Effect of Global and Local Brightness on Quality of 3D and 2D 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 investigate how the global and local change of brightness in a scene will affect the overall 3D visual perception. Our work contains two studies: 1) global change of brightness, which is achieved by setting different exposure times on the camera, and 2) local change of brightness, where the brightness of the background is consistent and the object's brightness is changed 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 of both studies demonstrate marginal difference in the brightness effects between 3D and 2D videos. The latter study 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 3D experience.**

Keywords-3D TV; brightness; 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 the 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 2D video. In general, 3D content production needs different considerations and provisions beside the ones found in the conventional 2D video production to guarantee high quality of the produced content and the comfort of viewers.

There are many factors and parameters that could affect the perceptual quality of 3D media. While the effects of different acquisition parameters on 3D perception have been studied before, their influence on the perceived quality has not been quantitatively assessed. More research and studies are required in order to improve our understanding of different factors that affect the viewers' 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 Pourazad et al. (CONTENT 2011) quantitatively investigates the effect of contrast (local brightness-change) on the visual quality of 3D content [1]. Scene detail has also been noted to affect the visual comfort and quality of 3D content [1]. Goldmann et al. has addressed the effect that the distance between stereo cameras has on the perceptual quality of the captured videos [3]. 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 has been investigated by Xu et al. [4].

Content producers recognize contrast and brightness as some of the important factors in capturing 3D content and based on their practical experience they suggest using higher light settings for capturing 3D videos compared to 2D ones [5]. In physiological studies it has been found that there is a relationship between contrast and the human visual depth perception [6]. In this paper, we perform a systematic study on the effect of the global and local brightness-change on the visual quality of 3D content, and compare it to that of 2D. This study is the extension of our previous work on the effect of local brightness change (contrast) on 3D visual perception [1].

The objective of this study is two fold: first to provide guidelines for adjusting brightness levels during 3D capturing in order to offer the best 3D quality of experience; second to determine how these levels differ from the case of 2D video and use this knowledge as a guideline for capturing 3D content. In our study we investigate the effect of both global and local brightness-change on the perceptual quality of 3D content. We first examine the scenario where the brightness of the whole scene is altered (change of global brightness). Global brightness-change can be achieved by setting different exposure times on the camera. In the second part of our work only the brightness of the object(s) of interest is altered and the brightness of the rest of the scene stays relatively unchanged (change of local brightness). This can be achieved using a light source or reflector disks. Since there is no standardized set of 3D or 2D video clips that record the same (sufficiently similar) scene in different brightness/contrast levels, for both of these scenarios, we decided to capture outdoor and indoor scenes for our test. Note that synthetic videos are not practical in our study. Simply changing the brightness or contrast of a recorded video is a lossy process and the resulting videos may have unwanted artifacts, which will hamper the 3D perception. Once the test videos are captured we perform extensive subjective quality assessment experiments to quantify the perceived quality of the 3D experience at different levels of global and local brightness. Understanding both of these scenarios will allow us to thoroughly identify criteria related to brightness for enhancing the viewers' 3D quality of experience.

The rest of the paper is structured as follows: Section II describes the experimental setup and discusses the results of the global brightness-change experiment, Section III provides the details of our subjective evaluations for the local brightness-change case, and conclusions are drawn in Section IV.

II. Experiment One – Global Change Of Brightness

In this section, we investigate the effect of global brightness on the perceptual quality of 3D content and compare it with that of 2D video. In this case, the captured brightness of the background and that of the object are changed simultaneously. The following subsections elaborate on the details of our experiment.

A. Capturing Setup

To capture test video sequences we use two identical full HD cameras (Sony HDR-XR500V 1080 60i NTSC) with baseline distance of 9cm. Fig. 1 shows the stereo camera setup used in our experiment. 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 [5], only the extreme ends of the zoom range were used to avoid any zoom correction post-processing. We set the cameras to manual mode with ISO equal to 100 and we disabled face-detection, and the backlight compensation mode. Note that the camera setup and configuration is more complex in the case of 3D video recording and stereoscopic geometry and camera calibration require special attention [7].

Figure 1. Stereo camera setup consisting of two identical HD camcorders.

In order to secure temporal synchronization of the two cameras, a single remote control was employed to activate both of them at the same time instance. The temporal synchronization of the video sequences is further confirmed in the post-processing phase. We checked the left and the right views of each captured video sequence on a frame-by-frame basis and ensured that the two views are temporally aligned. Even though the cameras are carefully lined up, the recorded videos may require rectification to compensate for vertical, horizontal and rotational misalignments that can hamper the perceptual quality of 3D content.

We set the exposure adjustment of the cameras on the manual mode and capture each scene using several different exposure levels. When recording each exposure level, to guarantee that brightness is the only varying parameter, we ensure that the scene relatively stays unchanged in terms of content, object motion and camera movement. This guarantees the consistency needed in our comparisons. The exposure levels are chosen between sufficiently bright to sufficiently dark levels; the number of steps varies depending on the brightness of the scene that is captured. Note that since our cameras do not provide a numerical value for the exposure setting, we divided the exposure range (under expose to over expose) to 6 equal steps for the indoor scenes and 8 equal steps for the outdoor scenes by counting the number of steps on the camera. As expected, outdoor scenes captured during the daytime allow for a wider range of exposures.

B. Subjective Evaluation

The subjective evaluation was performed to investigate the effect of picture brightness on 3D visual perception and then compare it to that of 2D videos. For this experiment, six stereoscopic test sequences were used (two outdoor and four indoor). Fig. 2 shows snapshots of our test sequences. Indoor scenes were captured at six different levels of camera exposures (very dark to very bright), and Fig. 3 shows an example of a scene captured with different brightness levels. Since outdoor scenes allow a wider range of brightness, the number of exposure levels for the outdoor sequences was increased to eight. In both cases, outdoor and indoor, each sequence is approximately 10 seconds long.

The viewing conditions were set according to the ITU-R Recommendation BT.500-11 [8]. Eighteen observers participated in our subjective tests: six females and twelve males, ranging from 23 to 63 years old. All subjects have none to marginal 3D image and video viewing experience. A 65” Full HD 3D display (©Panasonic, Plasma. TC-P65VT25) was used in our experiment. The TV settings were as follows: brightness: 80, contrast: 80, color: 50, R: 70, G: 45, B: 30.

At the beginning of the experiment a training section was provided: the “Running” test sequence was played starting from a very bright exposure to a very dark exposure to help viewers become familiar with the test process and show them the expected range quality-change. Note that “Running” was excluded from the subsequent testing process.

Our tests included two steps: rating the perceptual quality of 3D content in different exposure levels and grading the quality of the same content in 2D format. In order to maintain similar brightness conditions for both cases (3D and 2D), the left view of the captured video sequences was chosen and displayed to both eyes in the 2D case and the viewers were asked to use the glasses while watching the 2D video sequences. In our tests, subjects were aware if they were watching 2D or 3D videos. Both 2D and 3D subjective tests were conducted at the same time and the same room.

The single stimulus continuous quality evaluation (SSCQE) method is used in our subjective tests [8]. After the training sequence, the viewers were first shown each stereoscopic test sequence in random order of exposure levels. Between two consecutive videos with different exposures, a three-second gray interval is provided for allowing the viewers to rate the perceptual quality of the content 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]. Fig. 4 demonstrates the testing procedure. The scoring bar ranges from 0 – 10 in a continuous scale and a higher score correspond to better quality. Once all the stereoscopic sequences were played, there was a break interval of 5 seconds followed by the 2D sequences. The same process was followed in this case - the same sequences in 2D format

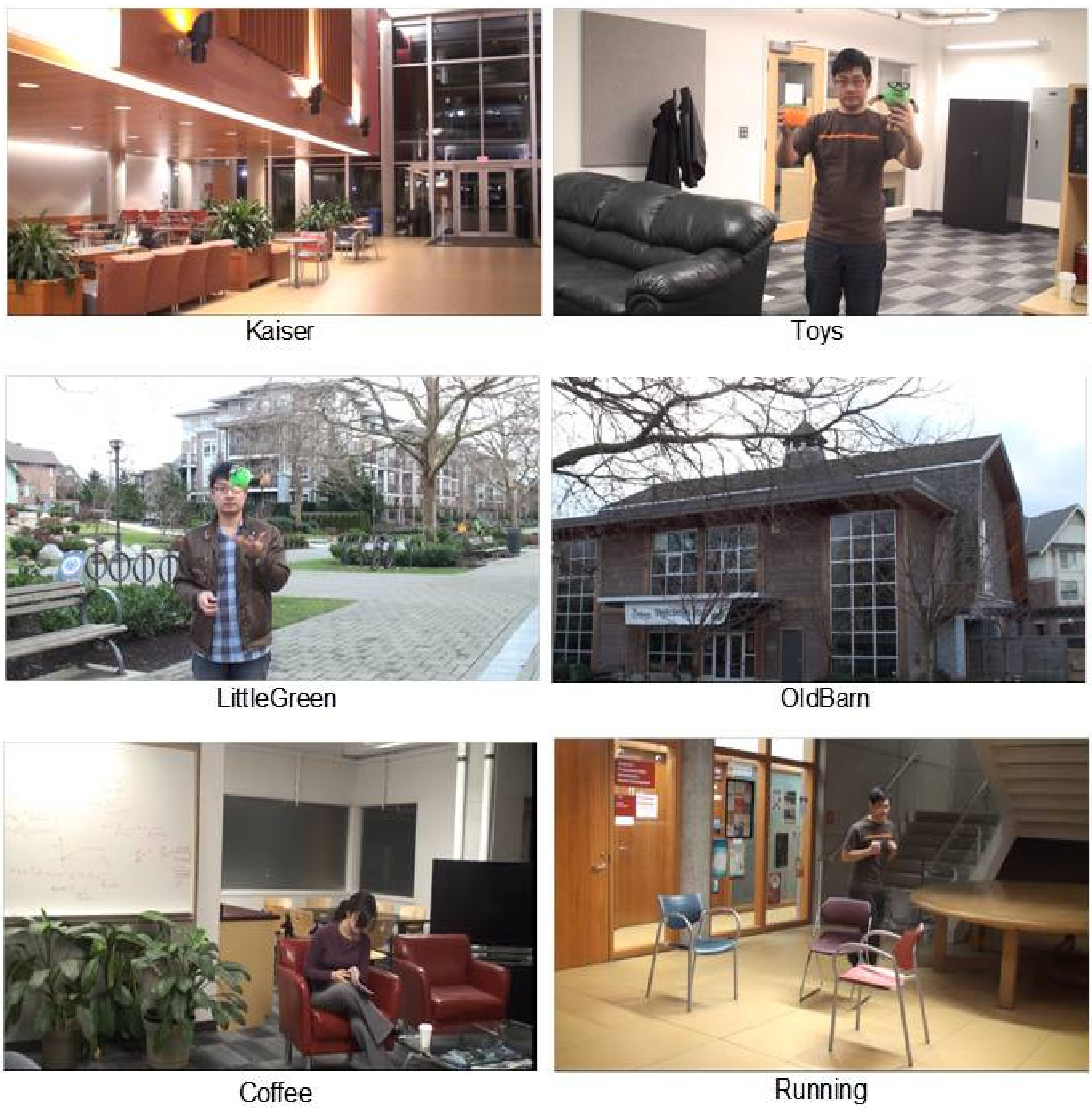


Figure 2. Snapshots of captured video scenes for the first experiment.

were shown in random order of brightness, with 3-second intervals between each sequence - with the viewers asked to rate the video quality of the 2D content.

C. Results and Analysis

After collecting the experimental results, we removed the outliers based on the TU-R Recommendation BT.500-11 [8] (there was one outlier) and then the mean opinion scores from viewers are calculated. Fig. 5 shows the results with 95% confidence interval. A general observation that applies to outdoor and indoor scenes is that the video sequences with brightness levels around the mid-band are more appealing to the viewers in both the 2D and 3D cases (rating scores are more than 6). Note that the exposure range is wider for the outdoor scenes and the highest brightness level for outdoors cannot be reached for the indoor scenes. The reason is that high levels of brightness in indoor scenes will introduce unacceptable degrees of noise caused by the sensitivity of the camera sensors. Regarding the indoor scenes, we observe that for scores above 6 (over which the quality may be regarded acceptable), the quality of the 3D experience increases as the brightness increases. This trend is also observed in the 2D case, with scores following the same pattern. If we would like to conclude something more from these findings, we could say that the 3D experience adds a bit more quality overall, although the difference is not very large.

For the outdoor sequences, we observe that the extreme levels of brightness, very dark and very bright, result in unacceptable quality. For the mid-band section, the quality stays at acceptable levels, with very small variations. The 2D performance is almost identical, with 2D ratings slightly

Figure 3. Different (global) brightness levels in the first experiment.

higher than those of 3D in this case. The main reason for this deviation from the indoor case is the actual content of the outdoor scenes. The objects with depth in the latter case are relatively darker than the background. In fact, a large portion of the background – more so in the "OldBarn" sequence than the "LittleGreen" – is the sky, which in both cases is very bright and lacks detail. According to the viewers, the lack of detailed information in the background (i.e., overexposed sky) drastically reduced the level of depth illusion, hampering the 3D perception when watching stereoscopic content.

III. Experiment Two – Local Change Of Brightness

In this section, we also study the effect of local brightness-change on the perceived 2D and 3D quality. The difference from the previous section is that, for each scene, the brightness of the background is kept relatively consistent while the brightness of the object(s) of interest is changed.

A. *Capturing Setup*

In our study, we intend to investigate the effect of the object's brightness-change with respect to the background on the perceived visual quality in both 2D and 3D cases. For this comparison, 3D videos of indoor and outdoor scenes are captured using stereo cameras. Obtaining 2D videos is trivial since they can be derived directly from the right or left view of the 3D counterparts. Below we present the setup of our 3D capturing.

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.

Figure 4. Our subjective test procedure.

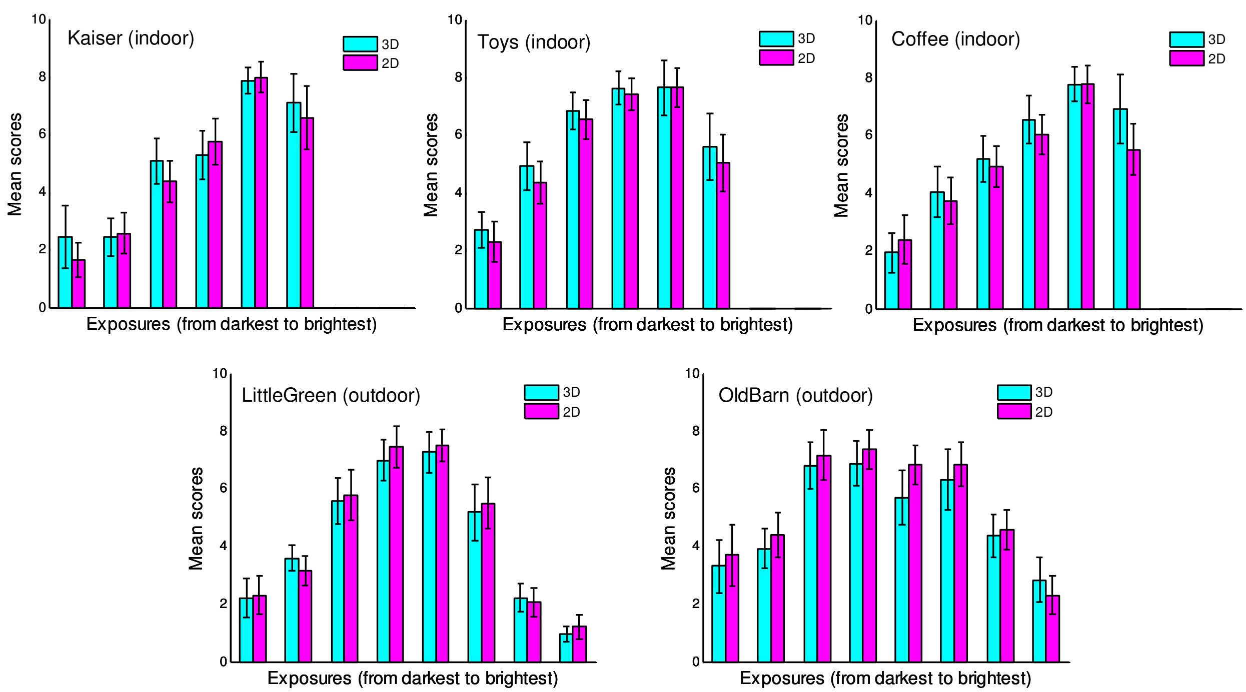


Figure 5. Subjective test results of the first experiment.

The same capturing set up as the one described in Section II.A for the first experiment (Fig. 1) was used. 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). Fig. 6 shows our capturing 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.

For our study, at each brightness level, the luminance of the object(s) and background is measured using a multifunction light meter (Sekonic L-758Cine). We measure luminance since it indicates how much luminous power is perceived by the human eye when viewing the surface from a particular angle. To measure the brightness of object(s), we took the measurement at each brightness level using a specific spot on the object(s) which subjective tests shown to be the focus of attention. For example, in the case of the object of interest being a human, all measurements were taken from face. Regarding the background, we conducted several measurements, we made sure that the fluctuations were very small, and then took the average value.

B. 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 previously. Fig. 7 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. The brightness of the object(s) between consecutive contrast levels are different by about 2/3 stop, which was achieved by measuring the luminance of the object(s) using a luminance meter. 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. 8). 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 brightness, 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. The same display as of our previous study was used for this experiment: a 65" Full HD 3D display (©Panasonic, Plasma, TC-P65VT25) and the subjective-test procedure was similar to our first experiment (see Section II, part B).

C. 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. 9 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, in other words, we can not conclude that there is a certain range of brightness of the object(s) that results in acceptable 3D quality (where MOS is greater than 6). The reason is that the measured brightness is not a good indicator of what the camera has captured. In order to remove the camera effect, we need to avoid using the brightness and instead calculate the contrast between the objects of interest and the background. There are many ways of measuring contrast. In this study we chose to use the Weber approach [10], which is one of the most commonly used in the field:

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

Figure 6. Capturing setup for the second experiment.

where L_o is the luminance of an object and L_b is the average luminance of the background.

Please recall that in this experiment, the brightness of background is kept relatively constant and only the brightness of object(s) of interest is changed for each scene. This allows us to create videos with the same content but different contrast between the object(s) of interest and the background, a necessary feature for our subjective tests, as we do not want the content itself to affect the viewers' decision.

Fig. 10 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. 9) 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. 10 appear at both ends of the horizontal axis, as contrast here is the difference between the objects' brightness and that of the background.

Fig. 11 shows the average perceptual quality versus contrast for all six scenes. Each point in the figure denotes the mean opinion score for a specific scene at a specific contrast level. The blue solid line is the average MOS over all the scenes, and the upper and lower red dash lines denote the 95% confidence interval. It can be observed that the

Figure 7. Snap shot of test sequences for the second experiment.

scores obtained from rating the 3D and 2D videos are following the same pattern, especially in the range of acceptable video quality (scores > 6), which indicates that the contrast or the brightness of the object of interest has almost equivalent influence on the perceptual quality for acceptable 3D and 2D videos. We also observe that scores for 2D are higher than those for 3D at the left end of the curve (where the object is much darker than the background). This is because crosstalk (ghosting) artifacts are severe whenever the background brightness is much higher than that of the objects of interest.

To further verify that the effect of contrast on the quality of 3D and 2D videos is similar, we performed the statistical significance test. Hogg's one-way analysis of variance (ANOVA) [11] is applied to 2D and 3D scores for each scene. We state the null hypothesis as: there is no significant distinction between the collected values for the perceptual quality of 2D and that of 3D. The higher the returned p value is (which considers the difference in average and variance as well as the sample size), the less significant is the difference. A typical threshold of the p value that rejects the null hypothesis is 0.01 or 0.05. The p values for six scenes are 0.3990 (Reading), 0.7663 (Interview), 0.9068 (Clapping), 0.4104 (SlowMotion), 0.8228 (McMillan) and 0.8499 (Painting) respectively, which are far above the threshold. Therefore, based on our experiment at each contrast level, there is no statistically significant difference between the perceptual quality of 3D and 2D videos of similar scenes. That is, given a large sample size, 3D and 2D videos should have virtually identical preferred contrast levels.

Based on our observations, 3D content captured according to the recommended contrast range can provide high quality 2D experience. In this case, if the system involves the use of glasses, the display should adjust the

Figure 8. Same scene with different (local) brightness levels of the object.

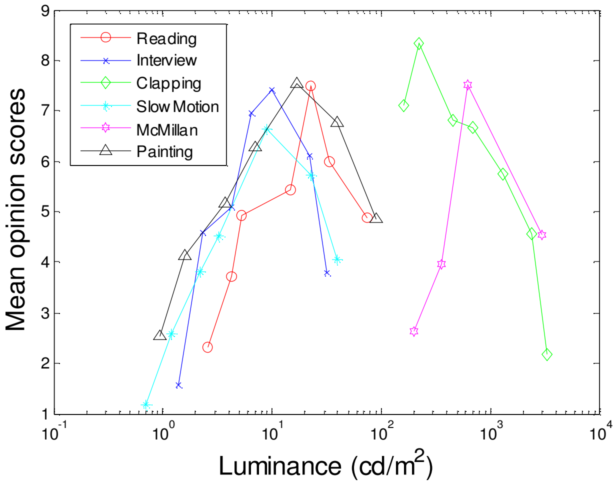


Figure 9. Perceptual 3D quality score versus measured brightness.

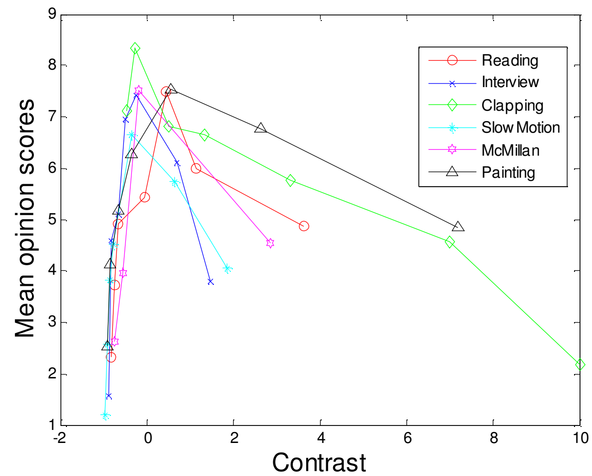


Figure 10. Perceptual 3D quality score versus the contrast between object and background.

contrast of the 2D stream, to compensate for the diming effect of the 3D glasses.

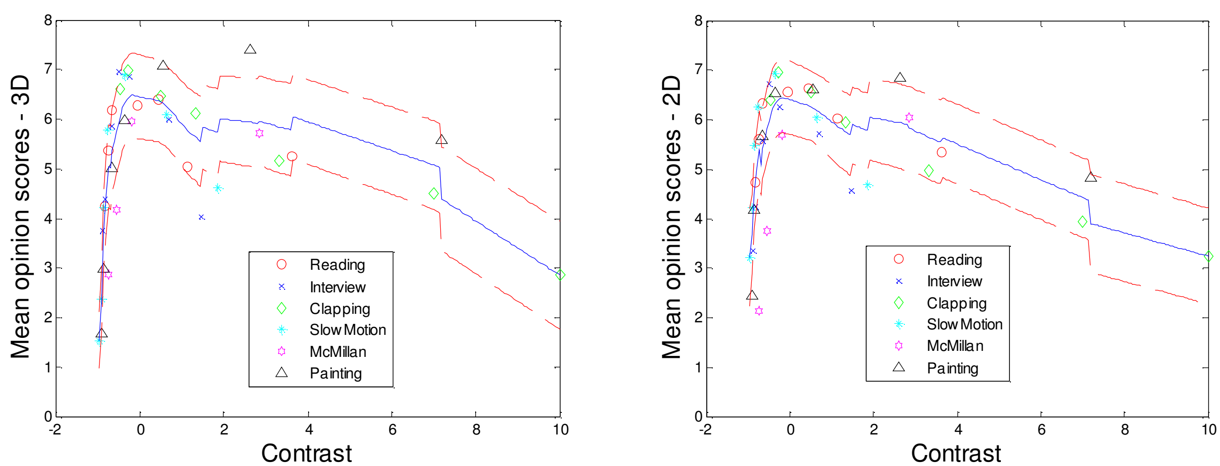
IV. DISCUSSION

Our psychophysical experiment involved considerable human power, including the subjects that took the tests and the researchers who prepared and organized the tests. These efforts could be reduced if a reliable 3D quality metric is available. Presently, the community is putting a considerable effort towards achieving this goal, but we are still far from an acceptable solution.

Our finding that brightness has similar effects on 3D and 2D videos is different from the practical observation in [5]. The latter suggests capturing 3D videos with higher light settings than 2D content in order to achieve good perceptual quality. This contradiction stems from the fact that we use 3D glasses in both 2D and 3D subjective tests so that the light reduction for 3D and 2D is similar, whereas in [5] the light reduction was considered only for 3D.

Our results on the relationship between 2D and 3D viewing (for both brightness and contrast) can be generalized for existing 3D displays, although the display systems deliver different amount of light when they display 3D content compared to 2D. In our study, this is due to the fact that both the 2D and 3D viewing tests were conducted while the display was set to the 3D mode and subjects wore 3D glasses during the entire experiment. On the other hand, the preferred range of contrast may vary depending on the displayed luminance range that the 3D viewing system supports. The variation, however, would not be large since contrast is defined as a ratio that is normalized by the background luminance.

The low scores at both ends on the x-axis in Fig. 10 and Fig. 11 are due to the effect of crosstalk. Crosstalk is an



(a) Scores for 3D video

(b) Scores for 2D video

Figure 11. Average perceptual quality versus contrast. Each point denotes the mean opinion score for a specific scene at a specific contrast level. The blue solid line cross the plot is the average MOS over all the scenes, and the upper and lower red dash lines denote the 95% confidence interval.

artifact where light that should be delivered to one eye is "leaked" to the other eye (it is also referred as the "ghosting" artifact) [12]. It is well known that crosstalk artifacts in 3D displays become severe when the contrast is high [13]. Note that all the existing 3D displays suffer from crosstalk. To reduce the crosstalk effect, we picked a 3D TV system, which based on subjective tests offers the best crosstalk reduction performance.

Eye strain and headaches have been noted as some of the most important factors that affect the overall 3D quality [14]. In our tests, subjects were not explicitly asked to evaluate this factor. Properly identifying eye strain and headache requires a long-time viewing of a stimulus [15]. This is not practical in our current design, since it would make the testing session too long, and as a result it may affect the reliability of the collected data.

V. Conclusion and Future Work

The era of user-centric multimedia has already begun, and quality plays a central role in it. Attention to the quality in 3D content case is even more important since low-quality 3D videos can produce eyestrain, headache, and generally unpleasant viewing experience for the viewers. Brightness is one of the important factors that affect the visual comfort and quality of 3D videos. In this work, we investigated the effect that global and local brightness-changes have on quality of 3D experience and its relation to the 2D scenario. This was done by performing extensive subjective quality assessments to quantify the perceived quality of the 3D and 2D experience at different levels of brightness.

Our work contained two studies: 1) global change of brightness, which is achieved by setting different exposure times on the camera, and 2) local change of brightness, where the brightness of the background was kept relatively constant 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 and 2D perceptual quality of each sequence.

A conclusion from both studies is that marginal difference is found in the brightness effects between 3D and 2D videos. According to our results from the second study, 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. Film industry could use our findings to produce 3D videos with different brightness levels or light-settings.

Our future work include: employ special lighting equipment in order to explore any possible case of brightness for foreground and background in outdoor and indoor conditions, conduct subjective tests with a much larger variety of content, and investigate the effect of different parameters on 3D perception quantitatively. This is towards our ultimate goal, which is providing guidelines for capturing and displaying 3D content as well as developing a 3D quality metric.

Acknowledgment

The authors thank all the subjects that participated in our test.

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