Subjective Quality Assessment in Stereoscopic Video Based on Analyzing Parallax and Disparity

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***Abstract*— Disparity may cause visual discomfort. Pairs of video sequences with different levels of parallax, both negative and positive, were presented together to the observers. The observers evaluated the cases in which visual discomfort occurred after visualizing the transition on each pair.**

I. Introduction

Recent research in the field of audiovisual system carried out by research workgroup "Qualinet" and collected in Qualinet White Paper [1] defines Quality of Experience (QoE) as the user´s degree of delight or annoyance with an application or service. That is the main purpose of this paper, defining the QoE when observing a 3DTV content, considering the delight or annoyance in human eye. So, cases where the disparity between left and right view is in the limit of these two concepts have been analyzed when causing visual discomfort.

The work in Quality of Experience for stereoscopic contents could be referred to different research fields: i.e. analysis of disparity, distribution of parallax, motion, encoding process or artifacts detection. This work is specifically focused on the content generation and the quality offered in transitions with abrupt variations in the general disparity of the sequences. Subjective assessment developed with real observers served as the basic methodology to evaluate different types of transitions after subjective assessment processes.

Applications in audiovisual systems where subjective assessment has been used are multiple, above all when it is difficult to find a reference as happens with tablets or smartphones [2]. In 3D stereoscopic television, subjective test are also available for evaluating visual discomfort and other artifacts related to human vision. In [3], an overview describing the main topics relevant to comfort in viewing stereoscopic television is developed, analyzed after subjective tests, related to accommodation-vergence conflict, parallax distribution, binocular mismatches, depth, and cognitive inconsistencies. In [4], it is reported that depth and motion are closely related in terms of calculating visual discomfort. And [5] offers a visual comfort model for detecting salient object's motion features in depth of field. Also, studies developed by Li and Barkowsky about visual discomfort in stereoscopic 3D video sequences, are included in [6]. An interesting subjective evaluation of visual discomfort is developed in [7]. Parallax limits, regions of comfort, screen size, and also disparity and viewing time are analyzed as main causes of visual discomfort. Shang-Hyun also proposes perceptual maps for evaluating discomfort [8].

After first experiences, collected in our previous research [9], the study attempts to go further, widening our horizons, with more tests and in-depth tests. The added value derived from the tests developed on this paper lies on the analysis of a specific effect not previously analyzed or quantified in other subjective assessment included in the state-of-the-art, which is the consideration of disparity in objects through the picture and its variations in video transitions. The paper distinguishes cases where disparity and parallax changes may cause visual discomfort.

In the following text, we make an overview of the related studies collected in Section I. The definition and description of subjective test are shown in Section II, presenting the conditions and settings. The sequences from the database used are described in Section III, the analysis of results appears in Section IV and in Section V a conclusion is reached.

II. Subjective Assessment

Methodologies for the assessment of picture quality were developed following procedures included in the Recommendation ITU-T P.910 [10] and BT. 2021 [11]. The method used was single-stimulus (SS), since the objective was to evaluate the quality perceived by the observer, while reducing the duration of each individual session. The test sequences were presented only once in the test session, while in the beginning, dummy sequences were presented as a reference for the user, just to make the procedure understandable. Observers taking part in the tests were asked to evaluate the transition between pairs of videos in each sequence. For expressing their disagreement if detecting visual discomfort while watching the change.

Table I. Levels of the scale used in tests

MOS Scale	Annoyance derived from transition	Quality of Experience
5	**Very comfortable**	Excellent Experience
4	**Comfortable**	Good Experience
3	**Mildly uncomfortable**	No visual discomfort
2	**Uncomfortable**	Visual discomfort
1	**Extremely uncomfortable**	High visual discomfort

Table II. Basic Characteristics and settings of devices

Device	Philips 65PFL9708S
Resolution	3840 x 2160p
Brightness	450 cd/m²
Size	65" Widescreen
Technology	LED Ultra HD
3D	Passive glasses

The observers were placed at 2.5 meters from the screen. It is commonly known that the recommended optimum distance for HDTV systems varies depending on the desired angle of vision. ITU-T P910 specifies a wide range of distances ranging from 1 to 8 times the height of the screen. A typical recommendation of 1.6 times the screen diagonal offers a 30º angle. Others prefer an even higher angle of 40º to increase immersive experience. This means a distance of 1.2 times the screen diagonal. In our tests the viewers were standing at 2.5 meters from the screen, 1.5 times the screen's diagonal (65").

A total of 72 observers took part in this testing and fulfilled the whole 20 sequences. It is recommended between 4 and 40 observers, but 72 will offer more accuracy to the study. They were previously explained the tests with video sequences as examples. Also their capacity to see 3D contents was analyzed with sequences to demonstrate their validity for tests. Most participants were male, not only scholars but also faculty staff, mainly led by curiosity to complete the test. A vast majority (90%) were considered non-professional observers. Only a small percentage of the tests was carried out by professional observers, used to this kind of assessment. People less than 20 years old and between 20 and 30 years old represent the highest percentage in the sample. Only a small group of people are over 30 years old. Only 3% of the observers were considered outliers. Their opinions were discarded because their scores were out of the correlation margin.

III. VIDEO DATABASE AND SESSIONS DESCRIPTION

Video sequences used for work development were mainly based on stereoscopic database by University of Nantes [12]. Also, synthetic sequences specifically created for this work with specific parallax conditions were used for this study. Professional software for 3D modelling allows obtaining effects of hyperstereoscopy. Finally, other sequences used came from different sources.

The advantage of using virtual cameras for creating synthetic sequences is that it helps to control disparity modifying the distance between left and right cameras, and position of the objects closer or further from the screen.

A session of twenty video sequences was presented to the observers in the subjective assessment tests. Each sequence was composed of two videos, and the users were asked to assess the visual effect provoked by the transition between them.

As mentioned, the method used for the tests was single-stimulus (SS). The observers, in groups of four or five people, are presented each video of a duration between 10 and 30 seconds only once.

Next, the pairs of videos are collected in Table III, describing the reason why they were selected. Most of the cases, each transition represents a variation in type of disparity (mostly in negative parallax environment) in the same or in a different area of the image, with a higher or lower temporal entropy, corresponding to different motion levels.

The selection of videos generating transitions depends on the distribution of parallax and disparity related to position, amount of pixels and type of parallax. Hyperstereoscopy was considered when there are groups of pixels with negative parallax of at least 10 pixels of disparity.

TABLE III. VIDEO SEQUENCES USED IN QUALITY ASSESSMENT, WITH DESCRIPTION OF PERCENTAGE OF PIXELS IN POSITIVE P+ (%) AND NEGATIVE PARALLAX P-(%) AND HYPERSTEREOSCOPY (HS).

S	Video 1	P+ (%)	P- (%)	HS	Video 2	P+ (%)	P- (%)	HS
1	Ladder	27	7	Y	Plunger	30	10	Y
	Negative parallax in center area of both videos Video 1: TI=20, SI=50. Video 2: TI=19, SI=62.							
2	Boxers	25	15	Y	Dance	24	15	N
	See Section V Video 1: TI=19, SI=50. Video 2: TI=16, SI=44.							
3	Barrier	27	10	Y	Basket	36	8	N
	High negative parallax in the right side of first sequence and general parallax in the second Video 1: TI=21, SI=59. Video 2: TI=41, SI=71.							
4	Hall	29	15	Y	Lab	33	12	Y
	See Section V Video 1: TI=5, SI=82. Video 2: TI=12, SI=53.							
5	Line	28	9	N	Front line	29	5	Y
	Balanced negative disparity and parallax in both sequences Video 1: TI=6, SI=40. Video 2: TI=13, SI=44.							
6	Phone Call	32	8	Y	Soccer	28.1	15	Y
	High well-located negative parallax to distributed negative parallax Video 1: TI=13, SI=36. Video 2: TI=38, SI=89.							
7	Earth	34	9.7	N	Explosion	32	6	N
	Quick variation of positive parallax and high motion Video 1: TI=11, SI=44. Video 2: TI=22, SI=20.							
8	Space	33	15	Y	Moon	25	13	Y
	Fast motion but positive parallax in both videos Video 1: TI=15, SI=32. Video 2: TI=18, SI=57.							
9	Shoot	31	5.5	N	Laser	31	5	Y
	Fast motion and negative parallax distributed Video 1: TI=64, SI=19. Video 2: TI=63, SI=19.							
10	Frontline	29	5.3	Y	Line	28	9	N
	Positive parallax in both videos Video 1: TI=13, SI=44. Video 2: TI=6, SI=40.							
11	Soccer	28.1	15	Y	Tree Branch	24.5	18	N
	Low but disperse and quick changing negative parallax. Video 1: TI=38, SI=89. Video 2: TI=14, SI=101.							
12	Angel	22.4	14.7	Y	Ladder	27.7	7.1	N
	See Section V Video 1: TI=7, SI=73. Video 2: TI=20, SI=50.							
13	Palco Hd1	12	9.5	Y	Tree Branch	24	18	N
	Progressive variance of negative parallax changes to distributed negative disparity Video 1: TI=2, SI=60. Video 2: TI=14, SI=101.							
14	Space ship	24	17	N	Astronaut	25	7	N
	See Section V Video 1: TI=14, SI=73. Video 2: TI=9, SI=96.							
15	Muscles	27	14	N	Aphrodite	25	17	N
	Balanced negative parallax in first term of both sequences with medium motion. Video 1: TI=2, SI=62. Video 2: TI=8, SI=80							
16	Station	24	13	Y	Itaca3d	25	5	Y
	See Section V Video 1: TI=32, SI=60. Video 2: TI=6, SI=53.							
17	Palco Hd2	32	10	Y	Phone Call	32	8	Y
	See Section V Video 1: TI=17, SI=60. Video 2: TI=13, SI=36.							

18	Chairs	23	10	N	Muscles	27	14	N
	Distributed negative parallax in both videos Video 1: TI=7, SI=76. Video 2: TI=2, SI=62.							
19	Hanging	30	6	N	Venus	23	15	N
	Distributed negative parallax in both videos Video 1: TI=13, SI=76. Video 2: TI=10, SI=90.							
20	Itaca 3d	25	5	Y	Tree Branch	24.5	18	N
	High synthetic negative parallax combined with motion to distributed negative parallax Video 1: TI=6, SI=53. Video 2: TI=14, SI=101.							

IV. ANALYSIS OF RESULTS

Visual discomfort is considered for users scoring 1 or 2 value of MOS scale, and the rest of scores are considered of producing no visual discomfort.

The sequences, in which more than 40% of the sample complained about the content, were considered as conflictive, as occurred in sequences: 4, 12, 13, 16, 17 and 20. Also, other sequences whose result is over 20% of the sample have been also considered, as happens with sequences: 3, 11 or 18. These sequences are analyzed in next section, to decide which characteristics of these videos affects to human eye, producing visual discomfort.

It is necessary to understand the scale in Fig. 1 for the interpretation of diagrams of disparity in Fig. 2 to Fig. 6. The shades of grey represent the negative parallax, and black would be the point when hyperstereoscopy occurs, i.e. in order to raise the 3D experience.

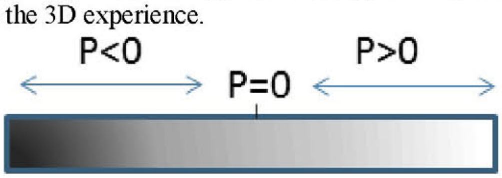

Fig. 1. Scale of levels of parallax necessary to understand disparity diagrams

1) Sequence 12: Transition "Angel" to "Ladder"

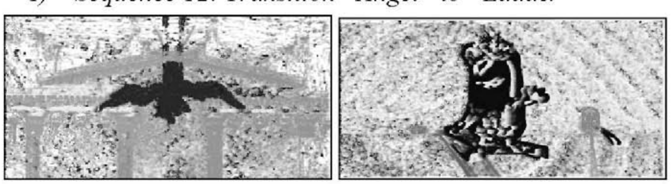

Fig. 2. Disparity diagram of "Angel" and "Ladder"

As shown in disparity diagrams of videos "Angel" and "Ladder", the negative parallax is in the center area of the picture. The abrupt change from negative parallax to a bigger amount of negative parallax pixels produces a visual discomfort in the observer. 40% of the people give a score that manifests visual discomfort, derived from a change in disparity that affects to the same area in the video sequence. Motion in the first video is medium, but faster in the second, what affects to the final score.

2) Sequence 14: Transition "Spaceship" to "Astronaut"

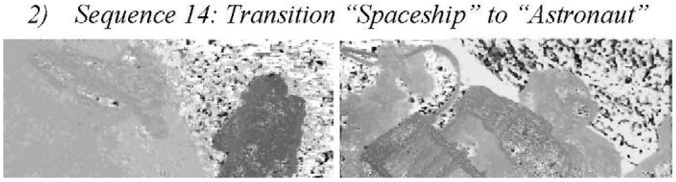

Fig. 3. Disparity diagram of "Spaceship" and "Astronaut"

This sequence was well scored by the observers. Fluctuation from negative parallax in right side of first video to negative/positive combination of parallax in the second one makes the human eye perceive no visual discomfort.

3) Sequence 16: Transition "Station" to "Itaca3d"

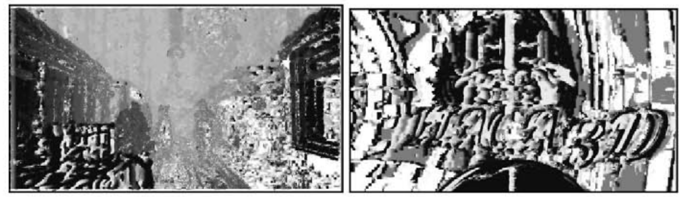

Fig. 4. Disparity diagram of "Station" and "Itaca3d"

The first video of this sequence is a long travelling with high motion and negative in both sides of the picture. On the other side, the second video is affected from hyperstereoscopy, derived from a synthetic modelling, with controlled and negative disparities. Motion and high negative parallax in the transition makes the human eye to assess this sequence as the worst scored in the tests.

4) Sequence 2: Transition "Boxers" to "Dance"

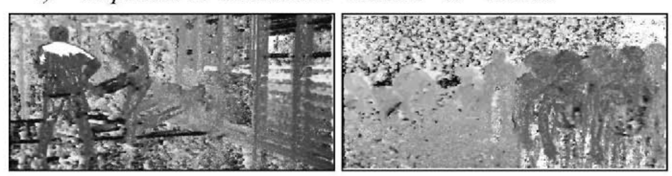

Fig. 5. Disparity diagram of "Boxers" and "Dance"

Moderated negative parallax is included in both videos. In first video the main disparity is found on the left side, changing in the second video to negative parallax in the right side, i.e. the other side.

5) Sequence 4: Transition "Hall" to "Laboratory"

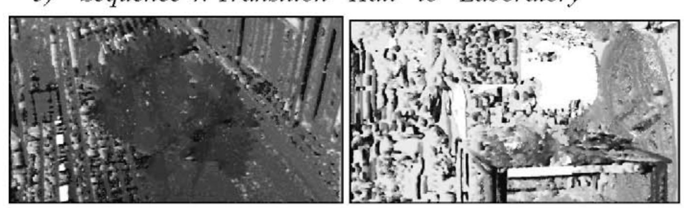

Fig. 6. Disparity diagram of "Hall" and "Laboratory"

The transition in this pair of videos consists of low negative parallax in both videos, in central area for first video and distributed all along the picture in the second one. Video "Laboratory" presents high window violation, what affects to scores from observers.

V. CONCLUSIONS

Analyzing the experiment results leads us to the conclusion that the usefulness of subjective tests is high, because it lets seeing the reaction to the changes of disparity when observing a movie. 3D Cinema and 3DTV contents present different levels of parallax between takes and guidelines are necessary in these transitions to help the filmmaker to design images out of visual discomfort. Sequences with negative parallax are the most conflictive ones for visual discomfort.

- Motion is a key element of production of visual discomfort, but it is not the only one. When it is combined with sequences with high negative parallax may generate visual discomfort.
- If the negative parallax in hyperstereoscopy is located in different parts of the sequences in the transition, visual discomfort appears less than when located in same areas.
- Fast variation of negative parallax is usually the main source of visual discomfort, especially when the transition is produced to a content with a completely different disparity diagram.
- Only hyperstereoscopy (i.e. pixels with negative parallax with disparities higher than 5) in the sequence is not enough for detecting visual discomfort, it is the transition what provokes the discomfort, as seen in Sequence 20, for example.

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