The Major Factors of Viewing Comfort on Autostereoscopic Display by Taguchi Experiment Design

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Abstract

The purpose of this study was to find out the impactful factors and the best levels combination of display luminance, ambient illumination, disparity, brightness contrast ratio, and viewing duration on visual comfort when watching the autostereoscopic display. The results can be applied in the 3D display industry.

Author Keywords

Taguchi method; comfort; fatigue; 3D; display luminance; ambient illumination; disparity; brightness contrast.

1. Introduction

Three-dimensional media services have been on the rise in recent years as they can provide more immersive and realistic experience to viewers [1]. Especially, the 3D TVs are expected to be the major commercial product regarding the increasing sales volume.

Visual fatigue is a common problem when viewing 3D images and numerous previous studies have investigated the major factors that cause visual fatigue [2-5]. The combination of display luminance and ambient illumination significantly affected depth perception, naturalness and overall image quality of subjective comfort [2]. The interaction effect among brightness contrast, display luminance and ambient illumination influenced the visual performance for TFT-LCD tasks [3]. Excessive disparity often occurs because of the content creator's desire to provide a more effective 3D impact [4]. In addition, the viewer felt visual fatigue after watching 3D films for 95 minutes [5].

There are various factors that cause visual fatigue when viewing 3D images. However, the complexity of the experiment increases with the number of the factors. As a result, the Taguchi method, a powerful tool to design optimization for quality engineering, was used in this study. An orthogonal, signal-to-noise ratio (SNR) and the analysis of variance (ANOVA) were employed to investigate the optimal parameters for viewing 3D images.

2. Methods

2.1 Experimental Material

The experimental material was the 3D pictures captured from four movies, including two animations and two real scenes. The experimental 3D pictures were divided into nine groups based on three levels of brightness contrast ratio and three levels of disparity range. There were 12 pictures in each group and 108 pictures totally used in the study.

2.2 Design of Experiment

Every subject finished the experiment under different conditions of level combinations based on a Taguchi L27 (313) orthogonal array of experimental design.

Each independent variable included three levels with low, moderate and high, illustrated as follows:

1. Display luminance: there were 24.6, 52.2 and 109.1 cd/m2, respectively, for the scale of autostereoscopic display itself.
2. Ambient illumination: the LED bulbs with the color temperature of 2804K changed from 0, 103 to 300 lux.
3. Disparity range: there were -0.9°, 0°, and 0.85° which were images that perceived of subjects in front of the display, on the display and behind the display, respectively.
4. Brightness contrast ratio: the ratios of the brightest point to the darkest point, which value were 8.49, 18.87 and 35.84.
5. Viewing duration: there were 30, 60 and 90 minutes.

The dependent variable was Likert's five scales of subjective comfort evaluation, which were the comfort degree of "eye fatigue," "dried eye," "focus changes (the optical power to maintain a clear image for focusing on an object as its distance changes)," "headache," "dizziness," "vomit," "concentration," and "overall fatigue." The score of one represented the less comfort and the score of five meant the most comfort in viewing 3D pictures.

2.3 Subjects

The subjects were eight experts who are engineers of 3D display division in Industrial Technology Research Institute, and 19 novices who were graduate students in National Tsing Hua University or National Chiao Tung University.

2.4 Procedure

Only the subjects who possessed the normal visual acuity, stereoscopic ability, and color blindness could participate in the formal experiment. The subjects read the purpose of the experiment and filled out the consent.

Each experimental material randomly showed 10 times in each condition for 15 seconds on a two-view autostereoscopic display. The task of the subjects was to view the 3D picture and orally answer the subjective comfort evaluation by observing the effect of the combination of different independent variables.

3. Results

The main effects of display luminance, ambient illumination, and the interaction effect between ambient illumination and viewing duration were significant on subjective eye fatigue (F > 4). The interaction effects between ambient illumination and disparity range, and between disparity range and viewing duration, had weak significant effects on subjective eye fatigue (2 < F < 4). The best combination of level combination for the least eye fatigue was high display luminance (109.1 cd/m2), low ambient illumination (0 lux), moderate disparity range (0°), and moderate viewing duration (60 min).

Less significant effects of display luminance, ambient illumination and brightness contrast ratio were found on dried eye in terms of subjective visual comfort evaluation (2 < F < 4). The level combination for causing the least dried eye was high display luminance (109.1 cd/m2), low ambient illumination (0 lux) and low brightness contrast ratio (8.49).

The main effect of ambient illumination was weakly significant on focus changes, headache and dizziness (2 < F < 4). The low ambient illumination (0 lux) was the best viewing 3D picture condition for focus changes, headache and dizziness.

A strong effect of ambient illumination on subjective vomit comfort evaluation was attained (F > 4). The interaction effect between ambient illumination and viewing duration was less significant on subjective vomit comfort evaluation (2 < F < 4).

The best level combination was between the low ambient illumination (0 lux) and the moderate (60 min) or long viewing duration (90 min). Nevertheless, no significant effects occurred among each factor on concentration and overall fatigue (F < 2).

4. Discussions and Conclusions

Table 1 demonstrates the main effect and interaction effect on each dependent variable. "vv" means the strong significant effect, "v" represents the weak significant effect, and "-" means no significant effect.

Table 2 exhibits the best combination levels of these five factors. Ambient illumination was the most significant factor on subjective visual comfort in this study. The bright lighting easily produces the blurred image on the display and generates the uncomfortable glare to the viewer. As a result, the subject avoided seeing the glaring part of the picture and subjectively preferred the low ambient illumination (0 lux).

5. Acknowledgements

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6. References

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Table 1. The effects of five independent variables on subjective comfort

Dependent variable		Independent variable							
		Display	Ambient	Disparity	Brightness	Duration	Ambient x Disparity	Ambient x Duration	Disparity x Duration
Subjective comfort evaluation	Eye fatigue	vv	vv	-	-	-	v	vv	v
	Dried eye	v	v	-	v	-	-	-	-
	Focus changes	-	v	-	-	-	-	-	-
	Headache	-	v	-	-	-	-	-	-
	Dizziness	-	v	-	-	-	-	-	-
	Vomit	-	vv	-	-	-	-	v	-
	Concentration	-	-	-	-	-	-	-	-
	Overall fatigue	-	-	-	-	-	-	-	-

Table 2. The best combination of significant variables

Dependent variable		Best level combination		
		Factor	**Level**	**Value**
Subjective comfort evaluation	**Eye fatigue**	Display	High	109.1 cd/m^2
		Ambient	Low	0 lux
		Disparity	Moderate	0°
		Duration	Moderate	60 min
	Dried eye	Display	High	109.1 cd/m^2
		Ambient	Low	0 lux
		Brightness	Low	8.49
	Focus changes	Ambient	Low	0 lux
	Headache	Ambient	Low	0 lux
	Dizziness	Ambient	Low	0 lux
	Vomit	Ambient	Low	0 lux
		Duration	Moderate	60 min
		Ambient	Low	0 lux
		Duration	High	90 min