Preference on High Frame Rate Stereoscopic 3D in TV

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Summary
Frame rates higher than the conventional 24 fps (frame per second), collectively referred as HFS (High Frame Rate), have been adopted in cinema movies recently. HFR is believed to resolve several issues related to the quality of stereoscopic images since it brings almost no artifacts as flickering and motion blur by its nature. In this paper, we evaluated how audiences appreciate the high frame rate over traditional frame rate used for TV. The result shows that participants have given preferences over higher frame rate playback in almost all cases of depth and speed combinations. The tendency, which is a favor over higher frame rate playback, becomes faint when the test image contains no movement.
Key words:
HFR, Watching satisfaction, ANOVA, Post-hoc test, Stereoscopic 3D

1. Introduction

"The Hobbit: *An Unexpected Journey*" was released in various formats in December 2012 including 2D, 3D, IMAX, IMAX 3D and brand new format; High Frame Rate (HFR) 3D. HFR refers to a shooting technique that employs a use of higher frame rate other than typical shooting practice. HFR, which is closer to what human eyes actually see, is a attempt to achieve following goals.

- More immersive 3D contents
- Realistic experiences

HFR, by its very nature, comes with almost no flicker, motion blur and stuttering and therefore is believed to provide more realistic watching experiences, as shown in figure 1. In film industry, 48 fps (frame per second) and 60 fps are called High Frame Rate or HFR for short.
Frame rates are the number of frames or images shown or displayed in one second. In filmmaking, video production, animation and other relevant fields, 24 fps (or 30 fps) has been the de facto standard choice. A higher frame rate is believed to make it possible to achieve clearer and smoother video outputs especially for fast moving objects. With the advent of UHD (Ultra High Definition) technology, the bandwidth-intensive requirement in order to avoid image smearing begins to arise. In ITU-R BT2020, two UHD formats are listed; 7680*4320 and 3840*2160 at 24/1.001, 24, 25, 30/1.001, 50, 60/1.001, 60 and 120 progressive frame per a second. There is also a movement exploring the possibility of adopting 120 fps as a standard.
Stereoscopic 3D makes the illusion of depth in an image by means of binocular disparity. Binocular disparity is natural and inevitable since human eyes are approximately 6.5cm apart, which is called interocular distance, and the images for left and right eyes are slightly different. Lots of research efforts have been done to make the perception of reproduced stereo space look more realistic. However there is no perfect method for perfect 3D reproduction method so far. Main causes of this include inconsistency between accommodation and convergence points, crosstalk, geometry errors, sudden changes in the depth, different brightness, color and contrast between left and right images, flickering.

Figure 1. Effect of High Frame Rate

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2. Related Works

There has been research effort to embrace HFR into stereoscopic 3D. In [1], they proposed a novel motion estimation for frame rate up-conversion (FRUC) algorithm. In stereoscopic 3D, immature application of FRUC may cause severe annoying artifacts resulting from inconsistency between two motion vector fields. They obtained reliable and consistent motions having only horizontal disparity by searching motion for correspondences in stereo views simultaneously. In [2], they evaluate the effect of the frame rate on the reception of stereoscopic content in a cinema environment. They performed subjective assessment in three categories related to image perception, being smoothness of motion, sharpness of motion and overall visual impression. Stereoscopic team at Emily Carr provides a basis in for discussing best practices in Stereoscopic 3D production with High Frame Rate technology. They have given results with the variable frame rates of 24, 48 and 60 fps have shown that the emotional impact of static shots far exceeds what was originally expected for the viewers and dynamic shots still suffer from motion artifacts that are actually caused by the HFR. In [3], They demonstrated the effect of VFR (Variable Frame Rate) on aesthetic and immersionin the context of a single narrative, as well as the standalone benefits of higher frame rates in S3D. In [4], they performed subjective assessments of visual quality on resolutions, color formats, frame rates and compression rates to provide basis information for standardization of signal specification of Ultra High Definition video and viewing environments for future UHD TV. For the comparison between different frame rates, 4K UHD test sequences of 60 fps gives better subjective visual quality than those of 30 fps.

3. Experiments

The purpose of our experiment is to examine the relationship between a set of parameters and visual fatigue along with watching satisfaction. The set of parameters includes depth, speed and frame rates. We wanted to find out which combination of these parameters affects the degree of visual fatigue (or watching satisfaction). Measurement of visual fatigue and watching satisfaction have been made in subjective and objective ways. The number of participants for the experiment was 45.

The number of participants for the experiment was 45. They are at their 20s and 30s. In order to deliver test image to participants, 55inch 3DTV was used and the viewing distance was set at 3m, following the suggested watching distance by Korea Radio Promotion Association. Prior to the experiment, experiment procedure was explained to the subjects. Basic information was gathered (age, if they wear glasses). Inter-pupillary distance was measured as shown in figure 2 and then stereogram pairs were used to verify stereoscopic congnitional distinction. Total of 4 rectangle images, which are stereogram pairs, were placed and only one rectangle image was stereoscopic. Participants were asked to identify which rectangle image is stereoscopic.

Figure 2. Experiment Setup

Background and car object within test image have been modeled using Autodesk Maya. 3D space has been created using 3D camera of which those parameters include IOD, focal length and object distance. Since the output of Maya is exported in the form of individual frame, in order to generate moving picture, Adobe Premiere Pro has been used to generate 30f, 50f and 60f movie clips.
In figure 3, shown is the image that has been used in our experiment. In the image, there is a yellow car with background. The background is where the convergence point is set at.

Figure 3. Test Image

In order to examine whether high frame rate play back, being combined with other parameters, can possibly affect the degree of visual fatigue and watching satisfaction, we have defined the parameters set as depth, speed and frame rate. The depth parameter is applied to the car object within in the image. Stereoscopic depth of the car object takes 1, 2 and 3 negative parallax values in percentile of the screen. We have used 55 inch TV for the displaying device. The car moves from the left side to right side during the playback with different speeds. The parameter speed is employed to examine whether high frame rate playback is adequate for high speed events as sports. Speed parameter has four integer values; 2, 4, 6 and 8.

Those integer values represent the time for the car object finishes moving from left to right within the image. We have used still image where the car object does not move. In that case, the speed parameter is defined to be 8. For the frame rate parameter, we have selected three values; 30, 50 and 60.
We measured and recorded inter-pupillary distance, which is the distance between pupils, for every participant prior to the experiment. For the subjective assessment, participants were asked to express their degree of satisfaction as scores (between 0 and 10) for each of three different frame rate playbacks after they watched three test images. 45 participants made scores for 36 images, which is a combination of three parameters, depth, speed and frame rates.

Table 1. Parameter Values

Depth (percentile)	Speed (seconds)	Frame rates
{1, 2, 3}	{2, 4, 6, 8}	{30F, 50F, 60F}

4. Results

An ANOVA was performed with depth, speed and frame rate as independent variables, and satisfaction score as dependent variable. Since the goal of ANOVA is to test the equality of two or more population means by comparing the variance between samples to variation within each sample group, we defined each group to be an instance from combinations of depth and speed parameters. As a result, we have twelve groups.

Depth=1_Speed=2,Depth=1_Speed=4,Depth=1_Speed=6,Depth=1_Speed=8,
Depth=2_Speed=2,Depth=2_Speed=4,Depth=2_Speed=6,Depth=2_Speed=8,
Depth=3_Speed=2,Depth=3_Speed=4,Depth=3_Speed=6,Depth=3_Speed=8

Given a group of depth and speed, we examined 1) Does frame rate parameter makes a difference with regard to watching satisfaction? 2) When is the watching satisfaction achieved mostly for each depth and speed combination?

Table 2. Result of ANOVA Test

Depth*Speed	Frame Rates	Mean	F	p
1, 2	30 50 60	4.98 6.89 7.76	30.016	0.000
1,4	30 50 60	5.18 7.49 8.24	44.320	0.000
1,6	30 50 60	5.80 7.47 8.38	30.301	0.000
1,8	30 50 60	7.80 8.11 7.96	0.458	0.633
2,2	30 50 60	4.58 6.22 7.49	27.393	0.000
2,4	30 50 60	4.93 6.87 7.82	31.802	0.000
2,6	30 50 60	5.69 7.40 8.11	29.241	0.000
2,8	30 50 60	7.67 7.98 7.98	0.588	0.557
3,2	30 50 60	4.29 6.11 7.02	23.545	0.000
3,4	30 50 60	4.93 6.76 7.82	37.316	0.000
3,6	30 50 60	5.33 7.40 8.22	44.979	0.000
3,8	30 50 60	7.44 8.16 8.11	2.484	0.087

The result shows that participants have given preferences over higher frame rate playback in almost all cases of depth and speed combinations. In other words, the result showed that there exists a statistically significant differences across the test cases. The tendency, which is a favor over higher frame rate playback, becomes faint when the test image contains no movement. The highest satisfaction score was 8.38 and it was the case when depth and speed was 1 and 6 respectively. One-way ANOVA, utilizing the F distribution, is used to test whether there exists a difference among at least three groups. However, ANOVA test does not tell us where the difference lies. In order to know where the difference lies among groups, one has to go through another test as Scheffe' or Tukey test. These tests are post-hoc meaning that they are performed after an ANOVA test is performed.

The purpose of Tukey test is to identify which groups differ. ANOVA can tell us whether the groups in sample differ but it does not tell us about which groups differ. Tukey test is valid only if the result of ANOVA is positive; there is a statistically significant difference among the groups. Tukey test works on a value known as Honest Significant Difference (HSD) which becomes a distance between groups. This value is calculated using studentized range statistic.

Table 3. Analysis by Tukey Test

Depth*Speed	Partition
1,2	{30F} and {50,60}
1,4	{30F} and {50,60}
1,6	{30},{50},{60}
1,8	None
2,2	{30},{50},{60}
2,4	{30},{50},{60}
2,6	{30F} and {50,60}
2,8	None
3,2	{30F} and {50,60}
3,4	{30},{50},{60}
3,6	{30},{50},{60}
3,8	None

Table 3 shows the result after the Tukey test. We have 12 cases obtained from combining depth and speed parameters under which we have three cases; 30F, 50F and 60F. In our experiment, Tukey test told us where the difference lies in each of 12 cases. For example, when depth is 1 and speed is 2, the difference renders the group partitioned as {30F} and {50F, 60F}, which means 50F and 60F are not statistically different from each other, whereas 30F and {50F, 30F} are statistically different.

We have three cases where there is no difference under frame rate. Those are {1, 8}, {2, 8}, and {3,8} and they are all when the speed value is 8 which means the test image is still cut. In plain English it means there is no effect of frame rate with regard to watching satisfaction when there is no movement in images.

5. Conclusion and future work

We made test footage for the purpose of comparing 30 fps, 50 fps, 60 fps for stereoscopic 3D. From the experiment, overall results showed a preference for HFRs amonst the participants. More specifically, for any combination of depth and speed, the satisfaction score increased linearly. The effect of frame rate in case of still image that contains no movement of object turned out to be void. By performing post-hoc test, we identified where the participants' favor becomes different. In this work, we used subjective assessment method. For the future work, objective method such as EEG (electroencephalography) needs to be employed for the experiment and various frame rates need to be considered.

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