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# PERCEPTUAL PREFERENCE OF S3D OVER 2D FOR HDTV IN DEPENDENCE OF VIDEO QUALITY AND DEPTH

*Pierre Lebreton<sup>1,2</sup>, Alexander Raake<sup>1</sup>, Marcus Barkowsky<sup>2</sup>, Patrick Le Callet<sup>2</sup>*

<sup>1</sup>Telekom Innovation Laboratories, TU Berlin, Ernst-Reuter-Platz 7, 10587 Berlin, Germany

<sup>2</sup>LUNAM Université, Université de Nantes, IRCCyN UMR CNRS 6597, Polytech Nantes  
Rue Christian Pauc BP 50609 44306 Nantes Cedex 3, France

## ABSTRACT

3D video quality of experience (QoE) is a multidimensional problem and many factors contribute to the global experience by the user. Due to this multidimensionality, this paper evaluates the integral 3D video QoE and relates it with image quality and depth. Subjective tests have been conducted using paired comparison to evaluate 3D QoE and the preference of 3D over 2D with different combinations of coding conditions. Depth scores were available from previous work and were used to check their relation with 3DQoE; the difference between 2D and 3D QoE is found to be a function of the picture quality, and the desired preference of 3D presentation over 2D can be reached when pictorial quality is high enough (VQM score lower than 0.24). A factor ranging from 0.08 to 0.76 with a mean of 0.71 between pictorial quality and preference of 3D was also found.

*Index Terms*— 3D video, pair comparison, preference, quality of experience, picture quality, depth, coding

## 1. INTRODUCTION

3D video Quality of Experience (QoE) is a multidimensional problem; many factors contribute to the global rating like image quality, depth perception, depth quality, visual discomfort, sense of presence, naturalness, etc. Evaluating QoE taking into consideration all these factors is no easy task. The simplest approach, namely to instruct observers in subjective experiments to judge the “Quality of Experience”, does not necessarily provide the expected result, but is rather often based on only one factor of QoE, the picture quality [1]. This type of results is due to the internal reference of the observer: when observers are asked to rate a 3D image/video, they base their judgment on their expectations. In a test with different coding conditions, the expectations of the observers are mainly driven by picture quality. Consequently, especially with an absolute, single stimulus rating paradigm, people have difficulties to consider factors other than image quality of 3D when they are asked for 3D video QoE. Hence, it is hard to quantify the added value of 3D as compared to 2D, as can be seen in [2] where 3D is not rated better than 2D in an absolute category rating (ACR) test, and no improvement of QoE due to the 3D effect can be measured.

Alternative evaluation schemes have been considered by Sentüens by addressing other dimensions like naturalness or immersion, or by investigating specific factors like depth perception or eye-strain [3], which provides some insight on isolated factors of the general QoE, but not the overall QoE. In the present study, as global measure of QoE, the subjective preference has been considered. It is believed that when subjects are asked for preference between two

videos, they may consider all factors (picture quality, both depth quantity and depth quality, visual discomfort and probably other factors) to take the decision which of two versions of a sequence they prefer. This way, the entire multidimensionality of 3D QoE is considered. Missing factors of 2D video QoE when evaluating it using ACR were shown by Belmudez [4], where another multidimensional question was studied. Here, image size and image resolution were compared in terms of quality ratings, one using ACR, one using paired comparison (PC). Results showed that the two test methods do not provide the same results: using ACR, observers give higher QoE ratings for images at their native resolution; using PC, observers prefer larger images obtained after upscaling. The results are different, and show that using the ACR methodology observers only judge image quality, but with paired comparison they extend their rating to other dimensions, including the image size. PC however has an important drawback: its cost and time consumption. To obtain scale value quality scores from PC data, two models exist: the Bradley-Terry model or the Thurstone-Mosteller model [5]. Both need a full PC matrix: each condition has to be compared to another. However, several efficient approaches have been developed in the literature to reduce the number of required comparisons [6], [7]. In [7] six video sequences were recorded. Each of these videos were captured at six inter-camera distances (10 cm to 60 cm). The 36 video sequences were then compared through paired comparison, and the Bradley-Terry scores of each condition were determined. Results show that the Bradley-Terry scores reveal quality fluctuation due to the different depth and comfort. The relation between inter-camera distance and QoE was found highly content dependent. In [8], 3D was compared to 2D using a PC approach on an auto-stereoscopic display. 3D was produced internally by the display based on a texture and a depth map. The texture was used at four different quality levels (three encodings and a reference). Results show that 3D was rejected in 70% of the cases and for the lowest quality rejected at 56%. However, the results may be influenced by the technology used at the time of the experiment and the quality of 3D rendering of the 3D display as mentioned by the authors.

In this study, paired comparison will be used to evaluate 3D and 2D video sequences to show the quality improvement/decrease due to 3D. In addition, coding conditions were created and included in the experiment. This enables the comparison between known artefacts such as coding and effect of content characteristics such as depth on 3D-QoE. This information was missing in [7]. An increase of the number of the number of contents enables also a content-based analysis

Section 2 provides information on the subjective experiment: the selection of source sequences, the generation of processed video se-

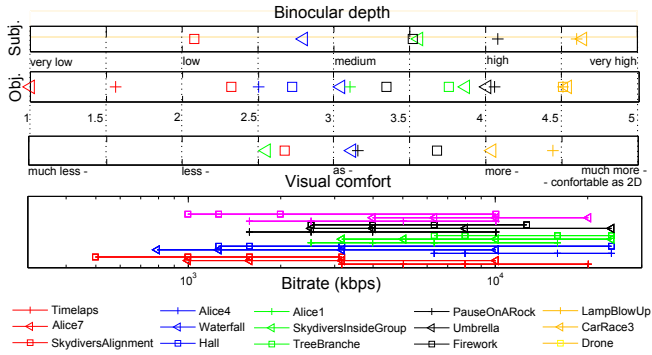


Fig. 1: Depth, visual comfort, bitrate of source sequences

quences (PVS), and the evaluation process. Section 3 links pictorial quality, depth and preference of 3D over 2D. Section 4 extends the analysis to quantifying the “3D added value” and shows to which extent depth contributes to QoE. Section 5 concludes the paper.

## 2. EXPERIMENTS

### 2.1. Definition of test conditions

#### 2.1.1. Selection of Source sequences

The selection of the source contents (SRC) is based on three databases. All sequences were full HD stereoscopic videos; each view had a resolution of 1920x1080, with a frame rate of 25 images per second and was of 10s length. Seven SRCs come from a first database composed of 64 source reference signals (SRCs) [9]. The SRCs were used at the highest quality available, and contained various types of scenes. They were rated on three different scales: overall quality of experience, depth and visual comfort. The methodology used was Absolute Category Rating (ACR). Perceived depth was rated on a five-point scale with labels: “very high”, “high”, “medium”, “low” or “very low”. Using this general depth scale, the observers rated their general impression of the depth, which takes into account both depth layout perceptions and depth quality. The comfort was evaluated on an absolute manner by asking subjects, if the 3D sequence is “much more”, “more”, “as”, “less”, “much less” - “comfortable than watching 2D video”. Based on this data, the seven SRCs were chosen to cover the entire range of depth ratings. To ensure the reproducibility of our results, it was decided to include five open video materials [10]. These sequences include “Tree Branches”, “Hall”, “Umbrella” and two new sequences designed to reach our depth effect requirements: one with low and high depth quantity, respectively, “Timelaps” and “Drone”. A third source of SRC coming from Blu-Ray disk where three other non-open sequences named “Alice” were added to the test. These last sequences were not available at the time of the previous test [9], our depth perception model developed in [9] was used to have an objective value of the perceived depth for these sequences. The top scatter plot of Figure 1 shows how the selected sources cover the depth scale, based on subjective data [9]. The second scatter plot shows the results of the depth score estimated from the depth model described in [9]. The third scatter plot shows the available subjective data regarding visual discomfort. This data has been added, however not used in this paper for content selection, and is shown to let the reader have a view on the principal characteristics of the 3D sequences.

#### 2.1.2. Selection of coding conditions

Coding was performed using a Harmonic Electra 8000 H.264 encoder at constant bitrate. Since it was planned to use a polarized display with horizontal interlacing, the 3D sequences were in the Top/Bottom frame compatible format, this choice limiting the loss of resolution. Each full-HD view was downscaled to half the vertical resolution using a lanczos filter. No further interpolation was done for optimizing resolution but have result in half a line of vertical parallax. Each sequence is then encoded to four different “quality levels” by using four different values of bitrate. The four bitrate values were defined for each source sequence individually, since each of them had different spatial and temporal complexity. In previous experiments, it was revealed that VQM (ITU-R Rec. J.144) performs sufficiently well in estimating picture quality of 3D sequences [11] (Pearson correlation of 0.89, and RMSE of 5.4). As a consequence, the procedure for determining the bitrate values corresponding to the “quality levels” is based on quality estimations obtained from the VQM general model. The four adequate quality levels have been determined as 0.1, 0.2, 0.3, and 0.4 on the VQM scale. These values correspond to the quality score of the most complex sequence of the test, “TreeBranches”, encoded respectively at a quantization parameter QP of 26, 32, 38, and 44 using the reference H.264 encoder JM 18.2. The range of bitrates used in the test is illustrated in Figure 1 and noted for example 2DQ1, for 2D at quality level 1. Quality level 0 being the reference.

At the end of the selection process, the 15 SRCs were encoded at four individually chosen bitrates leading to VQM scores close to 0.1, 0.2, 0.3 and 0.4 as described above. These sequences are used in two versions: 2D and 3D. The 2D sequences were encoded at the same bitrate as their respective counterpart sequences in 3D. In addition, a 3D reference with no compression was added to the test. This results in  $15 \cdot (2 \cdot 4 + 1) = 135$  video sequences to be evaluated.

### 2.2. Evaluation of 3D QoE using paired comparison

The global QoE of the video sequences was evaluated in a paired comparison experiment. 35 Observers participated in this test. The laboratory environment was in accordance with ITU-R Recommendation BT.500. The observers’ vision was screened in terms of acuity, color vision (Ishihara test), and stereovision (Randot stereo test). For the test, two polarized 23” Hyundai displays (ViewSonic V3D231) with horizontal interlacing were used. The displays were calibrated using a display calibration device (X-Rite i1 Pro) to make the rendering as similar as possible between the two displays. The observers were facing two distinct displays, and were instructed to give their preference between the two presentations they could see on the displays. Considering the number of possible presentations (3D or 2D, 4 quality levels in 2D and 3D, and a 3D reference), a full PC matrix approach would have required  $9 \times (9 - 1)/2 = 36$  comparisons per SRC, hence 540 comparisons for evaluating all video sequences. This high number of comparisons is impracticable for a subjective experiment [6]. For more efficient testing, the square design matrix was employed. Based on this approach it was possible to reduce the number of comparisons to 18 comparisons per SRC, hence  $15 \times 18 = 270$  comparisons. The comparisons made in the test can be found in listing 1. The sequence pairs were randomized such that in case of comparison A vs. B, both orders A vs. B and B vs. A were seen by the observers. This avoids any dependency of the preference ratings on the display and possible default answers by observers (right vs. left). The test was split into two sessions

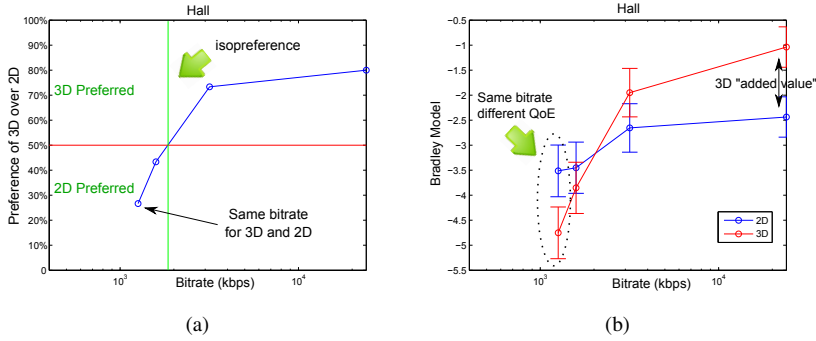


Fig. 2: Illustration of preference results for one source content (Hall).

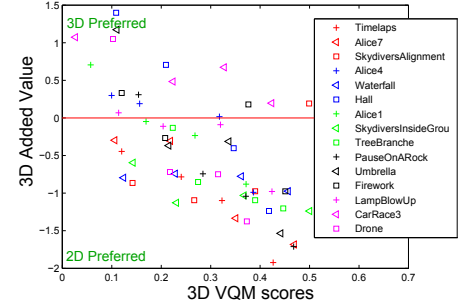


Fig. 3: 3D added value as a function of VQM scores.

of 45 min. The same observers participated twice with a minimum delay of one week.

Listing 1: List of sequence pairs compared by observers

3DQ4	vs	3DQ0	2DQ3	vs	2DQ1
3DQ4	vs	2DQ4	2DQ3	vs	3DQ2
3DQ0	vs	2DQ4	2DQ1	vs	3DQ2
3DQ3	vs	3DQ1	3DQ4	vs	3DQ3
3DQ3	vs	2DQ2	3DQ4	vs	2DQ3
3DQ1	vs	2DQ2	3DQ3	vs	2DQ3
3DQ0	vs	3DQ1	3DQ0	vs	2DQ1
3DQ1	vs	2DQ1	2DQ4	vs	2DQ2
2DQ4	vs	3DQ2	2DQ4	vs	2DQ4

### 3. PREFERENCE OF 3D OVER 2D AND PICTORIAL QUALITY

The main goal of the paired comparison test was to analyze how the preference of 3D over 2D would depend on the respective “pictorial quality”. As outlined in Section 2, pictorial quality was varied at four different bitrates, i.e. quality levels Q1-Q4. Figure 2a illustrates for one SRC, how observers answered. It is visible that when the bitrate increases, the preference of the 3D presentation over the 2D version increases. This is however not true for one of the contents, “SkydiversInsideGroup”. This content was found to be less preferred when the quality increased. In Figure 1, it can be seen that this content is the least comfortable sequence of the database. The blurring added by coding may have contributed in such way that this content was perceived as more comfortable. This would be in agreement with [12], where binocular fusion was found to be dependent on the retinal disparities and spatial frequencies within images. In the paired comparison tests, some video sequences were found to always be preferred in 2D “SkydiversAlignment”, “SkydiversInsideGroup”, and “Waterfall”. These sequences correspond to the least comfortable sequences of the test. In turn, one sequence was always preferred in 3D: “CarRace3”. Based on the test results, the bitrate at which 2D and 3D were equally preferred can be determined, as well as the respective VQM scores. In the following, these points are referred to in terms of *isopreference*. The VQM scores at isopreference has been estimated using linear regression between two known points in the 2D domain spanned by “preference percentage” and “VQM scores”. On average, it has been found that the isopreference at the same bitrate between 2D and 3D is reached when the picture quality of the 3D sequence measured by VQM is at least equal to 0.24. The relation between the VQM scores at isopreference and the

depth score rating (subjective depth score when available, and objective if not, see Section 2) was considered. However, no simple relation can be found between these two factors, and other factors have to be taken into account. These other factors may include monocular depth cues such as blur from defocus, linear perspective, texture gradient, motion parallax and also visual discomfort.

### 4. QUANTITATIVE ANALYSIS OF THE “3D ADDED VALUE”

Thanks to the test design it was possible to use the Bradley-Terry (BT) model. In Figure 2b, results of the model are depicted for one SRC. The BT-scores provide the continuous perceptual scale which quantifies the difference between 2D and 3D QoE. It is then possible to evaluate the “added value of 3D” by measuring the difference between the BT-scores at conditions where the bitrate is the same. As only pairs for the same source content were evaluated in our test, the BT-scores cannot be used to compare preferences across contents. For example, it is not possible to compare the content “Alice1” in 3D at quality level 3 to “SkydiversInsideGroup” in 2D at quality level 2. This inter-content comparison was not targeted, and instead the goal was to determine 3D preference thresholds as a function of pictorial quality for different degrees of depth information. Making inter-contents comparisons would have added individual judgement of the observer regarding his preference of one type of scene compared to another, which would have made the data noisy and hard to interpret. As a consequence, it is not possible to compare one BT-score from one SRC to another score from another SRC since it exists an unknown offset between these two scores. However, since the scale remains the same between SRCs, it is then possible to compare inter-SRC differences of BT-score. Let the “3D added value” be the difference of BT-score between two similar coding conditions reflecting the score fluctuation due to the presence of depth (see Figure 2b). At least two factors are of influence on the “3D added value” (3DAV) scores, one covers the 3D characteristics of the video sequences including depth, comfort, naturalness, immersion, etc. And the other one covers the pictorial quality of the video. Figure 3 depicts the relation between the quality factor measured through VQM scores of the 3D video sequences and the 3DAV. These two factors show a Pearson correlation of -0.65 and a Spearman correlation of -0.67. Using a N-Way Analysis of Variance (NANOVA) analyzing the 3DAV based on the factors “QualityLevels” as defined in Section 2 and “DepthLevels” (grouping the SRCs in five class of depth effect) shows that there is a strong influence of quality on the 3DAV ( $F = 13.5, p < 0.001$ ) and that there is also a significant influence

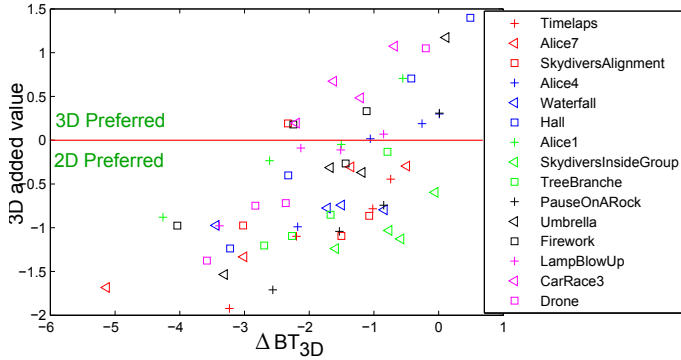


Fig. 4: 3D added value as a function of  $\Delta BT_{3D}$ .

of the “DepthLevel” on the  $3DAV$  ( $F = 3.98, p = 0.0069$ ). Considering the rather small amount of data (four  $3DAV$  values per SRC) no significant influence can be observed on a per-content analysis. Let  $BT_{3D}(k)$  be the BT-score of the condition  $3DQk$  as listed in listing 1. The 3D-QoE fluctuation due to coding can be obtained by:  $\forall k \in [1, 4], \Delta BT_{3D}(k) = BT_{3D}(k) - BT_{3D}(0)$ . The  $\Delta BT_{3D}(k)$  provide a subjective value of how coding affects 3DQoE. This includes loss in pictorial quality, loss in depth [13] and the impact on comfort. The relation between  $\Delta BT_{3D}(k)$  and  $3DAV$  is depicted in Figure 4. In the latter scatter plot, it should be reminded that both  $3DAV$  and  $\Delta BT_{3D}(k)$  have the same scale. To compare content’s specificities it is proposed to perform a regression of the 3D added value ( $3DAV$ ) as a function of  $\Delta BT_{3D}(k)$  (see Table 1).

The slope values ( $\alpha$ ) between the two factors range from 0.02 to 0.76. The result on the overall data is a slope of 0.71. This shows that on average, a quality variation of  $X$  will impact by  $0.71 \cdot X$  the added value of 3D over 2D. However, there are high fluctuations due to contents specificities (depth and comfort) which need to be studied further. The values of  $\beta$  provides information on the added value of the content when available at the highest quality possible and then its suitability to be presented in 3D. Considering the high variation inter-content of  $\alpha$  and  $\beta$  a characterization of the scenes appears to be needed for the development of 3D-QoE models. This is part of on-going work.

$3DAV = \alpha \cdot \Delta BT_{3D} + \beta$					
Content	$\alpha$	$\beta$	Content	$\alpha$	$\beta$
Timelaps	0.54	-0.10	Alice7	0.33	-0.07
Sky.Alignment	0.021	-0.94	Alice4	0.58	0.38
Waterfall	0.08	-0.67	Hall	0.68	1.05
Alice1	0.40	0.77	Sky.InsideGroup	0.38	-0.72
TreeBranche	0.57	0.23	PauseOnARock	0.76	0.13
Umbrella	0.76	0.90	Firework	0.38	0.65
LampBlowUp	0.41	0.53	CarRace3	0.51	1.33
Drone	0.71	1.15	overall	0.71	1.15

Table 1: Relationship between added value of 3D and difference of BT-score between coding and reference condition.

## 5. CONCLUSION

In this paper, 3D QoE was evaluated by using paired comparison. This way, preference of 3D could be investigated as a function of picture quality. Results show that increasing picture quality increases

the probability of preference of 3D over 2D. On average, a VQM score of 0.24 was found to be required to ensure preference of 3D over 2D. Bradley-Terry scores were estimated, and the “3D added value” was determined. The results show that, on average, there is a factor of 0.71 between variation of pictorial quality and “3D added value”. There is however lots of variation between contents, which will be investigated in further studies.

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