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Symmetric and Asymmetric Stereoscopic 3D Video Quality Assessment for Mobile Applications

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ABSTRACT

Due to advanced development of industry and key technologies, three-dimensional (3D) media has become a popular research area both for entertainment industry and scientific applications. However, the effects of these technologies on perceptual quality are still unexplored. Moreover, one of the key challenges of the 3D technology is provisioning of acceptable video quality for mobile video applications by meeting processing and network requirements over limited resources. In this paper, we have conducted subjective experiments to examine the effect of symmetric/asymmetric bit rate combinations as well as scene contents on overall perceptual quality and perceptual depth of 3D video in order that we can transmit sufficient quality video with optimum bit rate for mobile applications.

Keywords: Symmetric and asymmetric, 3D video, Stereoscopic, DSQS.

1. Introduction

The recent development of 3D display technology, 3D video communication and entertainment services are expected to become reality and redefine communication and entertainment services with high immersion. The demand of 3D imaging and video services are rapidly increasing in different applications such as entertainment, broadcasting both in 3DTV [1] and mobile 3DTV [2], robotic navigation [3], medical applications [4] etc. There are many alternative technologies for 3D image/video display and communication, including holographic, volumetric and stereoscopic; stereoscopic image/video seems to be the most developed technology at present [5]. Stereoscopic video consists of two views (left and right view) captured by two closely located cameras. These views constitute a stereo pair and can be perceived as a virtual view in 3D by human observers with the rendering of corresponding view points. Although subjective assessments are expensive for real time application, it provides the ultimate perceptual quality evaluation. In [6], the subjective impact of down sampling applied for one of the views in an uncompressed mixed-resolution stereoscopic video is studied. The result shows that lower-resolution view appeared to become dominant in the subjective quality rating at certain down sampling ratio which depend on the sequence, the angular resolution, and the angular width. In [7], the main issues relevant to comfort in viewing stereoscopic television is developed and analyzed after subjective tests related to accommodation-vergence conflict, parallax distribution, binocular mismatches, and depth, and cognitive inconsistencies. Barkowsky et al. developed studies about visual discomfort in stereoscopic 3D video sequences in [8, 9]. In [10], a subjective evaluation of visual discomfort is developed, where parallax limits and regions of comfort, depending on the screen size, disparity, and viewing time, are obtained. In [11], a subjective test methodology and 3D mobile video service scenarios such as environment of usage, user equipment and typical types of video content are investigated in order to achieve the best emulation of the real world scenario, covering the most frequent content classes. In [12], the paper provides an overview of the core technologies enabling the delivery of 3-D Media to next generation mobile devices. The comparative results identify the best coding and transmission approaches and the interaction between video quality and depth perception along with the influence of the context of media use. The user’s experienced quality of 3D visual content on mobile auto stereoscopic displays are studied in [13]. In [14], the authors examine the influence of depth and compression artifacts on the quality of experience of mobile 3D video content. One of the important conclusions is the strong dominance of compression over the varied depth levels. Although some researchers are still working to develop a new standard for efficient multi-view video coding, they believe the video compression technique that used in 2D video material can also be applied independently on the left and right videos of a stereo video pair to save valuable bandwidth and storage capacity [15], [16]. Accordingly, the H.264/AVC standard coder is applied individually to the left and right videos to compress the stereo video sequences [17]. Consequently, stereoscopic 3D video services require double bandwidth and storage space which is expensive compared to monoscopic video. Therefore, the challenge is to deliver adequate visual experience with limited resources that can satisfy the viewers. The technologies required for 3D video are emerging rapidly. However, the effect of these technologies as well as video compression on the perceptual quality of 3D viewing has not been thoroughly studied. Therefore, perceptual 3D video quality is an important issue to assess the performance of all 3D imaging applications. Although limited bandwidth, error-prone transmission channel, constrains of the receiving devices and amount of 3D data are the main factors for optimization of system resources [18], we consider only the factor limited bandwidth in this work. The goal of this paper is to examine the effect of bit rates both for symmetric/asymmetric bit rate combinations as well as scene contents on overall 3D quality and depth for mobile 3D video service. Subsequently, we recommend an optimum range of bit rate for the mobile application in order to get sufficient visual quality.

2. Subjective Experiments

2.1 Reference Sequences

We have used six high-quality reference sequences. The content of the videos comprised of indoor and outdoor scenes that ranges from low to medium motion, where the scenes were filmed at both close and faraway distances. Figure 1 shows one frame of each reference video. These videos show different contents.

(a) Balloon (b) Dancer (c) Kendo

(d) Lovebird (e) Newspaper (f) Poznan Street

Fig. 1: The sequences used in the experiment.

2.2 Test Sequences

Sixteen test sequences were created from each of the reference sequences by all possible symmetric and asymmetric combinations of four bit rates - 100, 150, 250 and 400 Kbps for left view and right view. Therefore, in total we had 96 test sequences. The videos were compressed by H.264 coder. The resolution of each video was 480×800 pixels (24 bit/pixel RGB color) and the duration was 8 seconds with 15fps.

2.3 Test Environment

The laboratory environment was set up according to the general viewing specifications of ITU-R BT.500 [19]. The mobile device chosen for subjective testing was LG P920 which has a 4.3 inch 3D LCD Auto stereoscopic display with a resolution of 480×800 pixels. The observers were allowed to adjust the position of the seat in front of the mobile device either in vertical or horizontal directions to get the best comfortable viewing position.

2.4 Visual Tests

All subjects participating in the study were students of University of Dhaka. They were entirely non-experts. Prior to the experiment the subjects had to go through two visual tests: Fract test (to examine normal or corrected binocular vision), the Ishihara test (to diagnose color blindness). The minimum requirement of visual acuity was set to 1. If subjects received a lower value than this or if they failed the Ishihara test, they would subsequently be pre-screened. A total of 31 subjects took part in the study.

2.5 Subjective Testing Design

We adopted the Double Stimulus Quality Scale (DSQS) method to judge 'perceptual quality' and 'perceptual depth' of the videos. The playlists were prepared for each subject by arranging 96 test videos in a random order to avoid contextual and memory effects in their judgment of quality. The judging of 'perceptual quality' and 'perceptual depth' individually required 45 minutes. To minimize the effects of viewer fatigue, the study was conducted in three sessions of 15 minutes each consisting of 32 sequences. In each sequence two versions of the same video clip were shown in succession. The first version is the 'Reference' which is an example of the best quality possible for that video sequence and it is an information only and not to be rated. The second version is the 'Test Sequence' and the task was to rate the 'perceptual quality' or 'perceptual depth' of this (and only this) second clip.

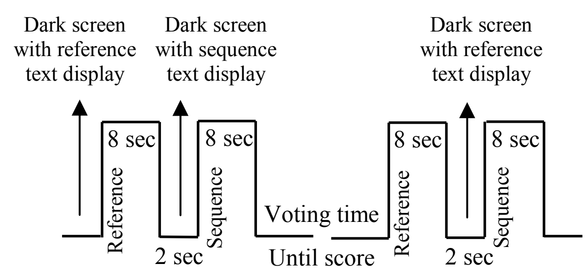

Fig. 2: Trial Structure of DSQS Method.

After displaying the Test video clip, the rating panel consisting of a discrete five point scale would appear on the mobile display. The five point 'perceptual quality' scales are Bad = 1, Poor = 2, Fair = 3, Good = 4, and Excellent = 5, and the five point 'perceptual depth' scales are Not perceptible at all = 1, Slightly perceptible = 2, Fairly perceptible = 3, Easily perceptible = 4, and Strongly perceptible = 5. Then the subjects selected their opinion regarding 'perceptual quality' or 'perceptual depth'. Once the vote was cast, the next video sequence was displayed. Note that the numerical values attached to each category were only used for data analysis and were not shown to the subjects. At the end of each experiment, the raw scores were collected in a data file of the mobile. Mean opinion scores (MOSs) were then computed separately for 'perceptual quality' and 'perceptual depth' for each video after the screening of post-experiment results according to ITU-R BT.500 [19].

2.6 Screening of the Observer Calculation of Mean Scores

At first the mean score, $\bar{u}_{jkr}$, for each presentation was calculated:

$$\bar{u}_{jkr} = \frac{1}{N}\sum_{i=1}^{N} u_{ijkr} \qquad (1)$$

where, u_{ijkr} is the score of observer i for test condition j, sequence/image k, repetition r and N is the number of observers.

Similarly, overall mean scores, $\bar{u}_j$ and $\bar{u}_k$, could be calculated for each test condition and each test sequence/image.

Calculation of Standard Deviation:

The standard deviation for each presentation, S_{jkr}, is given by:

$$S_{jkr} = \sqrt{\sum_{i=1}^{N} \frac{(\bar{u}_{jkr} - u_{ijkr})^2}{(N-1)}} \qquad (2)$$

Calculation of Kurtosis Coefficient:
For each test presentation, kurtosis coefficient, β_{2jkr}, where β_{2jkr} is given by:

$$\beta_{2jkr} = \frac{m_4}{(m_2)^2} \qquad (3)$$

$$\text{where} \quad m_x = \frac{\sum_{i=1}^{N} (u_{ijkr} - \bar{u}_{ijkr})^x}{N} \qquad (4)$$

Rejection of Observers:

For each observer, i, find P_i and Q_i, i.e.

for $j, k, r = 1, 1, 1$ to J, K, R

if $2 \le \beta_{2jkr} \le 4$, then:

if $u_{ijkr} \ge \bar{u}_{jkr} + 2\, S_{jkr}$ then $P_i = P_i + 1$

if $u_{ijkr} \le \bar{u}_{jkr} - 2\, S_{jkr}$ then $Q_i = Q_i + 1$

else:

if $u_{ijkr} \ge \bar{u}_{jkr} + \sqrt{20}\ S_{jkr}$ then $P_i = P_i + 1$

if $u_{ijkr} \le \bar{u}_{jkr} - \sqrt{20}\ S_{jkr}$ then $Q_i = Q_i + 1$

If $\dfrac{P_i + Q_i}{J \cdot K \cdot R} = 0.05$ and $\left|\dfrac{P_i - Q_i}{P_i + Q_i}\right| = 0.3$

then reject observer i

where N = number of observers, J = number of test conditions including the reference, K = number of test pictures or sequences, R = number of repetitions, L = number of test presentations.

3. Result Analysis for Perceptual Quality

3.1 Effect of Symmetric/Asymmetric Bit Rate Combination

In this study, the total bit rate ranges from 200 to 800 Kbps. For convenience, this range is divided into three bit rate bands: low, medium and high.

Low	Medium	High
200 to 350 Kbps	**400 to 550 Kbps**	**650 to 800 Kbps**

The effect of bit rate on perceptual quality can be analyzed from Figure 3 which shows MOS vs. bit rate combination for all sequences. It can be seen that with increasing bit rate the quality score increases as expected. The effect of symmetric bit rate combination on quality is shown in Figure 4. The lowest bit rate (100-100) Kbps shows the lowest quality score for all the sequences. For (150-150) Kbps, better quality score is seen in Dancer, Newspaper and Poznan Street sequences. All sequences show good quality score at (250-250) Kbps which is on an average MOS value 3.5.

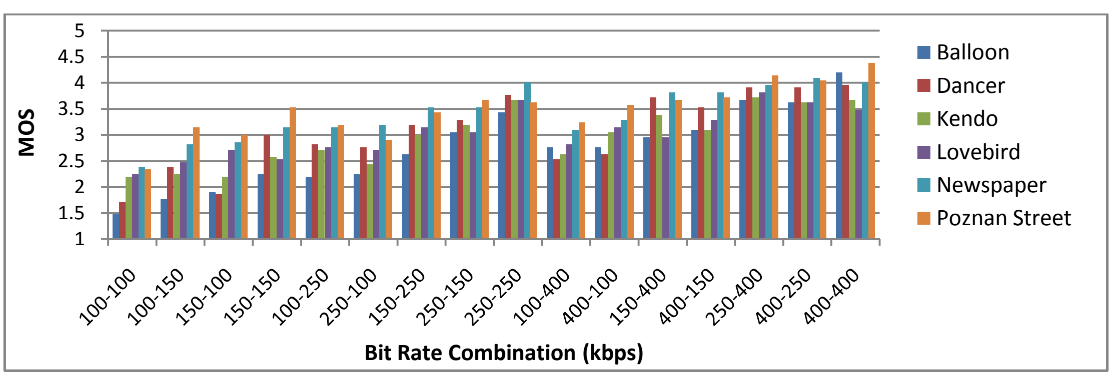

Fig. 3: Quality scores at different bit rate combinations.

The highest quality is perceived at (400-400) Kbps for all sequences. Moreover, (250-250) Kbps exhibits similar results as (400-400) Kbps except for the sequences Balloon and Poznan Street.

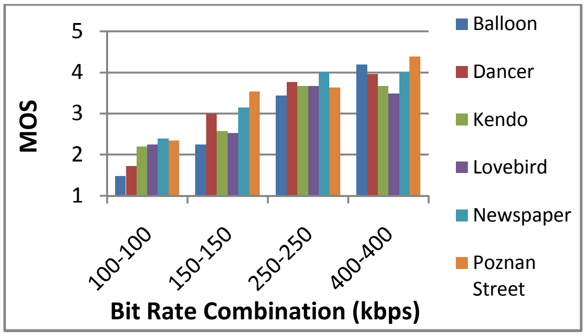

Fig. 4: Quality scores for symmetric bit rate combinations.

Figure 5 shows the effect of symmetric and asymmetric bit rate combination on perceptual quality. In the medium bit rate band, the symmetric combination (250-250) Kbps requires 500 Kbps for transmission. Let us consider some asymmetric combinations which require nearly 500 Kbps. The asymmetric combinations (150-250) Kbps and (250-150) Kbps require 400 Kbps while the combinations (100-400) Kbps and (400-100) Kbps require 500 Kbps for transmission. For all six sequences it is observed that the combinations (150-250) Kbps and (250-150) Kbps exhibit better quality scores than (100-400) Kbps and (400-100) Kbps.

For (100-400) Kbps and (400-100) Kbps, the difference between left and right view bit rate is 300 whereas for (150-250) Kbps and (250-150) Kbps this difference is only 100. Therefore, it can be said that whenever the difference between left and right view bit rate is greater the perceptual quality of 3D video degrades. Moreover we can say that even though the asymmetric combinations (100-400) Kbps and (400-100) Kbps require the same number of bits for transmission as the symmetric combination (250-250) Kbps, the former combination pair provides poor quality scores because of the large difference between left and right view bit rate. It is also observed that (250-250) Kbps gives better result than asymmetric combinations (250-150) Kbps, (150-250) Kbps, (100-400) Kbps and (400-100) Kbps for all sequences except Poznan Street. Now in the high bit rate band, the symmetric combination (400-400) Kbps requires 800 Kbps for transmission whereas the asymmetric combinations (250-400) Kbps and (400-250) Kbps require 650 Kbps but exhibit similar quality scores as compared to (400-400) Kbps and for some sequences (Lovebird, Kendo and Newspaper) even better.

Furthermore, (250-400) Kbps achieved higher MOS than (400-250) Kbps in all sequences except Newspaper. Finally, observing the quality scores for the combinations (250-250) Kbps and (250-400) Kbps, it was found that the quality scores for (250-400) Kbps are always better than (250-250) Kbps. Therefore, we can conclude with that symmetric bit rate is suitable in medium bit rate band. On the other hand in high bit rate band (above 650 Kbps), asymmetric bit rate combinations are preferable.

3.2 Effect of Left/Right View Dominance

Better quality score is observed when the left view bit rate dominates for all combinations except (400-250) Kbps for Balloon. In case of Dancer and Kendo, when the right view bit rate dominates better result is obtained except (150-250) Kbps and (100-400) Kbps. But for Lovebird and Poznan Street, it is found that the left view dominates for three combinations and the right view dominates on the other three. So for these two sequences, it is difficult to state which view dominates over the other. Again for Newspaper, the MOS is higher where the left view bit rate is higher than the right view bit rate for all different combinations.

An interesting observation is that (400-100) Kbps always achieved higher MOS than (100-400) Kbps for all the six sequences. So it can be implied that for any pair of asymmetric combination in the medium bit rate band, if the difference between left and right view bit rate is greater, then the left view bit rate dominates. Another observation is that (250-400) Kbps achieved higher MOS than (400-250) Kbps for all the sequences except Newspaper.

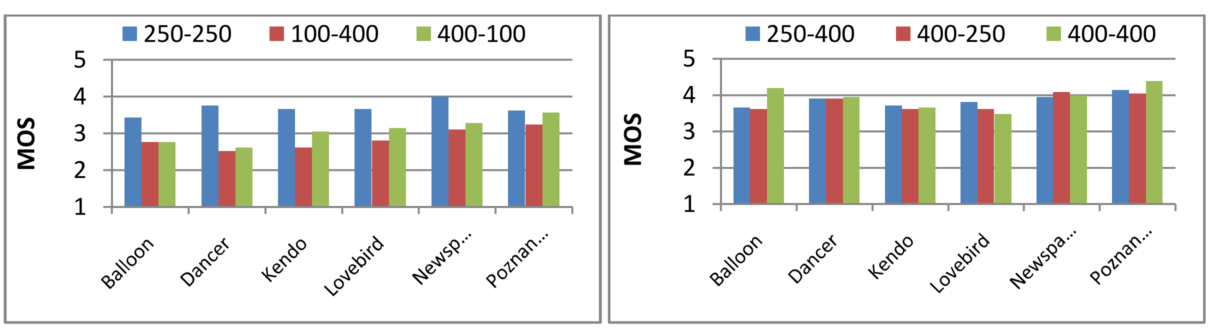

Fig. 5: Effect of symmetric and asymmetric bit rate combination on perceptual quality.

So in this particular case we can say that the right view bit rate dominates. Moreover the asymmetric combination (250-400) Kbps is found to give comparable results as (400-400) Kbps for all the sequences. Considering this it can be said that satisfactory results can be achieved in the high bit rate band when the right view bit rate dominates the left with a moderate difference between them.

3.3 Effect of Scene Content

It is observed that for the same bit rate combination, different sequences achieved different quality scores which indicate that perceptual quality of 3D videos depends on the scene content. The six sequences used in this study have a variety of contents comprising of low to medium motion.

Balloon is an indoor studio type video. The camera moves from left to right with medium motion. It consists of medium complex depth structure which shows balloons of different colors and a person showing magic. The mostly fixated object in this scene is the person i.e., the person's face grabs the visual attention more than any of the scene contents. At lower bit rates blockiness is more visible on human face than any other parts, moreover the edges of the balloons were not sharp enough, that's why the quality scores were relatively poor. It is seen that as the bit rate increases the blockiness on the human face decreases.

Dancer is a computer simulated synthetic video which does not have much scene content. It has medium motion. The camera used for capturing the scene moves from left to right. When the dancer dances, at lower bit rates blockiness is seen in his hand movements.

Kendo is an indoor studio type video containing complex object motion with fog, reflections and transparency. This sequence has high detail and medium complex depth structure in which two persons are fighting in front of some audience. At lower bit rates, blockiness is more visible at homogenous color than in contrasts. As a result in this sequence blockiness is seen in the background where the color is red. Moreover, the viewers' faces are blurred. With increasing bit rate these limitations slowly eradicates.

Lovebird represents a quiet dialogue in movie type of scene which was shot outdoor in natural light. It contains simple object motion but no camera motion. It has high detail and complex depth structure. It shows a couple walking slowly towards the camera. It has moderate scene content. At lower bit rates over long distance the faces of the couple are blurred but the blurriness is reduced as they walk towards the camera. If the background of the scene contains a lot of contrasting elements like in Lovebird then blockiness is not visible at lower bit rates. However, as the couple walks towards the camera it creates a sense of visual discomfort.

Newspaper represents a soap opera type of scene which was shot indoor in studio light. It contains simple object motion but no camera motion. It has high detail and medium complex depth structure. It shows two persons sitting in a table reading newspaper and then another person walks in. As blockiness is more visible at homogeneous color than contrasts, therefore blockiness is visible at the shirt of the men but not at the woman's sweater as it has different colors in it.

Poznan Street is an outdoor scene which shows a street with several cars in motion and a person crossing it. It was shot in natural light. The sequence exhibits medium motion while the camera is still. It has high detail and complex depth structure. When an object moves at a moderate speed it shows blockiness at lower bit rates like in Poznan Street. Blockiness is visible when the cars move along the road but when the human crosses the road it is not much visible.

The scene contents are affected mainly by two artifacts: blocking effect and blurriness. These artifacts are more visible in lower bit rates. However it is seen that if the background of the scene contains a lot of contrasting elements then blockiness is not visible at lower bit rates but if the background is shaded then blockiness is noticeable. With increasing bit rate the effect of these artifacts tend to decrease; as a result the overall quality increases. Finally we can conclude with that any sequence containing both moderate object and camera motion should be transmitted in medium bit rates for satisfactory quality.

4. Result Analysis for Perceptual Depth

4.1 Effect of Symmetric/Asymmetric Bit Rate Combination

Analyzing the MOS for perceptual depth for Figure 6, we observed that depth always achieved higher scores when compared to quality. Therefore we can say that depth is not much affected by bit rate combination as quality. However, in case of a suitable bit rate for transmission similar results as quality has been observed. Now, Figure 7 shows perceptual depth scores for symmetric bit rate combinations.

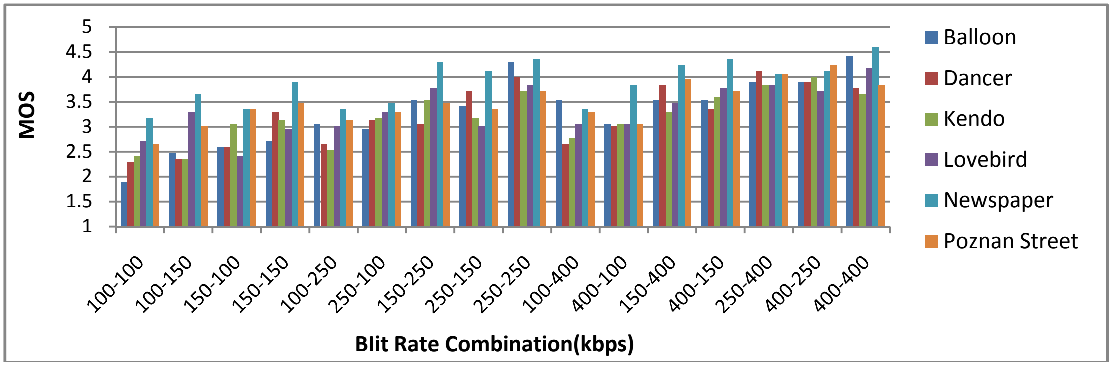

Fig. 6: Depth perception scores at different bit rate combinations.

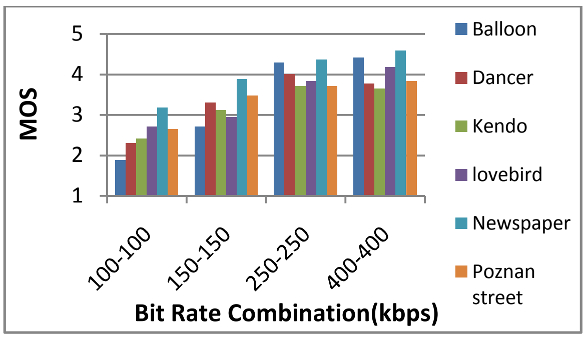

Fig. 7: Depth perception scores for symmetric bit rate combinations.

The lowest bit rate combination (100-100) Kbps shows the lowest depth perception scores for all the sequences. All the sequences show better depth perception score which is on an average

MOS 3.5 at (250-250) Kbps and (400-400) Kbps. The highest depth perception score for symmetric bit rate combinations is achieved at (400-400) Kbps for all the sequences except for Dancer and Kendo.

Figure 8 shows the effect of symmetric and asymmetric bit rate combination on perceptual depth. With increasing bit rate, the depth perception scores for all the sequences are observed to be varying slightly. In case of the medium bit rate band, even though the symmetric combination (250-250) Kbps and asymmetric combinations (100-400) Kbps and (400-100) Kbps require a total of 500 Kbps, but a noticeable difference is observed in the depth perception scores between these bit rate combinations. This discrepancy arises because there is a large difference between left and right view bit rate. We can say that for the transmission of equal number of bits, the symmetric combination achieves better score than the asymmetric combination having a large difference between left and right view bit rate. In case of high bit rate band, asymmetric bit rate combinations (250-400) Kbps and (400-250) Kbps show comparable score as (400-400) Kbps, and even better for Dancer, Kendo and Poznan Street Sequences. So similar to quality, at higher bit rate combinations the perceptual depth does not differ much for symmetric/asymmetric bit rate combinations.

4.2 Effect of Left/Right View Dominance

After considering all the sequences it can be said that it is difficult to summarize depth perception by left or right view bit rate dominance.

4.3 Effect of Scene Content

From our study, it is found that for same bit rate combinations just like quality, depth perception for different sequences varies with the scene contents.

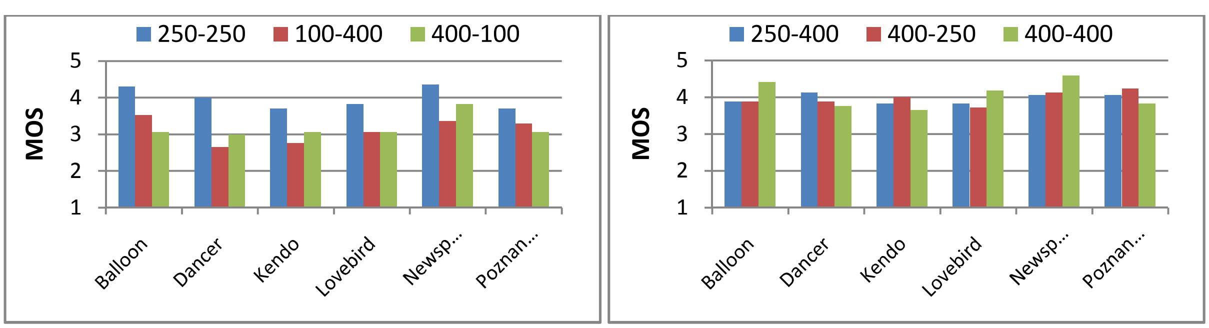

Fig. 8: Effect of symmetric and asymmetric bit rate combination on perceptual depth.

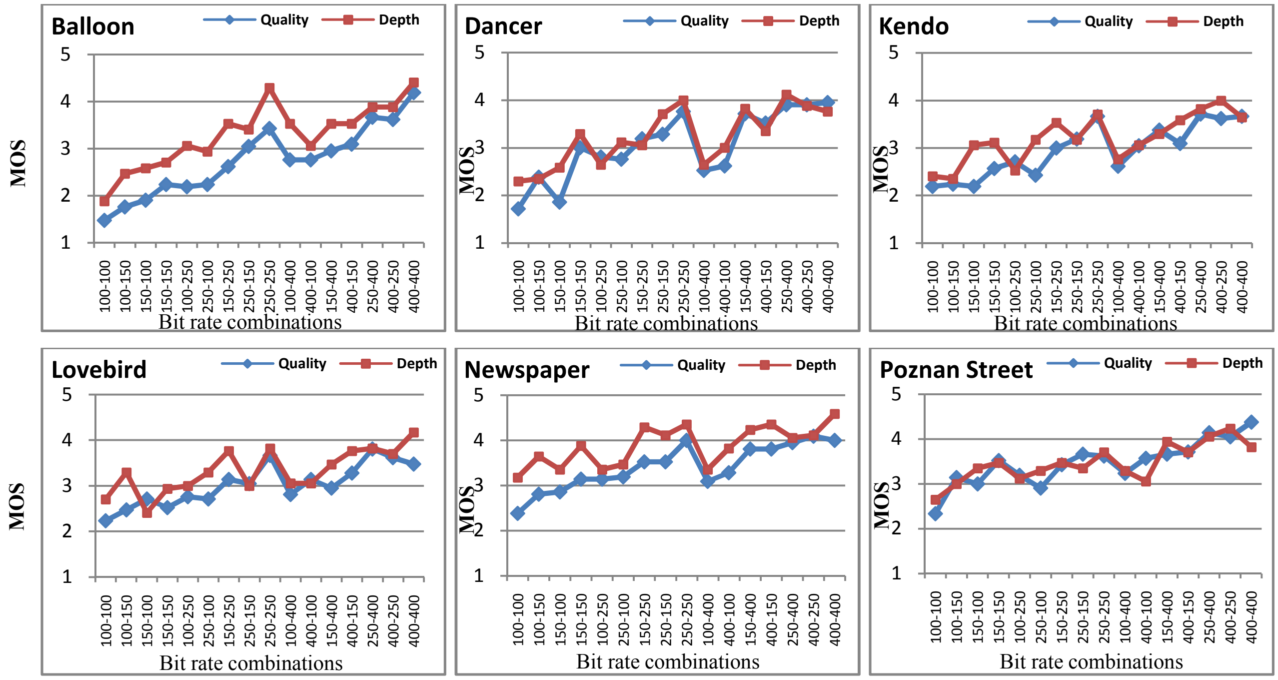

Fig. 9: Comparative analysis between quality and depth perception scores.

Balloon shows a large number of content in this scene, so when the observer moves from the fixed viewing position 'ghosting effect' occurs i.e. the sequence may appear as it isn't fused well which affects observer's opinion unfavorably.

In Lovebird, a couple walks towards the camera. As the distance between the couple and the camera becomes too small relative to the inter-camera distance, it creates a slight sensation of visual discomfort due to the high value of disparity which eventually led the viewers to give substandard ratings.

For Newspaper no significant variation in MOS is observed. This may be because the scene does not contain much motion. Moreover the MOS is higher than other sequences because it is easy to perceive depth between stationary objects.

5. Comparative Analysis of Quality and Depth

In this section, we intend to see if quality and depth perception scores follow any similar traits by comparing the MOS of perceptual quality with that of MOS of perceptual depth which are calculated by:

$$MOS_{Quality} = \frac{1}{N}\sum_{i=1}^{N} Q_i \quad (5)$$

$$MOS_{Depth} = \frac{1}{N}\sum_{i=1}^{N} D_i \quad (6)$$

From Figure 9 it is observed that depth perception scores are higher to some extent than the quality scores. Because, it is seen that the depth perception does not entirely depend on the bit rate combinations. Moreover, the figure validates the fact that quality and depth perception scores do not follow any similar pattern. The observation can be more generalized in future with the consideration of wide verities of scene contents and bit rates.

6. Conclusion

In this study, the objective was to find a suitable low bit rate combination through subjective experiments for mobile 3D video transmission that would give good quality and depth perception scores. To achieve fair quality and depth perception we can utilize the medium bit rate band. For that (250-250) Kbps symmetric combination can be used instead of its neighboring asymmetric combinations. Now for the high bit rate band, it is observed that the MOS of (250-400) Kbps and (400-250) Kbps are very close to that of (400-400) Kbps. Therefore, they can be used instead of (400-400) Kbps, and then the transmission bit rate would reduce from 800 to 650 Kbps. Moreover, it is apparent from the results that the depth perception scores are always higher than quality scores. This implies that bit rate combination do not affect depth perception as much as quality.

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