NEW REQUIREMENTS OF SUBJECTIVE VIDEO QUALITY ASSESSMENT METHODOLOGIES FOR 3DTV

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ABSTRACT

In this paper, the new challenges of 3DTV for subjective assessment are discussed. Conventional 2D methods have severe limitations which will be revealed. Based on the understanding of the new characteristics brought by 3DTV, changes and additions in the requirements for subjective assessment are proposed in order to develop a novel subjective video quality assessment methodology for 3DTV. In particular, depth rendering for 3D display is selected to give a further discussion. The depth rendering abilities are defined as a combination of the physical parameters and the perceptual constrains. We analyze different types of stereoscopic and multiview displays. Several problems regarding depth rendering are discussed in order to highlight the diversity and complexity of assessing 3DTV.

1. INTRODUCTION

Based on recent development of abundant micro-electronics and micro-optics technique, as well as further understanding of the physiological, perceptual, cognitive, and emotional human factors of 3DTV, a high quality 3DTV broadcast service is becoming more and more realistic. Today, stereoscopic displays based on different technique and autostereoscopic displays are available on the market. However, no optimal 3D system exists at the moment because no system is able to provide a sufficiently high resolution to each eye without exhibiting view asymmetries (e.g. degradation of color and luminance).

The human viewers are, of course, the final and the most important judge of the quality of any 3DTV systems and eventually, affect its widespread and commercial issues. In the scientific and industrial field, subjective assessment is the most direct way to evaluate the human perception and optimize 3DTV systems. It can be used to ease the specification process for end-to-end application (e.g. selection of video bitrates, 3D display technique and video encoder). Furthermore, subjective assessment results are used as a solid reference for identifying the performance of objective quality metrics. However, by following the current subjective quality assessment methods, optimum system conditions for different 3DTV technique can not be guaranteed and the added value or the issues of 3DTV can not be sufficiently measured (e.g. depth perception, visual comfort). Hence, the results from different laboratories will not be reproducible or comparable meanwhile the subjective quality results can not be used to guide the development of objective quality metrics.

Defining new subjective video quality assessment method for 3DTV should thus be considered as a necessary prerequisite for a fair comparison of 3DTV technologies They are also necessary in order to better understand end-user's opinion about 3DTV video quality. Several international activities may contribute to this field, e.g. the Video Quality Experts Group (VQEG) [1] has established a new 3DTV group and several European projects have been launched, e.g. 3D4YOU [2]. In the section 2, new requirements will be described considering new elements or new conditions for 3DTV video quality subjective assessment. In the section 3, firstly we define various physical and perceptual parameters related to depth rendering of 3D displays. Then a comparison of depth rendering abilities of 3D displays with different sizes and different techniques is given. Previously, in [3] only a comparison of different desktop displays was presented, while our study also covers different sizes and typical viewing distances for home and electronic cinema environments.

2. NEW REQUIREMENTS

Regarding 2D subjective video quality assessment methodologies, ITU-R BT.500 [4] is widely accepted as a recommendation for assessing the quality of television pictures. Earlier in 1992, Pastoor in [5] denoted that it seems necessary to define evaluation criteria adapted to the anticipated application scenario of 3D and to judge candidate systems against criteria when comparing 2D and 3D display system. Until the year 2000, the subsequent ITU-R BT.1438 [6] did a very first step for standardizing the 3D subjective test but it lacks many details. Table I. follows the organization used in [4, 6] and summarizes some novel conditions of 3DTV, which need to be addressed. They will be discussed in detail in the following.

A. General Viewing Conditions

TABLE I. New requirement of Subjective Video Quality Assessment methodologies for 3DTV

Feature	Condition	New elements
General Viewing Conditions	**Luminance and contrast ratio**	*Luminance reduction caused by additional optical instrument, minimum luminance necessary to sustain DOF, crosstalk affects contrast ratio*
	Background and room illumination	*Minimum distance between display and background necessary, technology of room illumination critical*
	Monitor resolution	*Recommendation of minimum values for spatial and temporal per view resolution and stereoscopic resolution*
	Viewing distance	*DVD sometimes fixed by display manufacturer and adding depth perception factor into PVD*
	Viewing position	*Avoidance of 3D geometry distortion, luminance reduction, suboptimal viewing position for autostereoscopic displays*
	Depth rendering	*Upper bounds for Depth Of Focus and binocular disparity*
Source signals	**Video format**	*Requirements for depth representation formats*
	Video format conversion	*Specification of accuracy for conversion*
Selection of test materials	**Video content complexity**	*Measurement tools for depth complexity of content*
Test method	**Visual discomfort**	*Questionnaires for visual discomfort and objective measurement of visual fatigue*
	Subjectively measured quality indicator	*Additional indicator besides image quality, e.g. Naturalness, Presence, Visual Experience*
Observers	**Number**	*Reevaluation necessary to guarantee stability and reliability of results*
	Viewer's stereopsis performance	*measurement of stereopsis, accuracy, ocular differences, etc.*
The test session	**Viewing duration**	*Re-evaluation of duration for presentation, voting, session length*
Test Results analysis	**Viewer factors**	*Rejection criteria, detection of bimodal distributions*
	Multi-dimension indicators analysis	*Statistical methods fro analysis, e.g. relation, interaction and combination of subjectively measured quality indicators*

Luminance and contrast ratio: Additional optical instruments for 3D viewing, e.g. glasses and filters, cause a reduction of luminance. Our experiments show that up to 80% of reduction occurs for active glasses based systems and about 60% were measured for polarization based systems. It seems mandatory that the peak luminance measurement should cover these aspects. In [7], it is suggested that the minimum luminance for 3D displays should be at least 30cd/m^2 to sustain depth of focus in order to guarantee the basic depth sensation. Moreover, crosstalk is still an unavoidable issue for 3DTV and it influences the final contrast ratio because the black level may be increased by the crosstalk.

Background and room illumination: The perception of real background depth and the perceived display depth may lead to conflicts if the position of the display is too close to the wall. In this case, objects may appear to be inside the wall. Moreover, the room illumination may need to be defined more precisely regarding different 3DTV technique, e.g. neon illumination source would possibly cause serious flickering, thereby inducing visual discomfort problems for viewers who are wearing the active shutter glasses.

Monitor resolution: Overall display resolution, per view resolution, and stereoscopic resolution should be considered as aspects of the monitor resolution. Spatially multiplexed 3D displays have possibly non uniform or non parallel physical pixel distribution for each view. Furthermore, time multiplexed techniques announce that the full spatial resolution can be kept, but temporal vision is degraded due to temporal asymmetries and the temporal luminance distribution. It is still an open question how the viewer perceives these changes in resolution.

The resolution in depth has been assessed in [8], where the definition of perceived depth voxels and perceived depth range was introduced. In [9], stereoscopic resolution was defined which relates to the number of planes of voxels within certain depth range.

Viewing distance: Three times the height of the screen for HDTV and six times for SDTV was adopted as a recommendation in the ITU standards BT.710[10] and BT.500. However, depending on the design parameters and on the specific use of equipment, manufacturers often recommend a designed viewing distance (DVD) which differs from the ITU standards. In some cases, e.g. autostereoscopic displays, 3D can only be watched at the DVD. Additionally, the Preferred Viewing Distance (PVD) was recommended in BT-500 for the 2D viewing in home environments. A subjective test had shown that PVD is a function of different parameters [11] such as human visual acuity, the amount of movement, screen size, picture resolution, etc. As explained in [7], due to the fact that binocular disparity must be visually scaled by viewing distance in order for binocular depth perception to occur, depth perception should be added as a new component for the PVD function.

Viewing position: 3D geometry distortions, e.g. shear distortion which are caused by a sideways movement of the observer [12] influences the decision of viewing position. The reduction of luminance will become more severe when the observation angle increases. This also applies to motion parallax which is seen on multiview autostereoscopic displays. The viewing angle relates to the correct perception of left and right eye image from a certain view.

Depth rendering: The way in which a display represents the perceived depth based on the input video is defined as depth rendering. Depth rendering has been proved to significantly influence the quality of experience for autostereoscopic displays [13]. At the display side, depth rendering depends on the viewing distance, the content disparity, and the property of display. Perceptual factors should be considered to avoid visual discomfort, e.g. depth of focus (DOF) and binocular disparity were suggested to be limited to 0.3 diopter (or even lower 0.2 diopter in [14]) and 60 arcmin [15] respectively. This may be considered as a general upper bound of the perceived depth range to ensure visual comfort for the majority of viewers. Further analysis about depth rendering will be given in the next session.

B. Source signals

Video format: traditional 2D video representations have been used to save stereoscopic video as well as multi view video. Several 3DTV formats are available including “video plus depth” [16], “multi video plus depth(MVC)” [17], and “Layer Depth Video(LDV)” [18] . These formats are used for transmission and in most cases a reconstruction of views is necessary prior to displaying. Because this reconstruction was reported to produce visual artifacts, it is difficult to define reference videos for widespread usage, e.g. in ITU recommendations.

Video format conversion: the conversion between the aforementioned video formats is lossy in most cases. For example, a systematic loss of information for occluded objects occurs if “video plus depth” with a single layer of depth is used. Moreover, the amount of loss depends on the implementation used. A minimum accuracy for the format conversion should thus be defined, e.g. by providing a validation testset.

C. Selection of test materials

Video content complexity: For 2D video, the ITU-T P.910 [19] defines the spatial perceptual information (SI) and the temporal perceptual information (TI) as main elements of 2D video complexity. Some new measurements, e.g. called depth perceptual information (DI), should complement these two measurements. Regarding DI, spatial and temporal maximum disparity and average disparity in pixels may be considered. Adding a third dimension to the video content complexity also requires more standardized video sequences, e.g. further shooting sessions are required in order to generate the new reference scenes with various complexity levels considering SI, TI and DI.

D. Test methods

Visual discomfort: Visual discomfort refers to a subjective perception and it also relates to the visual fatigue which is an objectively measurable quantity. There are several measurement techniques proposed to assess visual discomfort, including optometric tests of visual function, ERP (event-related potential) [20], eye tracking considering visual interest, snapshots of discomfort such as questionnaires used before and after viewing, and continuous assessment of comfort. These efforts may lead to standardized procedures and recommendations.

Subjectively measured quality indicator: In previous recommendations for 2D, only one quality indicator was used in each test session. For 3D, additional values are brought by binocular depth cues and motion parallax so that the new quality indicators should be involved, e.g. naturalness[21], presence, and visual experience. Thus, multi-dimensional quality indicator can be one possibility for 3DTV quality evaluation.

E. *Observers*

Number: The number of observers depends upon the sensitivity and the required reliability of the experiments. As explained in [22], inter-individual differences in susceptibility are still unclear. The viewers' opinion was reported to be not as stable as in 2D. Thus, an increase of the number of observers might be needed to guarantee the reliability of the test, i.e. the minimum number of 15 observers recommended in ITU-BT.500 may not be sufficient.

Viewer’s stereopsis performance: About 10-15% of the population can not well perceive binocular depth cues, therefore additional objective tests or subjective tests should be used to evaluate the viewer’s 3D vision performance. ITU-R BT.1438 [6] recommended different vision tests (VTs). Only VT-04 and VT-07 were used in order to test normal stereopsis.

F. *The test session*

Viewing duration: 10s was used as a reference value in ITU-R BT.500 for short duration samples of 2D video. For the transition to 3D, there are two conflicting arguments: The first states that since 3DTV is more close to the human natural viewing behavior, less time is needed to judge the quality; the second states that more time is needed since more information is contained in the additional dimension of 3DTV and the viewer got used to 2D displays. In [23], for a short duration test, the presentation time had little effect on subjective evaluation results, however, only 5s and 10s were tested. Further experiments are necessary which should also consider the longer viewing durations necessary for evaluating visual fatigue and visual comfort.

G. Test results analysis

Viewer factor: For 3DTV the statistical analysis needs to be reviewed in order to learn about the rejection of an incoherent viewer, or the analysis of multimodal viewer distributions which might occur because the subjective test results are more sensitive to inter-individual differences or preferences.

Multi-dimension indicator analysis: Using several indicators for the evaluation of 3D like quality of experience, depth sensation and visual comfort calls for new methods for summarization, statistical analysis, and careful interpretation of the results. It may also lead to new concepts of objective models for 3D video quality.

3. DEPTH RENDERING OF 3D DISPLAY

The key element of 3D displays comparing to 2D is the ability to present the binocular parallax information to the human visual system for inducing the perception of stereoscopic depth. As will be further explained in this section, depth rendering is related to viewing distance, content disparity and the property of display. We will propose measures for the depth rendering abilities of 3D displays. Based on that, we will analyze different technologies that are currently used for 3D displays.

3.1 Definition of depth rendering abilities

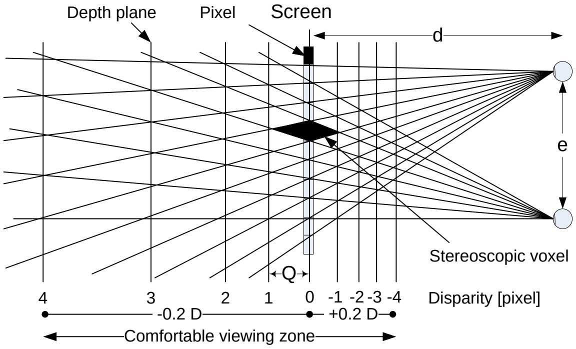

Figure 1- Schematic diagram of physical and perceptual parameters of depth rendering

A schematic diagram of the simplified geometry of stereoscopic depth perception on planar 3D displays is shown in Figure 1. It is adapted from [9]. It allows combining the physical parameters of the viewing environment with the constraints of DOF and binocular disparity.

The physical parameters are:

Inter-pupil baseline: The distance e between the eyes of the observer. An average of 65mm was used in our calculations.

Viewing distance: The distance d between the observer and the display plane.

Pixel: An idealized square pixel grid is assumed. The width of a pixel is denoted as p_w.

Stereoscopic voxel**:** The region of uncertainty for an object located in depth [8]. The volume is formed by the intersection of the lines of sight from each eye.

Depth plane**:** These planes are parallel to the display surface and offer the full horizontal and vertical resolution. They connect the centers of the stereoscopic voxels with the same screen disparity.

The perceptual constraints are:

Depth of focus: refers to the range of distances in image space within which an image appears in sharp focus and is given in terms of diopters. A value of ±0.2 diopter for the DOF was suggested in [14].

Limit of Binocular disparity**:** a region around the fixation point where disparities can still be comfortably fused. Its limitation is related to the human eye's aperture and depth of focus. 60 arcmin is generally acknowledged.

Comfortable viewing zone: in [15], combining the limit of disparity and DOF, the authors determine a perceptual depth range where binocular fusion is possible and blur is not perceived so that stereoscopic visual comfort should be maintained. Calculated in distance, the comfortable viewing zone for disparity and DOF show very high resemblance and can serve as a general limit. Assuming the DOF equals to ±0.2 diopter, we can derive Z_f as the foreground distance of the comfortable viewing zone and Z_b as the background distance:

$$Z_f = d - \frac{1}{\frac{1}{d}+0.2}, Z_b = \begin{cases} \frac{1}{\frac{1}{d}-0.2} - d, & \text{if } d < 5 \\ \infty, & \text{if } d \ge 5 \end{cases} \tag{1}$$

Max uncrossed disparity in pixels $D_b^{\max}$ **:** A divergence of the eyes beyond the infinite plane, e.g. beyond parallel view axis, is uncomfortable for the viewer. Thus, the uncrossed disparity in pixels should be limited as:

$$D_b^{\max} = \frac{e}{p_w} \tag{2}$$

Depth rendering ability in pixels D_f, D_b **:** is defined as the number of depth planes that can be represented within a comfortable viewing zone of display. D_f, D_b for foreground and background respectively can be acquired as follows:

$$D_f = \frac{Z_f \cdot e}{(d - Z_f) \cdot p_w}, D_b = \frac{Z_b \cdot e}{(Z_b + d) \cdot p_w} \tag{3}$$

Angular depth plane interval $Q_{angular}$ **:** The distance between two adjacent depth planes, shown in Figure 1 as Q, provides a measure of the quantization in depth. The value stays almost constant if measured in angular units

Table II. DEPTH RENDERING ABILITIES FOR DIFFERENT DISPLAYS

Characteristic	**Full Resolution**			**Line Interleaved**	**Column Interleaved**	**Autostereoscopic**
	Samsung	**2 projectors**	**cinema**	**Hyundai**	**DTI**	**Philips**
Total resolution	1680x1050	1920x1080	2048x1080	1920x1080	1280x1024	1920x1080
View resolution	1680x1050	1920x1080	2048x1080	1920x540	640x1024	640x360
Display Height [m]	0.3	1.35	8	0.572	0.3	0.61
Pixel width [mm]	0.285	1.25	7.4	0.53	0.29	0.565
Viewing distance [m]	0.9	4	8	1.6	0.8	3
Z_f / Z_b **[m]**	0.13(f)/0.19(b)	1.78(f)/16(b)	4.9(f)/∞(b)	0.39(f)/0.75(b)	0.11(f)/0.15(b)	1.125(f)/4.5(b)
$D_b^{\max}$ **[pixel]**	227	52	8	122	110	38
$D_f + D_b$ **[pixel]**	40(f)+40(b)	41(f)+41(b)	14(F)+8(B)	39(F)+39(B)	17(F)+17(B)	23(F)+23(B)
$Q_{angular}$ **[arcmin]**	1.1	1.1	3.3	1.1	2.5	1.9
Field-of –view [degree]	35°	35°	87°	37°	39°	21°

instead of meters. In [5] the authors suggested that less than 0.8 min of arc is needed in order to avoid a visible quantization in the depth rendering. $Q_{angular}$ can be approximated as follow:

$$Q_{angular} = 2 \cdot [\tan^{-1}(\frac{e}{2d}) - \tan^{-1}(\frac{e - p_w}{2d})] \qquad (4)$$

3.2 Analysis of depth rendering abilities of different displays

We classify the displays into four different groups based on their physical design. The characteristics of different displays regarding depth rendering abilities are given in Table II.

(1) *Full Resolution Displays:*

This kind of displays can deliver two full resolution images, one to each eye. Normally, these displays consist of two displays or one single display with temporal multiplexing. Examples are the Samsung 2233RZ with the shutter glass solution from NVIDIA or two projectors with HDTV or 2K resolution. As shown in Table II, the first two displays have around 80 depth planes within the visual comfort region, and their angular depth plane interval is close to the 0.8 min/arc. For digital cinema viewing conditions, the depth angular disparity per voxel is 3.3 which are likely to cause depth quantization artifacts. A resolution of at least 8192x4320 would be necessary to reach the limit of 0.8 arcmin in order to avoid discontinuous depth quantization.

(2) *Line Interleaved Displays:*

This type of displays spatially interleaves rows from the left and the right view. Thus, they only render half of the vertical resolution to each eye but they maintain the full horizontal resolution. A Hyundai S465D 46” display is used in our study. In terms of depth rendering ability and maximum disparity, it has a similar performance as the first two full resolution displays since the binocular parallax only depends on the horizontal resolution. However, for each eye, half of the rows will be seen as dark stripes. This may be seen by the viewer at a viewing distance of 3H because each line has an extent of 1.1 min of arc which is above the visual acuity threshold of 1 min of arc.

(3) *Column Interleaved Displays:*

This type of displays spatially interleaves columns from left and right views and provides only half of the horizontal resolution. The 19 inches DTI LCD display (Virtual Window® 19) is used as an example. Since the horizontal resolution is sub-sampled by a factor of two, its depth rendering ability is reduced. Moreover, it may have the same problem of visible dark stripes in the columns as described for the Row Interleaved Displays.

(4) *Multi-view Autostereoscopic Displays:*

This type of displays contains more than two views and can support motion parallax. However, each view resolution generally equals to the full panel resolution divided by the number of views. For instance, the Philips 423D6W0200 42” display supports 9 views. Consequently, each view will only contain about 1/3 of the horizontal and 1/3 of the vertical resolution. The results show a medium level of depth rendering ability but only 21° for the field of view because the fixed viewing distance specification is five times the height. As the viewing distance increases, the range of visual comfort region increases as well. This partly counteracts the effect of sub-sampling in the horizontal direction. However, the field of view decreases leading to a lower sensation of presence.

3.3 Discussion of the depth rendering of 3D display

Depth rendering ability mainly depends on two parameters: the viewing distance and the properties of display. It is apparent from Table II, that the best solution in our comparison is the system based on the two HD projectors. It provides a reasonably good visual comfort region and enough depth planes in order to give the viewer a good depth perception. It also features a 30° field of view that is necessary to create a remarkable sensation of reality[24]. It can be considered as the reference system with optimal depth rendering ability. For small size displays, e.g. the Samsung 2233RZ, a longer viewing distance might have priority over the field of view in order to guarantee a wider comfortable viewing zone. Similarly, for multi-view displays, increasing the viewing distance will contribute not only to a comfortable viewing zone but also to a reduction of artifacts due to depth quantization.

Besides the depth rendering ability, the content disparity also affects the depth rendering. It is highly related to the aforementioned depth perceptual information (DI). For stereoscopic production, often the left and the right view are recorded and stored. In this case, the content disparity range is fixed and cannot be modified without extensive and lossy processing. In Table II, the depth rendering ability of each display was provided as an upper bound of comfortable viewing for each display. When the disparity range of the content is outside the range indicated for each display, the observers might be unable to fuse the images. On the opposite side, when the disparity range of the content is much smaller than the depth rendering ability, the viewers will perceive a poor depth effect. As the depth rendering ability spans a range from 22 for electronic cinema to 82 for the HDTV projector solution, it might be difficult to use the same content in a subjective experiment.

In terms of subjective video quality assessment, the selection of test materials should cover the principle that content disparity should be adapted to the depth rendering ability of the display. Moreover, analysis or comparison of subjective assessment results should also consider carefully these two factors.

4. CONCLUSION

In this paper, various new requirements had been proposed and discussed as summarized in Table I. The depth rendering of 3D displays was selected as one point to give further analysis and discussion. We have explained that depth rendering ability of 3D display and content disparity affects the depth representation. Test material should be carefully selected and result analysis should cover these points. As explained in this paper, subjective video quality assessment for 3DTV shows its diversity and complexity comparing to 2D. In order to produce a reliable and comparable subjective experiment, the design rules for experiments should be discussed and merged. A recommendation in an international standardization organization is highly recommended. Our future work will concentrate in this direction.

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