Evaluation of stereoscopic image quality for mobile devices using Interpretation Based Quality methodology

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ABSTRACT

High-quality stereoscopic image content must be viewable in a variety of visual environments, from 3-D theaters to 3-D mobile devices. Stereoscopic effects, however, are affected by screen size, viewing distance, and other parameters. In this study, the authors focus on the stereoscopic image quality experience of viewing 3-D content on a mobile device in order to compare it with that of viewing 3-D content on a large screen. The stereoscopic image quality experience was evaluated using Interpretation Based Quality (IBQ) methodology, which combines existing approaches to image quality evaluation, such as the paired comparison and interview, and assesses the viewer experience using both quantitative and qualitative data. Five stereoscopic images were used in the experiment. The results of the experiment suggest that the discomfort felt while viewing stereoscopic images on a 3-D mobile device arise from not only visual fatigue but also the effects of the smaller screen size. The study also revealed the types of stereoscopic images that are suitable for viewing on 3-D mobile devices.

Keywords: stereoscopic 3-D images, stereoscopic image quality, mobile device, 3-D content, cardboard effect

1. INTRODUCTION

In the future, image media are expected to include stereoscopic images and 3-D cinema. In Japan and Finland, the number of 3-D theaters has increased rapidly since 2007. Stereoscopic image broadcasting by satellite began in December 2007 in Japan. Polarized 3-D glasses or liquid crystal shutter glasses are generally used to watch stereoscopic images in movie theaters and on home televisions, since these image display systems enable several people to simultaneously view the images. Moreover, some 3-D movies are released on DVD after they are shown in the theater. The anaglyph method is generally used for these movies because most homes do not have 3-D displays. Various types of autostereoscopic 3-D displays are also being developed, but many suffer from limited viewing points.

Because consumers prefer viewing full-color stereoscopic images without special glasses, the solution may be 3-D mobile devices. Such devices offer many attractive and practical features, including autostereoscopic capability, full-color presentation, personal viewing, portability, and a compact size. The small screen, however, has both good and bad points in terms of the stereoscopic viewing experience. On the one hand, the small screen may cause less visual fatigue and discomfort than other 3-D displays. The visual fatigue felt when viewing stereoscopic images is thought to be caused mainly by a conflict of vergence and accommodation [1-6]. The small screen of mobile devices may reduce this conflict. Our previous research showed that playing a mobile game with an autostereoscopic display did not cause visual fatigue that differed from visual fatigue caused by ordinary mobile device usage [7], which suggests that, with sufficiently small disparities, a mobile stereoscopic display can provide a comfortable user experience. However, sufficiently small disparities in 3-D mobile devices also mean fewer disparities in comparison with a large screen. In other words, 3-D mobile devices might lessen the stereoscopic effect.

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High-quality stereoscopic image content must be viewable in a variety of visual environments, from 3-D theaters to 3-D mobile devices. Stereoscopic effects, however, are affected by screen size, viewing distance, and other parameters. Previous studies have not explained how different visual environments affect the viewer's impressions and experiences. In this study, the authors focus on the stereoscopic image quality experience of viewing 3-D content on a mobile device in order to compare it with that of viewing 3-D content on a large screen.

2. METHODS

2.1 Interpretation Based Quality methodology

The stereoscopic image quality experience was evaluated using Interpretation Based Quality (IBQ) methodology, which combines existing approaches to image quality and assesses the perceptual attributes of the viewer using a combination of quantitative and qualitative data. These perceptual attributes reflect different levels of viewer experience [8-12].

Conventional studies of subjective image quality use psychometric methodologies, such as paired comparison or quality ratings, to measure the impact of image features or errors on the viewer. Although these methodologies are well established and very useful in many cases, they have some shortcomings, especially when comparing high-quality images or completely new image types. Standard methodologies provide information about error detection or allow selection of the best quality images, but they do not explain why viewers prefer one image over another. In the IBQ approach, conventional methodology is complemented with a qualitative interview in which the participant is asked about their responses to the images. The interviews are analyzed and the experience attributes are systematically coded according to grounded theory principles. The resulting codes are combined with the quantitative data and statistically analyzed. This approach has been successfully applied in studies related to paper quality [8, 9], consumer photographs [10], and video camera quality [12], each of which had over one thousand participants.

2.2 Viewing conditions

The experiment comprised three viewing conditions. In the first, stereoscopic images were presented on a 100-inch screen (100-inch 3-D screen). In the second, stereoscopic images were presented on a 2.6-inch 3-D mobile device (3-D mobile). In the third, non-stereoscopic images were presented on a 2.6-inch 2-D mobile device (2-D mobile). In the 100-inch 3-D screen condition, two liquid crystal display (LCD) projectors (EMP-7800, Epson) equipped with polarizing filters were used to present the stimuli at a resolution of 800 x 480 pixels. The subjects viewed the stimuli from a distance of 3 meters while wearing polarized glasses. In both the 3-D and 2-D mobile conditions, the stimuli were presented from mobile device prototypes and the viewers did not wear polarized glasses. The 3-D and 2-D mobile devices both had a resolution of 240 x 400 pixels. The stimuli were presented at a resolution of 240 x 144 pixels with the mobile devices in portrait orientation. The viewing distance was 0.39 m.

2.3 Images

The stimuli were five stereoscopic images [13]. Figure 1 shows the five images as well as their parallax distributions. As explained in the results and discussion section, these parallax distributions may have affected the results of the experiment. To calculate the parallax distribution of the stimuli, the correspondence between the pixels in the right and left images was calculated using a prototype scalable 3-D image conversion system [14] utilizing a block-matching method and recursive correlation [15]. In the parallax distribution, the positive number of disparity means that the perceived 3-D images appear to be in front of the screen, and the negative number of disparity means that the perceived 3-D images appear to be behind the screen. The zero disparity means that the images are displayed on the screen. The disparities were calculated on the assumption of the 100-inch 3-D screen condition. The left image in each stereoscopic 3-D image pair was used as the non-stereoscopic image.

Image 1

Image 2

Image 3

Image 4

Image 5

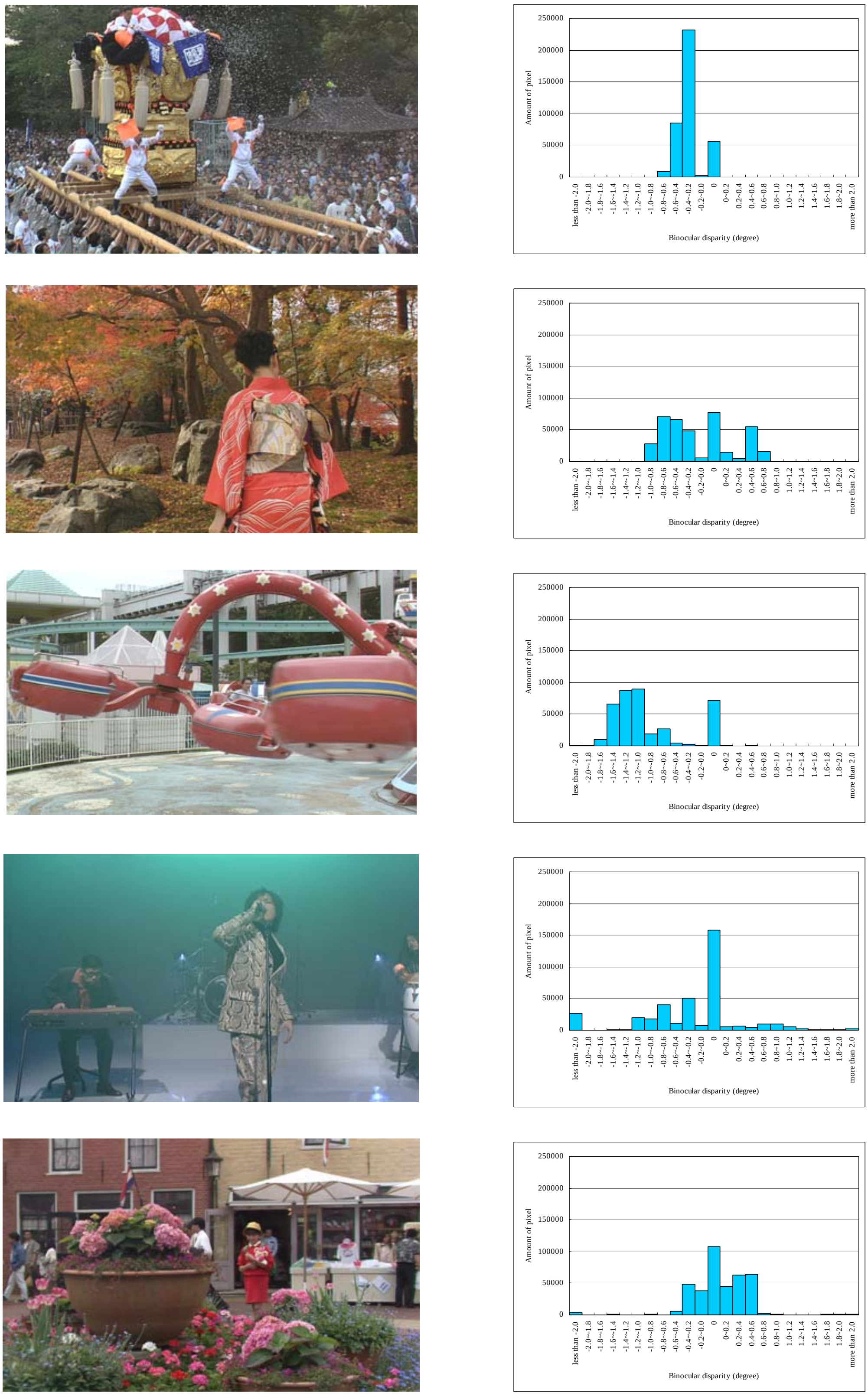

Fig. 1. The five images and their parallax distributions

2.4 Procedure

The subjects watched and compared a pair of images presented in two of the three viewing conditions (Fig. 2). The subjects rested their head on a chin rest. In the interview, the subjects were asked to respond voluntarily at the beginning of each trial. Next, the experimenter questioned the subject and recorded the details of the reasons and influences in the subject's responses. The subjects' responses in the interview were recorded by sound recording software on a personal computer.

Scheffe's paired comparison method, which is a conventional methodology, also was carried out in order to compare the rating scale values of the three viewing conditions. The subjects were presented with two of the three conditions and asked to rate according to a seven-point scale which and in what ways one condition was better than the other. The subjects were previously instructed to compare two images and choose the one with better stereoscopic effects. All combinations were presented in random order. The subjects were nine males and one female, aged 24 to 35 years, with normal stereopsis.

Fig. 2. Scenes from the experiment: left: 3-D mobile device vs. 100-inch 3-D screen; right: 3-D mobile device vs. 2-D mobile device

3. RESULTS AND DISCUSSION

3.1 Interviews using IBQ methodology

The subject's responses were collected for text analysis. The responses were divided according to the descriptive content into three categories determined from our previous research [16]. Table 1 lists the frequency of each response. In this analysis, we noted the characteristic symptoms (e.g., visual fatigue and nausea) and subjective attributes (e.g., three-dimensional, natural, and realistic).

Table 1. Frequency of responses

Category	3-D mobile vs. 100-inch 3-D screen		3D mobile vs. 2D mobile	
	3-D mobile	100-inch 3-D screen	3-D mobile	2-D mobile
Location reference	67	47	75	18
Symptoms	2	2	11	1
Subjective attributes	295	132	293	74
Total	364	181	379	93

Table 2 shows the frequency of responses related to symptoms for the 100-inch 3-D screen, 3-D mobile, and 2-D mobile conditions for each test condition. The small number of reported symptoms was remarkable. Although the frequency might depend on the time of the experiment and the subjects' visual impressions, etc., the small number was also reflected in the total number in Table 1. The most common symptom was "Troublesome feeling while watching," which includes many of the eye-related symptoms mentioned by the subjects (e.g., visual fatigue and a strange feeling in the eye). This symptom was not mentioned very often in the 3-D mobile vs. 100-inch 3-D screen viewing condition, but it was quite significant in the 3-D mobile vs. 2-D mobile condition. The result shows that visual fatigue was not a differentiating factor between the two 3-D conditions, but it was a differentiating factor between the 2-D and 3-D conditions. Moreover, ten of the "Troublesome feeling while watching" responses for the 3-D mobile device in the 3-D mobile vs. 2-D mobile condition came from just two of the ten subjects. The comments and profiles of each subject revealed that both subjects had prior experience in stereoscopic viewing and tended to point out problems peculiar to stereoscopic images.

Table 2. Frequency of responses by symptom

Description	3-D mobile vs. 100-inch 3-D screen		3D mobile vs. 2D mobile	
	3-D mobile	100-inch 3-D screen	3-D mobile	2-D mobile
Troublesome feeling while watching	1	0	10	1
Focusing difficulties	0	1	1	0
Dizziness	0	1	0	0
Double image	1	0	0	0
Total	2	2	11	1

Table 3 lists the frequency of the main subjective attributes for the 100-inch 3-D screen, 3-D mobile, and 2-D mobile viewing conditions. The most commonly mentioned impressions relate to the depth of the 3-D images, which is to be expected.

The second most common subjective attribute was "weird." Comments in the “weird” category included unnatural, strange, step-like, etc. These all relate to stereoscopic expressions. Interestingly, under both test conditions, stereoscopic images on the 3-D mobile device were clearly described as “weird.” Additionally, under both interview conditions, the “step-like” description comprised about a quarter of the "weird" responses. The subjects do not always use unambiguous terminology to describe reductions in image quality. Thus, it is interesting to learn that the subjective attribute, “weird,” also is associated with other types of distortion in stereoscopic 3-D displays. Moreover, the responses of “step-like” were mostly about images 2 and 4, indicating that different images can produce different stereoscopic image quality experiences. A lack of disparity gradients made the depth changes more step-like on the 3-D mobile device. This step-like perception of stereoscopic images is known as the cardboard effect [17] and is generally considered a problem of natural stereoscopic viewing. However, such stereoscopic images may be useful in recognizing the relative depth and may indicate the suitability of cartoon films and computer-generated animations as 3-D content for 3-D mobile devices.

The third most common subjective attribute was "Artificial, looks like a computer game." A clear difference was seen in the number of responses in the 3-D mobile vs. 100-inch 3-D screen comparison, indicating a significant difference in the realism of images displayed on small and large 3-D screens and suggesting that realism is one of the main factors that determine good stereoscopic image quality [18]. Thus, the level of comfort was reduced when stereoscopic images were viewed on a small screen. The result may be also connected to the attribute, "Real and life-like," which would seem to indicate the exact opposite. Moreover, the attribute, "Artificial, looks like a computer game," was cited only once when the subjects compared 2-D and 3-D images. Thus, other beneficial experience factors may override the effect in this situation.

Table 3. Frequency of responses for subjective attributes

Description	3-D mobile vs. 100-inch 3-D screen		3D mobile vs. 2D mobile	
	3-D mobile	100-inch 3-D screen	3-D mobile	2-D mobile
Depth impression	31	37	66	8
Weird	22	1	11	0
Artificial, looks like a computer game	12	0	1	0
Real and life-like	0	8	9	0
Presence	0	0	11	0
You notice more details	3	2	7	2
Some locations blurry and difficult to see	3	0	3	0
Dynamic, lots of movement	0	4	0	1
Minor total of the subjective attributes	80	60	116	15

3.2 Paired comparison

The paired comparisons from the three viewing conditions were analyzed separately for each image. The results are shown in Fig. 3. The same tendency was seen for all images: the 100-inch 3-D screen scored highest, the 3-D mobile device had the next highest score, and the 2-D mobile device scored lowest. One-way analysis of variance revealed significant differences in the main effect of the viewing conditions in each image (image 1: $F(2, 27)=228.73$, $p<0.01$; image 2: $F(2, 27)=83.78$, $p<0.01$; image 3: $F(2, 27)=47.96$, $p<0.01$; image 4: $F(2, 27)=58.45$, $p<0.01$; image 5: $F(2, 27)=65.52$, $p<0.01$). Additionally, because the scores for the paired comparison are the value scales in each result, they are meaningful relative to each other. In other words, the difference values for the samples (100-inch 3-D screen, 3-D mobile device, and 2-D mobile device) have important implications (Fig. 3). From the viewpoint of the difference value between each two samples, the scores of 3D-mobile were close to the scores of 100-inch screen for images 2 and 5. A similar tendency was subsequently seen for images 3 and 4. These results suggest that the five images used in the experiment contained suitable stereoscopic images for 3-D mobile devices, likely due to the parallax distributions of the images. In other words, the important factors for displaying stereoscopic images on 3-D mobile devices may be a wide range of disparity values, object placement, and the ability to recognize relative depth.

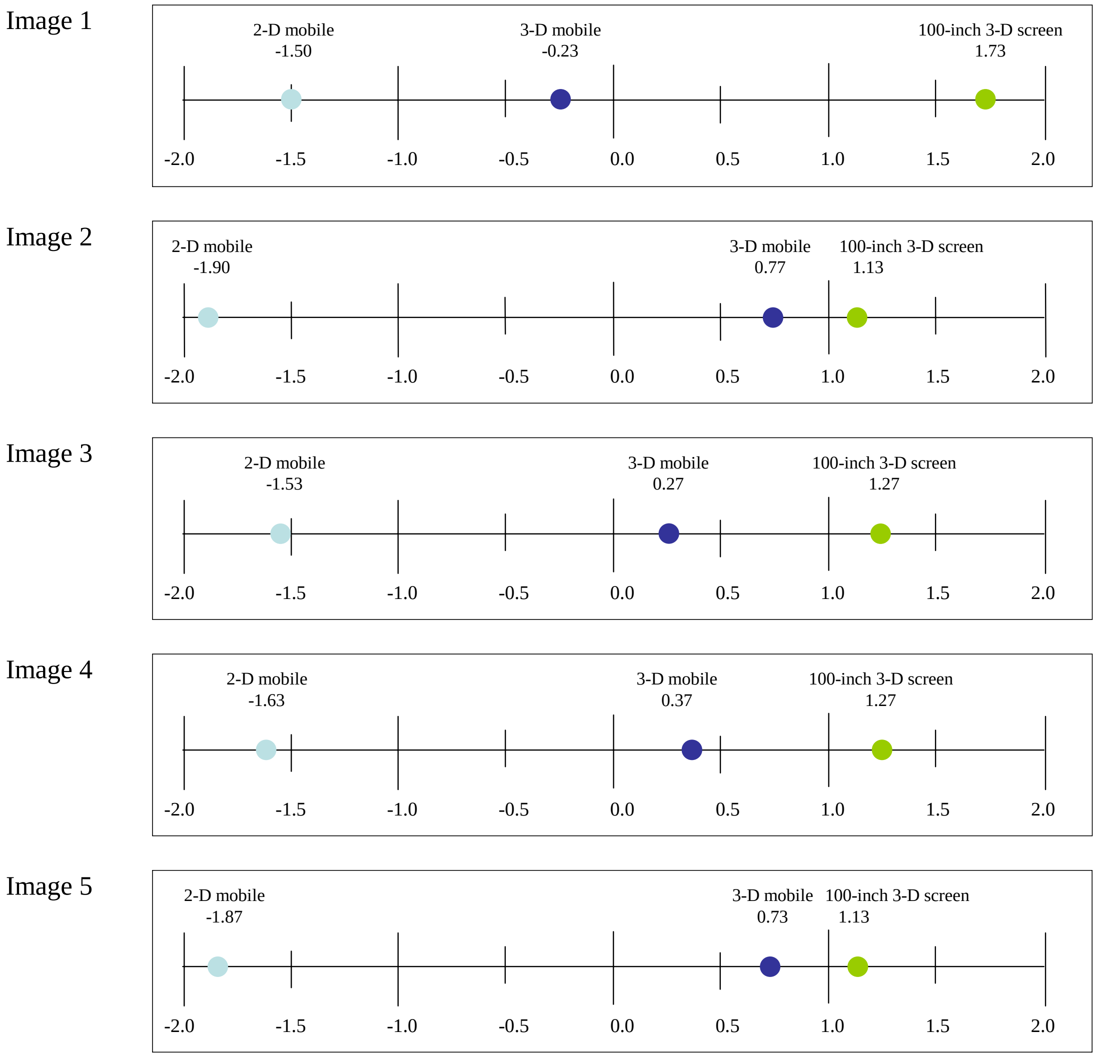

Fig. 3. Results of paired comparison

4. CONCLUSIONS

This paper describes the stereoscopic image quality experience on mobile devices. The screens of mobile devices are small enough to reduce the conflict of vergence and accommodation while viewing stereoscopic images. Therefore, 3-D mobile devices may offer the user a comfortable viewing experience. However, small disparities in the stereoscopic images may result in a reduced stereoscopic effect when such images are viewed on 3-D mobile devices. The following conclusions were drawn from the results of the experiment.

(1) Stereoscopic 3-D images on mobile devices may provide adequate stereoscopic effects in terms of viewing comfort.

(2) Feelings of discomfort from viewing stereoscopic images on a 3-D mobile device arose from not only visual fatigue but also the effects of the smaller screen.

(3) The cardboard effect is associated with a subjective feeling of weirdness, and may be an important factor for 3-D mobile devices.

(4) In terms of viewing comfort, "Artificial, looks like a computer-game" was an important experience attribute for comparing stereoscopic images on large and small displays.

(5) The viewer's perception of stereoscopic image quality must be considered when creating 3-D content for mobile devices.

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