Depth Budget for Visual Comfort in Stereoscopic Watching Environment

Jongyoung Kim†, Namgyu Kim††, and Seiwoong Oh†

†Stereoscopic Imaging Research Center, Busan IT Industry Promotion Agency, Busan, Korea
††Department of Game Engineering, Dong-Eui University, Busan, Korea

Summary
Depth budget (or parallax range) is a term for describing the amount of stereoscopic depth in an image. It is a quantity as a difference between the parallax of the farthest and closest objects. Depth budget has been suggested as a part of stereoscopic shooting guidelines for the visual comfort. In this paper, we derived the depth budget by statistical analysis. We performed experiment in which subjects evaluated test image by questionnaire. Experimental Data was analyzed firstly by factor analysis to identify dominant features. In our experiment, there existed two primary variables called "fatigue," and "depth." We applied t-test to identify the boundary on which the magnitude of fatigue or feeling of depth changes. Derived depth budget was 2% for negative and 4% for positive parallax.

Key words:
Depth Budget, Factor Analysis, t-Test, Visual Comfort

1. Introduction

Three-dimensional stereoscopic imaging technology uses the visual cognition principle of disparity and convergence. Hence, watching stereoscopic images increase activity of eye muscles. Furthermore, it gives diverse experiences such as discomfort or fatigue because it provides forced visual information of autonomic convergence and focusing ability in the practical life through weared-glasses. Through technological advances in the future, before the full three-dimensional space reproducing technology such as holograms, stereoscopic imaging technology by the principal of parallax and convergence will be advanced.
Likewise, various technological approaches such as stereoscopic shooting, editing, reproducing, transmitting and etc. will be necessary to viewers by applying two of two-dimensional images in order to maximize the three-dimensional restoring brain ability vivid. The accumulation of experience in variety of technologies can present the emotion that cannot be presented by existing images and can mitigate fatigue and uncomfort of personal cognitive differences.

Representative feelings of stereoscopic images to viewers are reality, in accordance with depth feeling, and immersion. In order for human to recognize much depth feeling, hardware component (watching distance and angle, size of screen as well as resolution and etc.) of watching environment, and software or content constituent of image-substance-bearing are influenced. In order to draw a normal standard for such individual distinction of various factors, evaluation and analyzing methods are utilized base on given conditions.
Guidelines of stereoscopic images are proposed based on an analysis which is analyzed comparative figures through defining various factors and stereoscopic image user test in accordance with standard.
Multifarious experimental studies by applying various conditions such as binocular disparity, regulation and convergence, perspective, occlusion, and etc. are researched by domestic and foreign. As three-dimensional stereoscopic images become generalized, various issues are raised toward stereoscopic imaging *per se* such as safety, health criterion, standard and etc. Especially, visual comfort of stereoscopic imaging display device (e.g., 3DTV) is a very serious issue. In many cases, discomfort and fatigue are equated, nevertheless there are fundamental difference. Discomfort can be attained by user experimental test, but fatigue is an observable phenomenon objectively. Fatigue can be attained through the level of muscle tension from eye malfunction (ex: range watching of binocular disparity, discordance between convergence and congestion) [1][2][3].
In order to determine discomfort or fatigue, next two methods can be applied. Subjective valuation and objective measure [1][4]. Subjective valuation is discrete and research study, survey based on inquiries are represented. Objective measure calculates factors after evaluating invested and non-invested standard [5]. Survey based on inquiries analyzes the result through answered data of random level inquiry (ex: 3 levels, good, average, poor) [3][4][5]. Stereoscopic factors and results are exist through experiments by standardizing binocular disparity mentioned earlier and various depths including regulation and convergence

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[6][7]. Stereoscopic imaging human factor researches are attempting variously in domestic presently and drew results incrementally [9][10][11]. Japanese 3D consortium suggested 1920 horizontal pixel standard disparity for comfort watching range [12].
In this study, fatigue is inquired based factor on depth and speed centrically, and draw depth range of fatigue induction by using statistical method. In the second chapter, related statistical method will be presented, in the third chapter, describes experiments method, and in forth chapter, conclusion will be proposed of this study.

2. Backgrounds

2.1 Factor analysis

Factor analysis is a method for identifying a smaller set of unobservable factors to which a number of observed correlated variables of interest are linearly related. The observed variables are modeled as linear combinations of the latent factors with some error terms. The independence information among observed acquired from analysis can be used to reduce the dimension of the original data set.
Those identified factors creates new dimension on which original variables are projected. This projection leads to two result; factor scores and factor loadings. Factor scores are the scores of each variables on each factor. Factor loadings are correlation coefficients between the variables and factors. The percentage of variance in all variables expressed by each factor can be computed by adding the sum of the squared factor loadings for the corresponding factor and dividing by the number of variables.

2.2 t-Test

A t-test is a common statistical analysis that is used to compare two groups. In other words, it is a test for the significance of the difference between the means of two independent samples. A general form of t-statistic t is as follows,

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

where $\bar{x}_1$ is sample mean of group 1 with sample size n_1, $\bar{x}_2$ is sample mean of group 2 with sample size n_2, s_1 and s_2 are standard deviations of group 1 and 2 respectively.

In [13], they used student's t-test to extract medial ridges from images for the purpose of image segmentation. Their goal was to find adjacent non-overlapping spherical populations of pixels that minimize the P-value and thus reject the null hypothesis that the two spheres are within the same object, given the presence of Gaussian noise. They showed how to automate boundary determination within a image by finding scale and orientation for the so called "sphere pair" with the highest student's t-test statistic and lowest P-value.

3. Experiment

3.1 Experimental procedure

The overall experimental process consists of experimental and analytical procedures. The experimental procedure is for getting experiment data from those subjects who participated in the experiment. The analytical procedure is for getting any meaningful results from the data.

3.1.1 Test image

A test movie, which contains grey background and a blue sphere moves back and forward, was produced in order to test the fatigue of depth and speed when watching stereoscopic images. This is to understand intuitively for general viewers, and to remove all other facts than depth and rate of movement.
The test movie contains a sphere at the center as figure 1. This sphere moves forward or back, and its position, on the basis of Zero point, was set as Positive 2%, 4%, 6% backward, and Negative 1%, 2%, 3%, 4%, 5% forward. Positive or negative X % means how much is the difference in distance, between left and right images on the basis of horizontal direction pixels on viewing display, separated. The speed was set time starting zero point to approach target positive or negative points. For example, the movie set as 'negative 5%', '1 second speed' means starting at Zero point to negative 5% takes 1 second. Thus, shorter the time means faster the speed. The speed was divided by 0.5 second in five steps (0.5s~2.5s) that produced the total number of 40 test movies. The length of all movies are 15 seconds, and, including 5 seconds of black images in start and end, total viewing time makes 20 seconds per test movie. In order to recognize the depth of sphere easily, blue outline without any depth was added so it can be compared with the sphere.

3.1.2 Questionnaire

Experiment survey consists of basic information (age, inter-pupillary distance) of test subjects, questionnaire about watching stereoscopic movie, and questionnaire about experiment movie. Basic information is a questionnaire in order to analyze the relationship between unique physical conditions of individuals and stereoscopic movie and IPD (inter-pupillary distance) is a representative sample. In case of general adult has

50~70mm IPD and the average value of 65mm is commonly used. In the other case of considering child and minority, the ranges can be expanded to 40~80mm.
Outside of that distinction of convergence ability, motion sickness of transportation, gender, and etc. can effect in various facts, hence, fundamental of depth recognition research needs long term experiment research. Questionnaire about watching stereoscopic movie consists of number of stereoscopic (movie, TV, game) experience, and concentration degree while watching movies.

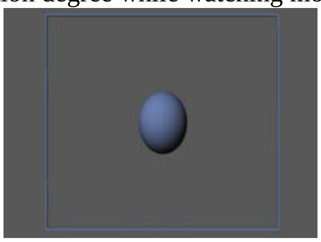

Fig. 1 Test image

Table 1. Description of questions and variables

ID	variable	description
1	Depth	Degree of depth
2	Clear	Degree of clearness
3	Flicker	Degree of eye flickering
4	Frown	Degree of frown
5	Close	Desire to close eyes
6	Sick	Degree of eye sickness
7	Headache	Degree of headache
8	Double	Degree of double images

Questionnaire of experiment movie is like table 1. Main purpose of this study is to find the position of lowest fatigue as well as the best expression of three-dimensional effect when consider depth and speed of the object in stereoscopic movie. Correspondence of this study, questionnaire consists of 8 questions related with three-dimensional effect, clearness, and fatigue, and suggested scale of 10(① for very low - ⑩ for very high) for detailed comparative measure of each variables. Out of 8 questions, question number 2(degree of clearness) and question number 8(degree of double images) are prepared for opposite meaning as reversed questions. For example, if question number 2 received high score, then question number 8 has to receive low score and this will be judged as proper answer. The reason of including reversed questions, is to sort out unfaithful surveys.

3.2 Experimental procedure

Number of test subject for the experiment was set at 30, and an age structure was set at 20s~30s, major target level of stereoscopic movie. In order to suggest 3D stereoscopic movie to test subjects, 55“ 3DTV was used as shown in figure 2 and viewing distance was set at 3m(Suggested watching between 2h~6h; h=TV height length) as referring suggested standard in ‘A Study on the Trend of 3DTV Standardization and Effect on the Biological system’ report by Korea Radio Promotion Association.
Before the experiment, experiment substance and object were explained to test subjects, then surveyed basic information (age, glasses wear and etc.). Then, in order to observe the relationship between stereoscopic movie and physical attribute, inter-pupillary distance was measured as shown in figure 3 and then stereogram pairs were used to verify stereoscopic cognitional distinction. Total of 4 rectangle images ‘stereogram pairs’ were placed and only one rectangle image applied stereoscopic so test subjects answered which rectangle image applied stereoscopic.

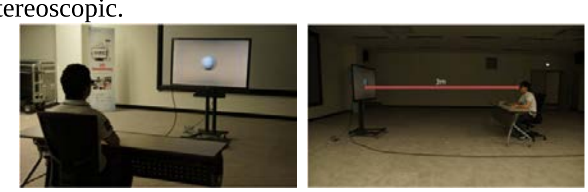

Fig. 2 Watching environment and distance

After survey data was entered, analysis was accomplished excluding non-proper checked data such as slipshod answers, non-checking answers and etc. First of all, factorial analysis of 8 variables on survey was processed. Through factorial analysis, descriptive statistics stats, of speed and disparity about extracted factors, were printed then examined overall distribution of data then examined which fact had the high score at which position.

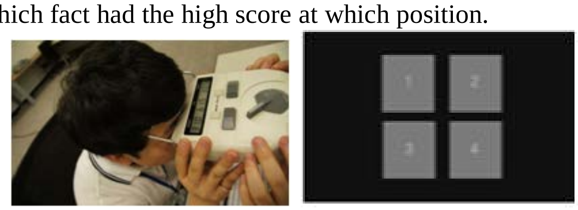

Fig. 3 IPD measurement and stereogram pairs

3.3 Experimental results

SPSS 19.0 was used for analysis. Total number of surveyed data is 1,200(number of subject x number of experiment) and, as mentioned earlier, excluding non-proper checked answers total number of data comes out to 928(Positive 380, Negative 548) for analysis. ‘Disparity’ and ‘Speed’ becomes independent variable, ‘depth range’ and ‘fatigue’ generated through factorial analysis becomes dependent variable. Figure 4 is factorial analysis and by the analyzing result of 8 variables in table 2, two new variable was created. As shown in table 2, Factor1 is composed by questionnaire associated with visual fatigue and physiological fatigue, is designated as 'Fatigue.' Factor2 is highly related with question number1, is designated as 'Depth Range.'

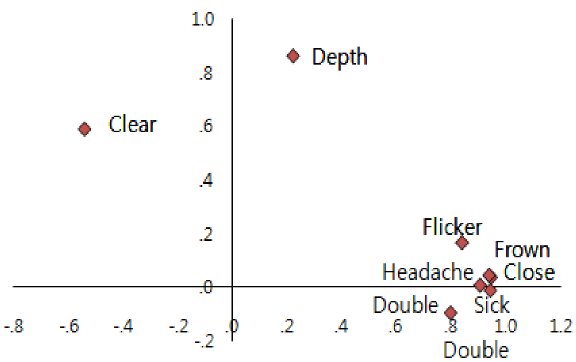

Fig. 4 Plot of variables on factor coordinates

Before analyzing, through file partitioning method of SPSS, the result of examining average three-dimensional effect, fatigue by speed, and disparity values by partitioning Positive and Negative equivalent to table 3 and table 4. The point needed to be defined here is finding proper boundary of higher three-dimensional effect and fatigue. In case of Positive, size of entire data set S, consisting of Row ($e_k, k = 1,\dots,N$), $N(=15)$, its boundaries were determined by using following methods. First, partition into and.

algorithm

For $k = 1,\dots,N-1$

$S = S_1 \cup S_2$

Where, $S_1 = \{e_1,\dots,e_k\}$, $S_2 = \{e_{k+1},\dots,e_N\}$

Table 2. Result of factor analysis

	Factor1	Factor2
Depth	.225	.863
Clear	-.538	.589
Flicker	.842	.165
Frown	.948	.035
Close	.941	.042
Sick	.946	-.015
Headache	.908	.005
Double	.800	-.099

e_k represents k th data point above. In next step, MAX and MIN of k was found for each t-statistic and p-value by determining S_1 and S_2 as a standard. In this case, entire set S partitioned into following two sets.

$$S_1 = \{e_1,\dots,e_k\} \text{ and } S_2 = \{e_{k+1},\dots,e_N\}$$

Hence, S_1 and S_2 is statistically different group, proper boundary of changing fatigue or three-dimensional effect located between e_k and e_{k+1}. In this study, another boundary was found about applying S_2 in above algorithm. The reason is to divide degree change of fatigue and three-dimensional effect by strength into two stages.

In Positive, as shown in figure 5, Fatigue starts to emerge at 4%, and since 6% and speed of 2 seconds, start to emerge fatigue highly. On the other hand, three-dimensional effect starts at 6%. Thus, in Positive, object position locates at 6%, when speed is very slow, has a three-dimensional effect in conjunction with reducing fatigue.

In Negative, as shown in figure 6, since 2% and 1.5 seconds starts to emerge fatigue, and since 3% and 1.5seconds start to emerge fatigue highly. High three-dimensional effect can be presented from 5%, however, it is accompanied by high fatigue, thus the optimum point can be judged at Disparity 3% and Speed of 2seconds.

4. Conclusion

Recently, researches, of various factors about stereoscopic contents quality evaluation, have been performed then results are introduced in some guideline-forms. Necessity is brought up in all stereoscopic related fields such as stereoscopic imaging design, filming, reproducing, transmitting, allied products and etc. In this study, safe three-dimensional depth budget was derived by using statistics method. In case of Positive depth, starting position of fatigue emerge at 4%, and in case of Negative depth, emerges at 2%. Thus, safe three-dimensional depth budget range arrives at a conclusion of [2%, 4%]. Henceforth, suggested safe three-dimensional depth budget range, could perform a basic role for producing safe stereoscopic images.

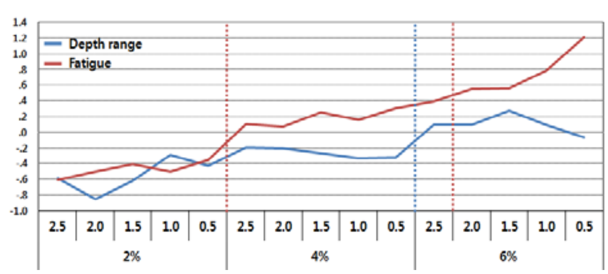

Fig. 5 Positive average graph

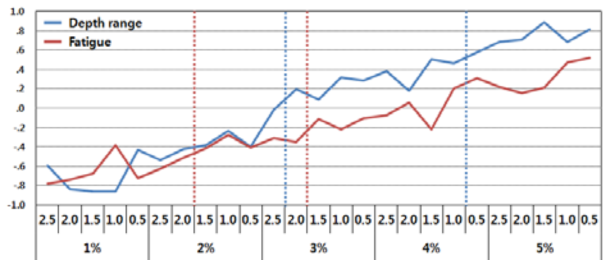

Fig. 6 Negative average graph

Table 3. Positive average value

%	Movement	Depth Range	Fatigue
2	2.5	-.580	-.608
	2.0	-.850	-.505
	1.5	-.620	-.402
	1.0	-.287	-.506
	0.5	-.419	-.356
4	2.5	-.189	.103
	2.0	-.198	.072
	1.5	-.265	.254
	1.0	-.331	.156
	0.5	-.321	.308
6	2.5	.101	.394
	2.0	.094	.547
	1.5	.279	.560
	1.0	.099	.783
	0.5	-.062	1.208

Table 4. Negative average value

%	Movement	Depth Range	Fatigue
1	2.5	-.591	-.784
	2.0	-.836	-.742
	1.5	-.859	-.678
	1.0	-.863	-.385
	0.5	-.429	-.727
2	2.5	-.536	-.626
	2.0	-.428	-.514
	1.5	-.382	-.413
	1.0	-.239	-.278
	0.5	-.403	-.411
3	2.5	-.018	-.314
	2.0	.192	-.350
	1.5	.092	-.114
	1.0	.317	-.224
	0.5	.285	-.106
4	2.5	.379	-.071
	2.0	.176	.056
	1.5	.507	-.224
	1.0	.459	.207
	0.5	.579	.307
5	2.5	.681	.222
	2.0	.702	.157
	1.5	.885	.216
	1.0	.679	.470
	0.5	.813	.522

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Jongyoung Kim received the B.S. and M.S. degrees in Computer Science Department from Hanyang University, Seoul, Korea. Now he is pursuing his Ph.D. degree in Computer Science Department from Hanyang University, Seoul, Korea. He joined the Stereoscopic Imaging Research Center (SIRC) in 2011. He is a research engineer.

Namgyu Kim received the B.S. degree in Computer Science from KAIST, Daejeon, Korea, and earned the M.S. and Ph.D. degrees in Computer Engineering from POSTECH, Pohang, Korea. He joined Advanced Telecommunications Research Institute International, Kyoto, Japan and Korea Telecommunication research center, Daejeon, Korea. He is now a full-time lecturer in the department of game engineering, Dong-Eui University, Busan, Korea.

Seiwoong Oh received the B.S. and M.S. degrees in Electronic Engineering from Hanyang University, Seoul, Korea and earned the Ph.D. degree in Information Engineering from Osaka University, Osaka, Japan. He joined Electronics and Telecommunications Research Institute, Daejeon, Korea. He is now a professor in the department of game engineering, Dong-Eui University, Busan, Korea.