Performance Evaluation of Structural Similarity Index Metric in Different Colorspaces for HVS Based Assessment of Quality of Colour Images

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Abstract: The evaluation of visual quality of color images has become very important and challenging task due to explosion of multimedia and graphics content on internet. An image exhibits loss in color information due to introduction of noise, blur, blocking artefacts, channel distortion and also during lossy compression. The primary goal of Image Quality Metric (IQM) is to measure emergence of such distortion and evaluate the image quality where the outcome is validated by its consistency with Human Visual System (HVS). In response to this need, researchers have developed many objective and subjective image quality assessment metrics. But most of the available assessment models measure the quality of color image by using the intensity plane of the image ignoring loss in color. This paper presents performance comparison of evaluation of quality of color image using Structural Similarity Index Metric (SSIM) based on luminance and color information computed in different HVS consistent colorspaces against subjective quality data. Results obtained through experimentation in YCbCr, HSI, YUV, YIQ and CIELab colorspace show that when color information is included in quality assessment, quality score of the metric becomes highly consistent with Human Visual System (HVS). Further it has been observed that SSIM calculated in CIELab colorspace is highly correlated with Differential Mean Opinion Score (DMOS) for all types of distortions used in experimentation.

Keywords- YIQ, HSI, YCbCr, DMOS, quality, SSIM, HVS, IQM, CIELab

I. INTRODUCTION

Image quality measures the usefulness and naturalness of image after degradation. Introduction of blocking and ringing artifacts during lossy compression, noise, channel distortion and blurring reduces visual information carried by the image.

Image quality assessment attempts to measure the image quality perceived by Human Visual System (HVS). Differential Mean Opinion Score (DMOS) is obtained through subjective image quality assessment. This conventional method is reliable and simple but it can not be incorporated in real time applications due to its time consuming limitation [1]. Hence researchers have focused on development of accurate and automatic image quality metrics using statistical methods called as objective image quality assessment metrics. The simplest way of objective image quality assessment is the full reference image quality measurement technique.

In everyday life, color serves as a powerful cue in distinction and recognition of objects. The number of colors that can be distinguished by human eye is much more than that of the graylevels. Color images play central role in many applications, such as multimedia systems, computer vision based applications and entertainment. Many types of distortions may affect these color images and cause color loss [7]. Current methods available in literature treat the three color planes as three independent gray scale images and evaluate the color image quality using averaging of grayscale image metrics of independent color planes [6]. But this approach ignores multidimensional characteristic of color perceived by HVS. Though the intensity plane in a color image contains significant amount of visual information some loss in color information is always observed during color image processing techniques. Therefore to develop HVS consistent metric for color images, consideration of loss in loss in color information is vital. This paper presents structural similarity index quality metric using luminance and color information contained in all three planes with its colorspace based performance.

This paper is organized as follows. Section II describes metrics that were developed for assessment of the quality of color images. It covers a brief overview of different methodologies and techniques developed by researchers for this purpose. Illustration of significance of YCbCr, HSI, YUV, YIQ and CIELab colorspaces used in evaluation of color image quality is described in section III. Finally, section IV presents comparison of experimental quality score obtained through experimentation using SSIM in different colorspaces. The results obtained are discussed in Section V. The future direction about related work is also discussed.

II. RELATED WORK

Literature shows many attempts to evaluate quality of gray scale images.

Y. Shi et al [5] proposed structure and hue similarity model (SHSIM) based on color information and structural information in HSI colorspace for color image quality assessment. Only one color plane and luminance plane is used for image quality evaluation. The authors have proved that structural and color information is important for color image quality evaluation.

In 2008, Y. Wang, et.al [6] used quaternion description of structural information for image quality evaluation. The metric combines local variance and pixel information of an image. The local variance of luminance layer of color image forms the real part of a quaternion. Then the three RGB channels of the color image are encoded into the three imaginary parts of the quaternion. The angle between singular value feature vectors of the quaternion matrices that correspond to the reference image and the distorted image is used to measure the structural similarity of the two images. The images whose size is different from that of the reference image can also be assessed by this method.

E. Zhang, et al [4] added a spatial filter process in CIELAB color difference model. Contrast Sensitivity Function in HVS is simulated by application of a spatial filter on the images before transforming them to opponent colorspaces. Result shows that color difference computed by Euclidean metric in opponent colorspace is consistent with HVS.

P. Le Callet, et al [3] proposed HVS based visual color image quality metric using day VDP model for full reference image quality evaluation. The first stage computes visual representation of images based on results from psychophysics experiments and masking effect. The distortion maps are computed by subtracting maps of distorted image from maps of reference image. The second stage pools errors between visual representations of the two images. This pooling stage is based on the density of errors and their structure. It leads to a metric with high performances for color images.

S. Albin, et al [2] developed HVS based metric which can assess the visual quality of digital simulations objectively in 2002. They proposed three algorithms using LLAB colorspace to compute a perceptual metric which is a recent modification of CIELab1976 colorspace. The first metric introduces a local distance map between two images. The second metric associates a global value to a pair of images. Finally, the third metric uses a recursive subdivision of the images to obtain an adaptive distance map. The algorithms provide favorable results. However, authors have concluded that a new parameter could be developed by using spatial and statistical distributions of the distances.

Literature shows that number of researchers have contributed significant research for quality assessment of images. Structure and hue based similarity metric is developed in [5]. Based on this study it is proposed to transform color image into other HVS consistent colorspaces and develop a quality metric based on similarity measure using the three planes of color images.

III. HVS CONSISTENT COLORSPACES and SSIM

Colorspace can be expressed in many ways, with its advantages and drawbacks. Proper use and understanding of colorspaces is necessary for the development of color image quality metric that are optimal for the HVS [21].

A. HSI Color Model

RGB (also called as additive color system) and CMY (also known as subtractive color system) color models are suitable for hardware implementations. But unfortunately RGB and CMY color models are not well suited for describing colors for human interpretation. Furthermore, human being cannot think of color images as being composed of three primary images that combine to form a single image.

HSI colorspace rearranges the geometry of RGB by decoupling color and intensity information and attempt to be more intuitive in color manipulation and description. They were developed in the 1970s for computer graphics applications and now a days they are used for color pickers and in color modification tools in image editing software. It is intuitive to HVS.

When human beings view a color object they describe it by its hue, saturation and brightness or value. Hue is an attribute associated with the dominant wavelength in a mixture of light waves. Hue represents dominant color as perceived by an observer. Saturation refers to the relative purity or the amount of white light mixed with hue. Hue and Saturation are together called as chromaticity while as intensity is a subjective descriptor [8]. Furthermore, the conversions of HSI to and from RGB colorspace are extremely fast to compute. This makes the HSI representation very useful for color image processing software like quality assessment. If an image in RGB color format is given in the interval [0, 1] the H component of each RGB pixel is obtained using Eq. 1

$$H = \begin{cases} \theta & \text{if } B \le G \\ 360 - \theta & \text{if } B > G \end{cases} \qquad (1)$$

$$\text{with } \theta = \cos^{-1}\left\{ \frac{\frac{1}{2}\left[(R-G)+(R-B)\right]}{\left[(R-G)^2+(R-B)(G-B)\right]^{1/2}} \right\}$$

where angle θ is measured with respect to red axis of HSI space [8]. Hue can be normalized to the range [0, 1] by dividing it by 360^0.

The saturation component is calculated by Eq. 2

$$S = 1 - \frac{3}{(R+G+B)}\left[\min(R,G,B)\right] \qquad (2)$$

The intensity component is given by Eq. 3

$$I = \frac{1}{3}(R+G+B) \qquad (3)$$

B. YIQ and YUV Colorspaces

YUV is a linear transformation between the gamma-corrected RGB components to produce a luminance signal and a pair of chrominance signals. The luminance signal conveys color brightness levels, and each chrominance signal gives the difference between a color and a reference white at the same luminance. The YIQ and YUV colorspaces are intended to take advantage of human color response characteristic for analog television transmission. YUV colorspace is used by the PAL (Phase Alternation Line) composite video standard. The monochrome system uses only luma (Y) information. Color receivers decode the additional color information (U and V planes) to display color picture.

YIQ colorspace is derived from YUV colorspace except that the YIQ colorspace is rotated 33^0 with respect to the YUV colorspace. ‘I’ and ‘Q’ terms are derived from the quadrature modulation method used to transmit the color information and stand for in phase and quadrature respectively. This colorspace is used by NTSC composite color video standard. The two chrominance values correspond approximately to the amounts of blue and red content in the color. Eq. 4 and Eq. 5 show the transformation from RGB to YIQ and YUV colorspace respectively.

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \left[\begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.212 & -0.523 & 0.311 \end{bmatrix}\right] \begin{bmatrix} R \\ G \\ B \end{bmatrix} \qquad (4)$$

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.147 & -0.289 & 0.436 \\ 0.615 & -0.515 & -0.1 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \qquad (5)$$

C. YCbCr Colorspace

YCbCr colorspace is specially designed by International Telecommunication Union for video processing. It is a scaled and offset version of YUV. It is specially designed by International Telecommunication Union for video and image compression schemes such as MPEG and JPEG. The transformation formulae for this colorspace depend on the recommendation used.

D. CIELab Colorspace

CIELab color model is a device independent color model designed to mimic logarithmic response of the eye. It approximates human vision in image editing. Photoshop uses CIELab as a reference colorspace while converting one RGB profile to another RGB profile.

The three parameters of CIELab represent the lightness of color (L), its position between magenta and green (a) and its position between yellow and blue (b). The measures in this colorspace are made relative to a reference white point. By using reference point, the transformations attempt to account for the adaptive characteristics of the visual system [21].

Image in RGB colorspace is first transformed to CIEXYZ colorspace using simple equation given below.

$$\begin{bmatrix} \mathrm{X} \\ \mathrm{Y} \\ \mathrm{Z} \end{bmatrix} = \begin{bmatrix} 0.4125 & 0.3576 & 0.1804 \\ 0.2127 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9502 \end{bmatrix} \begin{bmatrix} \mathrm{R} \\ \mathrm{G} \\ \mathrm{B} \end{bmatrix} \qquad (6)$$

CIELab is based on CIEXYZ colorspace and the non_linear relations for L, a and b are given by Eq. 7, 8 and 9 respectively.

$$L = 116\, f\left(\frac{Y}{Y_n}\right) - 16 \qquad (7)$$

$$a = 500\left[f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right)\right] \qquad (8)$$

$$b = 200\left[f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right)\right] \qquad (9)$$

where

$f(t) = t^{1/3}$ for $t > 0.008856$ (10)

$f(t) = 7.787t + {}^{16}/_{116}$ otherwise (11)

and X_n , Y_n, Z_n are the CIEXYZ tristimulus values for the illuminant. CIE standard illuminant D50 is used in this experimentation.

E. Structural Similarity Index Metric (SSIM)

The structural similarity index metric evaluates visual quality based on the assumption that the HVS is adapted to extract and process structural information from natural images and a high-quality image has structure closely matching to that of the original [1]. The SSIM computation is carried out on a local window by dividing the whole image into image blocks of N x N size. Luminance measurement, contrast measurement and structure measurement are the three SSIM functions which are combined to quantify the quality of image [10].

The luminance comparison of image x and y is defined as

$$l(x,y) = \frac{2\mu_x\mu_y + C_1}{{\mu_x}^2 + {\mu_y}^2 + C_1} \qquad (12)$$

Similarly contrast comparison function is given by Eq.13

$$c(x,y) = \frac{2\sigma_x\sigma_y + C_2}{{\sigma_x}^2 + {\sigma_y}^2 + C_2} \qquad (13)$$

Structure comparison is calculated using Eq. 14

$$s(x,y) = \frac{2\sigma_{xy} + C_3}{\sigma_x\sigma_y + C_3} \qquad (14)$$

where μ_x, μ_y are the mean values,

σ_x, σ_y are variance,

σ_{xy} is covariance and C_1, C_2, C_3 are small constants.

For a given local window SSIM is calculated using Eq. 15 [10].

$$\mathrm{S(x,y)} = \frac{2\left(\mu_x\mu_y + C_1\right)\left(2\sigma_{xy} + C_2\right)}{\left({\mu_x}^2 + {\mu_y}^2 + C_1\right)\left({\sigma_x}^2 + {\sigma_y}^2 + C_2\right)} \qquad (15)$$

Finally, mean SSIM evaluates the image quality by combining local window SSIM values.

$MSSIM(x,y) = \frac{1}{N}\sum_{k=1}^{N} SSIM(x_k,\, y_y)$ (16) where x_k and y_k are the image pixels at k^{th} local window. N is number local windows in the image [1].

IV. DETAILS OF EXPERIMENTATION

First step in this experimentation is to calculate SSIM for color images using Eq. 16 on luminance plane based on previous study. Since luminance plane consists of significant information in the image resulting score obtained is closer to human judgment.

Further in order to consider the color loss, color information is also introduced in the metric. Recently researchers have widely used publicly available LIVE Database which provides image datasets with five different types of distortions with respective DMOS values obtained as per recommendations set by ITU [9]. All images available in LIVE Database are used for evaluation in this experiment. YIQ, YUV, YCbCr, HSI and CIELab colorspaces are selected for performance comparison of SSIM as they are highly consistent with human perception. Reference and test images are transformed from RGB to these colorspaces. Then according to Eq. 13similarity between the color planes is calculated and Eq. 15 is used to calculate similarity measure between luminance planes. Finally these are combined together into a metric labeled as CSSIM which assigns higher weight to the luminance component than the color components by considering sensitivity of HVS. In this experimentation, when luminance component is assigned weight 1, the two chrominance components have weight of 0.1 each. These weights are selected after correlating the results with DMOS.

$$CSSIM = {}^{(w_1\ C(x,y) + w_2\ B\ (x,y) + w_3\ A\ (x,y))}/_{T} \qquad (17)$$

where $T = w_1 + w_2 + w_3$ (18)

In Eq. 17, w_3 is a weight assigned to luminance plane, w_2 and w_1 are the weights assigned to the two color planes. A is SSIM value after applying Eq.15on luminance plane while as B and C are the similarity measures calculated using Eq. 13 to chrominance planes of the color image.

Performance of SSIM and CSSIM is evaluated in five different colorspaces for a set of images. Such set of images degraded by five different types of distortions is available in LIVE Database [9]. Each image is transformed in five colorspaces namely YCbCr, HSI, YIQ, YUV and CIELab. The quality of each color image is evaluated using SSIM score by computation on only luminance plane (labeled as SSIM1 in table 1) and then it is modified as CSSIM by introducing chrominance information (labeled as SSIM2 in table 1) in each colorspace.

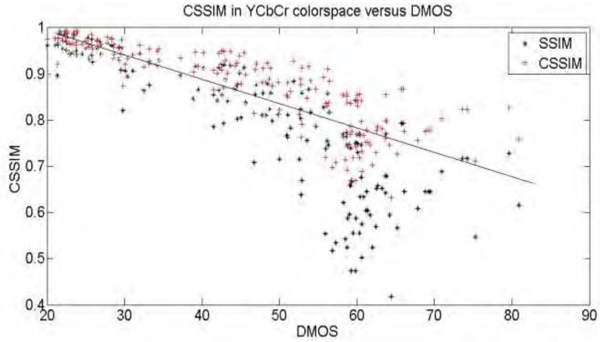

Fig.1.CSSIM evaluation on JPEG dataset of LIVE database in YCbCr colorspace

Fig. 1 shows scatter plot of SSIM and CSSIM calculated for JPEG dataset versus Differential Mean Opinion Score (DMOS) in YCbCr colorspace. Images available in JPEG Dataset of LIVE Database are used to calculate MSSIM and CSSIM using Eq. 16 and Eq. 17. In this plot the black color indicates the SSIM values calculated using only luminance component while as red indicates CSSIM values computed using luminance and chrominance components. It is examined in fig. 1 that if color information is included in assessment of image quality the resulting values are highly correlated with DMOS. Such experimentation is repeated for five datasets of different distortions in five different colorspaces and total twenty-five scatter plots are examined. Only five of them are presented here. In all the plots black color is used show SSIM values calculated using only luminance plane while as red is used to show CSSIM value computed using luminance and color information. Fig. 2 shows scatter plot of SSIM and CSSIM calculated for blurred image dataset with respect to DMOS in HSI colorspace.

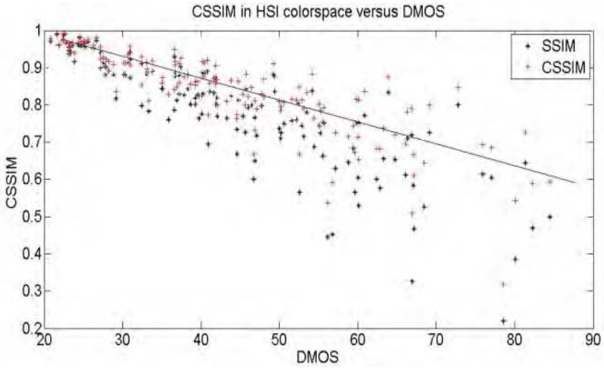

Fig.2.CSSIM evaluation on Gaussian Blur dataset of LIVE database in HSI colorspace

Fig. 3 shows scatter plot for SSIM and CSSIM with respect to DMOS in YIQ colorspace for JPEG2000 images with ringing and blurring artifacts.

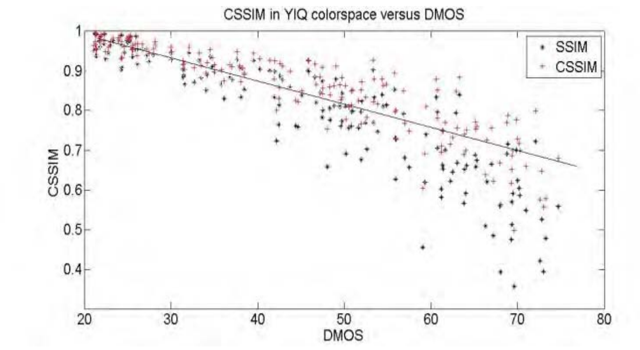

Fig.3.CSSIM evaluation on JPEG2000 dataset of LIVE database in YIQ colorspace

Fig. 4 shows scatter plot of SSIM and CSSIM with respect to DMOS calculated after transformation of image in YUV colorspace for image dataset with white noise.

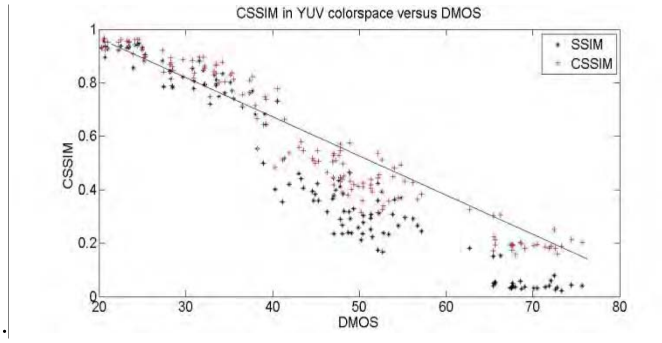

Fig.4.CSSIM evaluation on White Noise dataset of LIVE database in YUV colorspace

Fig. 5 shows scatter plot of SSIM and CSSIM with respect to DMOS calculated after transformation of image in CIELab colorspace for image dataset with white noise.

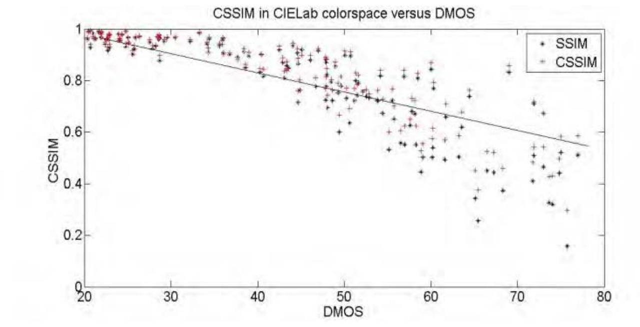

Fig.5.CSSIM evaluation on Fast Fading dataset of LIVE database in CIELab colorspace

All the scatterplots are identical as scattering is reduced due to introduction of chrominance component. To determine perceptual relevance of the measure in different colorspaces Eq. 19 is used to calculate correlation coefficient- r_{xy} between DMOS and CSSIM for same image dataset in different colorspaces with different distortions [12].

$$r_{xy} = \frac{N\sum xy - (\sum x)(\sum y)}{\sqrt{N\sum x^2 - (\sum x)^2}\ \sqrt{N\sum y^2 - (\sum y)^2}} \qquad (19)$$

where x and y denote DMOS and CSSIM values respectively. The results presented in table 1 are identical for all colorspaces.

TABLE 1
PERFORMANCE EVALUATION C SSIM IN DIFFERENT COLORSPACES

Metric/ Dataset	JPEG	JP2K	White Noise	Gaussian Blurr	Fastfading
SSIM-YCbCr	0.9698	0.9717	0.7826	0.9796	0.9796
CSSIM-YCbCr	0.9883	0.9888	0.9324	0.9919	0.9919
SSIM-HSI	0.9625	0.9664	0.7950	0.9749	0.9749
CSSIM-HSI	0.9620	0.9801	0.8693	0.9855	0.9855
SSIM-YIQ	0.9633	0.9664	0.7700	0.9751	0.9751
CSSIM-YIQ	0.9785	0.9823	0.9005	0.9872	0.9872
SSIM-YUV	0.9633	0.9664	0.7700	0.9751	0.9751
CSSIM-YUV	0.9620	0.9801	0.8693	0.9855	0.9855
SSIM-CIELab	0.9723	0.9749	0.7664	0.9816	0.9816
CSSIM-CIELab	0.9792	0.9822	0.8454	0.9865	0.9865

The performance comparison shows that CSSIM calculated using color information has higher correlation with DMOS and hence performs little better than conventional color quality metric based on only luminance information.

V. CONCLUSION and DISCUSSION

The conclusion of this paper is that there is some deviation in color information in any color image due to introduction of artifact. Hence CSSIM gives highly HVS consistent results when compared to SSIM. Scatter plots show that results obtained after introducing the color loss in color image quality measurement are highly consistent with HVS than quality measurement using only the luminance plane of color image. Performace evaluation of the metric in different colorspaces indicates that the metric in YCbCr colorspace is highly consistent with HVS and outperforms CSSIM metric in any other colorspace. This performance evaluation may vary with weights assigned to luminance and chrominance components. Higher weight of chrominance planes causes better performance of SSIM over CSSIM. In future, this experimentation can be extended to performance comparison of additional color features in different colorspaces which may help in blind color image quality assessment.

REFERENCES

[1] Z. Wang and A. C. Bowik, *Modern Image Quality Assessment*, Morgan & Claypool Edition Publisher, 2006

[2] S. Albin et al., “Quality image metrics for synthetic images based on perceptual color differences”, *IEEE transactions on image processing*, vol. 11, No. 9, September 2002, pp. 961-971

[3] P. Le Callet, D. Barba, “A robust quality metric for color image quality assessment”, *Proceedings of IEEE International Conference on Image Processing (ICIP'03)*, pp. 437–440, September 2003, pp. I 437-I 440

[4] E. Zhang, J. Yu, Y. Chen, Y. Yang, “A Study of Image Color Quality Evaluation based on S-CIELAB”, *IEEE 3rd International Congress on Image and Signal Processing*, 2010, pp. 1110-1114

[5] Y. Shi, Y. Ding, R. Zhang, J. Li, “Structure and Hue Similarity for Color Image Quality Assessment”, *Proceedings of IEEE International conference on Electronic Computer Technology*, 2009, pp. 329-333

[6] Y. Wang, W. Liu1, Y. Wang, “Color Image Quality Assessment Based on Quaternion Singular Value Decomposition”, *Proceedings of 2008 Congress on Image and Signal Processing*, May 2008, vol. 3, pp. 433-439

[7] N. Le Bihan, J. Mars. “Singular value decomposition of quaternion matrices: a new tool for vector-sensor signal processing”, *Journal on Signal Processing*, vol.84, no. 7, July 2004, pp. l177-1199

[8] R. C. Gonzalez, R. E. Woods, *Digital Image Processing*, Pearson Education Publisher, Second edition

[9] H.R. Sheikh, Z.Wang, L. Cormack and A.C. Bovik, "LIVE Image Quality Assessment Database Release 2",http://live.ece.utexas.edu/research/quality

[10] Z. Wang, A.C. Bovik, H.R. Sheikh and E.P. Simoncelli, "Image quality assessment: from error visibility to structural similarity," *IEEE Transactions on Image Processing*, vol.13, no.4, April 200, pp. 600- 612

[11] H. Joel Trussel, Eli Saber and Michael Vrhel, “Color Image Processing Basics and special issue overview”, *IEEE Signal Processing Magazine*, January 2005, vol. 22, no. 1, pp. 14-22

[12] M. R. Spiegel, L. J. Stephens, *Scaum’s Outline of Theory and Problems of Statistics*, McGRAW-HILL Publication, Third Edition, 1999

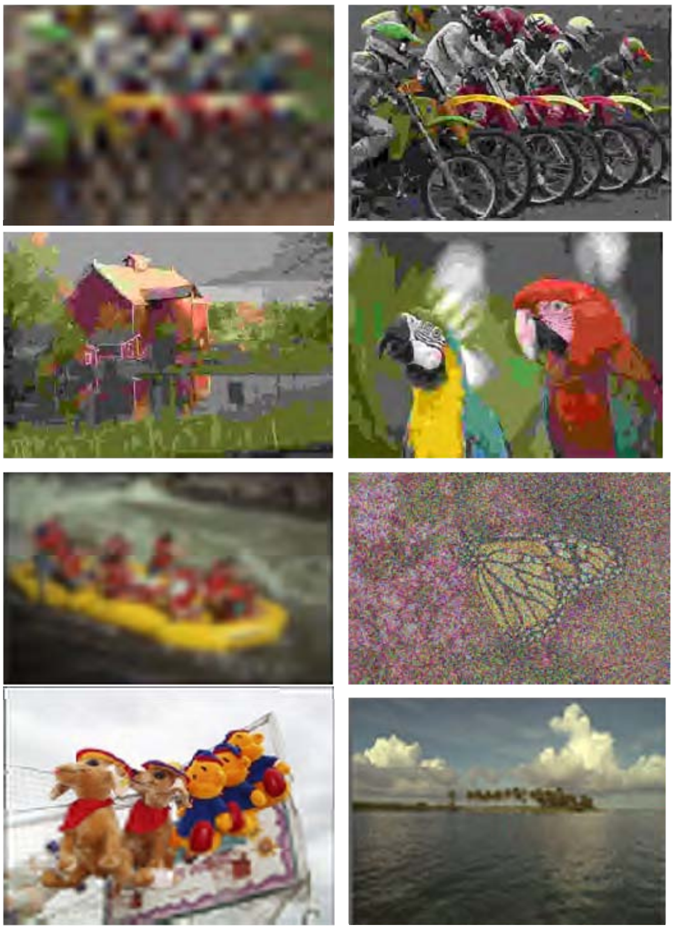

Fig.6. Few images used for the experimentation
(Courtesy: LIVE Database)