Effect of Contrast on the Quality of 3D Visual Perception

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***Abstract*—There are several different factors that affect the perceived quality of 3D content. Our objective in this paper is to study how the change of contrast between the objects of interest and the background in a scene will affect the overall 3D visual perception. For this study, we captured outdoor and indoor scenes in 3D format. For each scene, the brightness of the background was consistent and the object's brightness was changing using an external light source and/or a reflector disk. Subjective evaluations were performed, with the subjects being asked to rate the 3D perceptual quality of each sequence. The results showed that the Weber contrast between objects of interest and background should be within the range of -0.35 to 0.55 to provide viewers with high quality of 3D experience.**

Keywords-3D TV; quality of experience; 3D perception; contrast

I. INTRODUCTION

Recently, 3D video has received increased attention among investors, researchers and technology developers. The introduction of 3D TV can only be a lasting success if the perceived image quality provides a significant step up from conventional 2D television, while maintaining the same viewing comfort. The availability of high quality 3D content will also be a key factor to this success. Recoding 3D content – let alone high quality - is much more demanding and challenging than that of its 2D counterpart in terms of camera setup and configuration, requiring both the director and camera operators to be experts in stereoscopic geometry and camera calibration [1]. In general, 3D content production needs different considerations and provisions beside the ones found in the conventional 2D video production. There are many factors and parameters that could affect the perceptual quality of 3D media. While the effects of different acquisition parameters on the 3D perception have been studied before, their influence on the perceived quality has not been assessed quantitatively. More research and studies are required in order to improve our understanding of the different factors that affect a viewer's perception of 3D video content. This knowledge will allow us to capture high quality 3D content that may help reduce or even eliminate the visual discomfort of the viewers and thus improve the overall quality of experience. To this end, the study by Goldmann et al. has addressed the effect that the distance between stereo cameras has on the perceptual quality of the captured videos [2]. The work presented by Xu et al. [3] investigated the relation between the distance of the object(s) of interest from the camera and the quality of the perceived images when watched on different size displays. Another important factor that affects the visual quality of 3D content is brightness [4]. The study by Pourazad et al. [5] investigates the effect of the scene's brightness on perceptual 3D quality.

Inspired by the above work, in this paper we study the effect of the contrast between the object(s) of interest and the background on the visual quality of 3D content. In our study, we capture outdoor and indoor scenes with different contrast levels between the main object(s) and the background. Then we perform extensive subjective quality assessment experiments to quantify the perceived quality of the 3D experience at different levels of contrast. The objective is to identify if there is a contrast range that will lead to good 3D representation.

The rest of the paper is structured as follows. Section II elaborates on our experimental setup. Subjective evaluations are presented in Section III. Section IV elaborates on our experimental results. Conclusions are drawn in Section V.

II. EXPERIMENTAL SETUP

In our experiment, we aim at investigating the effect of changing the object's contrast with respect to the background on the perceived quality of captured 3D videos. For this comparison, 3D videos of indoor and outdoor scenes are captured using stereo cameras. For each scene the brightness of the object(s) changes from an under-exposed to an over-exposed level, while the brightness of the background is adjusted to a normally exposed level (not over/under exposed) and is kept relatively unchanged for all the different recordings of the same scene. As a result, the recorded videos have different contrast between the object(s) of interest and the background. To capture such test video sequences we use two identical full HD cameras (Sony HDR-XR500V 1080 60i NTSC) with baseline distance of 9cm. We used the same settings on both cameras, which were aligned in parallel and attached to a bar that was custom-made for this purpose. Subsequently, the bar was secured to a tripod. Since zoom lenses may differ [6], only the extreme ends of the zoom range were used to prevent unsynchronized zooming. For the indoor scenes, the brightness of the object(s) was changed by using a dimmable 1000W fluorescent video light source (FloLight FL-220AW). For the outdoor scenes, since the emitted light from the light source was insufficient for changing the brightness of the object(s) (due to the presence of sunlight), we used a collapsible circular reflector disc with multiple impacts to reflect different levels of sunlight on the object(s).

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Fig. 1 shows our camera setup, the light source and the reflector used in our experiments. In general, capturing outdoor scenes was much more challenging compared to indoor scenes, due to the presence of sunlight and the change of weather conditions which kept altering the background brightness.

Figure 1. Stereo camera setup used in the experiments.

In order to calculate the contrast between the object(s) and the background first we measured the luminance of the object(s) and background using a multifunction light meter (Sekonic L-758Cine). Then, we employed Weber contrast definition [7] as:

$$\text{Contrast} = \frac{L_o - L_b}{L_b} \qquad (1)$$

where L_o is the luminance of an object and L_b is the average luminance of the background. We measure luminance since it indicates how much luminous power is perceived by the human eye when viewing the surface from a particular angle.

III. Subjective Evaluation

For this experiment, six stereoscopic test sequences (two outdoor and four indoor) and one demo video were captured using the stereo camera setup described in Section II. Fig. 2 shows a snapshot of our test sequences. For each scene the camera exposure is adjusted such that the background area is neither overexposed nor underexposed. Then, the brightness of the object(s) is changed from an underexposed level to an overexposed level within multiple steps, with the brightness-change remaining visually differentiable (see Fig. 3). In both cases, outdoor and indoor, each sequence is approximately 10 seconds long. For each scene recording, we ensure that while the object's brightness changes, the content of the scene and the background luminance remain unchanged.

To quantify the perceived quality of the 3D experience at different levels of contrast, we performed subjective quality assessment tests. The viewing conditions of our subjective test were set according to the ITU-R Recommendation BT.500-11 [8]. Eighteen observers participated in our subjective tests: seven females and eleven males, ranging from 23 to 60 years old. All subjects had none to marginal 3D image and video viewing experience. A 65" Full HD 3D display (©Panasonic, Plasma, TC-P65VT25) was used in our experiment. Based on our own subjective tests of many 3DTV sets, the above display offers the best crosstalk reduction performance and that is the reason it was chosen for our tests.

At the beginning of the experiment, a demo was played starting from a very dark object-exposure to a very bright one to help viewers become familiar with the test process and show them the quality-change range expected. After the demo, the viewers were shown each stereoscopic test sequence in random order of object-exposure levels. Between stereo videos of different object-exposures, there were three-second gray intervals that allowed the viewers to grade the perceptual quality of 3D content from 1 to 10 (continuous scale) and relax their eyes before watching the next video. The perceptual quality reflects whether the displayed scene looks pleasant in general. In particular, subjects were asked to rate a combination of "naturalness", "depth impression" and "comfort" as suggested by Hyunh-Thu et al. [9].

IV. Results and Analysis

After collecting the experimental results, we checked for the outliers based on the TU-R Recommendation BT.500-11 [8] and then the mean opinion scores (MOS) from viewers were calculated. Fig. 4 shows the average perceptual 3D quality (MOS) versus brightness of the object(s) for all six stereo sequences. As it can be observed, the acceptable brightness level for objects in outdoor scenes is much higher than those in indoor scenes, due to the presence of sunlight. Here, the numerical value of object(s) brightness could not be used as a guideline for capturing high quality 3D content, i.e., we can not conclude if the brightness level of the object(s) falls in a certain range (where MOS is greater than 6) then the subjective quality of 3D picture will be acceptable. The reason is that what viewers see and evaluate (perceived 3D visual quality) is not really measured in the real world but rather what has been captured by the cameras and displayed on the 3DTV. In other words, the final brightness level of the objects has been influenced by the exposure settings of the cameras as well as the setting parameters (and limitations) of the 3D display system itself. A way of quantifying how the final brightness level affects 3D perception would take into consideration the luminance

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Figure 2. Snap shot of captured indoor and outdoor test sequences.

in a scene as well as the camera and display models. This study is part of our future work.

In order to investigate the effect of the contrast on 3D perception, the contrast between the object(s) and the background is calculated based on equation (1) as the difference between the average luminance of the background and that of the object of interest. Fig. 5 shows the average subjective scores for quality of 3D content versus contrast for all six sequences.

A general observation that applies to both outdoor and indoor scenes is that the stereo video sequences with Weber contrast levels of -0.35 to 0.55 between the object and background are more appealing to the viewers (these correspond to rating scores above 6, which may be regarded as acceptable quality). Note that although the visually acceptable range of object's brightness (MOS over 6) is higher for the outdoor scenes compared to that of the indoor scenes, as shown in Fig. 4, the range of contrast that ensures high 3D quality is similar for both cases. It is also observed that low scores are associated with high contrast scenes, which in Fig. 5 appear at both ends of the horizontal axis, as contrast here is the difference between the objects' brightness and that of the background. It is well known that crosstalk artifacts in 3D displays become severe when the contrast is high.

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Figure 3. Same scene with different brightness levels of the object.

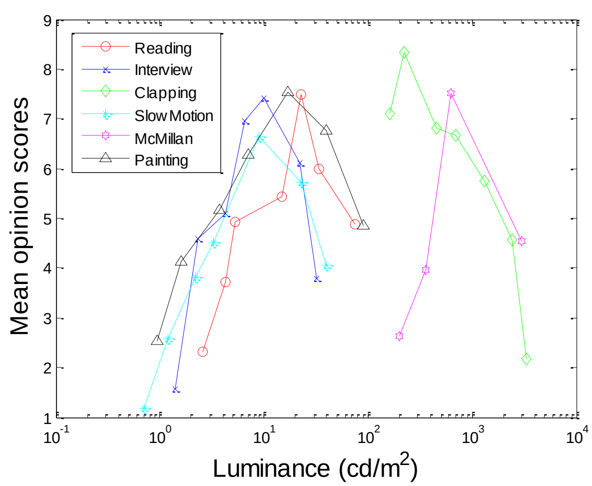

Figure 4. Snap shot of captured indoor and outdoor test sequences.

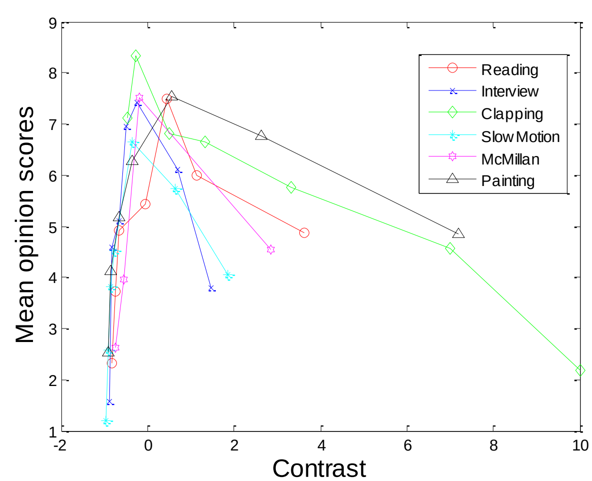

Figure 5. Perceptual 3D quality score versus the contrast between object and background.

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In summary, this study indicates that content producers may improve the overall 3D quality of experience by adjusting the brightness of the objects to ensure that the Weber contrast between the background and the objects of interest falls between -0.35 to o.55.

V. Conclusion

The era of user-centric multimedia has already begun, and quality plays a central role in it. Attention to the quality of 3D content is even more important since low-quality 3D videos can produce eyestrain, headache, and generally unpleasant viewing experience for the viewers. Contrast is one of the important factors that affect the visual comfort and quality of 3D videos. In this study we addressed the problem of understanding the effect of contrast on the 3D quality by performing extensive subjective quality assessment experiments to quantify the perceived quality of the 3D experience at different levels of contrast.

According to our results, a general observation that applies to outdoor and indoor scenes is that the stereo video sequences with Weber contrast levels of -0.35 to 0.55 between the object(s) and the background are more appealing to the viewers. In summary, content producers may improve the overall 3D quality of experience by adjusting the brightness of the objects of interest in a scene to ensure that the Weber contrast the objects and background falls within the suggested range levels.

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