ISSN 2250-3153

Color Image Compression using Hybrid Wavelet Transform with Haar as Base Transform

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Abstract- This paper proposes color image compression method using hybrid wavelet transform and compares it with results obtained using hybrid transform and multi-resolution analysis. Haar wavelet is widely used in image compression. So here Haar transform is selected as base transform and combined with non-sinusoidal transforms like Slant, Walsh and Kekre transform. Hybrid Haar wavelet transforms is generated using Kekre's hybrid wavelet generation algorithm. Different sizes of component transforms are used to generate hybrid wavelet transform. Haar (32x32)-Slant (8x8) gives less error as compared to Haar-Walsh and Haar-Kekre Hybrid wavelet. Performance of hybrid wavelet is compared with hybrid transform and multi-resolution by varying the size of component transforms. Mean Absolute Error (MAE) and Average Fractional Change in Pixel Value (AFCPV) are used to compare visual quality of an image. Structural Similarity Index (SSIM) of Haar-Slant hybrid wavelet is computed on 16x16 blocked images and compared with its hybrid transform and multi-resolution analysis. Least RMSE value obtained at compression ratio 32 by Haar-Slant hybrid wavelet with size 32-8 is 10.53. Mean absolute error is 7.32 in Haar-Slant hybrid wavelet with component size 16-16. Least AFCPV is 0.344 with component size 32-8 for the same.

Index Terms- Haar Transform, Hybrid wavelet transform, Multi-resolution analysis, Structural Similarity Index

I. INTRODUCTION

Advanced technology has increased the demand of using the information in the form of images and videos. Managing this huge amount of image and video data is essential. Storage space, bandwidth requirement and transmission time are key factors that get affected due to use of this multimedia data. One way to make use of these factors effectively is reducing the amount of information being transmitted or processed. Compression of digital images plays a vital role in this context. Effective compression methods are used to obtain good quality images. An effective compression method is one which extracts characteristic features of an image and neglects redundant and irrelevant information.

Transform based image coding is one of the popular image compression method. Transform when applied on images; change the image pixels to frequency domain coefficients. Desirable property of transforms is that most of the image energy is concentrated only in few significant transform coefficients. Retaining these significant coefficients and eliminating remaining coefficients results in image compression. Discrete Cosine Transform (DCT) [1] and wavelet transform are commonly used transform methods for image compression. They are used in JPEG and JPEG 2000 respectively. Recent advancements in this area show that transform based coding combined with other compression method results in better performance. In literature, transform based coding is added with vector quantization methods or neural networks or any other lossless coding method. Such methods are hybrid methods as they combine properties of two different methods.

In this paper, hybrid wavelet transform based image compression has been proposed. As the name suggests, it combines characteristics of two different transforms to produce better results.

II. REVIEW OF LITERATURE

Wavelet based image compression has gained more popularity over DCT based image compression because of its high energy compaction property. Haar wavelets are simplest wavelets and have been widely used for compression. Haar transform is a simple, orthonormal transform proposed by Alfred Haar in 1910 [2]. It serves as a prototype for wavelet transform [3]. It allows us to encode the information according to level of details. Modified fast Haar wavelet transform (MFHWT) has been discussed by Chang P. et al. [4]. It uses one dimensional approach and FHT is used to find N/2 detail coefficients at each level for a signal of length N. Extension of this work has been proposed by Anuj Bharadwaj and Rashid Ali [5]. It works for 2D images with the addition of considering the detail coefficients for N/2 elements at each level. Haar wavelet decomposes the image into different frequency sub bands. In the technique proposed by Shridhar et al. [6] scalar quantization and DPCM is applied on image which is decomposed into different frequency sub bands. Multilevel 2-D Haar wavelet transform is used for image compression in [7] by Ch. Samson and V.U.K. Sastry. Haar wavelet using singular value decomposition has been proposed by Zunera Idrees [8]. Apart from Haar transform, 2-D wavelet

ISSN 2250-3153

transform combined with other lossy or lossless compression method also has been widely used for image compression. Medical image compression using different wavelets like Daubechies, Coeflits, Haar and biorthogonal transform is proposed by Krishna Kumar et al.[9]. Compression based on five modulus method in JPEG has been proposed by Firas A. Jassim [10]. In this method, image is divided into 8x8 block size and value of each pixel in block is converted in multiples of five. It makes pixels in the image matrix correlated. Hence finding uncorrelated pixels is major task. Then pixel values are divided by 5 to reduce them into lesser values. It reduces the variation between pixel values. Inverse five modulus method is applied to reconstruct the image. CPU time and space taken to reconstruct the image is more in this case. To obtain better compression ratio, wavelet based methods are combined with classical methods of image coding. Hybrid compression method using discrete wavelet transform and Discrete Cosine Transform is proposed by Elharar et al. [11]. This compression algorithm is based on hybrid technique implementing a four dimensional transform combining the discrete wavelet transform and DCT. Wavelet based simple image compression method is proposed in [12]. In this method wavelet transform is generated from existing orthogonal transform [13]. It gives acceptable image quality of image. Further to save computational overhead column transform can be used in place of full transform.

Compression using hybrid wavelet is proposed by Dr. Kekre [14]. Two different orthogonal component transforms are combined to generate hybrid wavelet using algorithm proposed by H.B. Kekre and Tanuja Sarode [15]. Error between original and reconstructed image reduces drastically due to use of hybrid wavelet. It helps to achieve high compression ratio.

This paper proposes hybrid wavelet transform based color image compression and compares its performance with Multi-resolution hybrid wavelet and Hybrid Transform. Along with RMSE as conventional objective error measurement criteria, Mean Absolute Error (MAE) and Average Fractional Change in Pixel Value (AFCPV) are use to measure performance of different hybrid wavelet transforms.

III. PROPOSED METHOD

Hybrid wavelet is generated using Kronecker product of two component matrices as Kronecker product reduces computations considerably. Kronecker product of two matrices is given as

$$A_p \otimes B_q = a_{ij}\,[B_q] \tag{1}$$

A and B are component transforms of size pxp and qxq respectively. Individual element of matrix A is represented as a_{ij}. This full Kronecker product gives only global features of an image after transformation. It is the limiting case of hybrid wavelet transform and is called Hybrid transform. To include local features, Kronecker product with individual row of B_q is taken. It is given as

$$T_{AB} = \begin{pmatrix} A_p \otimes B_q\,(1) \\ I_p \otimes B_q\,(2) \\ I_p \otimes B_q\,(3) \\ . \\ . \\ . \\ I_p \otimes B_q\,(n) \end{pmatrix} \tag{2}$$

First p rows of transformation matrix T_{AB} gives global features. Here pxp identity matrix is used to translate rows of second transform matrix B. It gives local features of image. To focus on multi resolution analysis of wavelet transform semi global properties are included. Above matrix is modified as

ISSN 2250-3153

$$T_{AB} = \begin{pmatrix} A_p \otimes B_q\ (0:i_1) \\ I_{r0} \otimes (A_{p/r0} \otimes B_q\ (i_1+1:i_2)) \\ I_{r1} \otimes (A_{p/r1} \otimes B_q\ (i_2+1:i_3)) \\ \vdots \\ I_{rn-1} \otimes (A_{p/rn-1} \otimes B_q\ (i_{n-2}+1:i_{n-1})) \\ I_p \otimes (B_q(i_n:q)) \end{pmatrix} \quad (3) \quad \begin{matrix} \text{Global} \\ \text{Semi global 1} \\ \text{Semi global 2} \\ \vdots \\ \text{Semi global n} \\ \text{Local} \end{matrix}$$

Using eq. (2) hybrid wavelet transform is applied on individual plane of color image. From transformed coefficients high energy coefficients are retained and remaining is discarded. Image is reconstructed using inverse transform and respective compression ratio is calculated. Error in original image and compressed image is calculated. Compression ratio is varied and error is computed for various compression ratios. Similar procedure is adopted using hybrid transform matrix given by eq. (1) and multi-resolution analysis given by eq. (3).

IV. Error Measurement Parameters

In many compression methods, root mean square error (RMSE) and PSNR are used to measure the performance of that compression method. But these parameters have been proven to be inconsistent with human eye perception as they estimate the perceived error. Hence along with RMSE, Mean Absolute error, Average Fractional Change in Pixel Value and Structural Similarity Index (SSIM) are used to analyze the performance of compression method.
Formulas for computation of these parameters are as below:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{i=p}\sum_{j=1}^{j=q}(x_{ij}-y_{ij})^2}{p*q}} \quad (4)$$

$$\text{MAE} = \frac{\sum_{i=1}^{i=p}\sum_{j=1}^{j=q}(|x_{ij}-y_{ij}|)}{p*q} \quad (5)$$

$$\text{AFCPV} = \frac{\sum_{i=1}^{i=p}\sum_{j=1}^{j=q}(|x_{ij}-y_{ij}|) / x_{ij}}{p*q} \quad (6)$$

In above equations, x_{ij} is original image, y_{ij} is reconstructed image, p= number of rows and q= number of columns.

$$\text{SSIM}(x,y) = (2\mu_x\mu_y+c_1)\,(2\sigma_{xy}+c_2) \,/\, (\mu_x^2+\mu_y^2+c_1)\,(\sigma_x^2+\sigma_y^2+c_2) \quad (7)$$

Here, c_1 and c_2 are constants given by $c_1=(k_1L)^2$ and $c_2=(k_2L)^2$, where $k_1=0.01$, $k_2=0.03$ by default and $L=2^8-1=255$. μ_x is average of image x,
μ_y is average of image y,
σ_{xy} is covariance of x and y,
σ_x^2 and σ_y^2 are variance of image x and y respectively.
SSIM considers image degradation as perceived change in structural information.

V. Results and Discussions

Figure 1 shows test images of various classes used for experimentation. All images are color bitmap images of different classes with size 256x256.

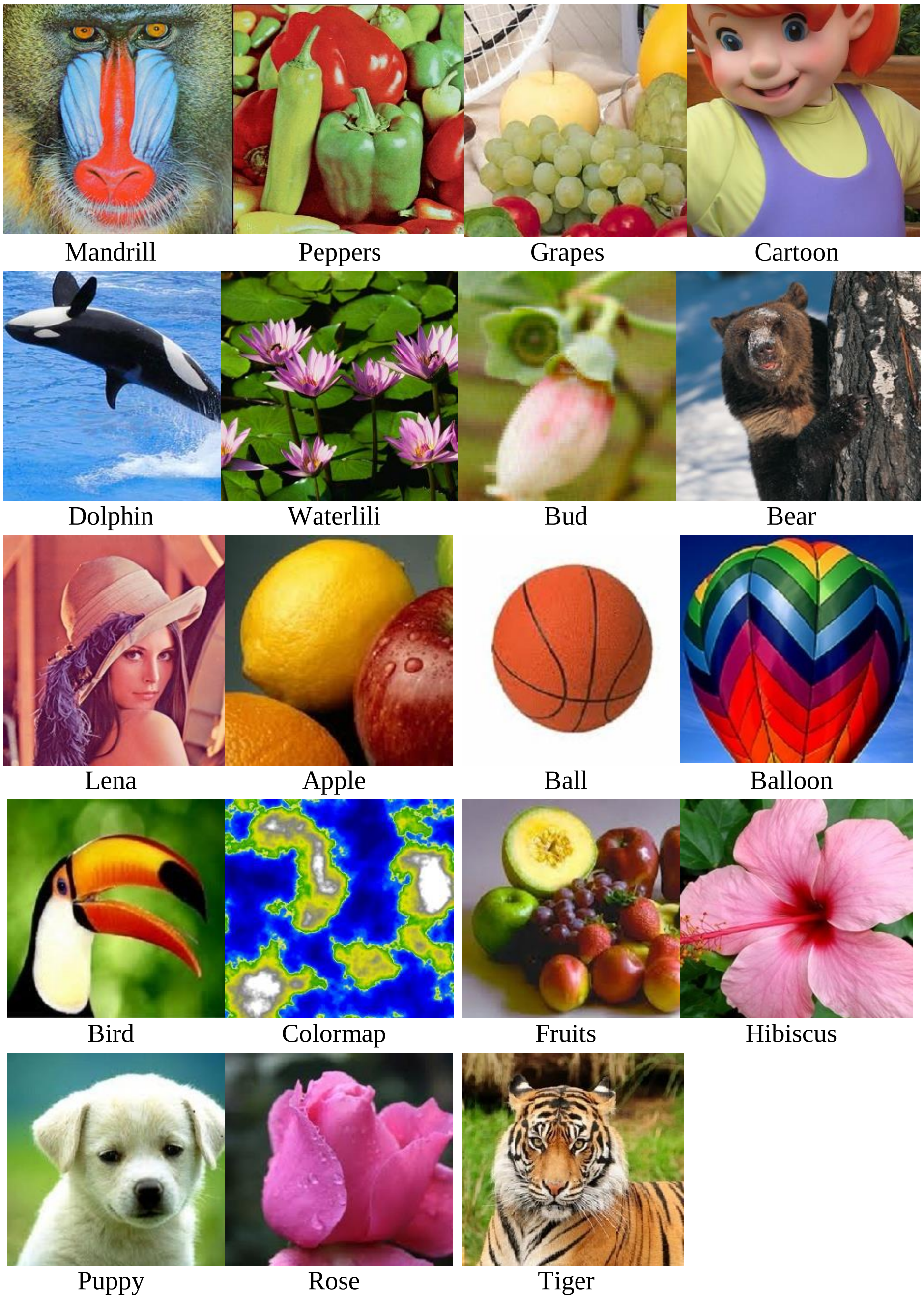

Figure 1 Set of Colour Images used for Experimental Purpose

Figure 2 shows RMSE at various compression ratios in hybrid Haar wavelet transform.

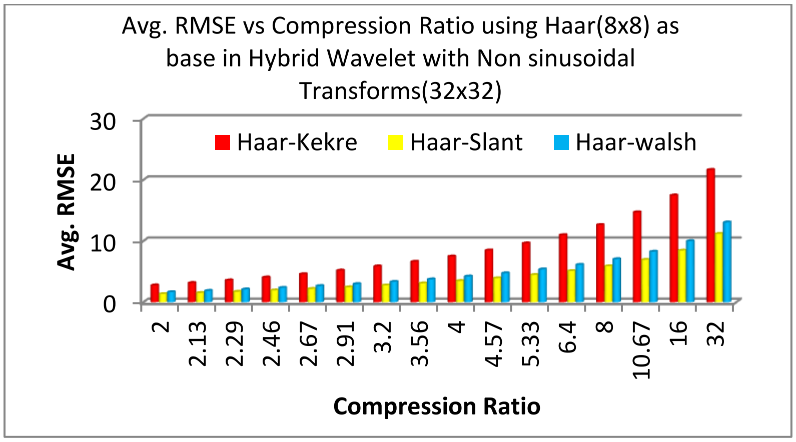

Figure 2 Average RMSE against compression Ratio using different Non sinusoidal transforms as Local components of size 32x32 with Haar Transform as Base Transform of size 8x8

Haar transform is used as base transform and it is combined with non sinusoidal transforms like Kekre Transform, Slant Transform and Walsh Transform. Base transform size is selected as 8x8 and local component size 32x32 is selected. RMSE of three hybrid wavelet transforms is compared. It has been observed that Haar-Slant hybrid wavelet gives less RMSE than other two. At compression ratio 32, RMSE 11.18 is obtained in Haar-Slant hybrid wavelet transform. With increases in compression ratio RMSE increases. Haar-Kekre transform shows higher error.

Figure 3 shows RMSE in Haar-Slant hybrid wavelet for different sizes of Haar and Slant pair. In graph, 8-32 means Haar transform size is 8x8 and Slant transform size is 32x32. Size 16-16 and 32-8 of Haar-Slant hybrid wavelet give almost equal RMSE for compression ratio above 16. For lower compression ratios, 32-8 Haar-Slant gives lower error.

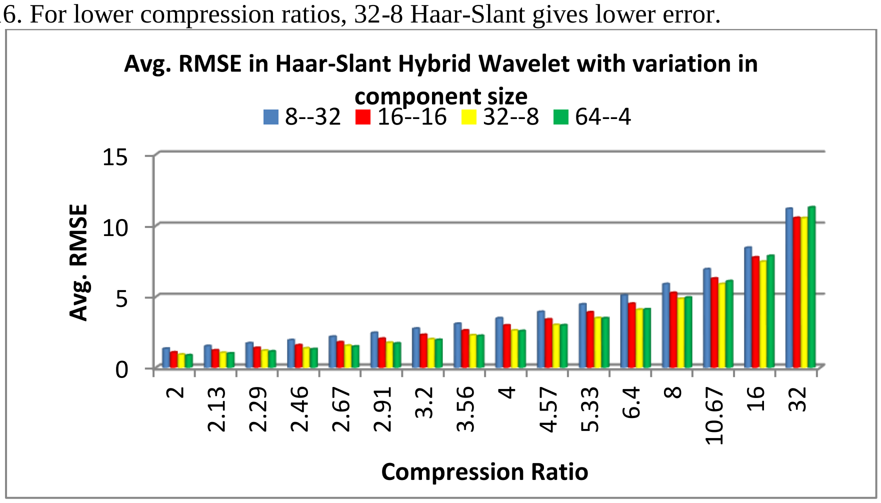

Figure 3 Average RMSE against compression Ratio using Haar-Slant Hybrid Wavelet Transform with Variation in Component Transform Size

Figure 4 shows Average RMSE versus compression ratio for multi-resolution analysis of Haar-Slant hybrid wavelet. In this case also 16-16 and 32-8 size gives equal performance.

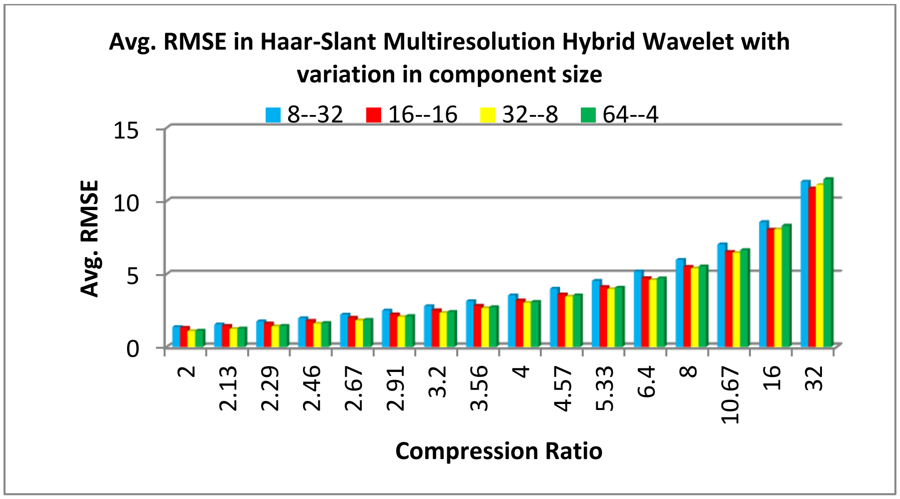

Figure 4 Average RMSE against compression Ratio using Haar-Slant Multi-Resolution Hybrid Wavelet Transform with Variation in Component Transform Size

RMSE in Haar-Slant hybrid transform is compared in Figure 5. Hybrid transform is generated using full Kronecker product of two component transforms as given in eq. 1. Component transform size is varied and respective RMSE values are observed.

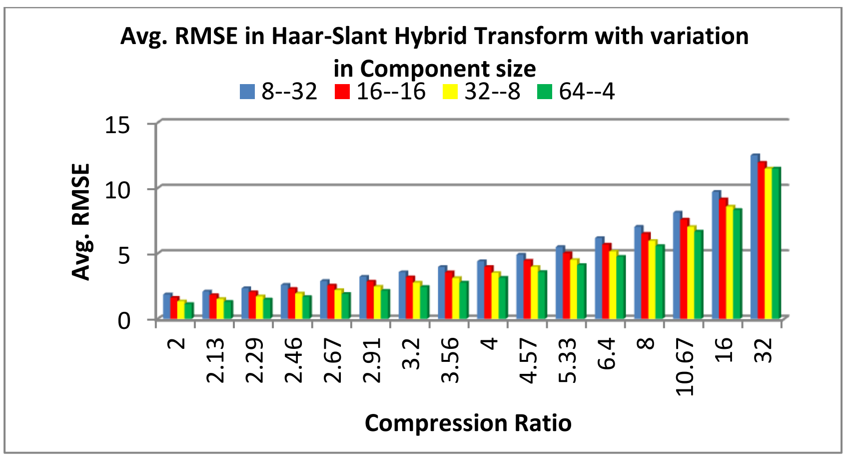

Figure 5 Average RMSE against compression Ratio using Haar-Slant Hybrid Transform with Variation in Component Transform Size

For all compression ratios, 64-4 size proves to be better in hybrid transform. It clearly indicates that larger the size of Haar transform i.e. base transform less is the RMSE. Figure 6 compares performance of hybrid wavelet; Multi-resolution hybrid wavelet and hybrid transform using RMSE. It shows that component transform Haar of size 32x32 and Slant 8x8 in hybrid wavelet gives lower RMSE than other possible size combinations of this pair in hybrid transform and multi-resolution hybrid wavelet transform.

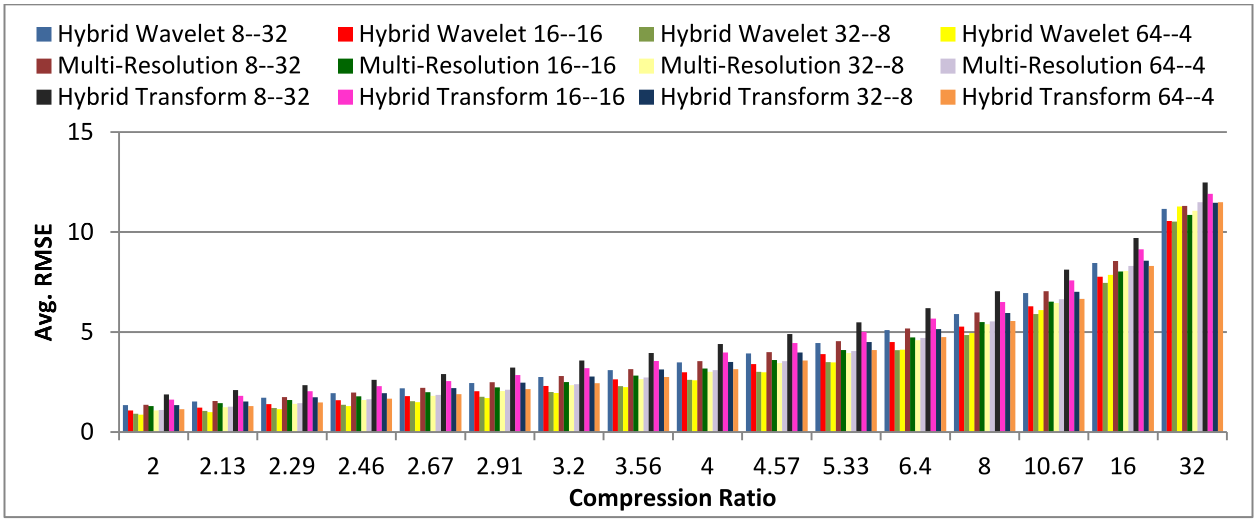

Figure 6 Comparison of RMSE against Compression Ratio in Different Cases of Haar- Slant Hybrid Wavelet Transform using Variation in Component Transforms Size

Figure 7 compares the performance of Haar-Slant hybrid wavelet using MAE as an error metric. MAE gives absolute difference between pixel values and hence is better objective error measurement criteria than RMSE.

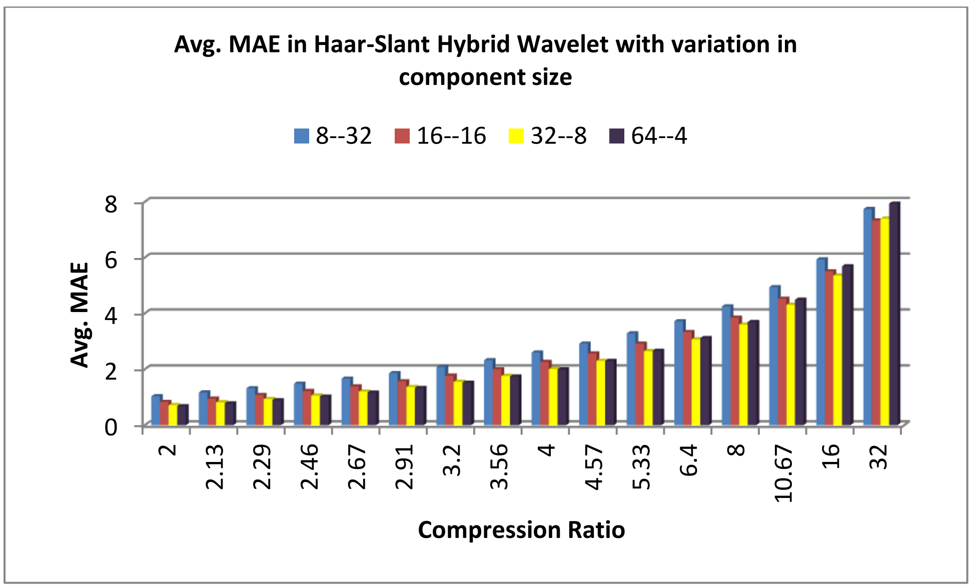

Figure 7 Average MAE against compression Ratio using Haar-Slant Hybrid Wavelet Transform with Variation in Component Transform Size

As shown in figure 7, possible size combinations of component transforms have been tried. And 32-8 has been observed to be more acceptable combination as it produces less MAE. Figure 8 gives performance comparison of multi-resolution hybrid wavelet transform with size variation. In multi-resolution also, 32-8 size of components is found to be acceptable.

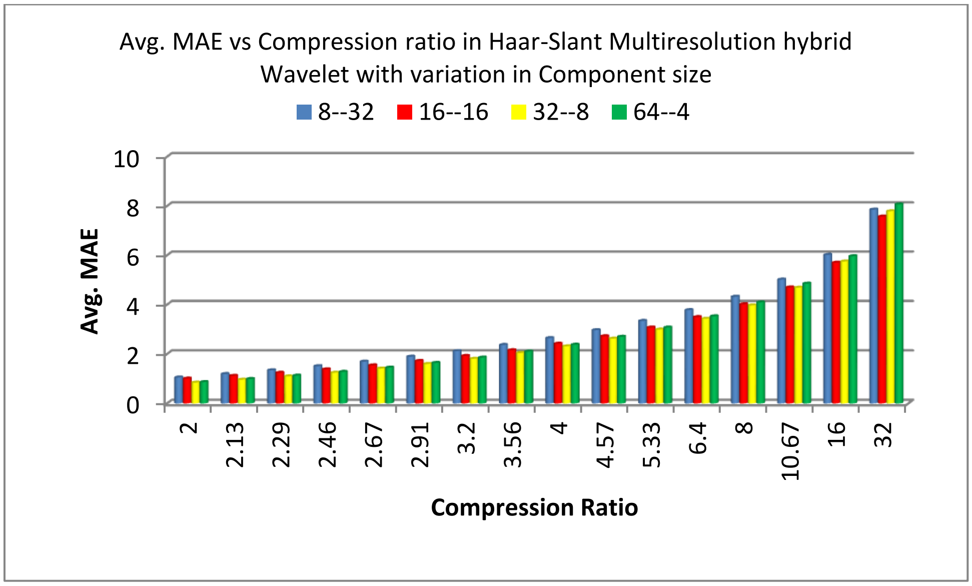

Figure 8 Average MAE against compression Ratio using Haar-Slant Multi-Resolution Hybrid Wavelet Transform with Variation in Component Transform Size

Figure 9 plots MAE vs. compression ratio in Haar-Slant Hybrid transform.

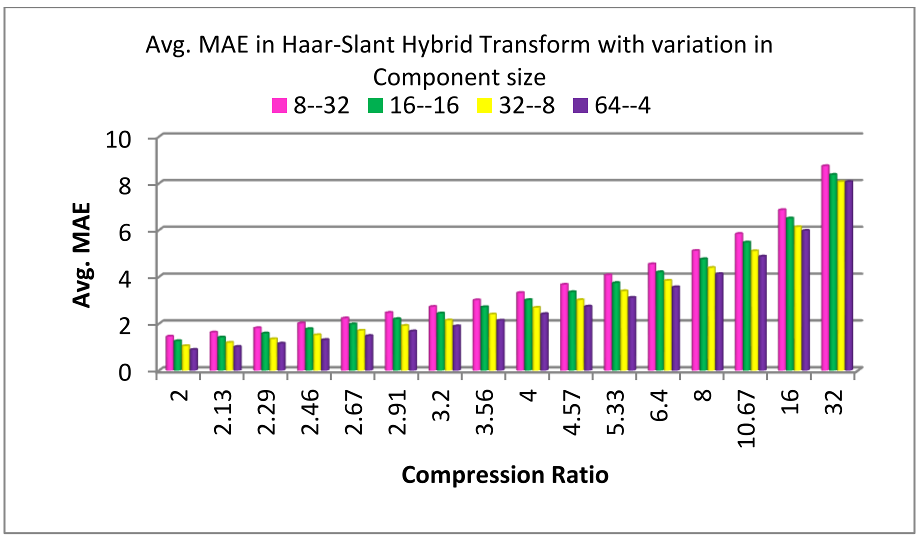

Figure 9 Average MAE against compression Ratio using Haar-Slant Hybrid Transform with Variation in Component Transform Size

Like RMSE, when 64x64 Haar and 4x4 Slant is used to generate hybrid transform, less MAE is obtained.
Figure 10 shows overall comparison of mean absolute error in three cases of Haar-Slant hybrid wavelet transform.

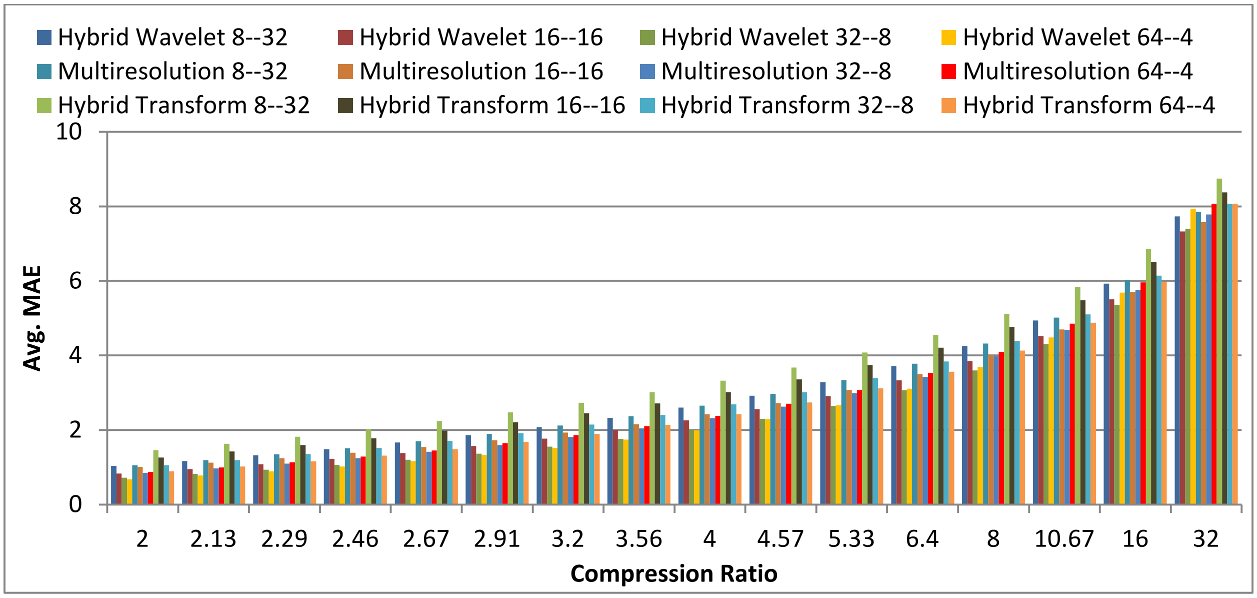

Figure 10 Comparison of MAE against Compression Ratio in Different Cases of Hybrid Wavelet Transform using Variation in Component Transforms Size

It follows similar pattern of results like RMSE vs. compression ratio shown in figure 6. Hybrid wavelet generated using component transforms 32x32 Haar and 8x8 Slant gives lower MAE. Figure 11 and 12 shows performance of Haar-Slant hybrid wavelet and its multi-resolution analysis using AFCPV as an error measurement criterion. It is a fractional change in pixel values. Therefore it gives more perceptibility than MAE.

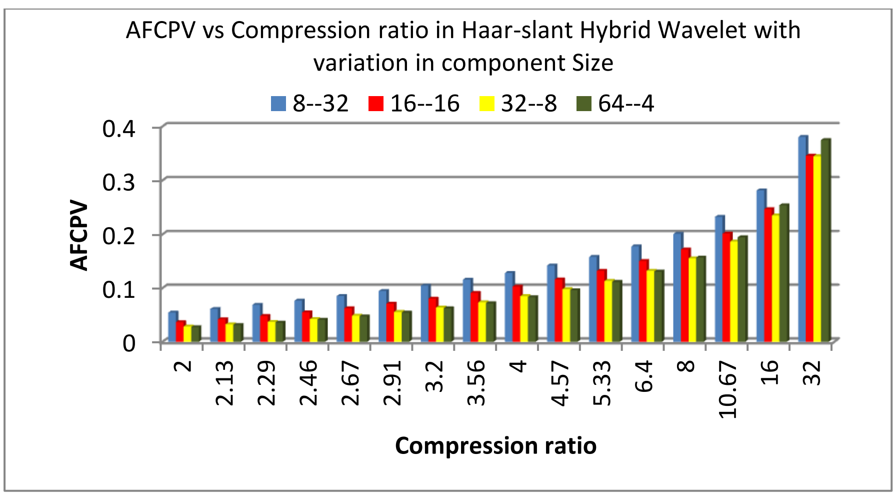

Figure 11 AFCPV against compression Ratio using Haar-Slant Hybrid Wavelet Transform with Variation in Component Transform Size

In both cases, this metric also shows similar error pattern like MAE. 32-8 component size is giving low value of AFCPV than any other component sizes of respective transform.

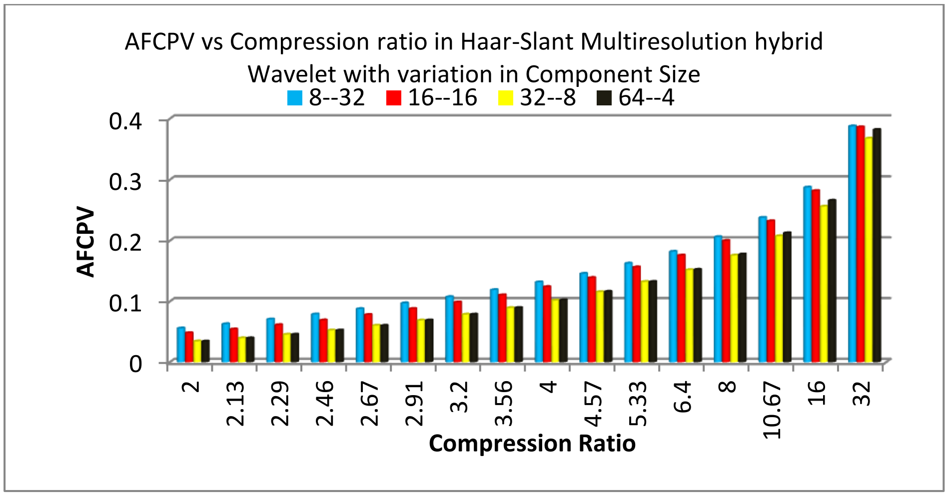

Figure 12 AFCPV against compression Ratio using Haar-Slant Multi-Resolution Hybrid Wavelet Transform with Variation in Component Transform Size

AFCPV in hybrid transform is plotted in Figure 13. Best size combination in Haar-Slant hybrid transform is 64-4 as depicted in figure.

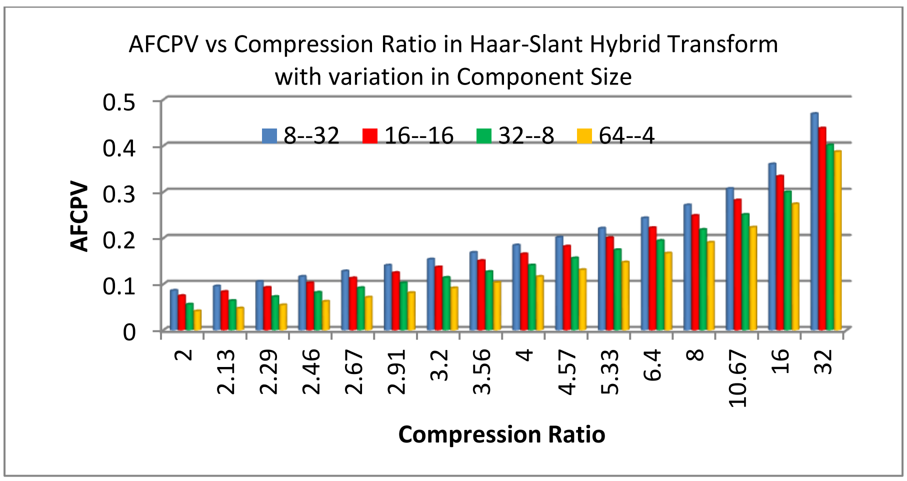

Figure 13 AFCPV against compression Ratio using Haar-Slant Hybrid Transform with Variation in Component Transform Size

Figure 14 shows comparison of Hybrid wavelet, hybrid transform and multi-resolution hybrid transform in terms of AFCPV. In all three cases, bi-resolution hybrid wavelet proves to be better than hybrid transform and multi-resolution analysis. It means that, inclusion of global and semi-global features of an image leads to increased error in compression. Lowest AFCPV 0.3456 is obtained by 32-8 pair of Haar-Slant hybrid wavelet transform.

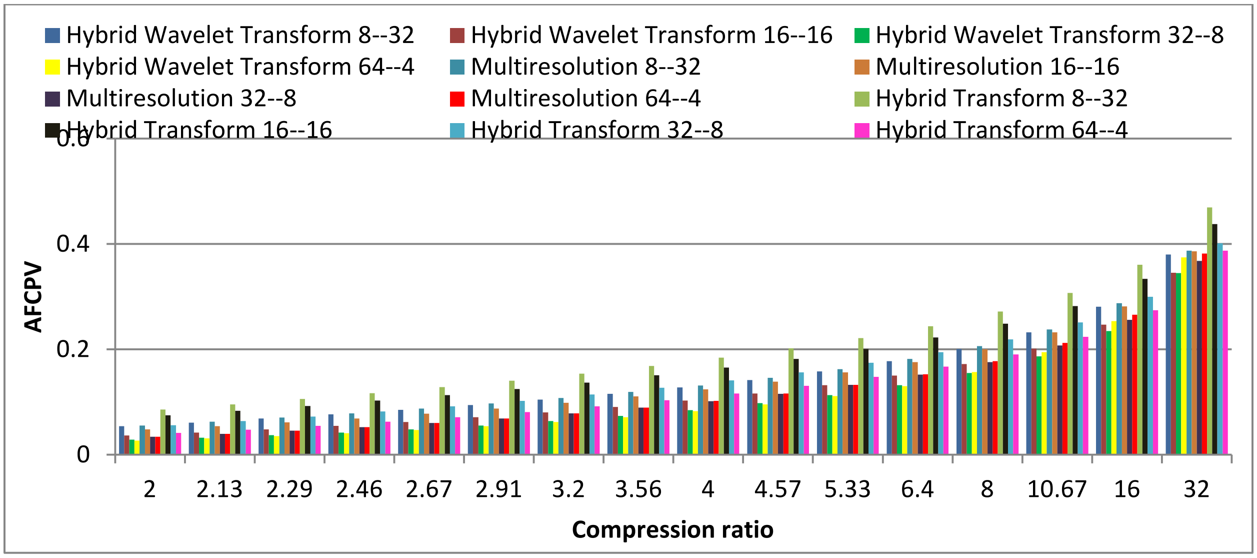

Figure 14 Comparison of AFCPV against Compression Ratio in Different Cases of Haar-Slant Hybrid Wavelet Transform using Variation in Component Transforms Size

Till now we have analyzed the performance of different cases of Hybrid Haar wavelet by varying the local component transform with Haar transform and then size of components has also been varied. RMSE estimates the perceived error. It is not consistent with human eye perception. Hence Structural Similarity Index between original image and reconstructed image is calculated on blocked image.

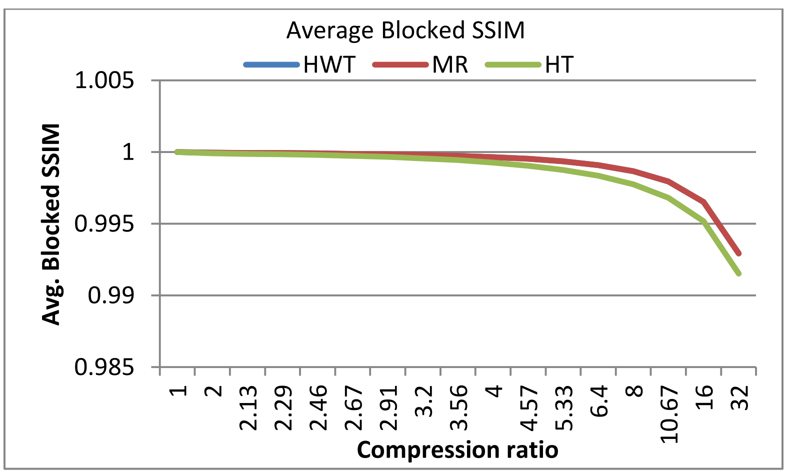

Figure 15 Average Blocked SSIM plotted against Compression ratio in Haar-Slant wavelet, its Multi-resolution analysis and Hybrid Transform.

Graph considers Haar-Slant hybrid wavelet, its multi-resolution analysis and hybrid transform for comparing their performances. SSIM equal to 1 indicates both images are equal. As SSIM gives perceived change in structural information of an image, it gives better perception of image to human visual system. From fig. 15 it has been observed that lower compression ratios up to 2.29 SSIM is almost equal to 1. Further it slightly decreases with increase in compression ratio. At compression ratio 32 SSIM is 0.992 indicating good quality of compressed image. For HWT and MR values of SSIM are equal and overlap in the graph. Hence we can say that both these methods perform equally.

<table>
<tr><td colspan="3">a) Reconstructed 'Lena' image using component transform Haar 32x32, Slant 8x8 at compression ratio 32</td></tr>
<tr><td>Hybrid wavelet</td><td>Multi-Resolution</td><td>Hybrid Transform</td></tr>
</table>

<table>
<tr><td></td><td></td><td></td></tr>
<tr><td>AFCPV= 0.104</td><td>AFCPV= 0.111</td><td>AFCPV= 0.117</td></tr>
<tr><td colspan="3">b) Reconstructed ‘Lena’ image using component transform Haar 32x32, Walsh 8x8 at compression ratio 32</td></tr>
<tr><td>Hybrid wavelet</td><td>Multi-Resolution</td><td>Hybrid Transform</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>AFCPV= 0.113</td><td>AFCPV= 0.123</td><td>AFCPV= 0.126</td></tr>
<tr><td colspan="3">c) Reconstructed ‘Lena’ image using component transform Haar 32x32, Kekre 8x8 at compression ratio 32</td></tr>
<tr><td>Hybrid wavelet</td><td>Multi-Resolution</td><td>Hybrid Transform</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>AFCPV= 0.131</td><td>AFCPV= 0.137</td><td>AFCPV= 0.142</td></tr>
</table>

Figure 16 Reconstructed Lena Image using Different Hybrid Haar Wavelet Transforms
a) Haar-Slant b) Haar-Walsh c) Haar-Kekre

VI. CONCLUSION

In this paper color image compression using Hybrid Wavelet Transform, its multi-resolution analysis and Hybrid transform is proposed. Two different transforms are used to generate hybrid wavelet transform. Haar transform which is simplest transform is chosen as base transform. It contributes to global features of an image. Non sinusoidal transforms like Walsh transform, Kekre transform and Slant transform are selected as local components. Among three hybrid wavelet transforms i.e. Haar-Walsh, Haar-Slant and Haar-Kekre, Haar-Slant gives less RMSE. Hence various size combinations of Haar-Slant are tried and best size is selected. It is observed to be 32-8 except compression ratio 32. As RMSE does not give clear idea about perceptual quality of image, Mean Absolute Error and Average Fractional Change in Pixel Value are the two more parameters used to analyze the quality of compressed image. Haar (32x32)-Slant (8x8) hybrid wavelet give lower value of MAE and AFCPV than other possible size pairs in hybrid transform and multi-resolution analysis. SSIM considers image degradation as perceived change in structural information hence give quality assessment similar to human visual system. Blocked SSIM is calculated as 0.992 at compression ratio 32 in hybrid wavelet and multi resolution analysis which is closest to one indicating better image quality.

ISSN 2250-3153

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