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Color Image Compression using DKT-DCT Hybrid Wavelet Transform in Various Color Spaces

[1]H.B. Kekre, [2]Tanuja Sarode and [3]Prachi Natu

[1]Sr. Professor Computer Engineering Department
MPSTME, NMIMS University
Mumbai, India
[2]Associate Professor Computer Engineering Department
TSEC, Mumbai University
Mumbai, India
[3]Ph. D Research Scholar Computer Engineering Department
MPSTME, NMIMS University
Mumbai, India
[1]hbkekre@yahoo.com, [2]tanuja_0123@yahoo.com, [3]prachi.natu@yahoo.com

Abstract

This paper proposes image compression in different color spaces using hybrid wavelet transform. To generate hybrid wavelet transform Discrete Kekre transform (DKT) and Discrete Cosine transform (DCT) are selected as component transforms. Due to high energy compaction property, DCT is selected as local component transform that contributes to local features of an image. Hybrid wavelet transform extracts features of both the component transforms and hence gives less error and better image quality. Component transforms of different sizes are selected to generate hybrid wavelet of size 256x256 and applied on images. In RGB color space 16-16 combination i.e. hybrid wavelet generated using DKT 16x16 and DCT 16x16 gives least error than other combinations like 8-32, 32-8 and 64-4. RMSE, MAE, AFCPV and Structural Similarity Index (SSIM) are the error metrics used to measure reconstructed image quality. Different color spaces have been used to observe the performance of this hybrid wavelet transform. In KLUV color space minimum RMSE and MAE is observed than RGB, YUV, YCbCr, XYZ and YIQ color space. Whereas RGB color space gives lowest AFCPV than other color spaces using 16-16 component size. Hence SSIM is used to eliminate this inconsistency in these traditional error metrics. KLUV color space gives highest SSIM 0.998 which is closest to maximum one proving it as a better choice than other color spaces.

Keywords: *Hybrid Wavelet Transform, Image compression, SSIM, AFCPV*

1. Introduction

Advancements in technology have made considerable changes in the usage of data. Today huge amount of multimedia data is being used and transmitted over the internet. As this multimedia data is continuously increasing day by day, large storage space and transmission bandwidth are the key factors to be considered. Here Image compression plays the vital role. Compression is broadly categorized as lossless and lossy compression. Medical imaging, text data compression are examples of lossless compression where data should be regenerated as it is without any loss. On the other hand, web applications, mobile applications are lossy

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compressions where some loss of original contents is acceptable. Lossy compression gives high compression than lossless compression.

In compression algorithms, redundant information in images which is not visible to HVS is removed. Transform based image compression methods have been widely used for image compression as processing of images in frequency domain is easier than spatial domain. Discrete Cosine Transform (DCT) is popular transform used for image compression. DCT has good energy compaction property. After DCT, wavelets have achieved more popularity in image compression because wavelets show higher energy compaction than DCT. Traditional study of wavelet shows that Daubechies wavelet [1] and Haar wavelets have been used and analyzed for image compression application. Recent research work also includes DCT wavelet, Walsh wavelet, Kekre wavelet Slant wavelet [2] and Hartley wavelet [3] which are generated using Kekre's algorithm. This paper analyzes image compression in various color spaces using different error parameters. Remaining sections of this paper are organized as follows: Section 2 contains work done on this topic in brief. Section 3 outlines proposed work. Experiments and results are discussed in section 4 and conclusion is stated in section 5.

2. Related Work

In literature transform based image compression started with Fourier transform [4]. But it cannot detect local properties of a signal. Hence Short time Fourier transform (STFT) was introduced which is also called as window transform. But it gives local properties of a signal at the cost of global properties. This drawback was overcome by wavelet transforms. Discrete cosine Transform (DCT) is widely used in compression due to its high de-correlation property [5]. But it introduces blocking artifacts in the image at the edges [6]. Wavelet transform provides solution to this problem. Wavelets are nothing but mathematical tool used to extract information from a signal or image [7]. It was first introduces by Jeans Morlet [8]. Wavelets have better energy compaction property than DCT. In the initial stage only Haar wavelets were studied. Wavelet based image compression analyzed by Arora, *et al.*, [9] shows usage of different wavelets like 2D Haar, Symlet, Coiflet and DB4 wavelets in image compression and it has been observed that Haar wavelet gives better results among these four wavelets. Compression using biorthogonal wavelet transform is proposed by Liu [10].Yi Zhang and Xing Yuan Wang have proposed fractal image compression using wavelet transform with diamond search approach. But it is very time consuming. Singh and Sharma have proposed wavelet based extension of JPEG 2000 standard [11]. Here first level wavelet decomposes the image only in vertical direction and subsequent wavelet levels use full horizontal and vertical splitting for all image components. But performance of this method degrades when images are with low colour depth. Singular value decomposition combined with linear and quadratic interpolation has been proposed by J Hizadian, A Hosaini and M Jalili [12]. But this method is also time consuming. A lifting scheme wavelet based transform with a modified entropy coding algorithm is proposed by Loay George and Aree Muhammad in [13]. It discusses effect of block sub-band coding on compression factor and quality of an image. Image compression using Walsh wavelet, Kekre wavelet and Slant wavelet with variation in component transform size is proposed by Kekre, *et al.*, in [14]. Here wavelet transform is generated using respective component orthogonal transform of different sizes using Kekre's algorithm. Component size pair giving less RMSE is selected as best size combination of that wavelet transform. Recent research work includes use of hybrid wavelet transforms in image compression. Dr. Kekre, *et al.*, has proposed compression using hybrid Haar wavelet transform is proposed in [15]. Haar transform is combined with different sinusoidal transforms like DCT, Discrete Sine Transform (DST), Real-DFT and Hartley transform to generate hybrid Haar wavelet transform. Performance of each pair is compared using various error metrics. Image compression using

hybrid wavelet of Real-DFT and DCT is proposed in [16] by Dr. Kekre, Dr. Tanuja Sarode and Prachi Natu where it has been observed that error in hybrid wavelet is considerably less than respective component transforms and their respective wavelet transforms.
This paper proposes image compression using DKT-DCT hybrid wavelet transform and compares their performance in different color spaces.

3. Proposed New Method

In this paper image compression using DKT-DCT hybrid wavelet transform has been proposed. Kekre transform is used as base transform and DCT is selected as local component of hybrid wavelet transform due to its good energy compaction property. Hybrid wavelet transform extracts features of both orthogonal transforms. It is generated using Kekre's algorithm. Let A denotes MxM Kekre transform and B denotes NxN DCT. Then DKT-DCT hybrid wavelet T will be of MNxMN size. First 'M' rows of resultant matrix are calculated by repeating each column of 'A', 'N' times and multiplying it with each element of first row of B. These 'M' rows represent global characteristics in hybrid wavelet transform. Remaining rows are obtained by translating the rows of matrix B from second row onwards. These rows contribute local features of an image. Generated hybrid wavelet transform is shown below in Figure 1.

Hybrid wavelet using different component size is generated and applied on images. To generate 256x256 size transformation matrix, different component sizes used are 8-32, 16-16, 32-8 and 64-4. Here 8-32 means 8x8 base transform *i.e.*, Kekre transform and 32x32 local transform *i.e.*, DCT is used to generate DKT-DCT hybrid wavelet of size 256x256.

$b_{11}\begin{pmatrix} a_{11} \\ a_{21} \\ . \\ . \\ . \\ a_{m1} \end{pmatrix}$	…	$b_{1n}\begin{pmatrix} a_{11} \\ a_{21} \\ . \\ . \\ . \\ a_{m1} \end{pmatrix}$	$b_{11}\begin{pmatrix} a_{12} \\ a_{22} \\ . \\ . \\ . \\ a_{m2} \end{pmatrix}$	…	$b_{1n}\begin{pmatrix} a_{12} \\ a_{22} \\ . \\ . \\ . \\ a_{m} \end{pmatrix}$	….	$b_{11}\begin{pmatrix} a_{1m} \\ a_{2m} \\ . \\ . \\ . \\ a_{mm} \end{pmatrix}$	…..	$b_{1n}\begin{pmatrix} a_{1m} \\ a_{2m} \\ . \\ . \\ . \\ a_{mm} \end{pmatrix}$
b21	…	b_{2n}	0	0	0	…..	0	…	0
0	0	0	b_{21}	…	b_{2n}	…..	0	…	0
. .	. .	. .	. .	. .	. .	…..	. .	. .	. .
0	0	0	0	0	0	.	b_{21}	…	b_{2n}
b_{31}	…	b_{3n}	0	0	0	.	0	…	0
0	0	0	b_{31}	…	b_{3n}	.	0	…	0
. .	. .	. .	. .	. .	. .	.	. .	. .	. .
0	0	0	0	0	0	.	b_{31}	…	b_{3n}
. .	. .	. .	. .	. .	. .	.	. .	. .	. .
b_{n1}	…	b_{nn}	0	0	0	.	0	0	0
0	0	0	b_{n1}	…	b_{nn}	.	0	0	0
. .	. .	. .	. .	. .	. .	.	. .	. .	. .
0	0	0	0	0	0	.	b_{n1}	…	b_{nn}

Figure 1. Generation of Hybrid Wavelet Transform using Kekre's Algorithm

4. Experiments and Results

Proposed method is applied on color images of different classes shown in Figure 2.

Figure 2. Color Images of Different Classes used for Experimental Purpose

All images are 256x256 size bitmap images. Experiments are done on AMD dual core processor using Matlab 7.0. Color spaces used are RGB, YCbCr, XYZ, KLUV, YIQ, and YUV. Hybrid wavelet with different component size is generated and applied on these color images. Image is first converted to required color space. Hybrid wavelet transform is applied

on image and it is compressed in transform domain. Reconstruction of original image is done by applying inverse transform. Reconstructed image is converted back to RGB color space to calculate error between this image and original image. Root mean square error (RMSE), Mean absolute error (MAE) and Average fractional change in pixel value (AFCPV) and SSIM are different error metrics used to measure the performance of proposed transform. RMSE gives the loss of perceptual quality which is directly related to visible error signal. Hence MAE and AFCPV are also used. Mean absolute error is given as

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

And AFCPV is calculated as

$$\text{AFCPV}=\frac{\sum_{i=1}^{i=p}\sum_{j=1}^{j=q}(|x_{ij}-y_{ij}|)/x_{ij}}{p*q} \tag{2}$$

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

In each color space error is calculated using above three parameters. Component transform of different size are selected and best component combination is observed in each color space for different error metrics. As compared to above mentioned error metrics like RMSE and MAE, AFCPV and SSIM can provide good approximation to perceived image quality. This is because human visual system can easily extract statistical structural information from still image and AFCPV indicates the change in individual pixel values.

SSIM is calculated as

$$\text{SSIM}(x, y) = (2\mu_x\mu_y+c_1)\,(2\sigma_{xy}+c_2) \,/\, (\mu_x^2+\mu_y^2+c_1)\,(\sigma_x^2+\sigma_y^2+c_2) \tag{3}$$

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.

4.1 RGB Color Space

Figure 3 shows RMSE plot in RGB color space. Different sizes of DKT and DCT are selected here to observe the best size combination.

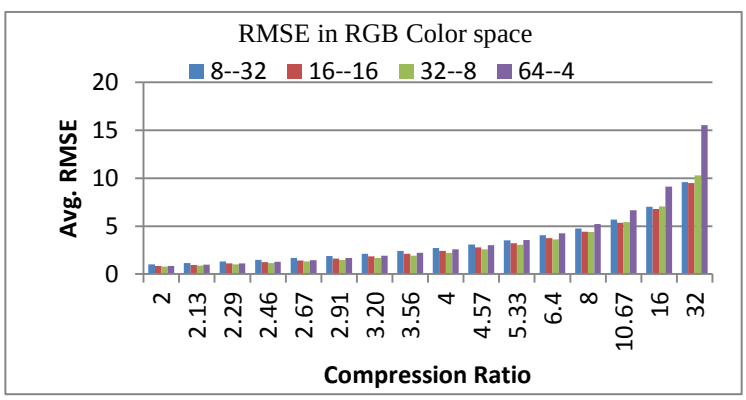


Figure 3. RMSE vs. Compression Ratio using Different Component Sizes of DKT-DCT in RGB Color Space

As observed from Figure 3, 16-16 component size gives less error at higher compression ratios. At lower compression ratios up to 6.4, 32-8 component size gives slight lower error. At compression ratio 8, RMSE given by 16-16 and 32-8 pair is almost equal. Error in 16-16 pair becomes slightly lesser than other size combinations from compression ratio 10.67 onwards. 64-4 size pair gives high error value for all compression ratios.

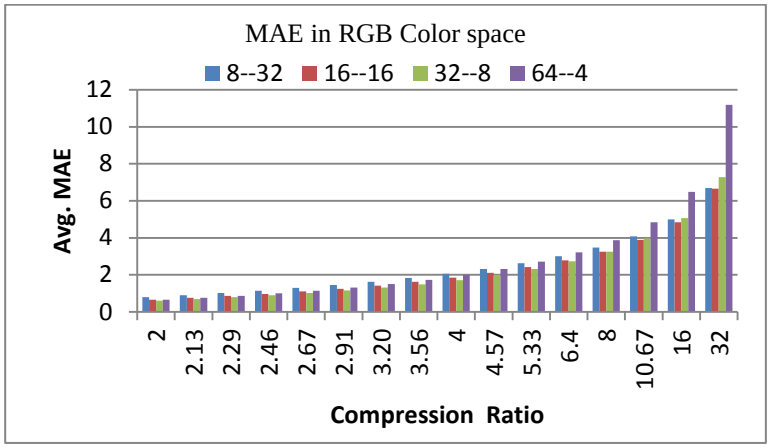


Figure 4. MAE vs. Compression Ratio using Different Component Sizes of DKT-DCT in RGB Color Space

Figure 4 shows MAE in RGB color space using different component sizes of DKT and DCT. Up to compression ratio 10.67, component size 16-16 and 32-8 give almost equal MAE. For further compression ratios, component size 16-16 gives less MAE than other combinations.

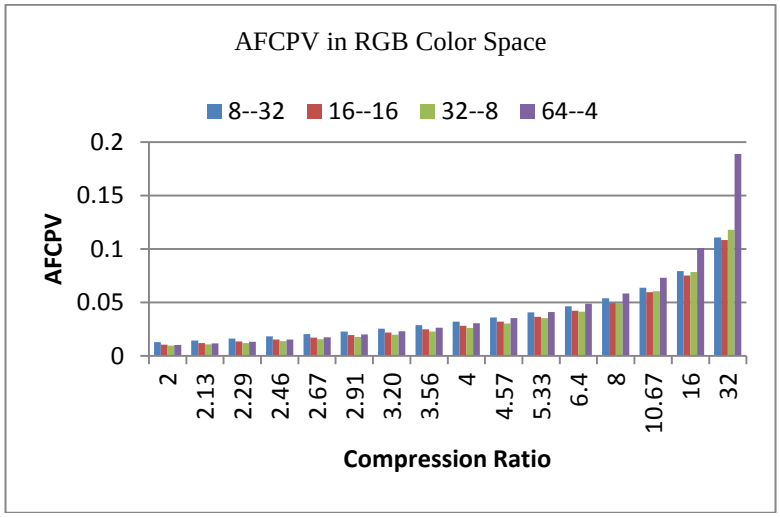


Figure 5. AFCPV vs. Compression Ratio using Different Component Sizes of DKT-DCT in RGB Color Space

Figure 5 shows AFCPV against compression ratio in RGB color space. Similar to RMSE and MAE, 16-16 component size gives low AFCPV.

4.2 YCbCr Color Space

Figure 6, 7 and 8 show different error metrics RMSE, MAE and AFCPV plotted against compression ratio in YCbCr color space.

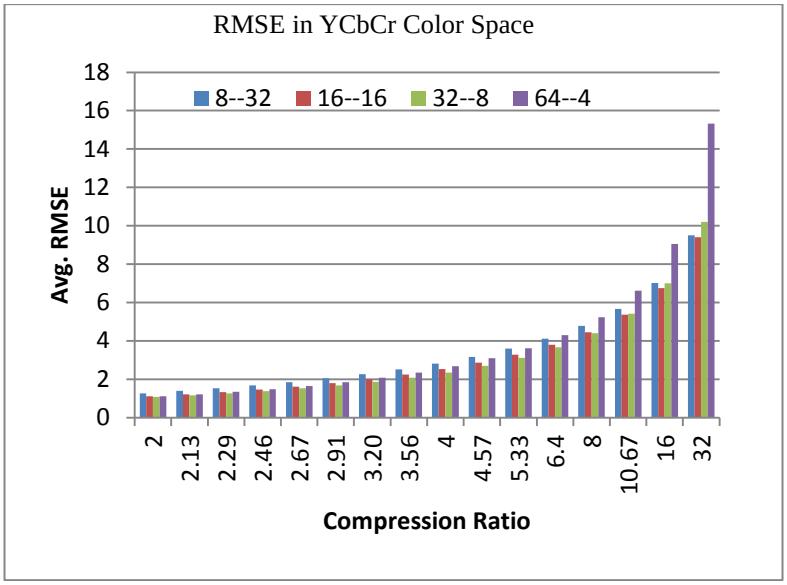


Figure 6. RMSE vs. Compression Ratio using Different Component Sizes of DKT-DCT in Ycbcr Color Space

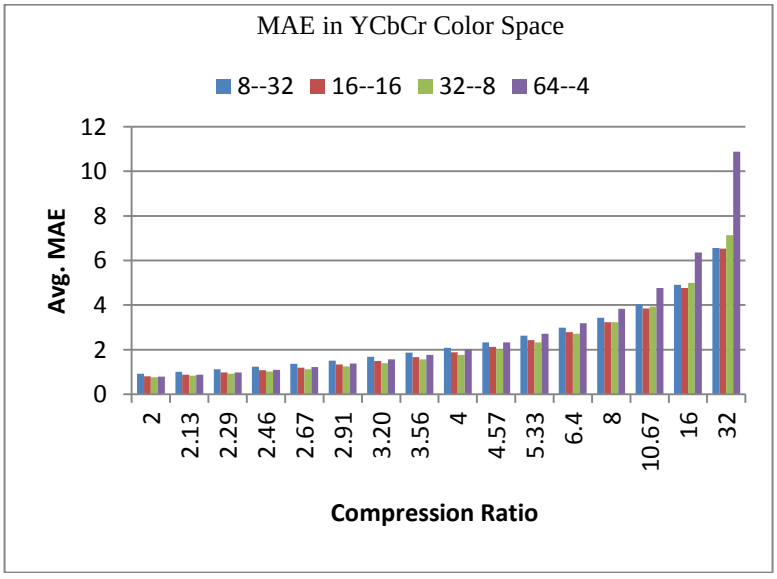


Figure 7. MAE vs. Compression Ratio using Different Component Sizes f DKT-DCT in Ycbcr Color Space

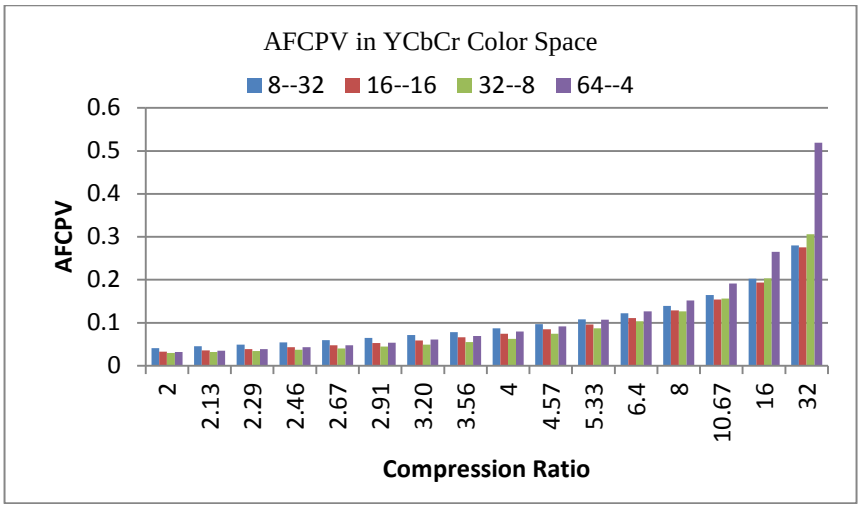


Figure 8. AFCPV vs. Compression Ratio using Different Component sizes of DKT-DCT in YCbCr Color Space

At lower compression ratios up to 6.4, component size 32-8 gives less error than other sizes. At compression ratio 8 component sizes 32-8 and 16-16 show almost equal error and for higher compression ratios 16-16 pair gives low error than 32-8 and 8-32 pair. 64-4 pair gives highest error at compression ratio 32.

a. XYZ Color Space

Figure 9, 10 and 11 show error parameters in XYZ color space.

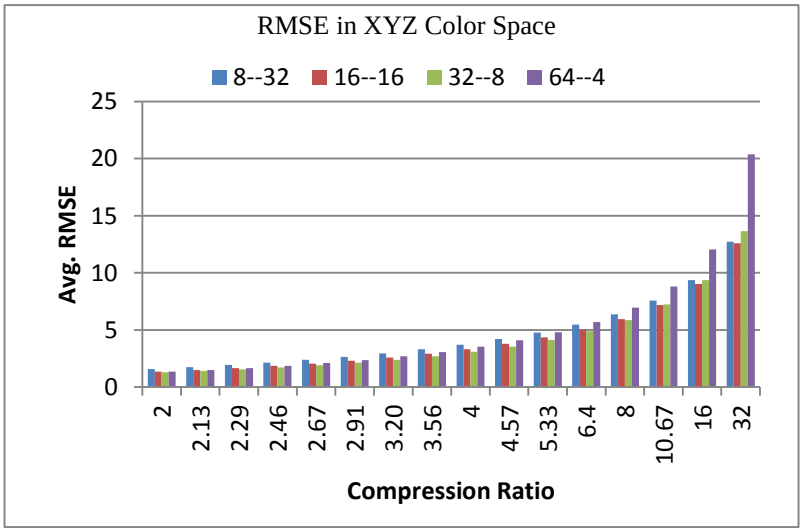


Figure 9. RMSE vs. Compression Ratio using Different Component Sizes of DKT-DCT in XYZ Color Space

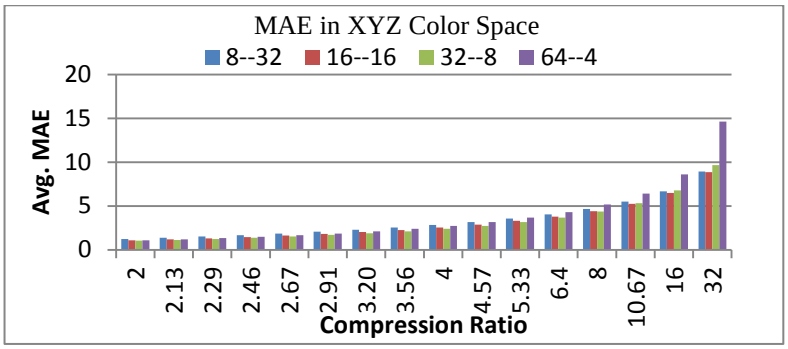


Figure 10. MAE vs. Compression Ratio using Different Component Sizes of DKT-DCT in XYZ Color Space

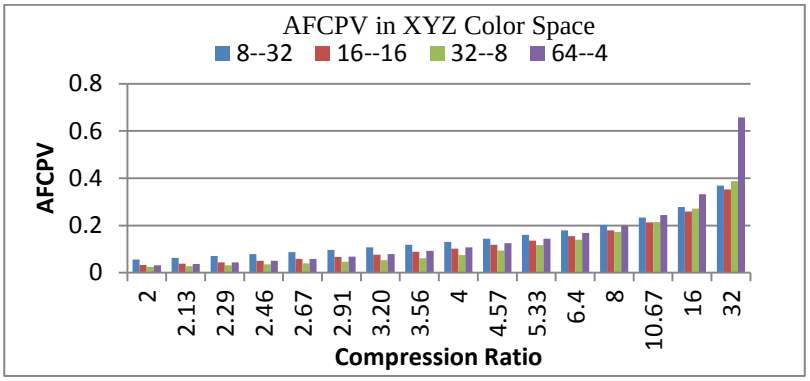


Figure 11. MAE vs. Compression Ratio Using Different Component Sizes of DKT-DCT in XYZ Color Space

It follows similar pattern as that of RGB and YCbCr color space *i.e.*, 16-16 component size gives lower value of error than other component size pairs at compression ratio above 8.

b. KLUV Color Space

Error metrics in KLUV color space are shown in Figure 12, 13 and 14.

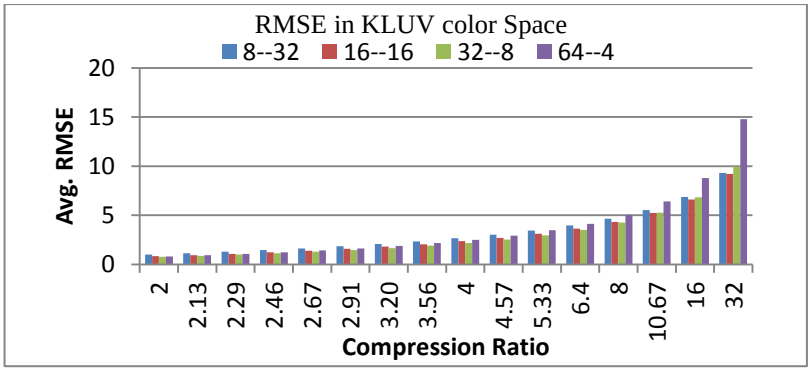


Figure 12. RMSE vs. Compression Ratio Using Different Component Sizes of DKT-DCT in KLUV Color Space

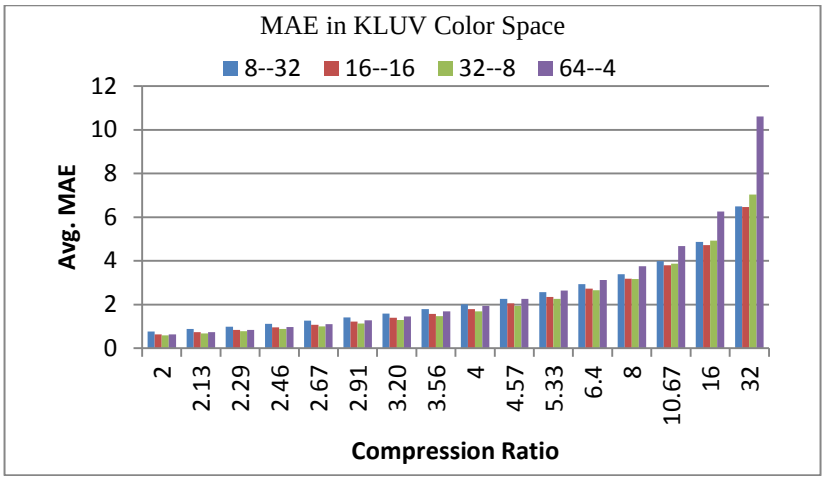


Figure 13. MAE vs. Compression Ratio using Different Component Sizes of DKT-DCT in KLUV Color Space

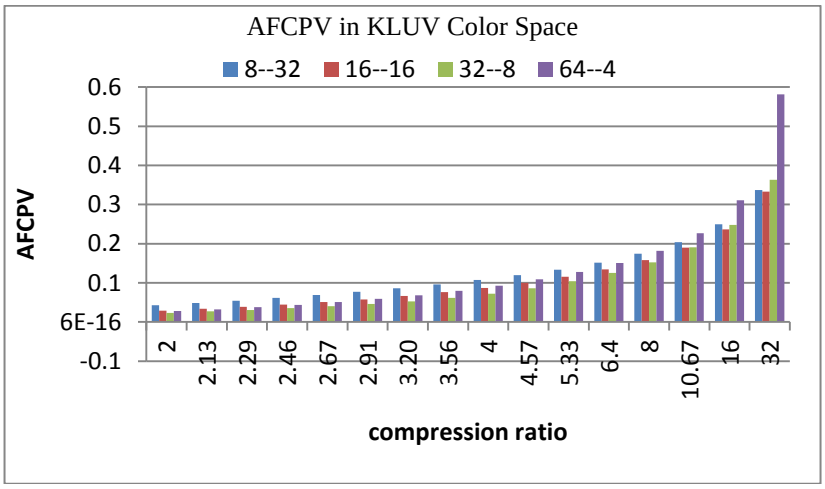


Figure 14. AFCPV vs. Compression Ratio using Different Component Sizes of DKT-DCT In KLUV Color Space

For compression ratios 2 to 8 component size 32-8 gives low error value. Further for high compression ratios 16-16 size is observed to be better. 64-4 component size cannot be chosen at high compression ratios as it gives very high error values.

c. YIQ Color Space

Figure 15, 16 and 17 show plot of RMSE, MAE and AFCPV against compression ratio respectively in YIQ color space.

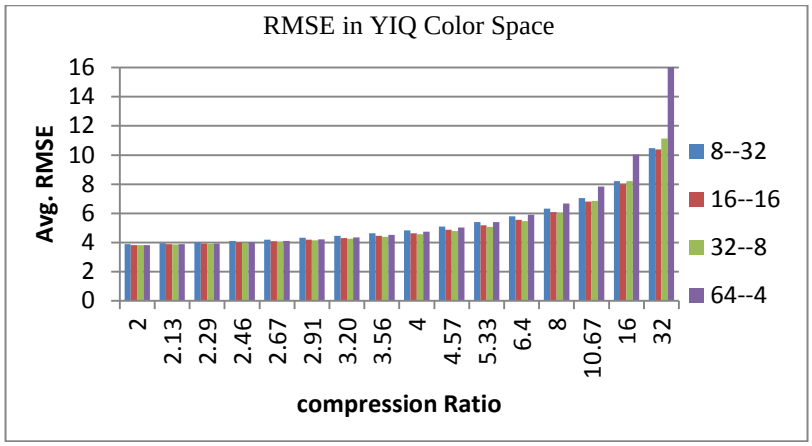


Figure 15. RMSE vs. Compression Ratio using Different Component Sizes of DKT-DCT in YIQ Color Space

Component size 16-16 of DKT-DCT gives less RMSE for compression ratios greater than 8. At compression ratio 8 and less than that component size 16-16 and 32-8 show almost equal error. 64-4 size cannot be used for higher compression ratios 16 and 32 as it gives higher error than other size pairs.

In Figure 16 MAE is plotted against compression ratio. Here component pair 8-32, 16-16 and 32-8 show almost equal MAE. Significant difference in MAE is observed using component size 64-4. This combination gives higher MAE and hence cannot be used.

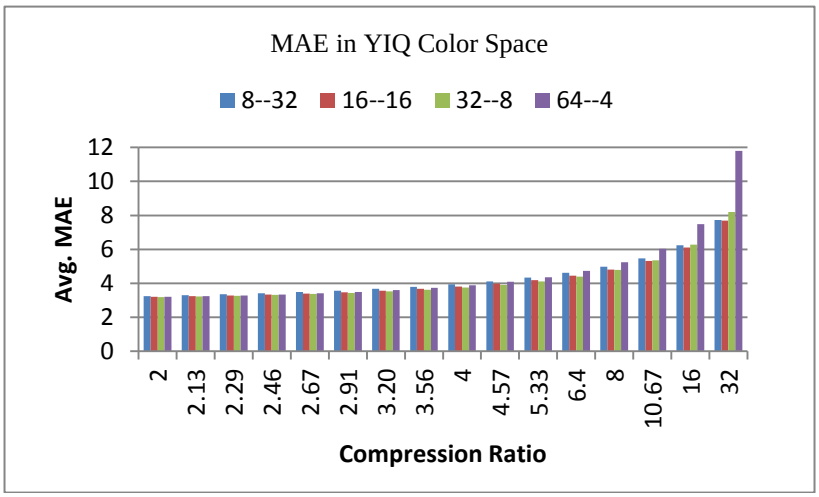


Figure 16. MAE vs. Compression Ratio using Different Component Sizes of DKT-DCT in YIQ Color Space

AFCPV is plotted in Figure 17. AFCPV shows clear perceptibility of image quality as average change in pixel value is considered. Component size 8-32 and 16-16 show similar performance at higher compression ratios 16 and 32.

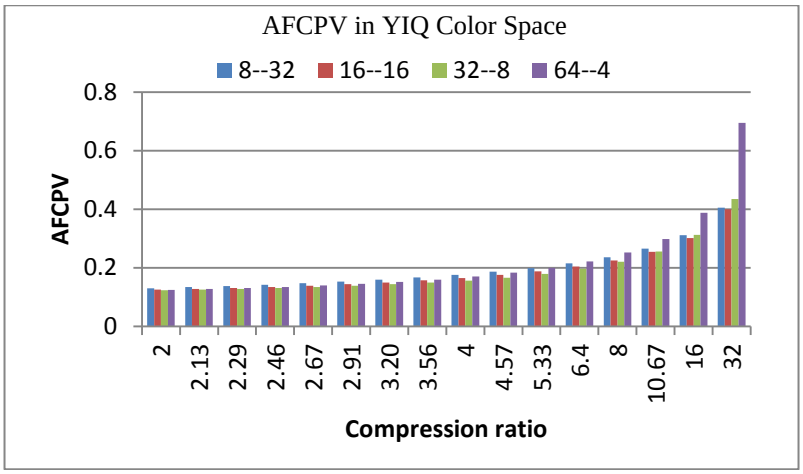


Figure 17. AFCPV vs. Compression Ratio using Different Component Sizes of DKT-DCT in YIQ Color Space

d. YUV Color Space

Figure 18 compares RMSE in YUV color space using different component sizes of DKT-DCT hybrid wavelet transform. Best component size observed is 16-16 for high compression ratios.

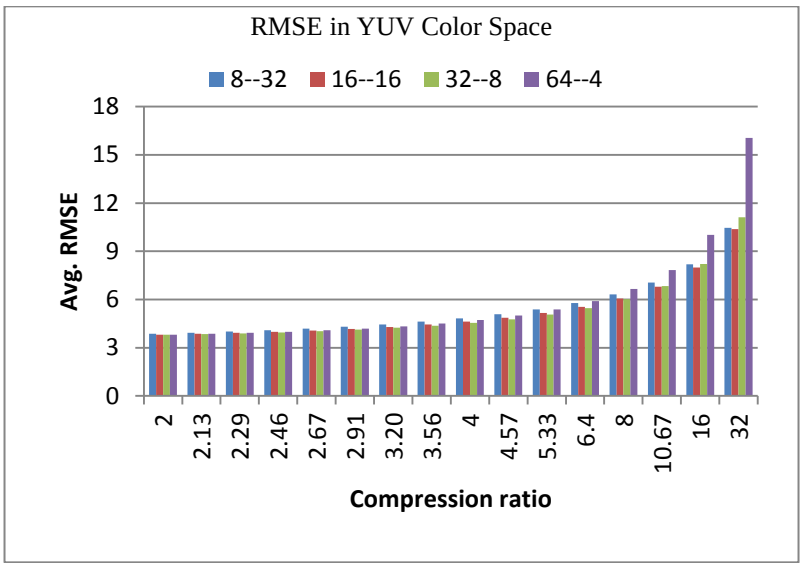


Figure 18. RMSE vs. Compression Ratio using Different Component Sizes of DKT-DCT in YUV Color Space

Figure 19 and Figure 20 show graph of MAE and AFCPV respectively. Here at lower compression ratios, component size 8-32, 16-16 and 32-8 show almost similar performance. Maximum error is given by component size 64-4.

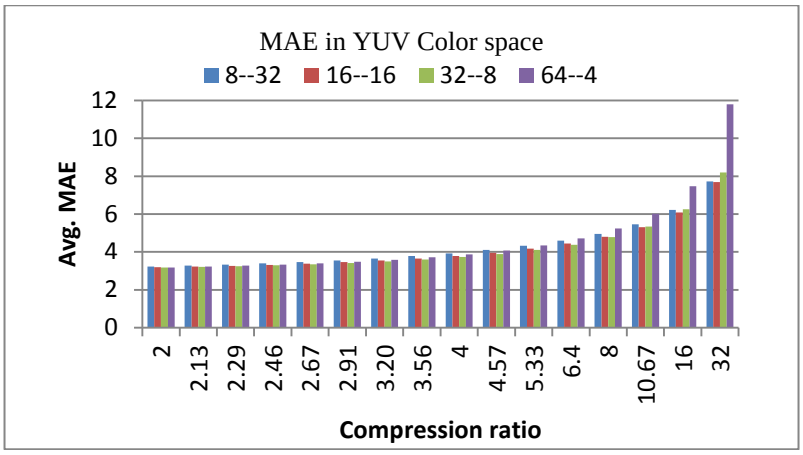


Figure 19. MAE vs. Compression Ratio using Different Component Sizes Of DKT-DCT in YUV Color Space

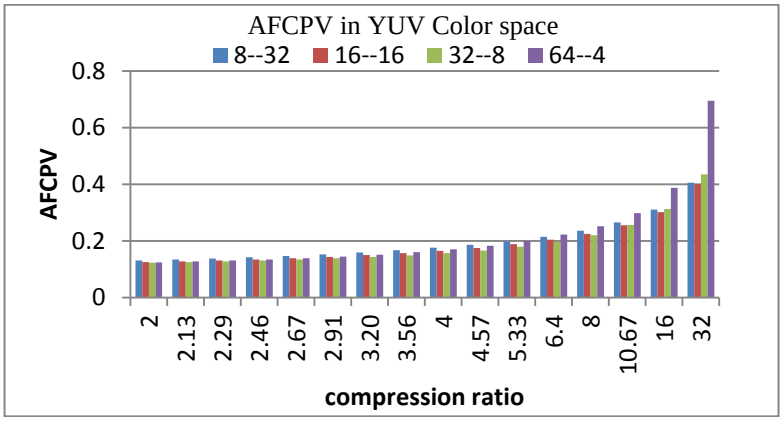


Figure 20. AFCPV vs. Compression Ratio using Different Component Sizes of DKT-DCT In YUV Color Space

5. Comparison of Error Metrics in Various Color Spaces

Figure 21 compares RMSE in various color spaces.

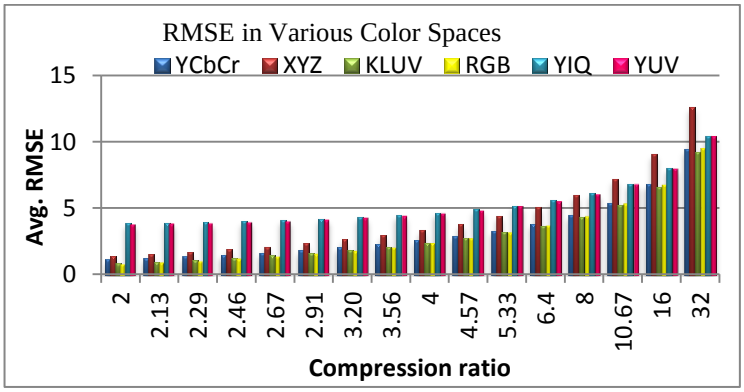


Figure 21. Comparison of RMSE in Various Color Spaces

YIQ and YUV color spaces show almost equal error at all compression ratios. Similarly RGB and KLUV color space show almost equal error up to compression ratio 10.67. It is less than all other color spaces. For compression ratio 16 and 32 KLUV color spaces show less error than RGB color space. YCbCr color space show slight high error than KLUV and RGB color space and XYZ color space show higher error than all color spaces at every compression ratio plotted in the graph.

Figure 22 compares MAE in different color spaces at various compression ratios.

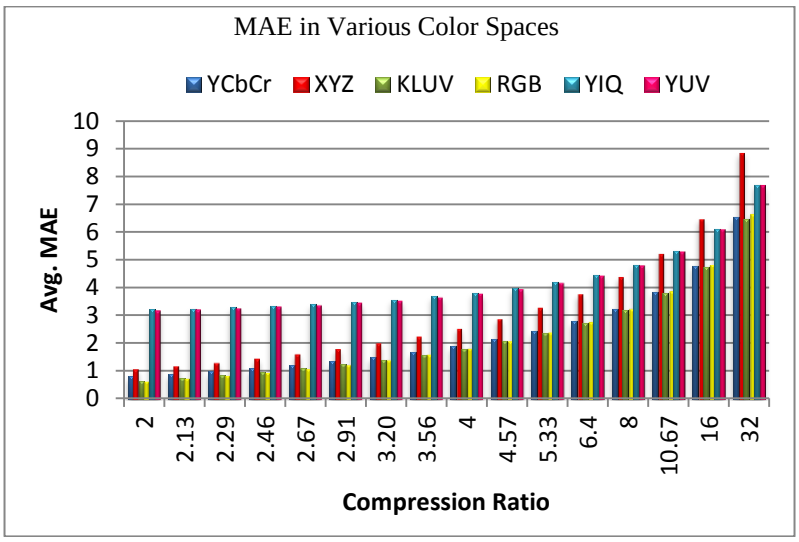


Figure 22. Comparison of MAE in Various Color Space

Similar to RMSE plotted in Figure 21, here also KLUV color space gives least MAE than all other color spaces at higher compression ratios 16 and 32. At this compression ratios MAE in RGB and YCbCr color space is slightly higher than MAE in KLUV color space. In XYZ color space maximum MAE is obtained.

AFCPV in various color spaces is plotted in Figure 23.

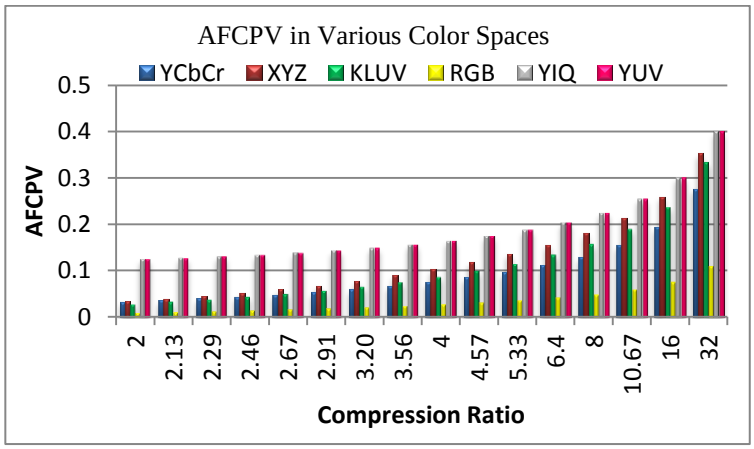


Figure 23. Comparison of AFCPV in Various Color Spaces

RGB color space gives lowest AFCPV and it is followed by YCbCr color space. YUV and YIQ color space show almost equal value of AFCPV and it is the highest value than all other color spaces.

As seen in earlier graphs, KLUV color space gives lowest RMSE and MAE as compared to all other color spaces at higher compression ratio. But RGB color space gives lowest AFCPV among all color spaces. Hence to decide which color space is better among these two, SSIM is used. Figure 24 compares SSIM in various color spaces.

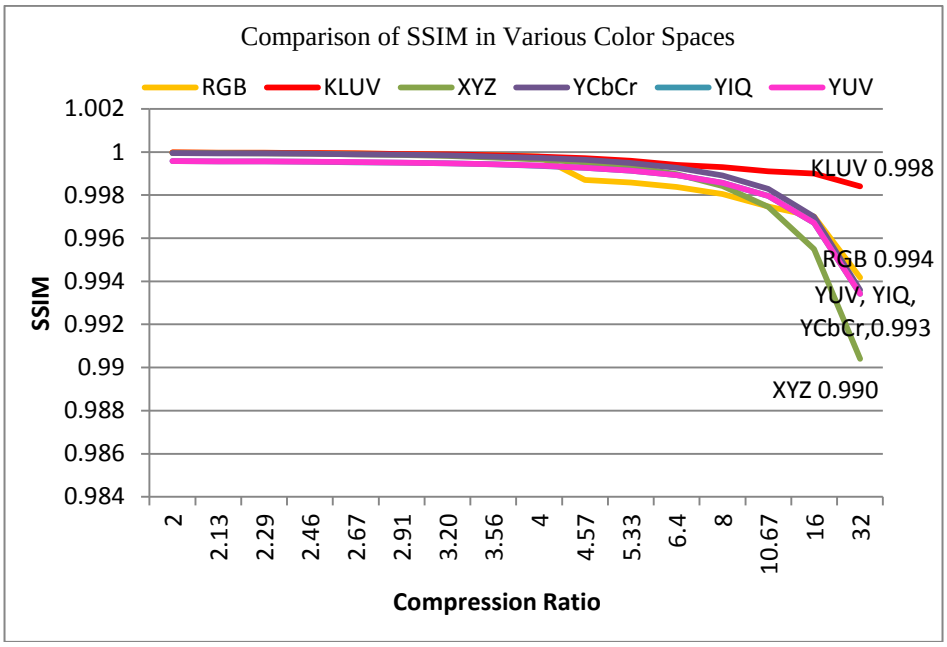


Figure 24. Comparison of SSIM in RGB and KLUV Color Space

Structural Similarity Index (SSIM) provides a good approximation to perceived image quality. SSIM considers image degradation as perceived change in structural information. Structural information is the idea that the pixels have strong inter-dependencies especially when they are spatially close. These dependencies carry important information about the structure of the objects in the visual scene. As RGB and KLUV color spaces show closer error values in terms of RMSE and MAE, SSIM is used to choose the best color space. SSIM closest to one indicates that reconstructed image is exactly similar to original image. From Figure 24 it is clear that KLUV gives SSIM 0.999 at compression ratio 32 whereas in RGB it is 0.994 for same compression ratio. Hence using SSIM as error metric it can be clearly decided that KLUV color space gives better image quality than RGB.

Figure 25 shows reconstructed 'Lena' image in various color spaces at compression ratio 4,8,16 and 32. At highest compression ratio 32, KLUV color space gives better SSIM indicating superior image quality than other color spaces. It is followed by RGB color space. YIQ, YUV and YCbCr show similar image quality in terms of SSIM and XYZ color space shows lower image quality than all other color spaces.

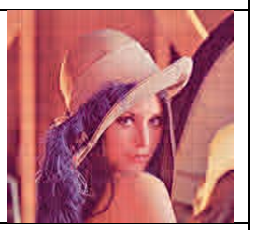
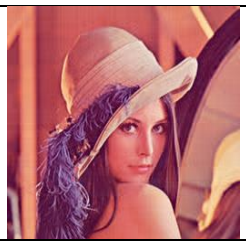
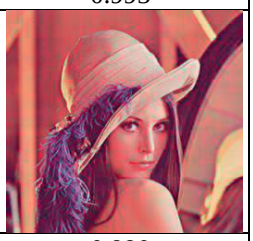
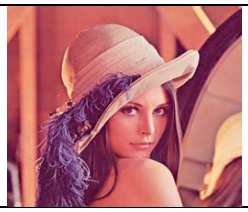
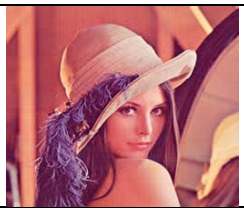
	Compression Ratio			
Color space	4	8	16	32
RGB				
SSIM	1	0.999	0.997	0.994
YCbCr				
SSIM	0.999	0998	0.996	0.993
XYZ				
SSIM	0.999	0.998	0.995	0.990
KLUV				
SSIM	1	0.999	0.998	0.997
YIQ				
SSIM	0.999	0998	0.996	0.993
YUV				
SSIM	0.999	0998	0.996	0.993

Figure 25. Reconstructed Lena image in DKT-DCT Hybrid Wavelet with Component Size 16-16 in Various Color Spaces

6. Conclusion

In this paper image compression using DKT-DCT hybrid wavelet in different color spaces is compared. Component transform size is varied to select best component size in particular color space. It has been observed that in all color spaces 16-16 combination proves to be better. Performance is measured using different error metrics: RMSE, MAE, AFCPV and SSIM. KLUV color space gives less error in terms of RMSE and MAE. But lowest AFCPV is given by RGB color space. Hence further SSIM is used to observe which color space gives better image quality. Structural similarity gives image degradation as perceived change in image information visible to human eye. In KLUV color space SSIM equal to 0.998 is obtained at compression ratio 32 which is closest to one indicating better reconstructed image quality is given by KLUV color space than other color spaces. In RGB this value is 0.994 at compression ratio 32. Other color spaces give lower value of SSIM than KLUV and RGB color spaces. YUV, YIQ and YCbCr show equal value of SSIM 0.993 and XYZ color space has SSIM 0.990 indicating that this color space shows poor quality of reconstructed images among all.

References

[1] I. Daubechies, “The wavelet transform, time-frequency localization and Signal analysis”, IEEE Transformation and Information Theory, vol. 36, **(1990),** pp. 961-1005.
[2] H. B. Kekre, T. Sarode and P. Natu, “Image Compression using Column, Row and Full Wavelet Transforms of Walsh, Cosine, Haar, Kekre, Slant and Sine and Their Comparison with Corresponding Orthogonal Transforms”, International Journal of Engineering Research and Development, vol. 6, Issue 4, **(2013)** March, pp. 102-113.
[3] H. B. Kekre, T. Sarode and P. Natu, “Performance Comparison of Hartley Transform with Hartley Wavelet and Hybrid Hartley Wavelet Transforms for Image Data Compression”, International Journal of Computers and Technology, vol. 12, no. 6, pp. 3634-3641.
[4] G. Strang, "Wavelet Transforms Versus Fourier Transforms", Bulletin of Amer. Math. Soc. 28, 288-305, **(1993)**.
[5] N. Ahmed, T. Natarajan and K. R. Rao, “Discrete Cosine Transform”, IEEE Transaction Computers, vol. C-23, **(1974)** January, pp. 90-93.
[6] S. Anitha, “Image Compression Using Discrete Cosine Transform & Discrete Wavelet Transform”, International Journal of Scientific & Engineering Research, vol. 2, Issue 8, **(2011)** August.
[7] H. B. Kekre, S. D. Thepade and A. Parkar, “A Comparison of Haar Wavelets and Kekre’s Wavelets for Storing Colour Information in a Greyscale Image”, International Journal of Computer Applications (IJCA), vol. 1, no. 11, **(2010),** pp 32-38.
[8] M. Sifuzzaman, M. R. Islam and M. Z. Ali, “Application of Wavelet Transform and its Advantages Compared To Fourier Transform”, Journal of Physical Sciences, vol. 13, **(2009),** pp. 121-134.
[9] R. Arora, M. Sharma and N. Birla, “An Algorithm for Image Compression using 2D Wavelet Transform”, International Journal of Engineering Science and Technology, vol. 3, no. 4, **(2011)** April, pp. 2758- 2764.
[10] H. Liu, L. P. Zai, Y. Gao, W. M. Li, J.-F. Zohu, “Image compression Based on Biorthogonal Wavelet Transform”, in Proc. of ISCIT, **(2005)**.
[11] S. Singh, R. K. Sharma and M. K. Sharma, “Use of Wavelet Transform Extension for Graphics Image Compression using JPEG2000 Standard”, International Journal of Image Processing (IJIP), vol. 3, Issue 1, pp. 55-60.
[12] J. Izadian, A. Hosaini and M. Jalili, “A Hybrid SVD Method Using Interpolation Algorithms for Image Compression”, International Journal of Image Processing (IJIP), vol. 6, Issue 5, **(2012),** pp. 273-282.
[13] L. A. George and A. A. Muhammad, “Intra Frame Compression Using Lifting Scheme Wavelet-Based Transformation (9/7-Tap Cdf Filter)”, International Conference on Multimedia Systems And Applications, MSA 2007, **(2007),** pp. 25-28.
[14] H. B. Kekre, T. Sarode and P. Natu, “Performance Comparison of Walsh Wavelet, Kekre Wavelet and Slant Wavelet Transform in Image Compression”, International Journal of Advanced Research in Computer and Communication Engineering, vol. 2, Issue 10, **(2013)** October, pp. 3834-3840.
[15] H. B. Kekre, T. Sarode and P. Natu, “Performance Comparison of Hybrid Haar Wavelet Transform with Various Local Transforms in Image Compression using different error Metrics”, International Journal of Image Processing (IJIP), vol. 8, Issue 4, **(2014)** July, pp. 186-203.

[16] H. B. Kekre, T. Sarode and P. Natu, "Image Compression using Real Fourier Transform, It's Wavelet Transform and Hybrid Wavelet with DCT", Accepted in International Journal of Advanced Computer Science and Applications,(IJACSA), vol. 4, no.5, **(2013),** pp. 41-47.

Authors

Dr. H. B. Kekre, he has received B.E. (Hons.) in Telecom Engg. From Jabalpur University in 1958, M.Tech (Industrial Electronics) from IIT Bombay in 1960, M.S. Engg. (Electrical Engg.) from University of Ottawa in 1965 and Ph.D. (System Identification) from IIT Bombay in 1970. He has worked Over 35 years as Faculty of Electrical Engineering and then HOD Computer Science and Engg. at IIT Bombay. After serving IIT for 35 years, he retired in 1995. After retirement from IIT, for 13 years he was working as a professor and head in the department of computer engineering and Vice principal at Thadomal Shahani Engg. College, Mumbai. Now he is senior professor at MPSTME, SVKM's NMIMS University. He has guided 17 Ph.Ds, more than 100 M.E./M.Tech and several B.E. / B.Tech projects, while in IIT and TSEC. His areas of interest are Digital Signal processing, Image Processing and Computer Networking. He has more than 450 papers in National / International Journals and Conferences to his credit. He was Senior Member of IEEE. Presently He is Fellow of IETE, Life Member of ISTE and Senior Member of International Association of Computer Science and Information Technology (IACSIT). Recently fifteen students working under his guidance have received best paper awards. Currently eight research scholars working under his guidance have been awarded Ph. D. by NMIMS (Deemed to be University). At present seven research scholars are pursuing Ph.D. program under his guidance.

Dr. Tanuja K. Sarode, she has received M.E. (Computer Engineering) degree from Mumbai University in 2004, Ph.D. from Mukesh Patel School of Technology, Management and Engg. SVKM's NMIMS University, Vile-Parle (W), Mumbai, INDIA. She has more than 11 years of experience in teaching. Currently working as Associate Professor in Dept. of Computer Engineering at Thadomal Shahani Engineering College, Mumbai. She is member of International Association of Engineers (IAENG) and International Association of Computer Science and Information Technology (IACSIT). Her areas of interest are Image Processing, Signal Processing and Computer Graphics.

Ms. Prachi Natu, she has received M.E. (Computer) degree from Mumbai University in 2011. Currently pursuing Ph.D. from NMIMS University. She has 10 years of experience in teaching. Currently working as Assistant Professor in Department of Computer Engineering at Mukesh Patel School of Technology, Management and Engineering. Vile Parle (Mumbai). Her areas of interest are Image Processing, Database Management Systems and Operating Systems. She has 30 papers in International Conferences/journal to her credit.

