Visual Clarity and Comfort Analysis for 3D Stereoscopic Imaging Contents

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Summary
In recent years 3D stereoscopic imaging contents are widespread in usual commercial markets such as films or movies, interactive games, advertisements, exhibition areas and so on. Even so, for common viewers, the 3D stereoscopic imaging contents are not comfortable to human visual sense because human stereoscopic depth fusion is dependent on individual brain processes. Among various human depth cues, the major depth cue is a retinal disparity on left and right eyes for each. Improper disparity causes physically headache or fatigue of viewers. We carried out an experiment in which visual clarity and comfort were measured in test stereoscopic imaging contents with different disparity levels. We assume that the disparity levels of both eyes is simulated with distance gap between convergence and focus point on two camera pairs' shooting image. The results of the experiments confirmed that disparity is a critical element to affecting visual clarity and comfort. Also, we find the visual clarity is proportional to visual comfort. With age-specific analysis, stereoscopic sensitivity of old age group is lower than other age group. These results will provide important insights into producing visually comfortable and clear 3D contents with stereoscopy.

Key words:
Stereoscopy, Visual Clarity, Visual Comfort, User Experiment, Human fatigue

1. Introduction

Over the last decade, various technologies for visualizing 3D scene have been demonstrated and refined among them such of stereoscopic, advanced rendering methods, light-weight and easy-wearable hardware, and so on. Owing to these technologies, 3D Stereoscopic imaging contents are widespread in usual commercial markets such as films or movies, interactive games, advertisements and exhibition areas. Despite the popularity of 3D imaging technologies, for common viewers of the contents, stereoscopy is regarded as un-comfortable or non-essential technologies.

Recent researches and papers consider the reason to varied visual 3D depth cues of human neural processing fundamentally, that is to say that various human cues take stereoscopic effect. Among the various depth cues, retinal disparity is directly related to visual comfort for viewers. Without loss of generality, we consider that the retinal disparity is a distance gap between convergence and focus point for both eyes. With the disparity measurement, we carried out an experiment in which visual clarity and comfort were measured in test stereoscopic imaging contents with different disparity levels.

In Section 2, we mention a brief related works about the human visual cues, discomfort and fatigue with principles of stereoscopy and user experiments. Section 3 explains our theoretical scope of "visual comfort" term. Section 4 and 5 show our experiment environments, methods and results. Subsequently based on the experimental results, we discuss the implication of the conclusion. In the end, more needed studies and plans are mentioned in Section 6.

2. Related Work

The human visual system perceives spatial information through various depth cues which are categorized as oculomotor and visual cues [1][2].

At first, oculomotor cues include accommodation and convergence rules. Accommodation means that the process by which the eye increases optical power to maintain objects at different distances into cleans focus on the retina. Convergence is the simultaneous inward movement of both eyes toward each other, usually in an effort to maintain single binocular vision when viewing an object. The other, visual cues can be classified into binocular depth cues and monocular depth cues. Binocular depth cues are caused that human eyes are horizontally separated. Each eye sees its own perspective of a natural scene. Stereoscopic is the perception of depth that is based on the difference between two retinal images. Monocular depth cues consist of pictorial depth cues such as occlusion, linear perspective, size gradient, texture gradient, relative height, relative brightness, aerial perspective, shadow, and shading, and motion related depth cues.

Recently, for 3D imaging contents, safety and health criterion or standards become an issue. Especially, on stereoscopic displays, visual comfort or discomfort is a major and active issue. In a number of studies, visual discomfort is used interchangeable with visual fatigue. However, there is distinct difference between visual discomfort and visual fatigue. Visual discomfort is subjective estimates and associated with jitter, flickering,

Manuscript received February 5, 2011
Manuscript revised February 20, 2011

image motion, poor resolution and so on. While visual fatigue is objectively measurable symptoms. It implies any visual dysfunction caused by the use of one's eyes [5][6][10][12]. In other word, visual fatigue is physiological strain or stress energy by the excessive use of the visual system.

To measure visual discomfort or visual fatigue, we can have a choice of experiment: a subjective measurement and objective measurement methods [5][9]. Subjective measure can be distinguished; explorative studies, psychophysical scaling, and questionnaires. Explorative studies can be used to evaluate the added value of stereoscopic displays both with and without predefined criteria, and determine the attributes that predefined multi-dimensional concepts such as visual discomfort [3]. Psychophysical scaling enables engineers to enhance and optimize their systems based on quantified perceptual attributes such as image quality and visual discomfort. Questionnaires are comprehensively used to evaluate the degree of visual discomfort [4][5][7][8].

3. Visual Comfort

Despite the ongoing boom in stereoscopic image, there are the serious difficulties in commercialization. As mentioned before, the stereoscopy means the process in visual perception leading to depth feeling from the two slightly different retinal images. Our brain fuses the retinal disparity according to the left and right images. Through this process the brain provides the depth information. Fusion is the neural process that merges the two retinal images into one single image. Fusion occurs to allow single binocular vision. Panum's fusional area is the region of binocular single vision. The outside of Panum's fusional area, double vision happens. As result of the double vision, a large number of people complain of uncomfortable, during seeing the stereoscopic imaging contents.

Generally, it is known that normal people experience visual discomfort after around 30 minutes, since start to see stereoscopic contents. However, according to the kinds of visual factors and attributes of contents, the discomfort can be occurred more quickly, or later. To solve visual discomfort, it is necessary to investigate various visual factors associated with users' seeing feeling.

Among the other reasons to bring about visual comfort, one is hardware factor. Especially, image distortion error is a very critical. The distortion error come from several stages on producing 3D imaging contents, that is to say choice of camera, camera shooting configuration, image conversion, image coding, image data compression, transmission, rendering, and so on. The other is images themselves' attribute, such as image keystone distortion, depth plane curvature, cardboard effect, puppet theatre effect, shear distortion, crosstalk, picket fence effect, image flipping, and so on. Another is images' quality. To increase image quality, resolution, clarity, and depth cues are considered factors. These various factors are able to give negative or positive effects to each other. Furthermore, we have to consider interaction among factors that make a positive or negative contribution to a visual comfort. For instance, the more perceived depth emphasize, the more double vision happen due to excessive disparity, namely, though benefit is caused by increased depth, perception is lacked. Therefore, interaction among factors is a crucial matter.

We postulate that the visual discomfort or comfort feeling of viewers is strongly related to visually retinal disparity of the stereoscopic imaging contents. With the disparity measurement, we carried out an experiment in which visual clarity and comfort were measured in test stereoscopic imaging contents with different disparity levels.

4. Experiment

4.1 Tested Environment and Independent Variables

We built 3D stereoscopic imaging contents as the tested for the experiment. The imaging contents are very simple movie clips to except other depth cue feeling. The clips include a moving car prop with a fixed velocity. Figure 1 shows an example of the test movie clip. As shown figure 1, the left and right image have disparity gap on image pixels.

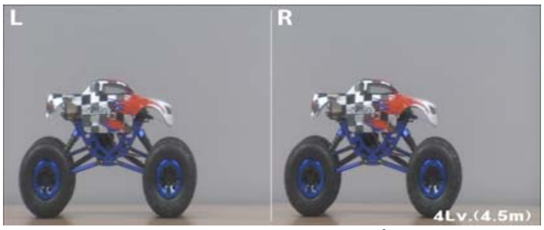

Figure 1. A 3D Stereoscopic image pair for experiment

The subjects experienced test given movie clips configured with different disparity levels and visual comfort and visual clarity levels were measured with a subjective questionnaire. Table 1 shows the summary of the independent variables and their level design. As mentioned, the eye's retinal disparity is simulated with distance gap between convergence and focus on two camera shooting images.

With different disparity levels, we also investigate effects of display size because the display size is dependent to 3D depth cue sense. Subjects viewed polarization-multiplexed (right and left) images with special glasses on projection and 3DTV screen from a fixed distance. Table 2 shows the projection and 3DTV displays' hardware environment.

Table 1: Disparity levels in testing environment

Levels	***Disparity***
Level A	0.0m
Level B	1.5m
Level C	3.0m
Level D	4.5m
Level E	6.0m

Table 2: Two display testing environment

Method	***Display Type***	***Specification***	***Size***
Passive	3D Project	1920x1080 resolution 7000:1 contrast ratio	180inch Silver screen
Passive	3DTV	1920x1080 resolution 3000:1 contrast ratio	46inch

4.2 Experimental Procedure

Subjects were first briefed about the purpose and the methods of the experiment and, in a random order, looked at each of the movie clips projected on a screen from a fixed location for about 20 seconds. After looking at each test configuration, the subject was asked to fill out a visual comfort and clarity questionnaire.

After all the disparity levels and given display environment were shown, the subjects were asked few final debriefing questions with individual physical conditions such as interpupillary distance (IPD), 3D movie watching experience, ages, and so on. Also, subjects were tested for their stereoscopic imaging feeling tendency and people in the middle of the spectrum were chosen for actual subjects (i.e. those who exhibited average level of tendency). Figure 2 is the 3D projection environment and Figure 2 is the 3DTV testing environment.

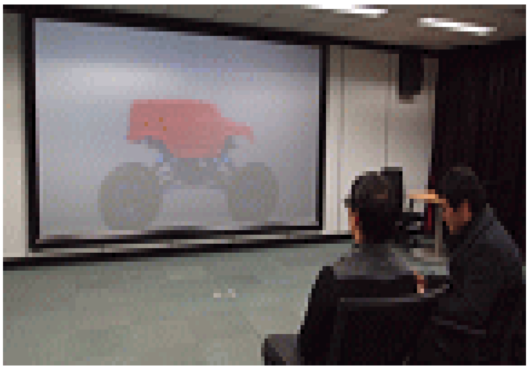

Figure 2. A subject show a given moving car movie clips on 3D projection environment after briefing the experiment purpose

Figure 3. A subject show a given moving car movie clips on 3D television environment

4.3 Visual Clarity and Visual Comfort Questionnaire

Because the subject had to view different moving car movie clips and answer to the comfort and clarity questionnaire every time, the comfort and clarity questionnaire was designed to be as easy and short as possible. The questionnaire comprised of two questions asking to rate (1) the visual clarity of the objects and (2) the feeling of comfort in the environment. After viewing a given movie clips, subjects are marking degree of feeling in scaling from 0 to 7.

5. Results and Discussion

In this paper we investigated in the relationship between visual clarity and visual comfort to create 3D stereoscopic imaging contents. Using a moving car movie clips that can be configured with different visual disparity level, we measured the level of visual clarity and discomfort, through a subjective questionnaire.

We obtained following various results with graph analysis. As shown Figure 4 and 5, the subjects feel the highest score of visual clarity and the lowest core of discomfort when the object is located 1/2 of the distance between screen and subject on 3D projection environment.

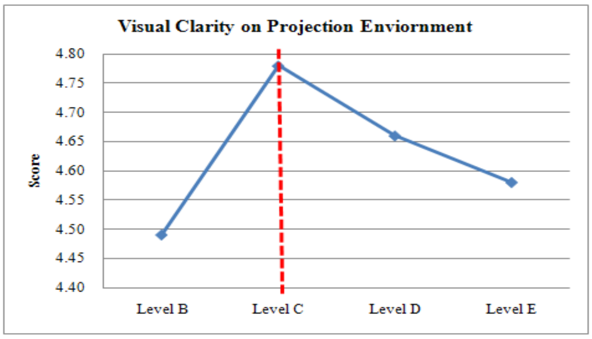

Figure 4. Visual clarity score on 3D projection environment

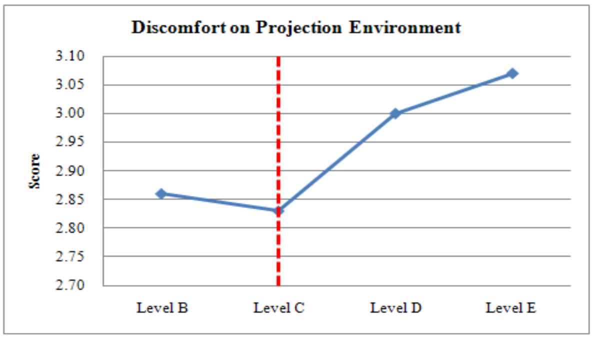

Figure 5. Visual discomfort on 3D projection environment (discomfort means the opposite of comfort feeling)

On 3D television, the subjects feel the highest score of visual clarity and the lowest grade of discomfort when the object is located 1/2 of the distance between screen and subject on 3D television like projection environment. In addition to the score of visual clarity is high and discomfort is high in Level E contents compare with projection environment as shown figure 6 and 7

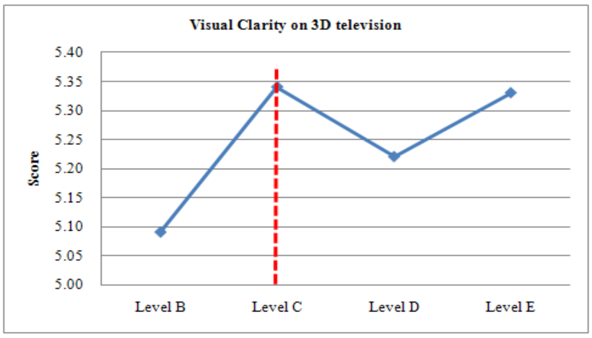

Figure 6. Visual clarity score on 3DTV environment

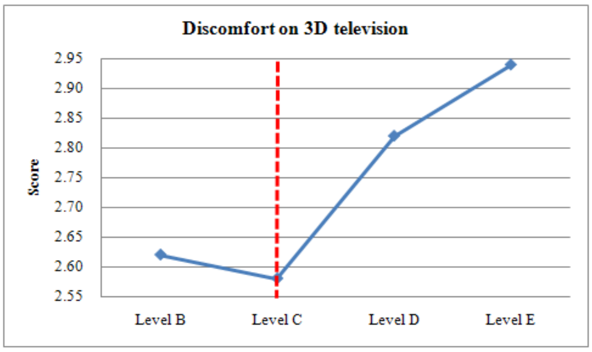

Figure 7. Visual discomfort on 3D projection environment

As shown the graphs, the disparity 1/2 value has important meaning on 3D stereoscopic imaging contents.

To investigate various effects dependent on individual physical conditions, we analyze relationship between ages and IPC. Figure 8 show the range of discomfort is small when the interpupillary distance (IPD) is more distant than IPD of average group. Generally, human's average of IPD is 6.5 centimeter. IPD1 group's IPD is more near and IPD3 is more distant that about 6.5 centimeter.

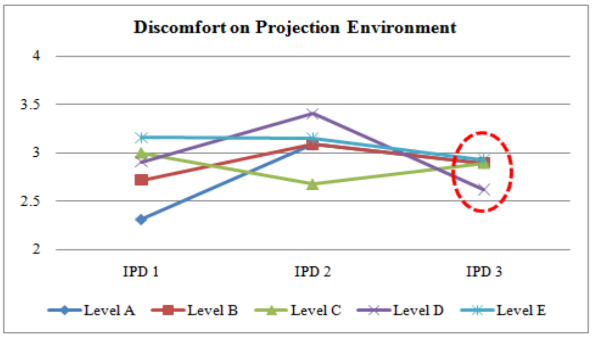

Figure 8. Individual IPD effect on 3D Projection environment

As shown figure 9, the range of visual clarity in 50s subject group is smaller than other age-groups. To analyze the phenomenon, we carried out χ^2 -test with ages, visual clarity and 3D movie experience. In the 50s group, about 86% has no 3D movie experience. The result says that 3D experience affect visual clarity and comfort on stereoscopic imaging contents.

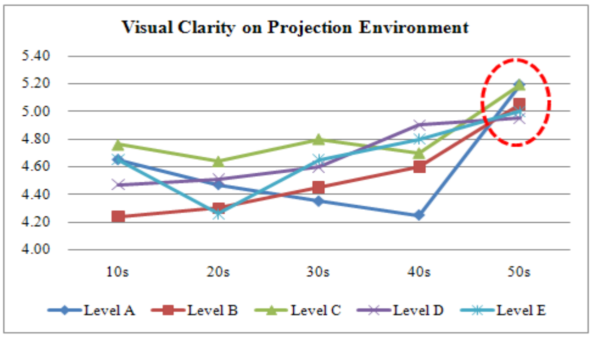

Figure 9. Visual clarity on different age groups.

6. Conclusion

Recently, although it has been reported the various factors that affect quality of 3D stereoscopic imaging contents, a general or common-used quality model of stereoscopic images has not been defined as yet. Establishing a quality model is very important because it serves as one of the basis for designing, developing, and evaluating 3D stereoscopic imaging contents. In this paper, we have argued for a model for visual comfort and clarity based on results from manipulating retinal disparity and viewing display size. The results of the experiments confirmed that disparity is a critical element to affecting visual clarity and comfort. Also, we find the visual clarity is proportional to visual comfort. With age-specific analysis, stereoscopic sensitivity of old age group is lower than other age group. These results will provide important insights into producing visually comfortable and clear 3D contents with stereoscopy.

To suggest comprehensive 3D stereoscopic images' quality model, we will investigate various factors influencing the stereoscopic images based on this work, and positive and negative attributions each factor. We also plan to research the relative benefits and effect of the mutual interaction among various factors.

Acknowledgments

This work was supported by the Culture Technology Joint Research Center Project of the Korea Creative Content Agency.

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