Limits of Geometrical Distortions Based on Subjective Assessment of Stereoscopic Images

Xiangdong Deng[1], Guanwen Zheng[1], Xun Cao[2]
[1]Academy of Broadcasting Planning, SAPPRFT, China
[2]Nanjing University, China

***Abstract*—The limits of geometrical distortions for stereoscopic images are presented. We experimentally determined the limits of geometrical distortions, including vertical shift, rotation error, and size inconsistency, between left and right images. The experiment result shows that vertical shift should not exceed 5 pixels, rotation error should not exceed 0.4°, and size inconsistency should not exceed 0.8%.**

I. INTRODUCTION

Recently, 3D technology became popular. 3D movies and 3D video programs become attractive contents of video website, also provide an important source of income for E-Business and E-Consumption in culture and entertainment field. Meanwhile, 3D technology is very suitable for E-Education.

As a novel stimulus to the human vision, 3D technology giving people a new visual experience and let the content become more eye-catching. Not only movies, televisions, but also online-shopping, Internet advertising, such as automobile, house, jewelry, clothes and so on, can take advantage of 3D technology to increase their attractiveness.

However, many studies show that stereoscopic images may cause visual fatigue, such as eye strain, headache, focusing difficulty and nausea. Viewing stereoscopic images, especially imperfect binocular image pairs may induce such symptoms have been widely recognized. In this paper, we experimentally determined the limits of geometrical distortions between left and right images.

In a study by H.Yamanoue[1], detection/tolerance limits of geometrical distortions, such as vertical shift, rotation error, and size inconsistency, between right and left images, are estimated. The study uses a 3D projector to show 3D images, and four different 3D images, three picked from HDTV program and one CG, are used as test material. Eleven subjects participated in the experiments. In ITU report ITU-R BT.2293-1[2], research on impairment caused by discrepancies and cross-talk between L/R stereo images is presented, which refer to H.Yamanoue's study.

Frank L.Kooi focuses on the viewing discomfort causing by imperfections in binocular image pairs[3]. He uses a wide range of binocular image imperfections, including some geometrical distortions, to test which one may reduce observer's visual comfort. From this data, he estimates threshold values for some discomforts. One binocular image pairs that represent a part of a typical office scene is used as the test material.

In China, a provisional technical documentation "Technical requirements for the program production and broadcast of the stereoscopic television"[4] is published by Radio and Television Shanghai, Jiangsu Broadcasting Corporation, CCTV, and Academy of Broadcasting Planning, SAPPRFT, in 2014. The technical requirements for the program production and broadcast, including tolerance limits of vertical shift, rotation error, and size inconsistency, is defined in this documentation. This documentation is the one and only standard in 3DTV programs production in China.

Compare to former experimental methods, our experiment take a further approach in three aspects. Firstly, 3D videos picked from nowadays 3DTV program are used as our test materials. Secondly, a polarized 3D monitor, which presents the current 3D technology, is used as our experimental apparatus. Thirdly, we use double stimulus continuous quality scale (DSCQS) method as our subjective method, and this method is included in Recommendation ITU-R BT.2021 "Subjective methods for the assessment of stereoscopic 3DTV systems".

II. TEST MATERIAL

A. The Selection of the Test Material

Three test sequences are picked form China's 3d TV test channel as our test materials. The content of the test material (e.g. Spring Festival gala, sport, etc.) and their spatiotemporal characteristics is representative of the programmes delivered by the service under our study. Test materials are copied from NLE workstation, all of the test materials are full resolution stereoscopic sequence. Representative scenes of test sequences in our experiment are as follows.

Sequence 1: Spring Festival gala (3D)

This sequence has a modest parallax range, and the movement is gentle. 3D CG and 3D subtitles are contented in this sequence.

Figure 1. Representative scenes of Sequence 1: Spring Festival Gala (3D)

Sequence 2: Table tennis competition

This sequence has a modest parallax range, and the movement is dramatic. 3D subtitles are contented in this sequence.

Figure 2. Representative scenes of Sequence 2: Table tennis competition

Sequence 3: Dance

This sequence has a large parallax range (max negative parallax is about -1°), and the movement is dramatic.

Figure 3. Representative scenes of Sequence 3: Dance

B. The Measurement and Adjustment of Distortions

The measurement of distortions is done by a stereo error detecting system named "PURE On-Set" (Stereolabs Co., France). "PURE On-Set" can detect geometrical distortions of a 3D video, including vertical shift, rotation error, and size inconsistency. The adjustment of distortions is done by a 3D NLE workstation named "Mistika" (SGO Mistika Co., Spain), which have been widely used in production of 3D films.

We adjust geometrical distortions of our test sequences in two steps. Step-one, named "distortions zero setting". In this step, we reduce the distortions of source materials, as small as possible, by "PURE On-Set" and "Mistika". Step-two, named "distortions setting". In this step, we adjust geometrical distortions of our test sequences as we want by "Mistika".

1) *Distortions Zero Setting*

Geometrical distortions, including vertical shift, rotation error, and size inconsistency, can be adjust by "Mistika". Using "PURE On-Set" to monitor the output signal of "Mistika" while adjustment. Geometrical distortions of test sequences after "distortions zero setting" are as follow: vertical shift, rotation error, and size inconsistency.

TABLE I. GEOMETRICAL DISTORTIONS OF TEST SEQUENCES AFTER "DISTORTIONS ZERO SETTING"

	Vertical shift	Rotation error	Size inconsistency
Maximum distortions of test sequences after "distortions zero setting"	<0.1pixel	<0.03°	<0.1%

2) *Distortions Setting*

Vertical shift adjustment: Adjust the vertical position of left image and right image. Horizontal position of left and right image should remain unchanged while adjustment. Blank areas will appear in top/bottom of screen while the adjustment of vertical position, so enlargements of left image and right image (at same proportion) should be done before vertical shift adjustment. A same proportion enlargement of source sequences is needed to be done as well.

Rotation error adjustment: Adjust the angle of rotation of left image and right image. Center position of left and right image should remain unchanged while rotation. Blank areas will appear in four corners of screen while the adjustment of rotation, so enlargements of left image and right image (at same proportion) should be done before rotation error adjustment. A same proportion enlargement of source sequences is needed to be done as well.

Size inconsistency adjustment: Adjust the size of left image and right image. Position of center pixel of left and right image should remain unchanged while adjustment. For example, after 1% zoom, the resolution of a HD image (1920x1080) will be resized to 1939x1091. When the resized images display on a HD monitor, the pixels in the area of top/bottom 5x1920, and left/right margin 10x1080, will be cut.

III. METHODS

A. Presentation of the Test Material

We use the presentation method of double stimulus continuous quality scale (DSCQS) method (recommended in ITU-R BT.2021 [5]) as our presentation method. The structure of presentation is shown in Figure 3. Prior to recording results, "Sequence A" and "Sequence B" are shown one time for an equal length of time to allow the assessor to gain the mental measure of the qualities associated with them, then the pair is shown again one time while the results are recorded. The duration of sequences is 10 second. "Sequence A" and "Sequence B" are supplied with reference sequence, or the sequence after adjustment, but which is fed to which one is random, noted by the experimenter, but not announced.

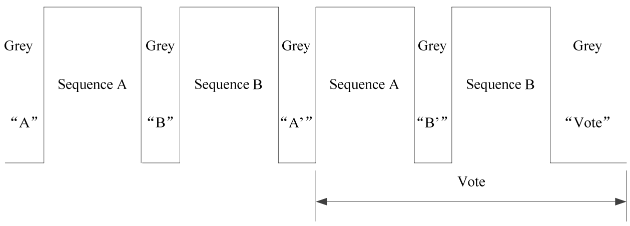

Figure 4. The structure of presentation

B. Grading Scales

Observers are asked to provide a judgment about which sequence is reference sequence or which one is the sequence after adjustment (i.e. "Sequence A with error" or "Sequence A with error"). If observers cannot differentiate between two sequences, a "No error in both sequences" judgment should be given.

C. Opinion Score Data

Opinion score data is obtained according to the arrangement of presentation and judgment of observer as below.

TABLE II. DISCRIMINATION FOR RESULTS

Arrangement of presentation / Judgment of observer	Sequence A with error	Sequence B with error
Sequence A with error	Detect the error	Cannot detect
Sequence B with error	Cannot detect	Detect the error
No error in both sequences	Cannot detect	

Experimenter accumulate the number of observers who can detect the error as the result.

D. Limits of Geometrical Distortions

The limits of geometrical distortions are defined in four steps:

(1) Find a approximate range $[e_{min},e_{max}]$ of the limit. This range may refer to some observers' results or other relevant studies.

(2) In the range of $[e_{min},e_{max}]$, take several $e_i \in [e_{min},e_{max}]$. For each e_i, do subjective assessment which is discribed above.

(3) For each observer, if he or she can detect error e_m, but cannot detect error e_n, and the error $e_m < e_n$. Then he or she has to do one more time subjective assessment for error e_m and e_n, until for each error pair $e_m < e_n$, this observer can detect error e_n and cannot detect error e_m.

(4) For each observer, if he or she can detect error e_n, and $e_n = e_{min}$. Then he or she has to do subjective assessment for an error $e_m < e_n$, until this observer cannot detect error e_m.

E. Viewing Conditions

Using "Mistika" 3D NLE workstation to output dual HD-SDI signal, and display the arranged sequences by a SONY 3D monitor.

The viewing conditions (including screen luminance, contrast, background illumination, viewing distance, etc.) should be consistent with those used for 2D as described in Recommendation ITU-R BT.2022 (Doc. 6/20)[6]. We build 3D subjective assessment environment based on our HD subjective assessment environment according to ITU-R BT.2022 (Figure 5).

Figure 5. Subjective assessment environment

IV. RESULTS

A. Observers

Since the number of observers participating in relevant studies conducted overseas ranges from 5 to 10, and the number dictated by ITU for evaluating two-dimensional videos is 15, the present research employed 16 observers. Their ages range between 23 and 42, and distance visual acuity tests and Titmus stereo tests have shown that their corrected visual acuity and stereopsis are normal.

B. Data Treatment

To illustrate the data treatment in the present experiment, we will take the treatment of observers' assessment of size inconsistency as an example. The table below summarizes part of three observers' results.

TABLE III. RESULTS OF SIZE INCONSISTENCY ASSESSMENT

Size inconsistency	sequence 1				sequence 2			
	0.75	1	1.5	3	0.75	1	1.5	3
Observer A	0	0	1	1	1	1	0	1
Observer B	0	1	1	1	0	0	0	1
Observer C	0	1	0	1	0	0	1	1

The horizontal headers are the names of sequence and size inconsistency, and the vertical headers are the three observers. "0" stands for observers' not perceiving the errors, and "1" perceiving the errors.

According to 3.4 limits of geometrical distortions, in the present experiment, the errors in the table is $e_i \in [0.75,3]$. When assessing sequence 2, observer A perceived $e_{0.75}$ and e_1, but did not perceive $e_{1.5}$. However, we know that $e_{0.75} < e_{1.5}$ and $e_1 < e_{1.5}$. For this reason, the results were not reasonable, and thus observer A had to re-assess sequence 2. Likewise, observer C had to re-assess sequence 1.

The results after re-assessment are shown in the table below.

TABLE IV. RESULTS OF SIZE INCONSISTENCY RE-ASSESSMENT

Size inconsistency	sequence 1				sequence 2			
	0.75	1	1.5	3	0.75	1	1.5	3
Observer A	0	0	1	1	1	1	1	1
Observer B	0	1	1	1	0	0	0	1
Observer C	0	1	1	1	0	0	1	1

For sequence 2, observer A perceived $e_{0.75}$, which was the minimum in the range, and so observer A needs to further assess a smaller error.

The results this time are shown as follows.

TABLE V. FINAL RESULTS OF SIZE INCONSISTENCY ASSESSMENT

Size inconsistency	sequence 1				sequence 2				
	0.75	1	1.5	3	0.5	0.75	1	1.5	3
Observer A	0	0	1	1	0	1	1	1	1
Observer B	0	1	1	1	0	0	0	0	1
Observer C	0	1	1	1	0	0	0	1	1

Post-treatment data meet the two conditions:

(1) For any $e_m < e_n$, under no situation is e_m perceivable while e_n is not.

(2) Under no situation is e_n perceivable while $e_n = e_{min}$.

C. Experiment Results

The horizontal headers are errors, and the vertical headers are the percentage of observers perceiving the errors. The results for vertical shift, rotation error and size inconsistency are shown as follows.

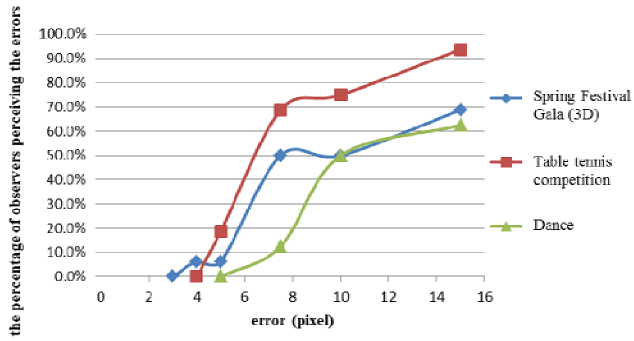

Figure 6. Results for vertical shift

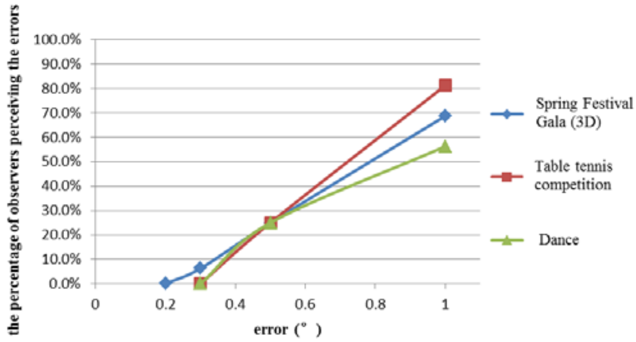

Figure 7. Results for rotation error

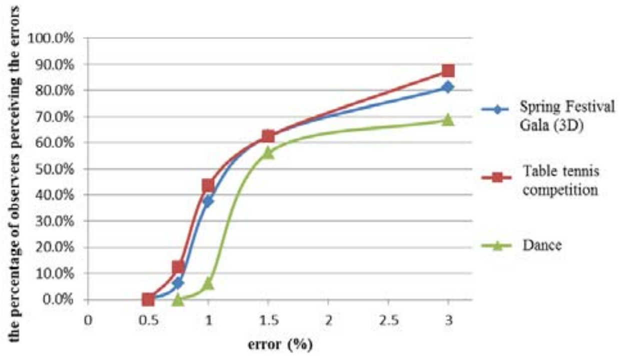

Figure 8. Results for size inconsistency

V. CONCLUSIONS

The present study identities the limits of geometrical distortions by employing the following method:

Given any t∈[0,100], when more than t% observers can perceive the error (taking the strictest sequence as the standard), the error is not accepted. So the limits of geometrical distortions are identified by the errors corresponding to exactly t%.

The limits of geometrical distortions of “more than 10% observers perceiving the error” and of “more than 20% observers perceiving the error” are given in the following table.

TABLE VI. THE LIMITS OF GEOMETRICAL DISTORTIONS OF 3DTV PROGRAMS IN THE PRESENT STUDY

	more than 10% observers perceiving the error			more than 20% observers perceiving the error		
Error type	vertical shift	rotation error	size inconsistency	vertical shift	rotation error	size inconsistency
limit	5pix	0.3°	0.7%	5pix	0.4°	0.8%

TABLE VII. THE RESULTS OF THE PRESENT STUDY AND EXISTING RESEARCH

Error type	Results of this paper (more than 20% observers perceiving the error)	Results of H. YAMANOUE etc.(adopted by ITU-R T.2293-1)	Results of Frank L. Kooi etc.	China’s GD/J 054-2014 “The Requirements for the Production and the Broadcast of Three-Dimensional Television Programs”
Vertical shift	5pixels	8pexels	32pixels	7pixels
rotation error	0.4°	0.5°	1°	1°
size inconsistency	0.8%	1.2%	2.5%	1%

The researcher undertakes the modification of China’s GD/J 054-2014 “The Requirements for the Production and Broadcast of Three-Dimensional Television Programs”. Based on the results of this study, it is suggested that the limit of vertical shift be modified as 5 pixels, the rotation error be changed to 0.4°, and the size inconsistency be changed to 0.8%.

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