A comparison of visual ergonomic measurements between active and passive 3DTV

Börje Andrén[1], Kun Wang[1,3], Kjell Brunnström[1], NiclasRydell[2], Stephen Fuller[2]

[1] NetLab: IPTV, Video and Display Quality, Acreo AB, 16440 Kista, Sweden

[2] TCO Development AB, 11394 Stockholm, Sweden

[3] Dept. of Information Technology and Media, Mid Sweden University (MIUN), 85170 Sundsvall, Sweden

Abstract

The two latest 3DTV types were tested; active shutter eye-glass type and passive eye-glass type with screen having film pattern retarder. Differences in vertical resolution, cross-talk and luminance were found. This difference in vertical resolution is visible for some types of objects. How this affects the image quality is unclear.

1. Introduction

Although it has still to find its way into people's living rooms, 3DTV's starts to become common as a product in the shops. They are mainly divided into two technical solutions to achieve the 3D experience. The 3DTV's are designed with active shutter eye-glasses or passive FPR (film pattern retarder) eye-glasses technology. Glasses free (auto stereoscopic) 3DTV's are still quite uncommon and to this day very expensive.

The development and improvements in 3D displays and especially the 3DTVs are very fast at present and the methods to objectively characterize the visual performance are not following in the same speed. In this study two 3DTVs of the latest models, one with active shutter eye-glasses and one with passive polarized eye-glasses were tested for some important visual ergonomic parameters, such us cross-talk [1], luminance, contrast, flicker and some colour measurements. One additional goal is to find difficulties, the degree of robustness and short comings of the test methods for 3D displays especially for 3DTVs. The method for visual ergonomics for 3D displays are far from the robustness of the methods for 2D image quality and are much more complicated to perform and the results are much more difficult to interpret. The active type shows the 3D content by displaying two slightly different images, one for each eye, at a fast rate. The eye-glasses are synchronized with the display and the left view is closed while the right view is open and vice versa. The passive type presents the two images at two different polarization states for each second row. In this study two 3DTVs, one with active eye-glasses and one with passive eye-glasses were tested for some important visual ergonomic parameters, such as cross-talk, luminance, contrast, flicker and some colour measurements. No visual ergonomic requirements for 3D displays have been presented. It could be argued that the results are valid only for the tested 3DTV samples and the settings used during the test. However, we still believe that the results can give a general idea about the differences between the two common technical solutions on the market today.

2. Test samples, conditions and set-up

The two 3DTV's had similar specifications, they where both 55" with LED backlight, 240Hz update frequency and 1080p 2D resolution. They were both tested on the HDMI port, feeding imaging in side-by-side format using a PC, however the computer graphic card was not involved in the process of 3D rendering, it was done by the TV internal 3D function. Local dimming was turned off for the passive eye-glass 3DTV and turned to medium for the active eye-glass 3DTV.

The tested TV was positioned in a specially designed holder, which can be rotated and tilted to almost any angle. Care was taken in the set-up so that the TVs were rotated or tilted around a vertical or horizontal axis through the centre of the screen. The cross-talk, luminance and colour measurements were made using a calibrated spectroradiometer from Photo Research (PR705) with a measuring angle of 1°. The measuring distance was 2 image heights (2h), all measurements were made in the centre of the display and in a dark laboratory (≤ 1 lux). For the contrast measurements and the resolution measurements were done at short distance with a specially designed and calibrated CCD camera was used based on a temperature stabilized camera from Dalsa with a telephoto-macro lens and a V(λ)-filter.

3. Measurements and results

3.1. Cross-talk measurement

The test pattern used for measuring crosstalk was full screen of homogenous either black or white for each view. In our notation we will give the colour of the left view first and the right view second. The measured view combinations were black/white, white/black and black/black. The crosstalk measurements were only done on the left view of active shutter/passive polarized glasses. We surmise in this test that the crosstalk effect was symmetric on both views of the eye glasses.

The Equation (1) was used for computing the crosstalk:

$$Cross\ talk(\%) = 100 \times \frac{L_{bw}-L_{bb}}{L_{wb}-L_{bb}} \qquad (1)$$

Where

L_{bw} is the luminance of the left view when the left view is black and the right view is white,

L_{wb} is the luminance of the left view when the left view is white and the right view is black,

L_{bb} is the luminance of the left view when the left view is black and the right view is black.

The results are summarized in Figure 1 below. The cross-talk values for the horizontal direction are low for both types. The cross-talk for the vertical direction is also low for the active eye-glass display at all angels and for the passive eye-glass display at angels below 10° to 15°. However, the vertical cross-talk starts to increase rapidly for the passive eye-glass display beyond tilt angles of ±15°. However, it can still be considered acceptable (below 10%) at angels up to ±15°. The perceived cross-talk is strongly dependent on the scene content [2][1].

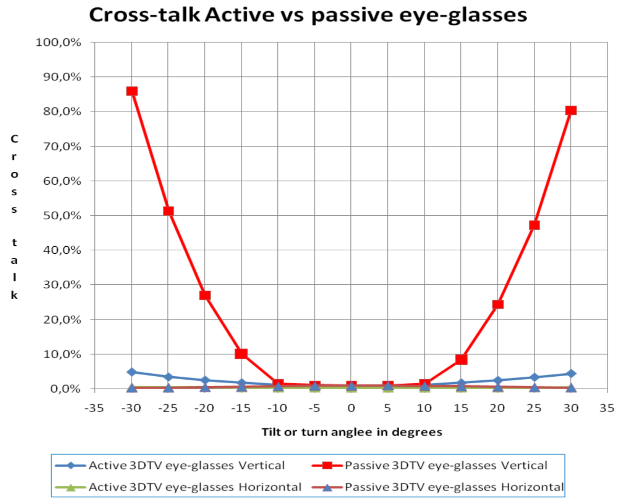

Figure 1: Cross-talk for an active and passive 3DTV vs vertical tilt and horizontal turn angles.

3.2. Luminance measurement

The calibrated luminance measurements were done with the same PR705 instrument as was used for the cross-talk and colour measurements.

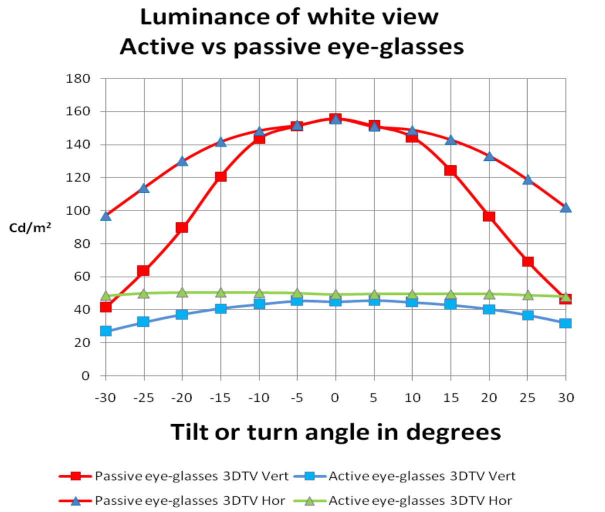

Figure 2: Luminance fall-off vs tilt and turn angle.

In the Figure 2 the luminance's of the white view are presented as function of tilt- or turn angle for active and passive eye-glass 3DTV types.

As shown the centre luminance of the passive type was about 155 cd/m^2 in the white/white mode and for the active type about 55 cd/m^2, which is just 35% of the luminance of the passive TV. For both 3DTV types the white luminance in the 2D mode were about 300 cd/m^2 (passive type 290 cd/m^2 and active type 306 cd/m^2). This means that the transmittance was about 54% for the passive type and about 18% for the active type. The luminance fall-off values were about 1.6:1 (centre luminance/30 degree luminance) for turn angles up to ±30 degrees and about 1.3:1 for tilt angles up to ±15 degrees for the passive type. These values were within the TCO Certified Displays 5 requirements for horizontal turn angles and the vertical tilt angles [3]. In the TCO Certified testing the vertical tilt angles above 15 degrees are not measured as it is considered unlikely that the display or TV are viewed from a vertical angle larger than ±15 degrees. The active 3DTV type had very good angular characteristics, even though there was a luminance fall-off for tilt angles above ±15 degrees.

3.3. Pixel size measurements, resolution and contrast modulation

With the Dalsa system (see section of Test samples, conditions and set-up) it is also possible to get contrast modulation values. Three bar patterns were tested, 1-pixel, 2-pixel and 3-pixel bars. For both displays the contrast modulation values were very high, about 90% or even higher (87% to 90% for the active type and 92% to 97% for the passive type) for the 1 pixel, 2-pixel and 3-pixel test bars tested [3][4][5][6].

$$n_r = n + \frac{C_T - C_m(n)}{C_m(n+1) - C_m(n)} \quad C_m = \frac{L_{white} - L_{black}}{L_{white} + L_{black}} \quad (2)$$

Resolution = Addressability/n_r

The Cm is contrast modulation, C_T is threshold contrast modulation which was set to 25% for these tests and since C_m was about 90%, n_r became 1 and the addressability was then equal to the resolution. The TCO Certified criteria for character contrast is >70% which means that both of the TV's would pass this TCO criteria. Even though this method is intended primarily for CRT office displays it could be used for other types of imaging devices.

The pixel size and contrast measurements were done using a Dalsa camera system, an image grabber and an image evaluation program**.** The system has in the used set-up a resolution of 0.02 mm. The values measured correspond to the theoretical. The calculated pixel size for a 55" display in the 16:9 format and HD resolution 1920 × 1080 is 0.634 mm and for the 1920 × 540 1.268 mm. Note that the resolution measured here was the 2D resolution measured through one eye-glass since at present there are a lack of measurement method to characterise the corresponding 3D "resolution".

3.4. Colour measurements

For both 3DTV types the angular white colour characteristics expressed in CIE 1976 u´v´-values, were very good as shown in Figure 3 and 4 with straight lines for both passive and active 3DTVs. The colour temperatures of white were about 7500K to 8500K for the passive type in the 3D mode and about the same in the 2D mode. The colour temperatures are about 8000K to 8500K for the active type in the 3D mode and about 11500K in the 2D mode.

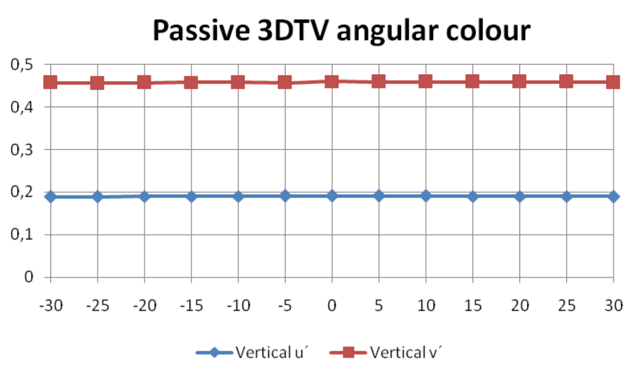

Figure 3: Passive 3DTV angular colour characteristics for

vertical tilt angles, but the horizontal were equally flat

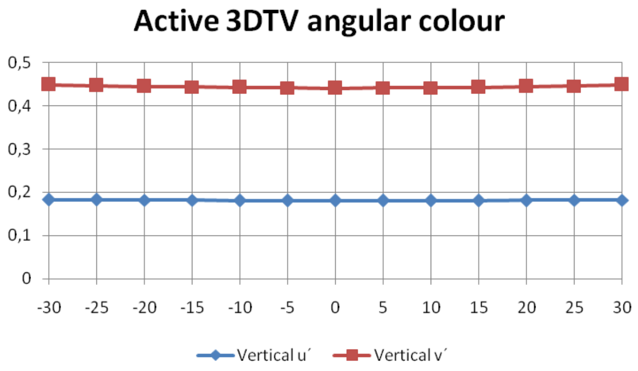

Figure 4: Active 3DTV angular colour characteristics for vertical tilt angles, but the horizontal were equally flat

The difference in colour temperature could be expressed in MireK (MK-1 = 106/CCT, 10^6/CCT) and was about 15 for the passive type and about 38 for the active type. Since the viewer's visual system will adapt to these lighting conditions as easily as it does for the change of daylight and indoor lighting, it will likely be few problems. However, common movies are as standard recorded with a colour temperature of 6500K and it is desirable that the display will present the movie in that colour temperature [7]. The 6500K has the chromaticity coordinates u´= 0.198 and v´= 0.468 and MK-1= 154, CCT = 7500 has a MK-1= 133 and CCT= 8500 a MK-1= 118 giving a difference of MK-1 21 and 36 MK-1. A MK-1 about 5.5 could be detectable in a critical comparison [8]. In Figure 5, the colour errors MK-1 and Δu´v´ are shown. The TCO Displays 5.0 has a requirement of Δu´v´ ≤ 0.012. This corresponds to about MK-1 ≤ 25 as can be seen in Figure 5.

Measurements of red, green and blue were performed only in the 2D mode. The results are shown in table 3 and as a comparison the sRGB standard [9].

Table 1 Red, green and blue for active and passive type and for the sRGB

Active type	**Red**	**Green**	**Blue**
u´	0,447	0,126	0,184
v´	0,524	0,560	0,144
Passive type	**Red**	**Green**	**Blue**
u´	0,453	0,126	0,177
v´	0,526	0,565	0,167
sRGB	**Red**	**Green**	**Blue**
u´	0,451	0,125	0,175
v´	0,523	0,563	0,158

Both types are close to the sRGB standard for red and green and Δu´v´ is about 0.009 for the passive type and about 0.017 for the active type compared to the sRGB. The ITU Rec 709 [7][10] has the same values as sRGB, but another gamma curve.

4. Discussion

The perceived cross-talk will be dependent on the adaptive state of the visual system and of the type of test image used. In this

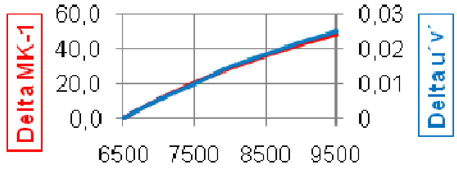

Figure 5: Colour error compared to the 6500K of the movie industry.

case completely white or black images were used for testing, which are not very realistic for real world images. A checkerboard with white and black checks in one view and a white or black in the other view would have been closer to real world images. More grey scales would also have been useful. However, most of the few standards that exit for 3D measurements use black and white images. The settings of the display could also affect the cross-talk results. The setting of local or global dimming will likely affect the cross-talk results. However, each display model has its own interpretation of what is meant by i.e. medium, high etc. setting and will likely not give the same dimming as the same setting at another brand. From the measurement point of view the dimming should be turn off. However, this may not be the way the display is commonly used. Since there are a lot of different settings that are possible to alter on modern TVs, it is most convenient to use a default factory setting if available for testing.

It could be argued that it is not meaningful to measure vertical angles larger than ±15°. It is always recommended to place a TV at the correct seated eye height of the viewer. If the TV must be placed higher or lower it should be tilted accordingly in its stand or wall mount. For a TV that is placed at the correct height or tilted towards the viewer it is unlikely that the viewing angle will be larger than ±15° in the vertical direction. A conclusion however, is that a tilting function and correct placement are more important for the passive eye-glass type 3DTV. Keep this in mind as some wall mounts may have limited tilting functionality.

Horizontal angles are more important as several users may want to view the TV together whilst placed at a distance from each other. Both TV's performed very well for horizontal angels all the way up to ±30°.

When wearing the dark 3D eye-glasses the viewer will adapt to the average luminance perceived through the eye-glasses, which means that the big difference in luminance will not be perceived by the viewer in the same degree as the luminance ratio of 2.81 indicates. One way to find out what the difference could mean is to calculate the retinal illuminance, that is, to calculate how much light that really hits the retina. At 55 cd/m2 the retinal illuminance becomes about 492 Td (Trolands) and at 155 cd/m2 1167 Td. The pupil sizes were calculated to 4.9 mm and 4.4 mm and the retinal illuminance is based on the luminance and an age of 40 years according to Bartens model [11]. It means that the retinal illuminance is 2.37 times brighter for the passive type than for the active type. Higher luminance is considered advantageous for the image quality, but other parameters are also important, e.g. black level, resolution and crosstalk, for the experienced quality of the viewer. In a short side-by-side pre-test with test subjects, the higher luminance of the image of the passive display was considered the most important image quality parameter. When wearing dark glasses it becomes harder to see things around the TV, like for example the remote control. This is true for both types of glasses but the active ones are darker than the passive ones.

The passive eye-glass 3DTV must sacrifice vertical resolution in order to show the images for each eye with different polarization. A passive eye-glass 3DTV with (1920 x 1080) will thus only have a measured resolution in 3D-mode of (1920 x 540) for each eye where an active eye-glass type 3DTV will have (1920 x 1080) for each eye. However, the human visual system will fuse the two images together in doing a 3D representation in the brain. There cannot be any 3D vision without this fusion. The 540 resolution will be seen if one eye is covered. However, for the active display the 1080 resolution is seen even if one eye is covered but the 3D vision will disappear. The only way to side-step this fusion is to present two identical images to the two eyes and get the lower 540 vertical resolution, but this is 2D not 3D vision. Therefore for 3D vision the vertical resolution is something between 540 and 1080 depending on i.e. the image content. More research is needed to more exactly determine the perceived resolution for this type of passive displays. For some type of pattern containing high contrast vertical bars it is possible to experience some lost resolution. Studies [12] suggest that images with the same resolution are perceived in more detail in 3D than in 2D. This means that the perceived detail of watching both (passive 1920 x 540) and (active 1920 x 1080) in 3D will be slightly higher than watching of each eye (passive 1920 x 540) and (active 1920 x 1080). There are at present no explanations for this increase in perceived 3D resolution.

Most test subject in a pre-test experience that the passive display had a warmer colour temperature. However, the default colour settings were used for testing in this study and it is possible that another preset setting will perform closer to 6500K.

5. Conclusions

From the cross-talk measurements it is clear that the passive type has higher cross-talk values for larger viewing angles than 10-12 degrees vertically than the active type in this investigation. The passive type has to be positioned more carefully to be at its best.

The vertical resolution for the passive type of display is about half of the full HD, e.g 540 for each eye, but since the other eye receives the same resolution but shifted one row, the human The transmittance of the eye-glasses makes the active type darker than for the passive type. The human visual system adapts to the lighting condition, but not to 100%. The difference in retinal illuminance makes the passive display about 2.37 times brighter.

The contrast measurements of 1-, 2- and 3- columns or rows bar pattern show that the contrast is very high for both passive and active displays.

The measurements of colour parameters reveal good colour rendering for both display type. However, the active display has a colour temperature in the tested mode that is a bit colder than for the passive display. The 6500K used by the movie industry is a bit warmer than both the active and the passive display.

6. Acknowledgement

This work has been partly supported by VINNOVA (The Swedish Governmental Agency for Innovation Systems), which is hereby gratefully acknowledged{Heynderickx, 2009 621 /id}.

7. References

[1] IEC 6269-X-X 6.8

[2] Seuntiëns, P.J.H., Meesters, L.M.J., IJsselsteijn, (2005), Perceptual attributes of crosstalk in 3D images, Displays 26., 177-183

[3] TCO Certified Displays 5 §A.2.1.1, TCO Development AB (www.tcodevelopment.com), Stockholm, Sweden,

[4] ISO9241-305 6.9.2

[5] ISO 9241-305 6.9.9

[6] VESA FPDM 307-1

[7] ITU-R Recommendation BT.709-5: Parameter values for the HDTV standards for production and international programme exchange.

[8] Wyszecki, G., Stiles, W.S., (1982) Color Science: Concepts and methods,quantitative data and formula, Second Edition, John Wiley & Sons, Inc., Chapter 7, Visual thresholds, pp 574-575

[9] IEC 61966-2-1 (1999-10) Multimedia systems and equipment - Colour measurement and management - Part 2-1: Colour management - Default RGB colour space – sRGB

[10] ITU-R Recommendation BT.470-6: Conventional television systems.

[11] Barten, P.G.J., (1999) Contrast sensitivity of the human eye and its effects on image quality, SPIE Optical Engineering Press., Bellingham, WA, USA

[12] Ingrid Heynderickx and Ronald Kaptein, (2009) Perception of detail in 3D images, *Proc. of SPIE-IS&T Image quality and system performance VI, 7242,* S. P. Farnand and F. Gaykema Eds.,