each participant answered a questionnaire. All questions related to visual discomfort and the amount of depth change were answered using a five-point scale.

B. Results

To statistically analyze the experimental results, we used the analysis of variance (ANOVA) test. The variance was measured repeatedly for each of the nine considered cases. However, since it was found that the distance had no effect, we also carried out a secondary analysis using the Bonferroni scheme. For these nine cases, three of the proposed methods, namely the CCT, FCC, and FCP, were used; the measured variances are listed in Table 2.

Table 2 presents the results of the variance analysis. As shown in Table 2, the variances of the CCT method are more accurate statistically than those of the FCP and the FCC methods. Fig. 4 shows the average scores of the variance analysis.

We obtained meaningful results from the subjective test performed using three of the proposed methods with four distances and nine cases. As shown in Fig. 5, the FCP method had the lowest score and the CCT methods had the highest score for visual comfort under all conditions.

As shown in Fig. 6, the FCP method yielded the highest score and the CCT method, the lowest score for the change in visual distance under all conditions.

VI. CONCLUSION

Usually, to magnify objects in a dual-lens stereoscopic camera, a zoom-in function is exploited. However, since the convergence point is not coupled with the zoom-in function, it is possible to cause visual discomfort or bring about a change in the visual distance. To solve these problems, we designed and implemented methods that adjust a convergence point to prevent visual discomfort according to the defined relational model depending on the locations of the focus, object, and convergence point. We also conducted a subjective test; its results showed some of the proposed methods were more efficient than the others. We expect that these proposed high-efficiency methods can be applied to produce a dual-lens stereoscopic camera that allows convenient stereoscopic photography.

REFERENCES

[1] S. Yano, M. Emoto, and T. Mitsuhashi, "Two factors in visual fatigue caused by stereoscopic HD TV images," *Displays*, vol. 25, no. 4, pp. 141-150, 2004.

[2] T. Motoki, H. Isono, and I. Yuyama, "Present status of three dimensional television research," *Proceeding of the IEEE*, vol. 83, no. 7, pp. 1009-1021, 1995.

[3] 3D Consortium, *3DC Safety Guidelines for Popularization of Human-Friendly 3D*. 3D Consortium, 2010.

[4] H. Ujike, "Estimation of visually induced motion sickness from velocity component of moving image," in *Proceedings of the 3rd International Conference on Virtual and Mixed Reality*, San Diego, CA, pp. 136-142, 2009.

[5] S. Knorr, K. Ide, M. Kunter, and T. Sikora, "The avoidance of visual discomfort and basic rules for producing good 3D pictures," *SMPTE Motion Imaging Journal*, vol. 121, no. 7, pp. 72-79, 2012.

[6] T. Shibata, J. Kim, D. M. Hoffman, and M. S. Banks, "The zone of comfort: predicting visual discomfort with stereo displays," *Journal of Vision*, vol. 11, no. 8, article no. 11, 2011.

Jong-Soo Ha
received his M.S. in Fine Arts from Osaka University of Arts in 2002 and his Ph.D. in Design from Kyushu University in 2014. His research interests include 3D stereoscopy, 3D displays, and 3D cameras.

Dae-Woong Kim
received his M.S. and Ph.D. in Design from Kyushu University in 1998 and 2014, respectively. His research interests include 3D graphics, 3D stereoscopy, and artificial intelligence.

Dong Hyun Kim
received his M.S. and Ph.D. in Computer Engineering from Pusan National University in 1997 and 2003, respectively. His research interests include databases, spatial databases, stereoscopic image processing, and stereoscopic cameras.