Comparison of Steroscopic Display Systems by Subjective Testing

Ondrej Kaller, Libor Bolecek, Martin Slanina, Tomas Kratochvil
Department of Radio Electronics
Brno University of Technology
Brno, Czech Republic
e-mail: xkalle00@stud.feec.vutbr.cz, xbolec01@stud.feec.vutbr.cz, slaninam@feec.vutbr.cz, kratot@feec.vutbr.cz

Abstract — **This short paper compares 3D video image quality and perceived 3D video image depth of three present-day stereoscopic displays for home entertainment. These stereoscopic displays are represented by the commercially available plasma display panel (PDP) with active shutter glasses, digital light processing (DLP) projection also with active shutter glasses and liquid crystal display (LCD) with passive polarization glasses. Subjective tests and assessment of 3D video image quality and stereoscopic effects have been organized with help of 128 respondents in various age categories and 32 various 3D video or image sequences. The paper presents results of subjectively evaluated 3D video image depth and determination of the viewing conditions impact on perceived 3D depth.**

Keywords – stereoscopic display; 3D passive display; 3D polarization display; shutter glasses; circle polarization glasses, 3D video image quality; subjective testing; viewing angles

I. INTRODUCTION

Today's development of stereoscopic imaging and 3D video image quality evaluation is divided mainly into three branches. Testing methodology for 3D video image quality evaluation is the first one, which tries to define testing conditions and processing of data from subjective tests. These tests could be classical deliberation or behavioral evaluation [1], where the quality and fidelity of 3D imaging is evaluated by biological responses of tested subject. These responses are produced automatically such as postural responses, skin conductance or heart rate. The second way is to find possibilities how to describe projection of objective video image parameters to the space of subjective test results and to define metrics for their evaluation [2]. The third type of contemporary research in this area is focused on Quality of Service (QoS) determination in concrete application such as 3D IPTV [3] or wireless transmission is [4].

This paper describes subjective tests that we have recently organized and brings preliminary and partial results with their discussion. These tests have been quite complex and intended to investigate the subjective 3D video image quality and stereoscopic effect related to different display technologies, content parameters, light conditions, viewing angles and characteristics of respondents. This contribution selects only a fragment of our results. It focuses only on the influence of the viewer position on the Quality of Experience (QoE) for three present-day 3D display technologies.

We have tested three different technologies, currently widespread on the market for 3D home entertainment (Table I). These present Plasma Display Panel (PDP) and Digital Light Processing (DLP) projection, both with active shutter glasses, and Liquid Crystal Display (LCD) with passive polarization glasses. Our analysis aims at the comparison of the technologies in terms of perceived quality of stereoscopic content and in terms of naturalness of the perceived 3D video image depth.

The rest of the paper is organized as follows. Section 2 summarizes relevant information about the mentioned display technologies and it needed for understanding the subjective test adjustment. Section 3 contains description of individual technical equipment used for testing and subjective tests arrangement. It also mentions the parameters of the tested 3D image video content. Next, Section 4 provides some information about our respondents and also shows the results. Finally, in Section 5, the results are discussed and a brief outlook for the future work is given.

II. 3D DISPLAY TECHNOLOGY

Time multiplexing is the most extended technique for stereo pair discrimination today. The display itself can be a classical 2D panel with higher video frame rate. The most important part of the system is synchronization of active shutter glasses, which switch light sequentially in time multiplex to both eyes. This approach has theoretically limitless horizontal and vertical viewing angles, in fact limited just by the display itself. However, in reality, the manufacturers admit some limitation in light separation, because of the directional characteristic of active LCD glasses [5] [6].

For this purpose, it seems very convenient to use a PDP, which has in principle no problem with fast refresh rate (e.g., 0,001 ms - Panasonic TX-P42GT20E [6]). That is because the gas discharge ignition is practically immediate. In spite of this potential parameter, the current systems use only 120 Hz frame rate for 3D. It leads to 60 frames per eye, which is a lower rate compared to what the classical 2D systems use today. Also it is not a problem for concurrent products based on LCD panels to reach the same parameters.

Due to its simple configuration, the DLP technology is widely used for home 3D projection with time multiplexing of both halves of stereo pair. DLP technology can reach higher frame rate in comparison with LCD projectors. Frame rate is the same (low) as in previous system (e.g., BenQ W710ST, frame rate 119 Hz), but we can remark, that it is going to be increased in next generation of projectors.

 ISBN: 978-1-61208-193-9

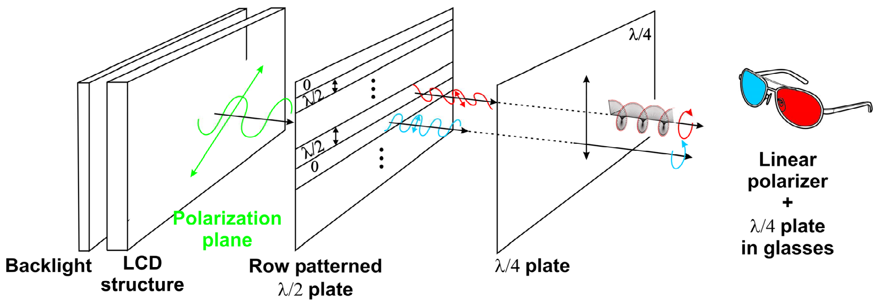

Figure 1. Principle of polarizated discrimination display demonstrated on cross section.

Generally, a characteristic property of projectors is the higher diagonal dimension of the image.

In case of 3D utilization, it brings a higher parallax and consequently larger 3D effect in the same viewing conditions. This "advantage" should also cause problems, because the available content is usually calculated for smaller diagonal dimension and due to adaptive parallax [7] the 3D effect can be higher and perceptual depth can leave the comfortable zone. This could cause so called "dizziness".

Besides time multiplexing, the new implementation of the old known polarization technology celebrates success at present. Its novelty lies in using a patented system for circular light polarization called Film-type Patterned Retarder (FPR), which decreases production costs. Demonstrational cross section is shown in Fig. 1 [5]. Unpolarized light from Cold Cathode Fluorescent Lamp (CCFL) or Light Emitting Diode (LED) is in principle linearly polarized in the system of LCD panel. A half-wave row slice structure rotates the light polarization plane by π/2 radians in case of odd rows of image. In this plane of the structure, the information for the left and right eye is separated spatially and by linear polarization. Circular polarization, which is used for the intra-eye crosstalk minimization, is then obtained by quarter-wave plate.

Separation of polarized light in glasses uses a reverse mechanism [8]. One advantage of passive system is of course the weight of glasses, which achieves 15 g in case of polarized discrimination glasses (LG) compared to 50 g or 28 g for active shutter glasses (NVIDIA and Panasonic, respectively). The design of Panasonic glasses has been criticized for wearing discomfort by respondents.

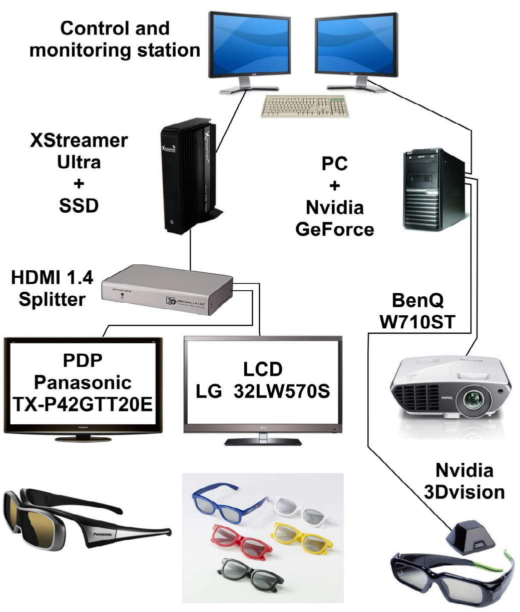

Figure 2. Illustrative scheme of laboratory arrangement for testing.

III. SUBJECTIVE TESTING

A. Technical Equipment

The laboratory equipment (Fig. 2) consists of two sources of 3D video signal, HDMI 1.4 splitter, 3 different stereoscopic displays (Table I) and control and monitoring displays.

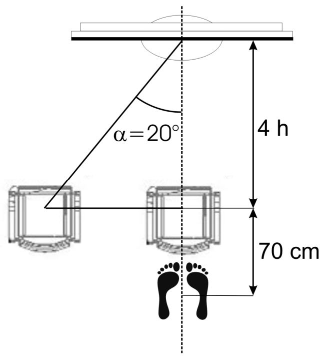

Figure 3. Floor projection of test arrangement.

TABLE I. PARAMETERS OF THE TESTED 3D SYSTEMS

3D System	Display Technology	Stereo Pair Discrimination	Native Displayed Resolution in 3D	Diagonal [cm]
LG 32LW570S	LCD	Polarization	960 x 540	82
BenQ W710ST (NVIDIA)	DLP	Time multiplex	960 x 720	196
Panasonic TX-P42GT20E	PDP	Time multiplex	960 x 1080	106

 ISBN: 978-1-61208-193-9

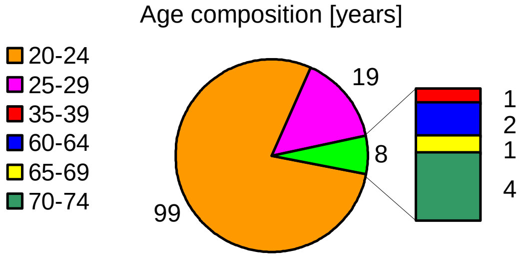

Figure 4. Age composition of the respondents.

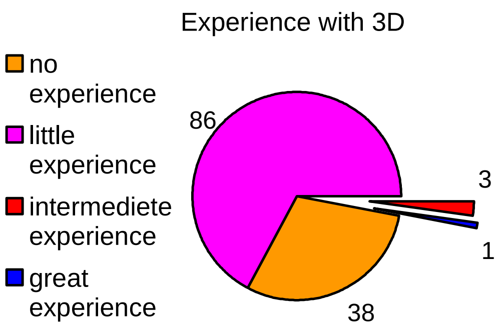

Figure 5. Previous experience with 3D television.

Two independent signal sources were used, because it is necessary to generate separate video signals. One of them is time multiplexed for 3D projector – a PC with graphic card NVIDIA GeForce 8000 has been used. To control the other two displays, the home theater PC XStreamer Ultra with built-in SSD hard drive has been used.

B. Laboratory Arrangement

Fig. 3 shows a floor projection of the testing site. In all three cases, the same viewing conditions have been defined, especially the horizontal and vertical viewing angles.

The viewing distance has been calculated as four times of the picture height (4h) in case of ideal viewing condition [9]. While horizontal angular displacement α has been set directly by the seat position, vertical displacement β depends on the tested subject height. We have asked for it in the evaluation form.

The average height has been 180.2 cm (values from 166 to 196 cm). These values lead to the mean vertical viewing angle β of 14° (from 11° to 18°) in case of LCD display, assuming the average distance of eyes (optical axis) from the top of the head is 12 cm. For PDP, the same value was 11° (from 8° to 14°). For projection, the mean vertical angle was 2.5° (from 0.5° to 4.5°) in case of positive vertical displacement (standing observers) and 3.2° (from 1.5 to 4.3) in case of negative vertical displacement.

C. 3D Video Image Content

We have utilized three sources of content to evoke impression of standard home usage: Blu-ray disc, 3D satellite digital television broadcasting and amateur 3D camera captured sequences. Four sets of sequences have been prepared for testing. Three from the previously mentioned content types with an additional set containing static images, created from the sequences in the other sets.

The sources used had variable native 3D format, compression and resolution. The original content was coded with Multiview Video Coding (MVC) format (for Blu-ray sequences), spatially compressed side-by-side and H.264 encoded (for satellite television broadcasting) and spatially compressed and Advanced Video Coding High Definition (AVCHD) encoded (for amateur capture).

For playback during the test session, we have converted all the sequences to spatially compressed (side by side) “Full HD” format 1920x1080/25p. The sequences were stored in YUV raw video format and played back with no compression. Native pixel resolution in Table I is calculated for one half of stereo pair of this input format.

D. Test Session

Structure of each set is done according to ITU recommendation ITU-R BT.710 [9], where 10 to 15 s of video sequence/static image is followed by 5 s of mid gray color. The sequences were played back in random order, 8 sequences per format, resulting in the total of 32 sequences.

After viewing the set of sequences on one 3D system, the observers were asked to perform the test on another system. The order of the sequences was different for this following test. We repeated the same procedure for all the three 3D systems under test. At the end of the subjective test session, the observers were asked to fill in a simple questionnaire including several personal questions and an overall judgment comparing the three systems in terms of 3D effect quality and depth naturalness. The task was to select which of the three systems performed 3D display and according QoE the best [10].

E. Observers

We have tested a sample of 128 people of age between 20 and 74 years (Fig. 4). The yield of test has been over 95 %. In total 74 respondents compared all three 3D technologies in their subjective tests.

We have not done any training of our respondents; we have just allowed them some time to read the test form. The tested sample of people has consisted mainly of students (93%), which have no experience with video image and multimedia subjective quality tests at all.

At the beginning of the test we have asked the subjects about personal information, including gender, age and employment. We have investigated for how long they watch TV per week, whether they suffer from eye defect and what their experience with 3D technology is. We have asked in particular about 3D home television/cinema systems, not about 3D cinema (Fig. 5). Scale has been four-level, where intermediate/great experience means, that the subject owns a 3D display and watches 3D content sporadically/regularly.

 ISBN: 978-1-61208-193-9

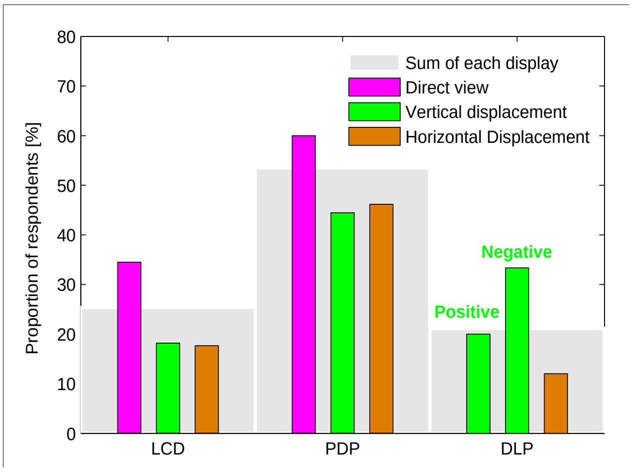

Figure 6. The best 3D video image quality in dependence on 3D system and actual viewing position of the respondent.

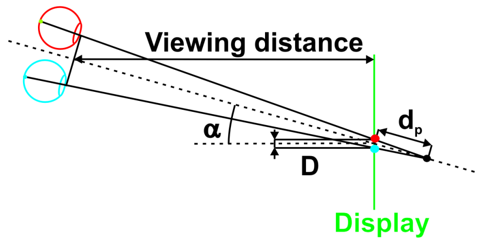

Figure 7. Illustration for the perceived depth ratio evaluation.

The eye defects we distinguish among corrected ones as myopia/astigmatism, in that case were questioner classically processed, then serious defects as amblyopia, or disorder of spatial perception, where respondents has been discarded and daltonism, where only questions about perceived 3D video image depth has been taken into account when processing the results.

IV. Results

In this paper, the answers for two questions from our complex questionnaire are only presented, associated with the technological aspects of the used 3D displays.

A. *Perceived Quality*

The first test question deals with 3D video image quality evaluation (Fig. 6). Percentage of respondents evaluating video image quality of a particular system as the best is shown by a gray bar. The colored columns show the proportion of respondents, who decided for a concrete horizontal or vertical viewing angle. This percentage is calculated among the respondents, who participated in the subjective test in a particular position [7].

The best 3D video image quality is given by, according to test results, the PDP system. This fact could be associated with the highest native resolution of the one displayed image from the stereo pair (Table I).

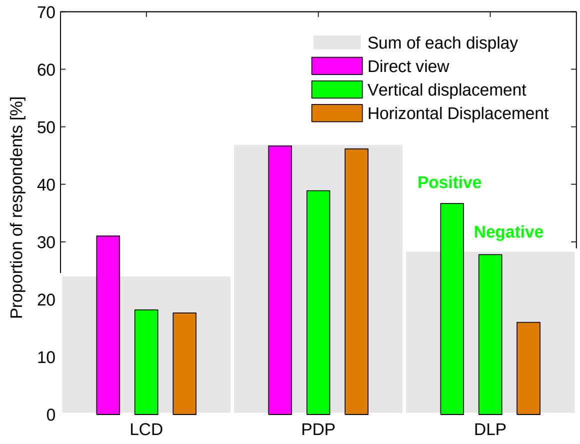

Figure 8. The highest 3D depth perception in dependence on 3D system and actual viewing position of the respondent.

TABLE II. Theoretical Percieved Depth Ratio for Various Viewing Conditions

Technology	Viewing position	α [°]	β [°]	Perceived depth ratio
Polarization LCD	Horizontal displacement	20	0	**1.00**
	Direct View	0	0	**1.02**
	Vertical displacement	0	14,3	**1.03**
Time-multiplex PDP	Horizontal displacement	20	0	**1.47**
	Direct View	0	0	**1.53**
	Vertical displacement	0	10,9	**1.53**
Time-multiplex DLP	Horizontal displacement	20	0	**5.66**
	Vertical displacement +	0	2.5	**6.67**
	Vertical displacement -	0	3.2	**6.67**

B. *Perceived Depth*

The second test question discussed in this paper is which system and configuration provides the highest depth perception. The answer for this could be, unlike the previous, theoretically calculated from the known viewing position under the condition that the same 3D content is displayed on the compared displays (Table II).

The perceived depth ratio, which we have defined for this purpose as our own and original measure, gives an objective comparison of the 3D systems under given observation conditions. It is computed as follows (Fig. 7). At first, the perceived distance (d_p) of static stereoscopic parallax is calculated. The value depends on pixel disparity (D), defined viewing distance (4h) and horizontal displacement (α). The pixel disparity increases with the 3D display diagonal size. Perceived depth ratio is then defined as normalized value of the d_p to the viewing distance. From the results, the rows and their order in the Table II show, that the DLP projection should provide the highest perceived depth and the best stereoscopic effect to the viewer.

Unfortunately, the described calculation is in contradiction with the test results (Fig. 8). The tested

 ISBN: 978-1-61208-193-9

subjects consider PDP depth perception the highest. One of the aspects, where test results correspond to theoretical computations, is the lowest depth of LCD polarization system. How to explain the general difference? One hypothesis says that the stereo effect of DLP system may be so strong, that the brain of some part of respondents can not process it. We may also suppose that level of light, which has been changed during the subjective test, but intentionally not discussed in this paper, degrades the results of DLP system. Lighting conditions influences the quality of experience for sure and they are important topic for forthcoming investigation. In fact, variety of illumination during the test was set from 10 lx to 500 lx, but light conditions have not been strictly complied with ITU recommendation [9]. They have been specified as a most common and comparable with home environment and scenario.

V. Conclusions and Future Work

In this short paper, we presented a comparison of performance of present-day stereoscopic display systems by subjective testing. The aim of this short paper was not to bring complete study and present all the results from our subjective tests, but only describe the present commercial 3D display technologies and then our methods, technical equipment, laboratory arrangement, definition of 3D video image content and group of observers. The results are very brief and evaluate just answers to the two questions from our complex questionnaire for the 3D video image quality and its subjective evaluation related to QoE.

Within the evaluation and subjective testing of 3D systems that was discussed in this paper, we have also measured some objective parameters of the individual displays. The technological limitations of the used 3D systems were taken, such as the maximum useable displacement or crosstalk between the halves of stereo pair.

The aim of our future work is to find and quantify all technological aspects of 3D video image quality and image depth to improve these parameters. Of course, our findings could have some discrepancies with theory and the data will be statistically processed in a more complex manner to find hidden dependences.

Acknowledgment

This paper was jointly supported by the grant project of the Czech Science Foundation no. 102/10/1320 “Research and modeling of advanced methods of image quality evaluation (DEIMOS)” and internal project FEKT-S-11-12 MOBYS. The described research was performed in laboratories supported by the SIX project; the registration number CZ.1.05/2.1.00/03.0072, the operational program Research and Development for Innovation. The support of the project CZ.1.07/2.3.00/20.0007 WICOMT, financed from the operational program Education for competitiveness, is gratefully acknowledged.

References

[1] W. Ijsselstein, H. de Ridder, J. Freeman, S. E. Avons, and D. Bouwhuis, ”Effect of stereoscopic presentation, image motion, and screen size on subjective and objective corroborative measures of presence,” Presence, vol. 10, no. 3, June 2001, pp. 298–311.

[2] A. Benoit, P. Le Callet, P. Campisi, and R. Cousseau, “Quality assessment of stereoscopic images,” EURASIP Journal on Image and Video Processing, vol. 2008, Article ID 659024, 2008, pp. 1-13, doi:10.1155/2008/659024.

[3] M. Barkuowsky, K. Wang, R. Cousseau, K. Brunnstrom, R. Ollson, and P. Le Callet, “Subjective quality assesment for error concealment strategies for 3DTV in the presence of asymmetric transmission errors,” Proceedings of the 2010 IEEE 18th International Packet Video Workshop, Dec. 2010, pp. 193-200, doi: 10.1109/PV.2010.5706838.

[4] S. L. P. Yasakethu, W. A. C. Fernando, B. Kamolrat, and A. Kondoz, ”Analyzing Perceptual Attributes of 3D Video,” IEEE Transaction on Consumer Electronic, vol. 55, no. 2, May 2009, pp. 864-872, doi: 10.1109/TCE.2009.5174467.

[5] H. Urey, Chellappan, K. V., E. Erden, and Surman, P., “State of the art in stereoscopic and autostereoscopic displays,” in Proceedings of the IEEE. Feb. 2011, pp. 540-555, doi: 10.1109/JPROC.2010.1098351

[6] Datasheet and manuals of panasonic PDP panel TX-P42GT20E [14. 2. 2011 available at Panasonic.cz]

[7] K. Ide and T. Sikora, Adaptive parallax for 3D television, in “3DTV-Conference: The TrueVision – Capture”, in Transmission and Display of 3D Video (3DTV-CON). Tampere, 2010. s.1-4. ISBN: 978-1-4244-6377-0

[8] Y. Yosihihara, H. Ujike, and T. Tanabe, “3D Crosstalk of stereoscopic (3D) display using patterned retarder and corresponding glasses”, in IDW ´08, pp.1135-1138.

[9] The ITU Radiocommunication Assembly, “Recommendation ITU-R BT.710-3 Subjective assesment for image quality in high-definition television,” 1997.

[10] J. Gutiérrez, P. Pérez, F. Jaureguizar, J. Cabrera, and N. García, “Subjective assessment of the impact of the of transmission errors in 3DTV compared to HDTV,” 3DTV Conference: The True Vision - Capture, Transmission and Display of 3D Video (3DTV-CON), May 2011, pp. 1-4, doi: 10.1109/3DTV.2011.5877209.

 ISBN: 978-1-61208-193-9