Computational Model for Stereoscopic Image Quality Prediction

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Abstract. In the modern era of Internet along with 3D imaging and communication system, many user-end applications require the estimation of quality of 3D images directly from the bit streams, as the original image may not be available. Though several metrics have been proposed in literature to assess the full reference perceptual quality of 3D images, however no reference quality assessment is still undeveloped which is a challenging issue. Therefore, in this paper, we propose a no reference stereoscopic image quality evaluation model based on image artifacts and disparity measure with the incorporation of Human visual system (HVS) characteristics. Based on HVS, we believe that perceptual artifacts of any image are strongly dependent on local features, such as plane and non-plane areas. For this reason, plane and non-plane area based blockiness and blur artifacts and also disparity are measured in this model. The experimental results show that the proposed model gives high correlation with subjective Mean Opinion Score (MOS).

Keywords: No-reference, Disparity, JPEG, Auto stereoscopic display, Segmentation, Blockiness.

1 INTRODUCTION

The stereo image is regarded as an important trend of image technology with variety of potential application ranging from entertainment (video, games) to more specialized application such as the educational ones[William 2006] and medical application like body exploration[Ljung 2007, Westin 2007],therapeutic purposes[Kort 2006], and so forth. Since stereoscopic vision is a subjugation of left and right views of the same scene, it requires additional storage and bandwidth for transmission. Therefore, each stages of communication such as manipulation, processing, storing, and transmission over noisy channels may introduce perceivable distortion. To quantify these types of degradations, either subjective tests or objective metrics are used. Generally speaking, subjective image quality scoring is closer to human's perception; yet it needs more time, manpower as well as higher costs. On the other hand, objective quality testing needs less time and is convenient to implement. There are three types of objective quality metric used for image quality evaluation, full reference (FR), reduced reference (RR) and no reference (NR). Among these quality metrics, NR method is the most attractive since it does not need any prior knowledge about the reference image in order to quantify the degraded one. Moreover the objective quality assessment should be linked with human visual characteristics rather than traditional path concerningS errors in statistics. Therefore, perceived image quality assessment based on human visual system (HVS) is required to ensure the applied compression techniques and the levels for the target stereo image processing applications.

Existing work on perceptual quality evaluation for 3D stereoscopic images is mostly focused on assessing the quality degradation of the image by comparing with its undistorted(Full Reference method) or some extracted feature of the original(Reduced reference method) one. Different types of subjective assessments are conducted in [Stelmach 2000, IJsselsteijn 2000, Seuntiens 2006].

Xinga et al. [Xinga 2010] proposed a perceptual quality metric which takes characteristics of stereoscopic images into account for predicting quality levels of crosstalk perception in stereoscopic images. Whereas Besalma's[Bensalma 2010] proposed quality metric was based on spatial-frequency transform which replicates the behavior of human visual cortex to merge left and right image. Besides, yang et al. [Yang 2010], proposed a model based on human visual system. Again, [You 2010, Benoit 2008] have evaluated whether 2D objective image quality metrics are suitable for quality assessment of stereo images. In addition, other perceptual quality metrics have been proposed, which originate from findings that the perceived quality of stereoscopic images is strongly dependent on the distribution of artifacts at different depth layers [Olsson 2007], the sensitivity of the human visual system (HVS) to contrast and luminance changes in regions with high spatial frequency [Gorley 2008], and local features, such as edge, flat and texture [Sazzad 2009], respectively. An objective metric that considers both acquisition and display induced issues has also been proposed in [Kim 2009]. On the other hand, Stelmatch et al.[Stelmach 2000], proposed subjective quality assessment based on Mixed spatio-temporal resolution. It was found that perceived depth is relatively unaffected by mixed resolution. [IJsselsteijn 2000 Seuntiens 2006] have evaluated subjectively effect of camera parameter, display duration on stereoscopic images. So it is clear from the above discussion that most of the proposed quality assessment models are based on full reference method where a reference / original image is required to assess the quality of the distorted image. Whereas, it is highly desirable to develop quality assessment methods that do not require full access to the reference images. Again different sensitivity of human based on local features such as uniform (i.e., area with less edges) and non-uniform (i.e, area with more edges) areas remain unexplored in most of them. So the objective of this paper is to develop a NR objective quality assessment method for coded stereoscopic images based on local feature supported by HVS. Since JPEG is one of the most commonly used coding scheme, this work deals with the issues of measuring the image quality of JPEG images. Under the assumption that human visual perception is very sensitive to edge information of an image and any kinds of artifacts create pixel distortion, a discrimination algorithm is required and developed in this paper. The result of this algorithm is evaluated by using Toyama database [MICT 2009]. The rest of the paper is spitted as follows. In the next section, we describe my approach and the techniques to construct an automatic NR objective method for stereoscopic image quality assessment. The results and the discussion of our algorithm are given in Section 3. Finally, Section 4 concludes the paper. Future works are also mentioned in the same section.

2 OBJECTIVE STEREOSCOPIC IMAGE QUALITY EVALUATION

Image Compression and delivery process causes artifacts, which result in annoying effects to the viewer. Major coding artifacts include blockiness, blurring, edge damage and ringing [Sazzad 2008]. However the perceptual distortion strength and the location of the distortions are not only determined by the level of Compression but also by the scene. For instance, JPEG coding introduces blockiness that is most easily perceived in uniform regions whereas the introduction of Blurriness is perceived mostly in non uniform area. On top of that, the blur and blockiness increase significantly when the level of compression is high (i.e., low bit rate per second). Thus higher the blur, more smoother the image signal is which causes the reduction of signal edge points. Consequently, the average edge point detection of a block give more insight about the relative blur in an image. Here, zero-crossing [Jain 1988]; an edge detecting technique is used for edge detection. These results suggest that, Blur and blockiness artifacts can be determined by using zero-crossing and blockiness algorithm respectively. Here we have calculated horizontal blockiness only because perceived blockiness depends on horizontal blockiness rather than the vertical one. To get the effect of overall image artifacts for an asymmetric stereo pair, we take the maximum blockiness and blur values between the left and right views of a stereo pair. Therefore, we consider the higher blockiness and the lower zero-crossing values between the two views. For simplicity, only the luminance component is considered to make quality prediction of the color stereo images. The details of my segmentation algorithm to classify an image into uniform and non-uniform areas are discussed in [Won 1999, Won 2002]. Again we believe that 3D depth perception is strongly dependent on objects, structure or texture edges of stereo image content. Therefore, an NR perceptual stereoscopic image quality assessment method is proposed based on segmented local features of artifacts and disparity in this research. The proposed NR objective stereoscopic image quality assessment method based on artifacts and disparity measures distinctly for uniform and non-uniform areas is shown in Fig.1.

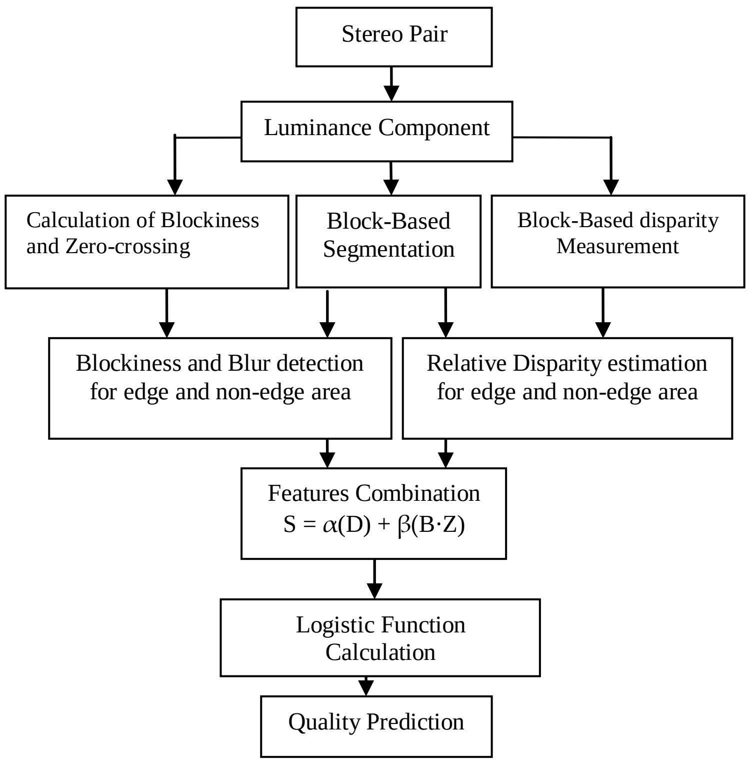


Fig. 1. NR objective Quality Evaluation Model.

2.1 Image artifacts measure

To measure JPEG coded stereo image artifacts, we estimate blockiness and zero-crossing in spatial domain based on segmented local features. To measure these two artifacts the following steps are used. At first, we calculate the blockiness and zero-crossing of each block of the stereo image pair separately (left and right images). In the second, the block (8×8) based segmentation algorithm is applied to the left and right images separately to classify uniform, and non-uniform blocks within the images. The average value of Blockiness and zero-crossing are calculated separately for the edge, and non-edge blocks (for uniform and non-uniform areas) for each of the stereo pair. The total blockiness and zero-crossing of a stereo image pair is calculated by taking the maximum blockiness and the minimum zero-crossing between the left and right of a stereo image pair. Finally, we update the total blockiness and zero-crossing values with weighting factors by using the Optimization algorithm.

The mathematical features, blockiness and zero-crossing measures within each block of images are calculated horizontally and then vertically.

For horizontal direction: Let the test image shown in Fig.2 is x(m,n) for m ϵ [1,M] and n ϵ [1,N]. For that image a differencing signal ($d_h(m,n)$) along each horizontal line is calculated by,

$$d_h(m,n) = | \, x(m,n+1) - x(m,n) \, | \tag{4}$$

where n ϵ $[1, N-1]$ $and\ m\ \epsilon\ [1, M]$.

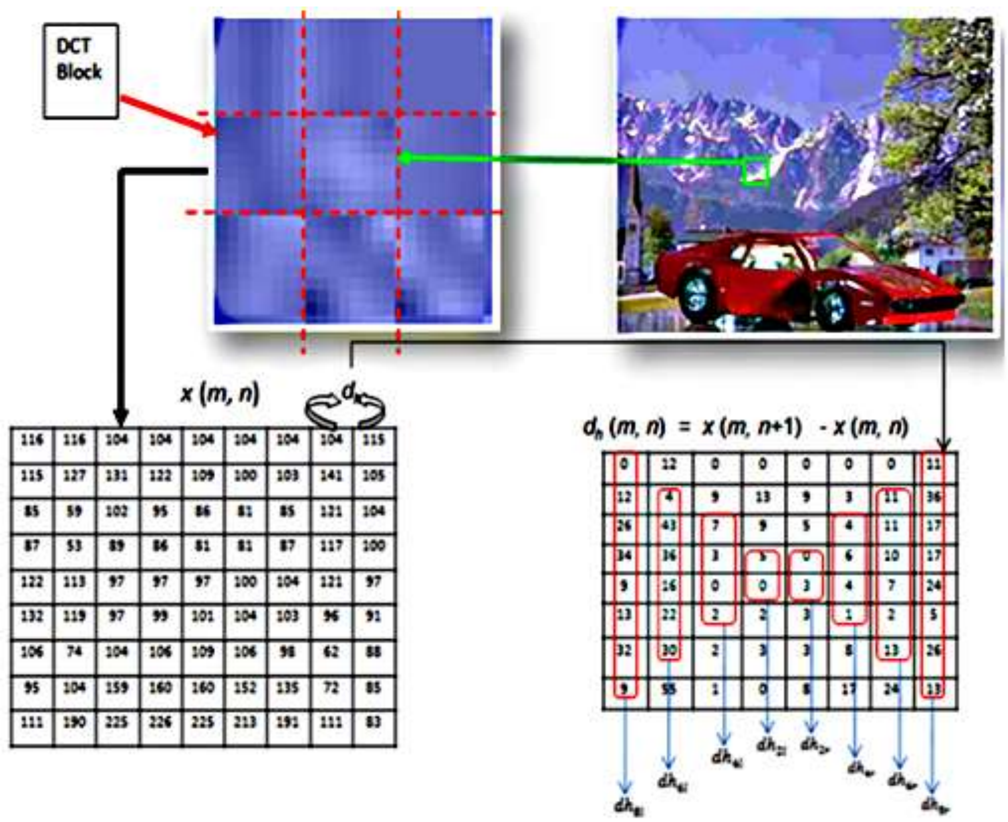


Fig. 2. Calculation of Blockiness.

Blockiness of a block(8×8) in horizontal direction is estimated by, averaging the pixel values 2x2, 4x4, 6x6, 8x8 from left and right side separately,

$$dh_{2l} = \frac{1}{2}\sum_{i+3}^{i+4} d_h(i, j+3) \tag{5}$$

$$dh_{2r} = \frac{1}{2}\sum_{i+3}^{i+4} d_h(i, j+4) \tag{6}$$

$$dh_{4l} = \frac{1}{4}\sum_{i+2}^{i+5} d_h(i, j+2) \tag{7}$$

$$dh_{4r} = \frac{1}{4}\sum_{i+2}^{i+5} d_h(i, j+5) \tag{8}$$

$$dh_{6l} = \frac{1}{6}\sum_{i+1}^{i+6} d_h(i, j+1) \tag{9}$$

$$dh_{6r} = \frac{1}{6}\sum_{i+1}^{i+6} d_h(i, j+6) \tag{10}$$

$$dh_{8l} = \frac{1}{8}\sum_{i}^{i+7} d_h(i, j) \tag{11}$$

$$dh_{8r} = \frac{1}{2}\sum_{i}^{i+7} d_h(i, j+7) \tag{12}$$

Then, maximum *dh* from left and right is calculated.

$$dh_{2(max)} = \begin{cases} dh_{2l} & if\ dh_{2l} > dh_{2r} \\ dh_{2r} & if\ dh_{2r} > dh_{2l} \end{cases} \tag{13}$$

Similarly $dh_{4(max)}, dh_{6(max)}, dh_{8(max)}$ are obtained.

Finally, the horizontal blockiness of a block ($B_{h(block)}$) is found by,

$$B_{h(block)} = \sqrt{\left(dh_{2(max)}\right) + \left(dh_{4(max)}\right) + \left(dh_{6(max)}\right) + \left(dh_{8(max)}\right)} \tag{14}$$

Now, for the horizontal zero-crossing (ZC):

$$d_{h-sign}(m,n) = \begin{cases} 1 & if\ d_h(m,n) > 0 \\ -1 & if\ d_h(m,n) < 0 \\ 0 & otherwise \end{cases} \tag{16}$$

$$d_{h-mul} = d_{h-sign}(m,n) \times d_{h-sign}(m,n+1) \tag{17}$$

We define for n ϵ [1, N-2]:

$$z_h(m,n) = \begin{cases} 1 & if\ d_{h-mul} < 1 \\ 0 & otherwise \end{cases} \tag{18}$$

where the size of $z_h(m,n)$ is M × (N −2). The horizontal zero-crossing of a block (8 × 8), ZC_{bh}, is calculated as follows:

$$ZC_{bh} = \sum_{i=1}^{8}\sum_{j=1}^{8} z_h(i,j) \tag{19}$$

Similarly, the vertical zero-crossing of a block (8 × 8), ZC_{bv} can be measured.

Thus, We can calculate blockiness and zero-crossing of each available block of the left and right images. Therefore the overall feature B_b and ZC_b per block are given by,

$$B_b = B_h \tag{20}$$

Since horizontal blockiness is more prominent than the vertical one.
Again,

$$ZC_b = \frac{ZC_{bh}+ZC_{bv}}{2} \tag{21}$$

Consequently, the average blockiness value of uniform, and non-uniform areas of the left image are calculated by:

$$Bl_e = \frac{1}{N_e}\sum_{b=1}^{N_e} B_{be} \tag{22}$$

$$Bl_n = \frac{1}{N_n}\sum_{b=1}^{N_n} B_{bn} \tag{23}$$

Where N_e, and N_n are respectively the number of uniform, and non-uniform blocks of the image. Similarly, the average blockiness values of Br_e and Br_n for the right image are calculated. Accordingly, the average zero-crossing values of ZCl_e and ZCl_n for the left image are estimated by:

$$ZCl_e = \frac{1}{N_e}\sum_{b=1}^{N_e} ZC_{be} \tag{24}$$

$$ZCl_n = \frac{1}{N_n}\sum_{b=1}^{N_n} ZC_{bn} \tag{25}$$

Similarly, the average zero-crossing values of ZCr_e and ZCr_n for the right image are calculated. Afterward we calculate the total blockiness and zero-crossing features of uniform and non-uniform areas of the stereo image. For the total blockiness features (B_e and B_n) of a stereo image, we consider the maximum values for a pair by using following algorithm:

$$B_{e/n}\text{ (Bl, Br)} = \text{max (Bl, Br)} \tag{26}$$

However for zero-crossing features (ZC_e and ZC_n), we estimate the minimum values of a stereo image pair by using the following equation:

$$ZC_{e/n}\text{ (ZCl, ZCr)} = \text{min (ZCl, ZCr)} \tag{27}$$

Finally, the overall blockiness, and zero-crossing of each stereo image pair are calculated by

$$B = B_e^{w_1} + B_n^{w_2} \tag{28}$$

$$Z = ZC_e^{w_3} + ZC_n^{w_4} \tag{29}$$

Where w_1 and w_2 are the weighting factors for the blockiness of uniform, and non-uniform areas and also w_3 and w_4 are the weighting factors for zero-crossing.

2.2 Disparity Estimation

Although, many feature based approaches are used for stereo matching/disparity estimation [Sazzad 2009], a simple block based structural similarity index matching (SSIM) [Won 1999] is used here. The principle of the disparity estimation is to divide the left image into non overlapping 8x8 blocks with classification of edge and non-edge blocks. For each 8x8 block of the left image, stereo correspondence searching is conducted based on maximum quality index and up to ±128 pixels of the right image. As the stereoscopic images database that we consider in our research is epi-polar rectified images, the displacement between the left and right view of a stereo pair is considered in horizontal direction only.

In order to measure disparity, firstly, the segmentation algorithm is applied to the left image only to classify the edge and non-edge block. Secondly quality index is measured in the two corresponding blocks between the left and right images. The quality index Q is defined by,

$$Q = \frac{4\sigma_{xy}\bar{x}\,\bar{y}}{(\sigma_x^2 + \sigma_y^2)[(\bar{x})^2 + (\bar{y})^2]} \tag{30}$$

Where, $\boldsymbol{x} = \{x_i |\, i = 1,2,\ldots\ldots\ldots,64\}$ and, $\boldsymbol{y} = \{y_i |\, i = 1,2,\ldots\ldots\ldots,64\}$ be the left and right image blocks, respectively. And,

$$\bar{x} = \frac{1}{64}\sum_{i=1}^{64} x_i \quad , \quad \bar{y} = \frac{1}{64}\sum_{i=1}^{64} y_i$$

$$\sigma_x^2 = \frac{1}{63}\sum_{i=1}^{64}(x_i - \bar{x})^2 \,,\; \sigma_y^2 = \frac{1}{63}\sum_{i=1}^{64}(y_i - \bar{y})^2$$

$$\sigma_{xy}^2 = \frac{1}{63}\sum_{i=1}^{64}(x_i - \bar{x})\,(y_i - \bar{y})$$

The dynamic range of Q is[-1,1]. The best value 1 is achieved if and only if $x_i = y_i$ for all i=1,2,……….64.

For each 8x8 block of the left image, disparity index is found by searching the position of maximum quality index up to ±128 pixels of the right image. Disparity estimation using quality index Q is shown in Fig. 3.Fig. 4 shows the Depth index DI of two stereoscopic image pairs.

$$DI = max\begin{Bmatrix} Q_{-128}, Q_{-127}, Q_{-126}, \ldots\ldots\ldots\ldots \\ \ldots, Q_{-1}, Q_0, Q_1 \ldots\ldots\ldots\ldots\ldots\ldots, Q_{127}, Q_{128} \end{Bmatrix}$$

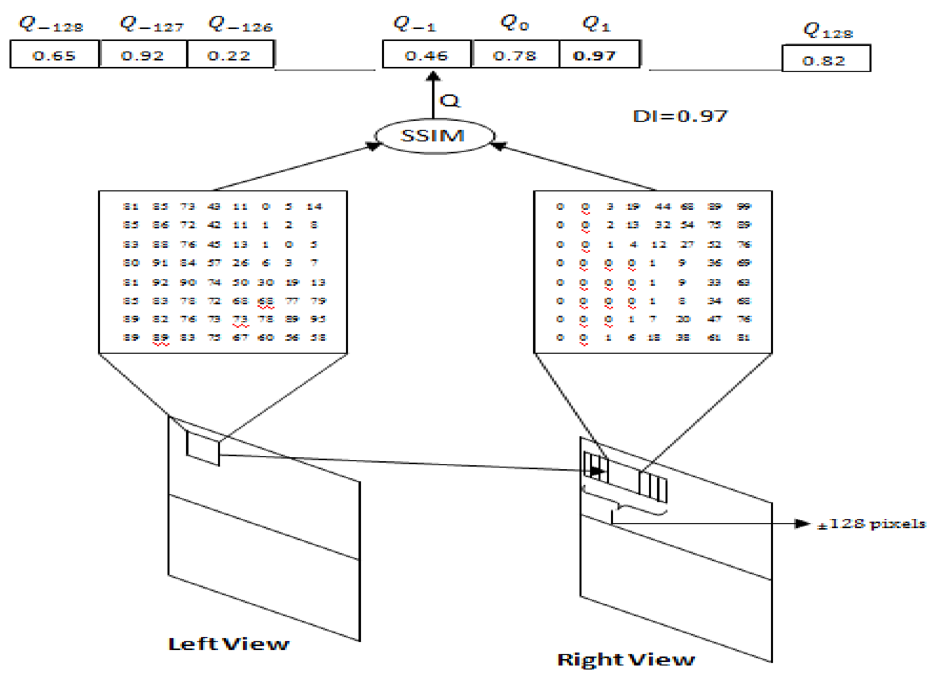


Fig. 3. Disparity Estimation Approach.

Thirdly, we average the quality index value for edge (DI_e) and non edge(DI_n) block separately.

$$D_e = \frac{1}{N_e}\sum_{b=1}^{N_e} DI_e \tag{31}$$

$$D_n = \frac{1}{N_n}\sum_{b=1}^{N_n} DI_n \tag{32}$$

Finally the overall disparity feature is estimated by,

$$D = D_e^{w_5} + D_n^{w_6} \tag{33}$$

Where w_5 and w_5 are the weighting factors.

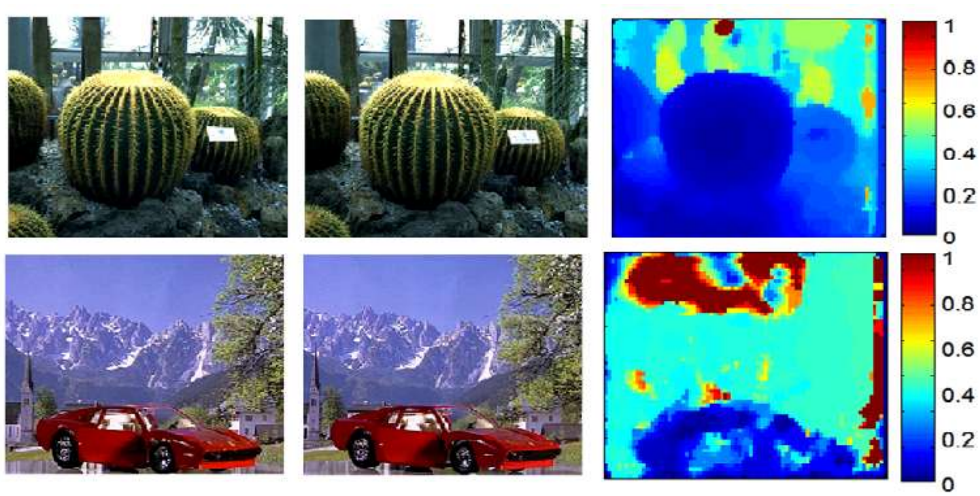


Fig. 4. Stereo image pairs and its depth maps.

2.3 Features Combination

Finally, in our algorithm all features, both artifacts and disparity, are combined to construct a stereoscopic quality prediction model. The following equation is used to combine the artifacts and disparity features in our proposed NR stereo quality assessment metric:

$$\mathrm{S} = \alpha(\mathrm{DZ}) + \beta\mathrm{B} \cdot \mathrm{Z} \tag{34}$$

where α, and β are the model parameters. The model parameters and weighting factors must be estimated by an optimization algorithm with the subjective test data.

We consider a logistic function according to VQEG recommendation as a non-linear property between the human perception and the physical features [VQEG 2003]. Finally, the obtained MOS prediction, MOSp, is given by the following equation.

$$MOS_p = \frac{4}{1+\exp[-1.0217(S-3)]}+1 \tag{35}$$

Here, the PSO algorithm is used to optimize the model's parameters and the weighting factors [Kennedy 1995, Eberhart 1998].

3 RESULTS

We have used Model performance Evaluation According to VQEG.To measure the prediction performance of this objective model qualitatively, we followed the standard performance evaluation procedure recommended by VQEG [VQEG 2003], where linear correlation coefficient (CC), average absolute prediction error (AAE), root mean square prediction error (RMSE), and outlier Ratio (OR) between predicted objective scores (MOSp) and subjective scores (MOS) were used for evaluation. In order to verify the permanence of this model, we consider the MICT stereoscopic image database [MICT 2009]. The database is divided into two parts for training and testing. The method's parameters and weighting factors are obtained for the quality scales (scale, 1-5) by using the PSO algorithm for all of the training images. These values are shown in Table 1.

Table 1. Model parameters and weighting factors for quality scale, 1-5.

$\alpha = 31.526623$	$\beta = 20.556421$	
$w_1 = 0.345233$	w_2=-0.011882	w_3=0.046468
w_4= -0.136976	w_5= 0.025572	w_6= 0.040866

Now our Proposed Method considering horizontal blockiness, zero-crossing, and disparity is formularized with linear weighting (i.e., linear weighting approach) by the following equation to combine the individual features:

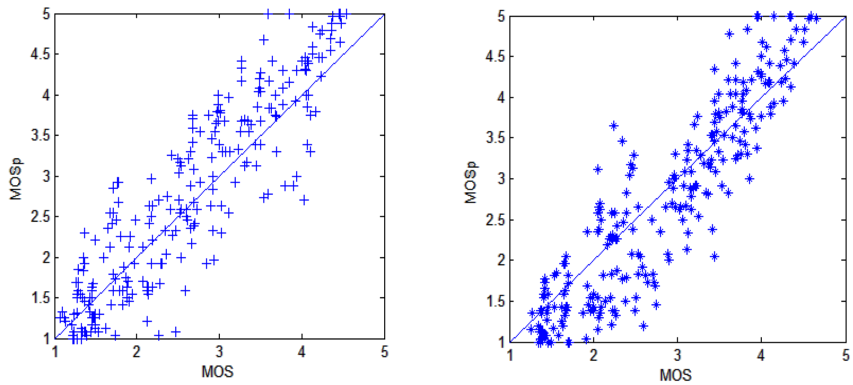
$$S = \alpha(D) + \beta B \cdot Z \tag{36}$$

Where,

$$B = B_e^{w_1} + B_n^{w_2}$$
$$Z = ZC_e^{w_3} + ZC_n^{w_4}$$
$$D = D_e^{w_5} + D_n^{w_6}$$

Table 2. Methods' evaluation results for training and testing (Scale, 1-5) with disparity.

Model	Training				
	CC	AAE	MAXE	RMSE	OR
Proposed model with SSIM based disparity	0.90	0.43	1.40	0.53	0.04
Model with Zero-Crossing Based Disparity	0.81	0.71	1.83	0.76	0.19
	Testing				
	CC	AAE	MAXE	RMSE	OR
Proposed model with SSIM based disparity	0.89	0.42	1.40	0.53	0.07
Model with Zero-Crossing Based Disparity	0.80	0.72	1.73	0.76	0.19



(a)Training image pairs (b)Testing Image Pairs

Fig. 5. MOS versus MOSp of my proposed model.

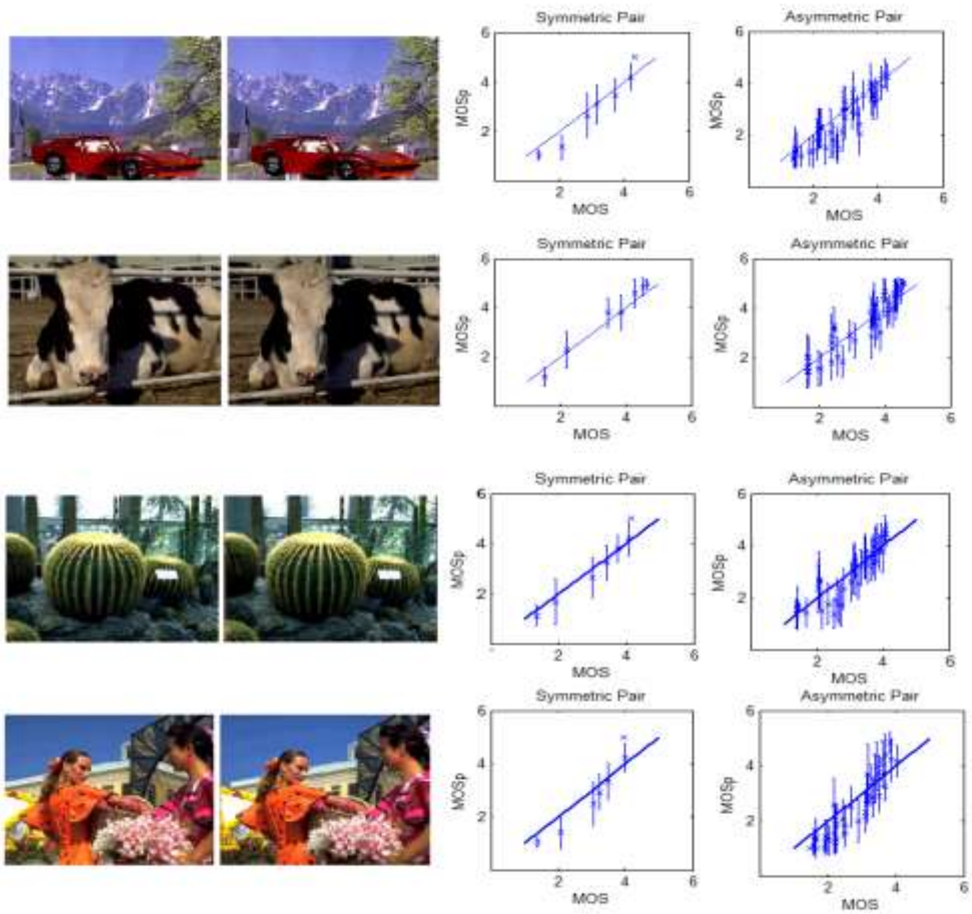


Fig. 6. The MOSp performances on texture variety of stereo pairs over the quality range. The predictions points * and ± 2 standard deviation intervals are shown for each stereo pair. Stereo image pairs from the MICT database [MICT 2009].

The MOS versus MOSp of my proposed model for training and testing images are respectively shown in Figures 5(a), and 5(b). The symbols '+' and '∗' respectively indicate MOSp points for the databases of training and testing.

The MOSp points and the error bars of ±2 standard deviation intervals of each different stereo image are shown in Figures 6.

4 CONCLUSION

We develop a fully automated NR image quality assessment metric which can assess the quality of processed images without human intervention or any reference image. Again well-renowned full reference method SSIM is used to establish disparity map which gives a better result than existing Zero crossing based disparity estimation [Sazzad 2009]. Also the human eye sensitivity on Blocking artifacts primarily depends on the horizontal blockiness rather than vertical one is evaluated here. In future, this approach can be applied for any other coded images irrespective or certain coder or coding techniques. The improved approach may also include color information which may lead to better quality prediction accuracy. In the next step, 3D video quality assessment is possible by incorporation of the temporal dependency between adjacent images (frames) of the video. Another direction for the future research is to evaluate the disparity in real time.

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