Visual Experience of 3D-TV with pixelated Ambilight

Pieter Seuntiens, Ingrid Vogels, Arnold van Keersop
Philips Research Laboratories
High Tech Campus 34
5656 AE Eindhoven, The Netherlands

Abstract

Nowadays, imaging systems can be equipped with immersive enhancements like 3D and Ambilight. In this experiment, a demonstrator with state of the art 3D technology and pixelated LED based Ambilight was built. The goal of the experiment was to investigate the concepts naturalness, viewing experience, and presence in relation to image quality, depth, and Ambilight. Results show that the concept viewing experience is a nice example of a concept taking into account the quality level of the video as well as enhancements like 3D and Ambilight. The viewing experience is significantly higher for a set-up with 3D and Ambilight compared to a set-up without 3D and without Ambilight. The concept presence takes into account the quality level of the video but to a lesser extend than naturalness and viewing experience. On the other hand, enhancements of depth and Ambilight have a larger effect on presence ratings than on naturalness or viewing experience. Depth and dynamic Ambilight give more sensory information to the viewer which results in a higher sensation of presence.

Keywords--- **IQ, naturalness, viewing experience, 3D, Ambilight, presence**

1. Introduction

Since the introduction of television, much has been done to improve the experience of watching TV. Improvements in image quality and sound quality have contributed to a better overall experience. Nowadays, new dimensions such as depth and ambient light are added to the displays to further enhance the viewing experience.

Research in the area of stereoscopic and auto-stereoscopic displays has made it possible to provide viewers a pleasant depth sensation nowadays. The most suitable display configuration for 3D in the home will be a multi-view auto-stereoscopic display [1]. The advantage of this display, besides 3D viewing without glasses, is the support of motion parallax enabling the viewers to look around objects by moving their head. Real-time conversion algorithms make it possible to convert 2D video material into 3D.

Another attractive feature of current television sets is the presence of Ambilight [2]. An ambient lighting system generates dynamic light effects around the television set that correspond to the video content. This results in an extension of the display colors and leads to a larger perceptual view. In addition, it will relax the eyes while viewing the content [3].

One of the methods to evaluate the subjective performance of an imaging system is to assess the perceived image quality. The perceived image quality is a multidimensional construct and is affected by several technical parameters. Engeldrum [4] has developed the Image Quality Circle model to investigate the relation between technical parameters and the perceived image quality.

Perception research in the area of 3D-TV has shown that the 2D Image Quality Circle model as proposed by Engeldrum is not adequate to measure the added value of depth since the depth reproduction is not incorporated in the perceived image quality [5,6]. However, we believe that the framework of the Image Quality Circle model can be very useful for evaluating new display features when extended with higher level concepts that also incorporate 3D and Ambilight.

Recent research of Seuntiens [5] has shown that the concepts naturalness and viewing experience take into account the image quality as well as the depth reproduction. IJsselsteijn et al. and Freeman and Avons [7,8] applied the concept of presence to 3D-TV research. They showed that viewers reported a higher sensation of presence for 3D sequences compared to 2D sequences. They concluded that an increase in sensory information may enhance the viewers' sense of presence.

The relation between presence and dynamic lighting (e.g. Ambilight) is not well understood yet. Therefore, it is interesting to investigate the concept presence in relation with 3D and Ambilight. It is not known whether the concepts naturalness, viewing experience, and presence take into account the effect of dynamic light (such as Ambilight). Also, the impact of 3D and the impact of Ambilight have never been compared directly.

No comprehensive experience model has been formulated to date, yet it is likely that the overall experience is a trade off between attributes such as image quality, depth, and Ambilight. In this experiment, a demonstrator with state of the art 3D technology and Ambilight was built. The goal of the experiment was to investigate the concepts naturalness, viewing experience, and presence in relation to image quality, depth, and Ambilight. More specific, we want to investigate whether the concepts take into account the added value of new display developments like 3D and Ambilight.

2. Method

The experiment had a within subjects design with Scene, Quality level, Depth level, and Ambilight level as independent variables and perceived image quality, perceived depth, perceived Ambilight, naturalness, viewing experience, and presence as dependent variables.

2.1. Observers

Twenty observers participated in this experiment. The observers, mostly students and employees of a research environment, had no prior knowledge about the experimental set-up. All observers had good stereo vision (<40 seconds of arc as tested with the Randot stereo test) and good color vision (as tested with the Ishihare test).

2.2. Equipment

The set-up consisted of a Philips 42-inch 3D WOWvx display. The display was based on the multi-view lenticular technology. A sheet of transparent lenses was fixed on an LCD screen sending different images to each eye (see Figure 1). Our brain combines the two different images and the 3D effect becomes visible. The transparency of the lenses preserved full brightness, full contrast and true color representation. Dedicated hardware and software allows us to vary the amount of depth in the 3D display.

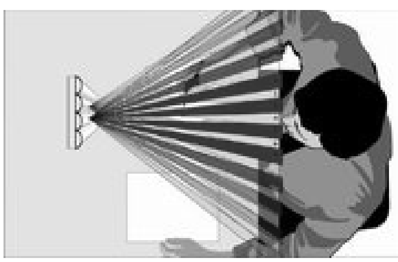

Figure 1: Philips’ lenticular technology provides the viewer 9 different views.

The pixilated Ambilight system (see Figure 2) consisted of RGB LEDs mounted on the back of the 3D-TV. On each side (left, right, and top) the LEDs were positioned on a metal strip with a fixed distance between the LEDs. The display was driven by a dedicated PC and the LEDs were operated by a 24 V power supply and an ordinary PC. The intensity of the LEDs could be varied using a software application. In this experiment the color of the LEDs changed dynamically with the 3D content.

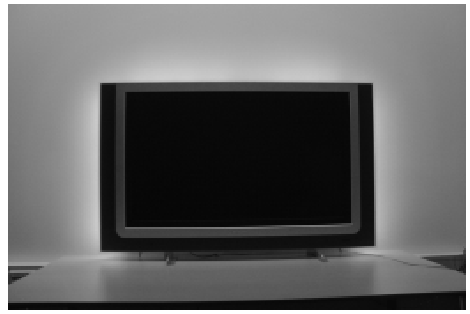

Figure 2: Pixelated Ambilight set-up.

The advantage of this pixelated set-up is that, for instance, an image with a horizon on the screen (see Figure 3) will extend onto the wall. This is not the case when the color on one side of the display is uniform. Previous research has shown that the pixelated set-up is highly preferred over the non-pixelated (uniform color) set-up.

Figure 3: Color at the screen border is extended onto the wall using LEDs.

2.3. Stimuli

The experiment contained two video scenes (HD-format) of 45 seconds each. The *Balloon* scene was a natural slowly moving scene containing a blue sky with different colored balloons. The *Adventure* scene was a scene with fast motion and fast color transitions. (Figure 4)

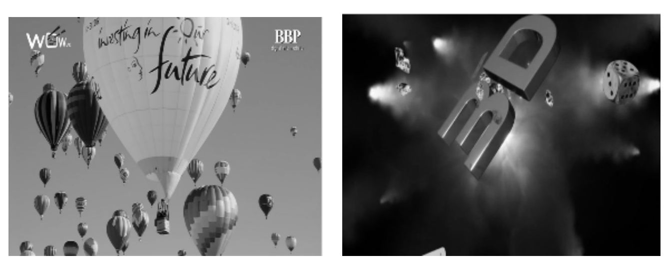

Figure 4: In the left figure a snapshot from the balloon sequence is shown and in the right picture a snapshot from the adventure scene is shown.

In the experiment two Quality levels were presented to the observers. The original scenes were shown uncompressed and compressed (786 KB/s). The three Depth levels were 2D (no depth), a moderate depth level (50), and a high depth level (100). The Ambilight intensity level was 0 (no Ambilight), 50% and 100%.

2.4. Procedure

Observers had to evaluate each of the 36 stimuli (2 Scenes x 3 Depth levels x 3 Ambilight levels x 2 Quality levels) using six different criteria, namely: perceived image quality, perceived depth, perceived Ambilight, naturalness, viewing experience, and presence. This was done in 2 sessions of 45 minutes each with some days in between the two sessions. In each session the observers had to rate three criteria on a five point numerical scale [9] using a laptop in front of them. All observers participated in the two sessions. In each session all 36 stimuli were presented in random order.

Prior to the actual experiment, observers were given instructions on paper about the experiment followed by a training session. The description of the criteria given to the subjects is shown in Table 1.

Table 1: Description of the criteria given to the subjects

Image Quality	Perceived degree of excellence of the image
Depth	Perceived depth
Ambilight	Perceived Ambilight
Naturalness	Perceived degree of perceptual realism
Viewing Experience	Perceived degree of overall viewing experience
Presence	Perceived degree of becoming part of the displayed space

A training session consisting of four sequences preceded the actual experiment in order to make the observers familiar with the assessment method and with the extremes used in the experiment. The ambient lighting of the room was kept constant at a relatively low level of 3 lux measured on the screen.

3. Results

First, the data obtained in this experiment was analyzed using Thurstone's law of categorical judgment [10] to check whether equal distances on the numerical scale corresponded with equal differences in the judgments. The Thurstone model assumes that the attribute strength is measured on an internal psychological scale that corresponds to an interval scale with Gaussian noise distribution. For all observers, the raw data were transformed to a Thurstone scale using the software package ThurcatD [11]. As input, the program needs frequency distributions per rating category for each stimulus that was presented in the experiment. ThurcatD calculates the stimulus scale values in standard deviation units and, also, the interval borders that define the intervals on the psychometrical scale. The results showed that for all criteria (perceived image quality, perceived depth, perceived Ambilight, naturalness, viewing experience, and presence) equal distances of the scale corresponded with equal differences in the judgments. The Mosteller's Chi-square test, which checks the adequacy of the model fit for Thurstone scaling models, showed a very good model fit for all six criteria (min. p=0.80, max. p=0.99)

An ANOVA was carried out on the raw subjective ratings to test the main effects and interaction effects for statistical significance. The results revealed a main effect of Scene ($F(1,4084)=6.10$, $p=0.014$), but for both scenes all trends and significant effects were in the same direction. Therefore, it was decided to average the results of the scenes.

Figure 5 shows the average results of the image quality ratings and the 95% confidence intervals. On the x-axis the three Ambilight intensity levels (0, 50, 100) are presented with increasing intensity to the right. The y-axis represents the averaged scores for perceived image quality. The three bars in the figure represent the three Depth levels (0, 50, 100) and the sub-figures show the two Quality levels (768kBs and original). For perceived image quality, the ANOVA revealed a main effect of Quality level ($F(1,670) = 1617$, $p<0.001$) and a main effect of Depth level ($F(2,670) = 37.1$, $p<0.001$). No significant effect of Ambilight level was found. A significant interaction effect was found for Quality level x Depth level ($F(2,670) = 19.5$, $p<0.001$). An increase in Quality level showed an increase in perceived image quality, as expected. An increase in Depth level from 0 (2D) to 50 did not have any effect on the perceived image quality. The main effect of Depth was mainly due to a depth level of 100 introducing some artifacts (blur) in the image which were most visible in the high Quality level (org) and less visible in the low Quality level (768kBs). Increasing Ambilight intensity levels did not have an effect on perceived image quality.

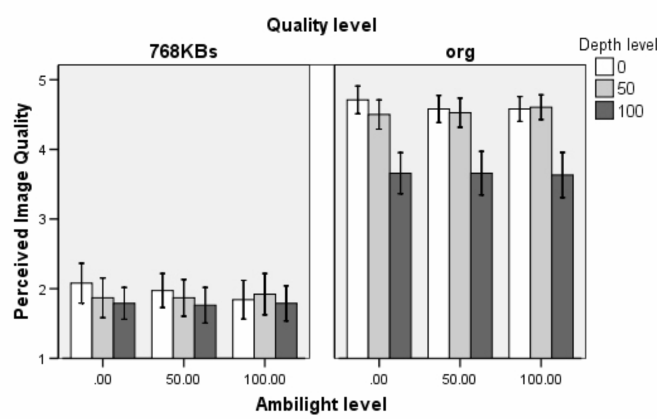

Figure 5: Results perceived image quality

Figure 6 shows the average results of the depth ratings and the 95% confidence intervals. The ANOVA for perceived depth showed a significant main effect of Quality level ($F(1,670) = 40.5$, $p<0.001$) and a significant main effect of Depth level ($F(2,670) = 504$, $p<0.001$). No significant main effect of Ambiligth level was found and no significant interaction effects were found. As expected, an increase in Depth level increased the perceived depth of the scene. The perceived Depth for the low Quality level was slightly lower than for the high Quality level.

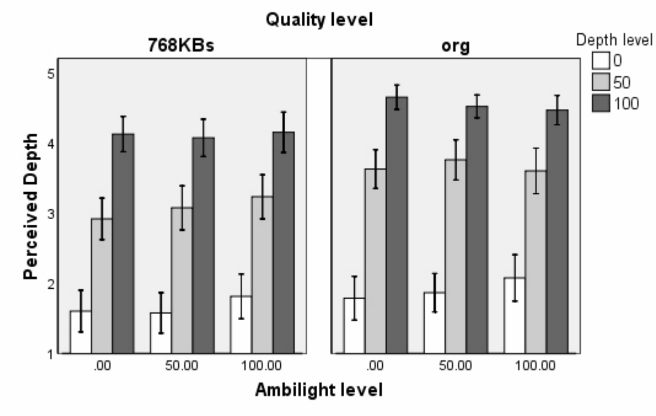

Figure 6: Results perceived depth

Figure 7 shows the average results for the Ambilight ratings and the 95% confidence intervals. The ANOVA for perceived Ambilight only showed a significant main effect of Ambilight level ($F(2,670) = 824$, $p<0.001$). No significant main effects were found for Quality level and Depth level and no significant interaction effects were found. An increase in Ambilight level increased the perceived Ambilight as expected, although the difference between levels 50 and 100 was rather small. Perceived Ambilight was not affected by the Quality level of the video nor by the Depth level.

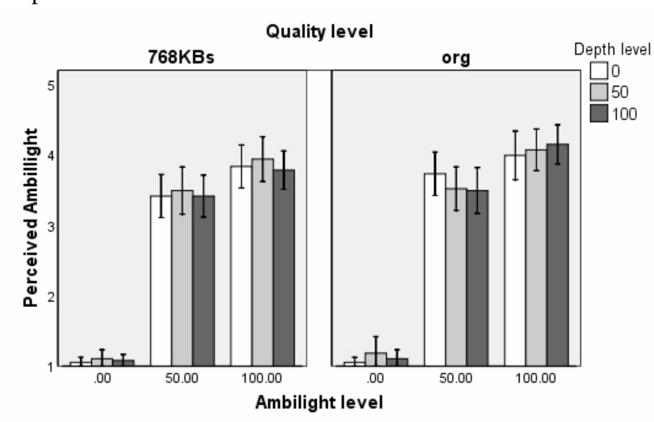

Figure 7: Results perceived Ambilight

Figure 8 shows the average results for the naturalness ratings and the 95% confidence intervals. The ANOVA for naturalness revealed a significant main effect of Quality level ($F(1,670) = 443$, $p<0.001$) and Depth level ($F(2,670) = 12.3$, $p<0.001$). No significant effect of Ambilight level was found. A significant interaction effect was found for Quality level x Depth level ($F(2,670) = 10.4$, $p<0.001$). Figure 8 shows a clear increase in naturalness with increasing Quality level. An increase in depth from 0 (2D) to 50 showed a small increase in naturalness, while a depth level of 100 decreased the naturalness for the high Quality level. This is due to artifacts in the high quality video at a depth level of 100 which caused the interaction effect Quality x Depth. An increase in Ambilight level had no significant effect on the naturalness.

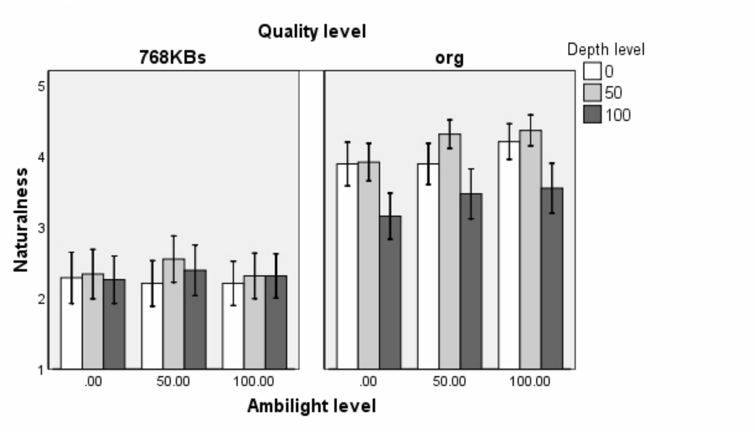

Figure 8: Results naturalness

Figure 9 shows the average results for the viewing experience ratings and the 95% confidence intervals. The statistical analysis for viewing experience revealed a main effect of Quality level ($F(1,670) = 668$, $p<0.001$), Depth level ($F(2,670) = 11.7$, $p<0.001$), and Ambilight level ($F(2,670) = 17.2$, $p<0.001$). A significant interaction effect was found for Quality level x Depth level. The viewing experience increased with increasing Quality level. Furthermore, the viewing experience increased significantly as soon as the Depth level was increased from 0 to 50. Increasing the Depth level further to 100 decreased the viewing experience for the high Quality level. This was again due to image distortions at a Depth level of 100. An increase in Ambiligth level also significantly increased the viewing experience, where the difference between level 0 (no Ambilight) and level 50 (moderate Ambilight) shows the largest effect. This result is not surprising because of the enlarged perceptual view, and a more relaxed viewing condition. This, however, does not mean that Ambilight level 50 is the optimum setting. Increasing Ambilight beyond level 100, with an improved lighting system, can still enhance the viewing experience.

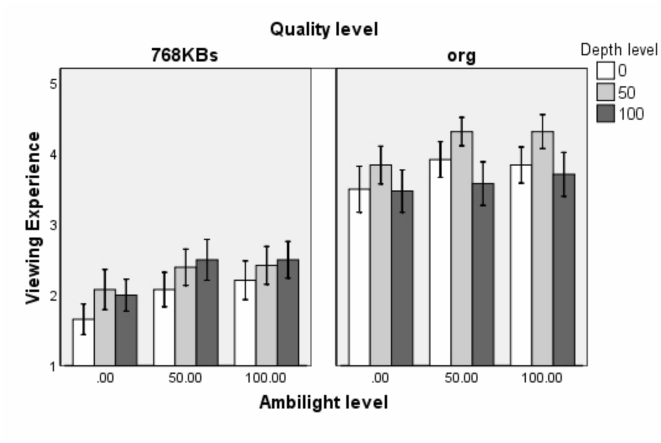

Figure 9: Results viewing experience

Figure 10 shows the average results for the presence ratings and the 95% confidence intervals. The results for the presence ratings showed a main effect of Quality level ($F(1,670) = 272$, $p<0.001$), Depth level ($F(2,670) = 49.2$, $p<0.001$), and Ambilight level ($F(2,670) = 21.5$, $p<0.001$). The analysis showed no significant interaction effects. Presence ratings increased with increasing Quality level, but the effect of Quality level was less pronounced compared to the ratings for image quality, naturalness, and viewing experience. The feeling of presence increased significantly with increasing Depth level and Ambilight level. Especially, the introduction of depth (0 to 50) and the introduction of Ambilight (0 to 50) revealed the largest increase in presence.

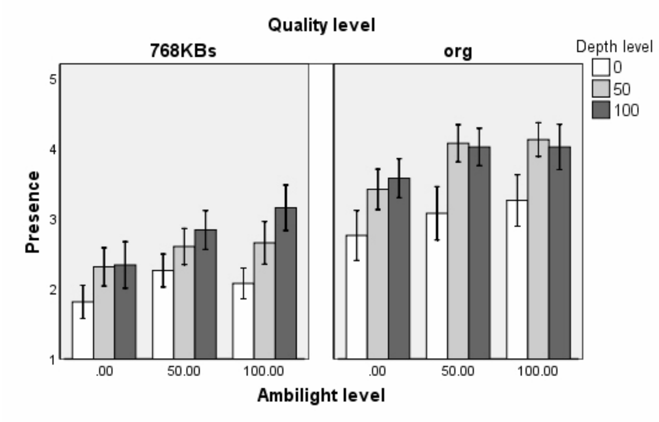

Figure 10: Results presence

4. Conclusions

The results demonstrate that the evaluation concept image quality does take into account the added value of depth. However, negative aspects of depth (artifacts at high depth levels) are taken into account in the image quality criterium. In addition, this experiment shows that the added value of Ambilight is also not taken into account in the image quality scores. The perceived depth was slightly influenced by the Quality level of the video but was not affected by the Ambilight. The scores for perceived Ambilight were independent of changes in Quality level or Depth level.

The naturalness concept takes into account the quality level of the video and also the added value of depth, but the contribution of depth was less pronounced in this experiment compared to earlier research [5]. The concept viewing experience is a nice example of a concept taking into account the quality level of the video as well as enhancements like 3D and Ambilight. The viewing experience is significantly higher for a set-up with 3D and Ambilight compared to a set-up without 3D and without Ambilight.

The concept presence takes into account the quality level of the video but to a lesser extend than naturalness and viewing experience. On the other hand, enhancements of depth and Ambilight have a larger effect on presence ratings than on naturalness or viewing experience. Depth and dynamic Ambilight give more sensory information to the viewer which results in a higher sensation of presence. Research of IJsselsteijn et al. [7] revealed that video sequences in contrast to still scenes had a large significant effect on presence ratings. The effect of the depth dimension (2D/3D) on presence ratings was significant but smaller. In our experiment only video sequences were shown, which may be an explanation why the effect of the depth dimension was larger in our experiment.

In conclusion, presence may be a very useful concept for measuring the added value of immersive enhancements like 3D and Ambilight. The addition of binocular depth and dynamic lighting gives people a higher sense of “being there” in the displayed scene. However, the concept viewing experience is a better concept to measure the overall performance of a display including enhancements of depth and Ambilight. It better accounts for quality issues in the video than presence and, like presence, also takes into account 3D and Ambilight features. The best viewing experience was found for a moderate depth level and full intensity pixilated Ambilight. The development of a viewing experience model and long term effects of 3D in combination with Ambilight will be investigated in the near future.

References

[1] Van Berkel, C. and Clarke, J. (1997). Characterization and optimization of 3D-LCD module design. *Proceedings of the SPIE*, 3012:179-186.

[2] Salters, B.A. and Krijn, M.P.C.M., Color reproduction for LED-based lighting systems, *Proceedings of the SPIE,* 6338, 2006

[3] Bullough, J.D., Akashi, Y., Fay, C.R., and Figueiro, M.G. (2006). Impact of surrounding illumination on visual fatigue and eyestrain while viewing television, *Journal of Applied Sciences*, 6(8):1664-1670.

[4] Engeldrum, P. (2004). A theory of image quality: The image quality circle, *Journal of Imaging Science and Technology*, 48:447-457.

[5] Seuntiens, P.J.H. *Visual experience of 3D-TV,* PhD Dissertation, 2006.

[6] Tam, W, Stelmach, L, and Corriveau, P. (1998). Psychovisual aspects of viewing stereoscopic video sequences. *Proceedings of the SPIE*, 3295:226-335.

[7] IJsselsteijn, W.A., de Ridder, H., Hamberg, R., Bouwhuis, D., and Freeman, J. (1998). Perceived depth and the feeling of presence in 3DTV. *Displays*, 18:207-214

[8] Freeman, J. and Avons, S. (2000). Focus group exploration of presence through advanced broadcast services. *Proceedings of the SPIE*, 3959:530-539

[9] ITU (2000). Methodology for the subjective assessment of the quality of television pictures. *Recommendation BT500-10.*

[10] Thurstone, L. (1927). A law of comparative judgment. *Psychological Review,* 34:273-286.

[11] Boschman, M. (2000). ThurcatD: A tool for analyzing ratings on an ordinal category scale. *Behavior Research Methods, Instruments, and Computers,* 32:379-388.