PERFORMANCE ANALYSIS OF WATERMARKING USING SVD AND COLUMN/ROW HYBRID WAVELET TRANSFORM OF DCT WITH WALSH, HAAR AND DKT

H. B. Kekre[1] and Tanuja Sarode[2] and Shachi Natu[3]
[1]MPSTME, Department of Computer Engineering, NMIMS University, Mumbai, India
[2]Department of Computer Engineering, TSEC, Mumbai University, India
[3]Ph. D. Research Scholar, MPSTME, NMIMS University, Mumbai, India

ABSTRACT

A robust watermarking using SVD and hybrid wavelet transform is proposed in this paper. Instead of using traditional wavelet transforms, hybrid wavelet generated from two different component transforms of different sizes is used to embed and extract watermark. Watermark is embedded in low and middle frequency bands separately. Various attacks like compression, cropping, noise addition, Histogram equalization and image resizing are performed to observe robustness in these frequency bands. Sinusoidal DCT is used as base transform and non-sinusoidal transforms Walsh, Haar and Discrete Kekre transform (DKT) are used as local transforms while generating hybrid wavelet. DCT-Walsh and DCT-Haar hybrid wavelet transforms are found to be better in robustness than DCT-DKT hybrid wavelet. Combination of SVD with hybrid wavelet adds to robustness of proposed method. Selection of Low frequency band to embed watermark proves to be more robust than middle frequency band against all attacks but cropping.

Keywords: *watermarking, Hybrid wavelet, SVD, column transform, row transform, DCT-Walsh hybrid wavelet, DCT-Haar hybrid wavelet.*

I. INTRODUCTION

In today's digital era, use of internet to disseminate digital images and other multimedia contents is inevitable. This imposes an immense need of security of digital contents transmitted over network. Availability of various tools and techniques allows easy manipulation of digital contents. To protect the digital contents from such undesirable alterations was the motivation for watermarking techniques. Though cryptographic techniques are there to provide security to digital contents, they don't contribute in protecting copyright of content owner. Watermarking techniques are explicitly meant for protecting the identity of owner of digital contents so that no one else can claim the ownership and can alter the contents.

While using Discrete Wavelet Transform, selection of appropriate frequency band plays an important role as it affects robustness and imperceptibility. Low frequency bands are normally major information contents of an image. Any modification to low frequency components therefore causes degradation into host image which is easily perceptible to Human Visual System [1]. However, in literature many methods of watermarking have been proposed which embed watermark in lower frequency components without losing imperceptibility of watermarked image. High frequency components in an image carry minimal information contents but they are responsible for edges in image. Since they carry minimum information about an image, alteration of these components due to embedding watermark is not easily sensed by human visual system. But it leads to high susceptibility to attacks like lossy image compression which eliminates high frequency components from image [1]. However it may prove more robust to other image processing attacks. To eliminate drawbacks of altering low frequency and high frequency components and to achieve benefits in terms of imperceptibility, selection of mid-frequency components is getting more attention in watermark embedding. Remaining paper is organized as follows. Section II presents review of literature. Section

III briefly introduces hybrid wavelet transforms and Singular Value Decomposition. Section IV describes the proposed method. Section V provides the performance analysis of proposed watermarking method against various image processing attack. Section VI ends the paper with conclusion.

II. REVIEW OF LITERATURE

Lot of work has been done in transform domain watermarking using DCT [2], [3], [4], wavelet transform [5], [6], [7] singular value decomposition [8], [9] and wavelet packet transform [10]. Methods are also proposed using combination of two or more transforms like DWT-DCT [11], DWT-SVD [12], DCT-SVD [13]; DWT-DCT-SVD [14] Combination of two or more transforms has proved to be more robust than using any single transformation technique. Attempts are still made to improve the performance of transform based techniques.

In literature, various approaches have been tried out for digital watermarking using wavelet transform and singular value decomposition. Veysel Atlantas, A Latif Dogan, Serkan Ozturk [15] proposed a DWT-SVD based watermarking scheme using Particle Swarm Optimizer (PSO). Singular values of each sub-band of cover image are modified by different scaling factors. Modifications were further optimized using PSO to obtain highest possible robustness. Yang Qianli and Cai Yanhong [16] have proposed a DWT-DCT based watermarking wherein image is decomposed into its wavelet coefficients up to three levels. DCT of these coefficients is taken. Watermarking components are also transformed into DCT coefficients and then embedded into DCT coefficients of wavelet transformed image. Normalized Cross Correlation is used to detect the existence of watermark and PSNR is used to test the quality of watermarked image. In a watermarking method given by Xi-Ping He and Qing-Sheng Zhu [17], the wavelet transform is applied to local sub-blocks of image extracted randomly. Watermark image is then adaptively embedded into part of the sub-band coefficients by computing their statistical characteristics. SVD-DCT based watermarking technique is proposed by Zhen Li, Kim-Hui Yap and Bai-Ying Lei [18]. In this technique first SVD of image blocks is computed. Then first few singular values are selected and DCT is applied to them. High frequency band from this SVD-DCT block is selected for watermark embedding. In [19], Rahim Ansari, Mrutyunjaya M Devanalamath, K. Manikantan, S. Ramachandran, proposed a Digital Watermarking Algorithm using a unique combination of Discrete Wavelet Transform (DWT), Discrete Fourier Transform (DFT) and Singular Value Decomposition (SVD) for secured transmission of data through watermarking digital colour images. The singular values obtained from SVD of DWT and DFT transformed watermark is embedded onto the singular values obtained from SVD of DWT and DFT transformed colour image. Scaling and shift invariance property of DFT, rotation invariance property of SVD and robustness of DWT to compression are used to perform secure transmission of data through watermarking. Yan Dejun, Yang Rijing, Li Hongyan, and Zheng Jiangchao in [20] proposed a robust digital image watermarking technique based on Singular Value Decomposition (SVD) and Discrete Wavelet Transform (DWT). Spatial relationship of visually recognizable watermark is scattered using Arnold transform. Further, security is enhanced by performing chaotic encryption using chaotic Logistic Mapping. Host image is decomposed into four frequency bands using wavelet decomposition. LL frequency band is decomposed into non-overlapping 4x4 blocks and SVD is applied to each block. Largest singular value of each block is modified with the help of watermark. Inverse SVD followed by inverse DWT is applied to get watermarked image. Reverse steps are followed to recover the watermark from watermarked image. PSNR and Normalized Cross Correlation (NCC) are the metrics used to measure imperceptibility and robustness of the technique.

III. HYBRID WAVELET TRANSFORMS AND SINGULAR VALUE DECOMPOSITION

Instead of using traditional Haar wavelet, wavelet transforms are generated from orthogonal transforms using a new hybrid wavelet generation algorithm proposed by Dr. Kekre in [21]. These transforms can be generated using different possible size combinations of orthogonal transforms. Required global or local properties of component transforms can be varied by changing the size of component matrix.

In past few years, wavelet transforms and SVD are being widely used for many image processing applications including digital watermarking.

Using singular value decomposition, any real matrix A can be decomposed into a product of three matrices U, S and V as $A=USV^T$, where U and V are orthogonal matrices and S is diagonal matrix. If A is mxn matrix, U is mxm orthonormal matrix whose columns are called as left singular vectors of A and V is nxn orthonormal matrix whose columns are called right singular vectors of A [22].

Some properties of SVD which make it useful in image processing are:

- The singular values are unique for a given matrix.
- The rank of matrix A is equal to its nonzero singular values. In many applications, the singular values of a matrix decrease quickly with increasing rank. This property allows us to reduce the noise or compress the matrix data by eliminating the small singular values or the higher ranks [23].
- The singular values of an image have very good stability i.e. when a small perturbation is added to an image; its singular values don't change significantly [24].

IV. PROPOSED METHOD

In the proposed method, hybrid wavelet transform matrix is generated using the algorithm proposed by Kekre et. al. in [21] using pair of sinusoidal transform DCT and non-sinusoidal transform Walsh, Haar and DKT. Instead of taking full transform of host/watermark, column/row transform is taken to reduce computational complexity. To increase the robustness, hybrid wavelet transform is accompanied with SVD due to its properties described above. For simulation of proposed method, five host images of size 256x256x3 bytes and watermark of size 128x128x3 is used which are shown in Figure 1.

(a) Lena (b) Mandrill (c) Peppers (d) Face (e) Puppy (f) NMIMS

Figure1 (a)-(e) Host images and (f) watermark image used for experimental work

For host, generate 256x256 hybrid wavelet transform matrix is generated from pair of sinusoidal transform DCT and non-sinusoidal transform Walsh/Haar/DKT. This matrix can be created using different sizes of component transforms like (64, 4), (32, 8), (16, 16), (8, 32) and (4, 64). Similarly for watermark, 128x128 hybrid wavelet transform matrix is generated with possible size combinations of component transforms (32, 4), (16, 8), (8, 16), (4, 32). After testing all possible combinations for embedding and extracting watermark we found that using (16,16) and (32,4) size combinations for generation of 256x256 and 128x128 size wavelet matrix respectively gives best robustness. Hence these size combinations are used throughout the proposed work.

Detailed steps of embedding and extracting watermark are given below.

1. Take column transform of host and watermark using hybrid wavelet transform matrix.
2. Due to column transform, maximum energy of image is concentrated in upper rows and as we move towards lower rows, we move towards lower energy region. Hence low frequency band is selected by taking first few rows of transformed host. Similarly middle frequency band is selected by selecting middle rows of transformed host.
3. SVD of watermark is taken. These Singular values of watermark are used to perform embedding. Due to high energy compaction and stability of SVD only first few singular values of host are used for embedding. We select first 30 values which contribute to 99.47% of watermark energy.
4. To embed these 30 values we select low/middle frequency band consisting of 30 rows. Thus rows 1-30 of transformed host are chosen as low frequency band and rows 101-130 are chosen as middle frequency band. Selection of middle frequency band is done after rigours

testing of different 30 consecutive rows to embed watermark and then by observing their performance against various attacks.

5. SVD of selected frequency band of host is obtained.
6. To bridge the energy gap between singular values of host and watermark, singular values of watermark are scaled down adaptively using singular values of transformed host.
7. Singular values of low/middle frequency band of host are now replaced by singular values of watermark.
8. Inverse SVD of frequency band followed by Inverse wavelet transform of transformed host yields watermarked image.

Extraction Process:

1. Take column transform of watermarked image.
2. Extract the low/middle frequency band.
3. Apply SVD to the extracted frequency band.
4. Scale up the singular values to get singular values of watermark.
5. Using singular values from above step perform inverse SVD to get transform coefficients of watermark.
6. Take inverse column wavelet transform of these coefficients to get watermark image.

Same steps are repeated by taking row transform of host and watermark instead of column transform. Columns 1-30 are selected as low frequency region and columns 101-130 are selected as middle frequency regions.

To check robustness of proposed method, different attacks are performed on watermarked images. These attacks include cropping of images, compressing watermarked images, adding noise to them, equalizing histogram equalization of watermarked images and resizing of images. These attacks are performed in different ways to observe the response of proposed method to them. Quality of watermark extracted from attacked watermarked image is compared with embedded watermark by computing average of absolute pixel difference or Mean Absolute Error between them. These attacks and their results are described in detail in the following section. For each attack, sample results of Lena image are shown. These results are for DCT-Walsh, DCT-Haar and DCT-DKT column hybrid wavelet transform where DCT acts as a base transform and other transforms act as a local transform. Since five host images are used, average MAE for these five hosts is considered to measure the performance of proposed method. These average values using column and row hybrid wavelet transforms are then presented in Tables/graphs.

V. PERFORMANCE ANALYSIS OF PROPOSED METHOD AGAINST VARIOUS ATTACKS

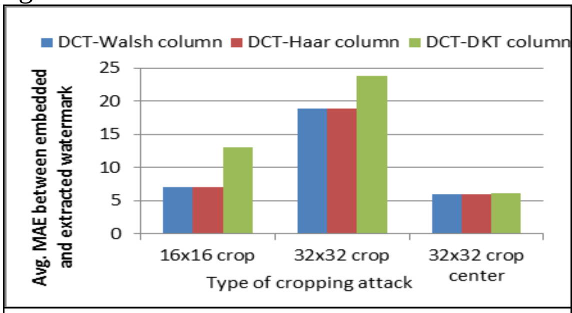
5.1. Cropping Attack

In this attack, watermarked image is cropped at four corners and at centre separately. Cropping at corners is done in two ways: 16x16 and 32x32 size squares are cropped at corners. Cropping at centre includes cropping 32x32 size square at centre. Thus area cropped in 16x16 size squares at corners and 32x32 sizes square at centre are same. Figure 2 shows watermarked image Lena with 16x16 size corners cropped and watermark extracted from it using DCT-Walsh, DCT-Haar and DCT-DKT column hybrid wavelet transform when watermark is embedded in low frequency band.

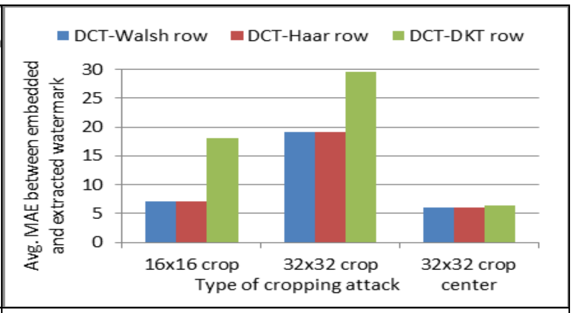
2.145	8.679	2.145	8.679	2.145	9.115
DCT-Walsh Column transform		DCT-Haar Column transform		DCT-DKT column transform	

Figure 2 Watermarked Lena after cropping 16x16 portions at corners and watermark extracted from it when low frequency band is used for embedding

Among Walsh, Haar and DKT used as local component transform, Walsh and Haar give slightly better visual quality of extracted watermark as shown in Figure 2 for Lena. Performance of proposed method against cropping attack over five different host images using DCT-Walsh, DCT-Haar and DCT-DKT column transforms for embedding in low frequency band are shown in Figure 3 (a). Figure 3(b) shows performance against same attack when embedding is done in low frequency band using above mentioned row wavelet transforms.



(a) Column transform

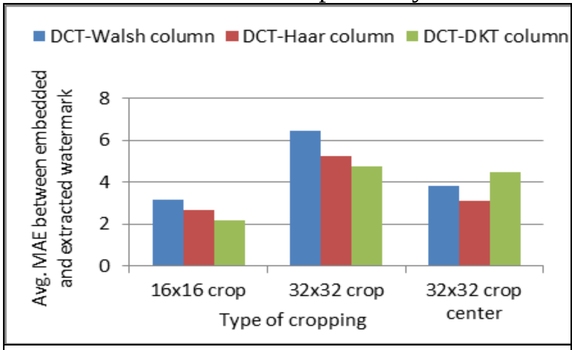


(b) Row transform

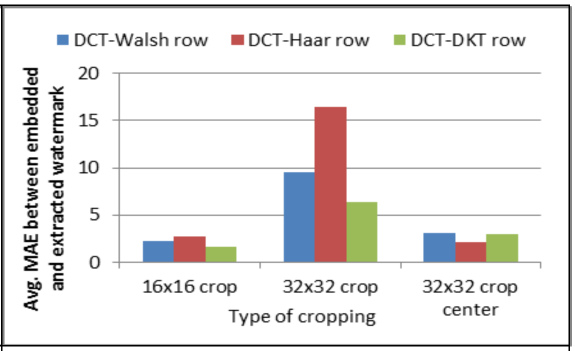
Figure 3 (a) Performance against cropping attack when watermark is embedded in low frequency band using column hybrid wavelet transform with DCT as base (b)) Performance against cropping attack when watermark is embedded in low frequency band using row hybrid wavelet transform with DCT as base

From Figure 3 we can state that column and row hybrid wavelet transform exhibit similar behaviour against cropping attack. DCT-Walsh and DCT-Haar column/row wavelet transform perform equally well whereas DCT-DKT column/row wavelet transform shows higher MAE values for cropping at centre. For cropping at centre DCT-DKT is also equally good as DCT-Walsh and DCT-Haar. Also range of MAE values in column transform is better than row transform.

Figure 4 (a)-(b) show the graphical representation of performance of proposed method against cropping attack when embedding is carried out in middle frequency band using column and row hybrid wavelet transforms respectively.



(a) Column transform



(b) Row transform

Figure 4 (a) Performance against cropping attack when watermark is embedded in middle frequency band using column hybrid wavelet transform with DCT as base (b)) Performance against cropping attack when watermark is embedded in middle frequency band using row hybrid wavelet transform with DCT as base

When watermark is embedded in middle frequency band, DCT-DKT column/row wavelet transform is found to be better in robustness than DCT-Walsh and DCT-Haar for cropping at corners. For cropping at centre, DCT-Haar column wavelet transform is better immediately followed by DCT-Walsh and then DCT-DKT column wavelet transforms. In row version, it is first followed by DCT-DKT and then DCT-Walsh row wavelet transform. Row wavelet transforms results in higher range of MAE for cropping at centre.

5.2. Compression Attack

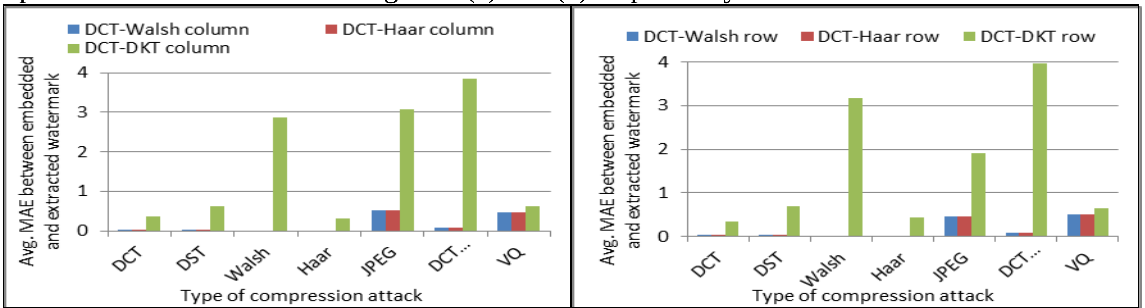
For optimal usage of limited bandwidth, compression of data to be transmitted is very common. This applies to transmission of watermarked images also. Hence different types of compression attacks are performed on watermarked images to evaluate performance of proposed method. Watermarked images are compressed using different transforms like DCT, DST, Walsh, Haar and DCT wavelet. Later they are compressed using JPEG compression with quality factor 100 and then using Vector Quantization. To perform compression using VQ, Kekre's Fast Codebook Generation (KFCG) algorithm [25] is used and codebook of size 256 is generated. Watermarks extracted from all such compressed images are compared with embedded watermark to test robustness.

Figure 5 shows compressed watermarked image Lena using JPEG compression and extracted watermark from it when low frequency band is chosen for embedding watermark.

1.946	0.520	1.946	0.520	1.946	0.757
DCT-Walsh Column transform		DCT-Haar Column transform		DCT-DKT column transform	

Figure 5 Watermarked Lena after JPEG compression and watermark extracted from it when low frequency band is used for embedding

From MAE values in Figure 5, proposed technique can be claimed to be highly robust against JPEG compression. Average MAE values over five different hosts using DCT-Walsh, DCT-Haar and DCT-DKT column and row wavelet transform with low frequency band for embedding watermark against compression attack are shown in Figure 6 (a) and (b) respectively.

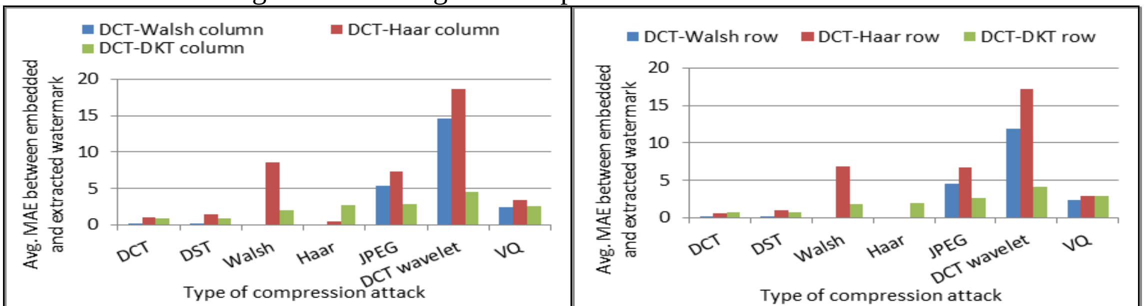


(a) Column transform	(b) Row transform

Figure 6 (a) Performance against compression attack when watermark is embedded in low frequency band using column hybrid wavelet transform with DCT as base (b)) Performance against compression attack when watermark is embedded in low frequency band using row hybrid wavelet transform with DCT as base

DCT-Walsh and DCT-Haar column wavelet show excellent robustness against cropping attack as shown in Figure 6(a). Though the error value shown by DCT-DKT column wavelet transform is higher as compared to DCT-Walsh, DCT-Haar, it is also strongly acceptable. Similar observations can be made for row wavelet transforms using DCT base and Walsh/Haar/DKT as shown in Figure 6(b). These results are for embedding in low frequency region.

When watermark is embedded in middle frequency band, performance of column and row wavelet transforms are shown in Figure 7 (a)-(b). When watermark is embedded in middle frequency band, robustness shown by DCT-Walsh is very good. However this better robustness is observed only for compression using transforms. For JPEG compression and compression using DCT wavelet, DKT-DCT is observed to be better than other two. For VQ compression, DCT-Walsh is closely followed by DCT-DKT column/row transform. The overall range of error values is increased for compression attack in middle frequency region. Thus low frequency region is more suitable for embedding watermark to achieve high robustness against compression attack.



(a) Column transform	(b) Row transform

Figure 7 (a) Performance against compression attack when watermark is embedded in middle frequency band using column hybrid wavelet transform with DCT as base (b)) Performance against compression attack when watermark is embedded in middle frequency band using row hybrid wavelet transform with DCT as base

5.3. Noise Addition Attack

Two types of noises are added to watermarked image namely binary distributed run length noise and Gaussian distributed run length noise. Binary distributed run length noise has discrete magnitude 0 or 1 and has different run length as 1 to 10, 5 to 50 and 10 to 100. Gaussian distributed run length noise has discrete magnitude between -2 and 2.

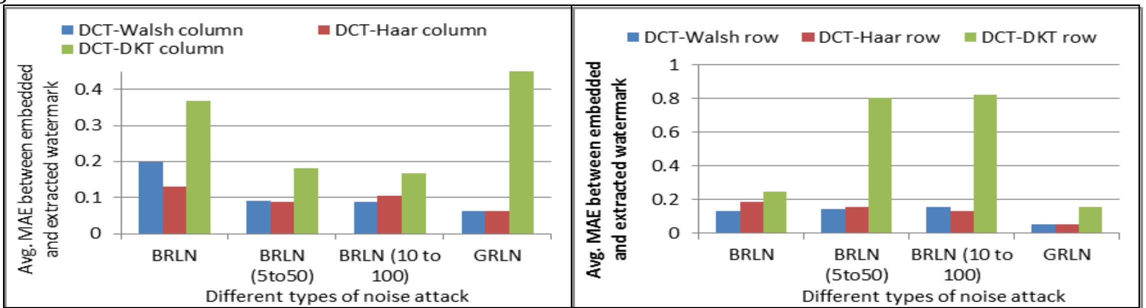
Figure 8 shows Gaussian distributed run length noise added watermarked image and extracted watermark from it when watermark is embedded in low frequency region using DCT-Walsh, DCT-Haar and DCT-DKT column wavelet.

0.746	0.066	0.746	0.067	0.746	0.098
DCT-Walsh Column transform		DCT-Haar Column transform		DCT-DKT column transform	

Figure 8 Watermarked Lena after adding Gaussian distributed run length noise and watermark extracted from it when low frequency band is used for embedding

In all the three types of transforms, there is close match between embedded and extracted watermark is observed with very small value of MAE. Thus embedding watermark in low frequency region using proposed method is strongly robust against noise addition attack.

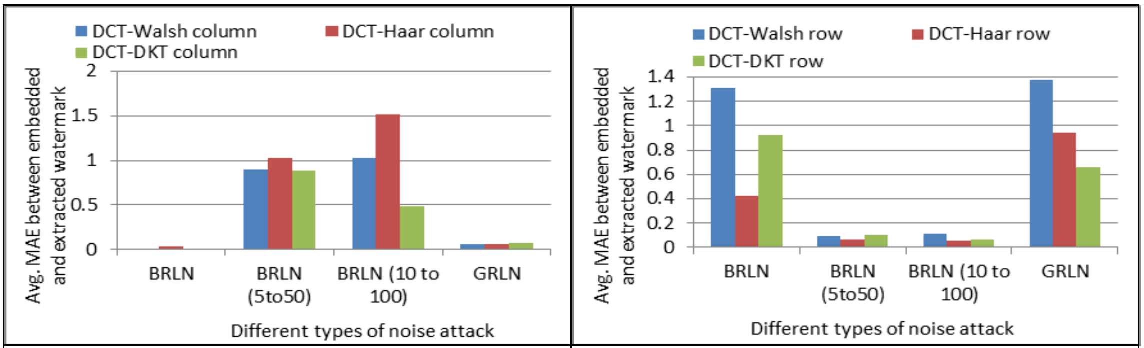
Comparison of different hybrid wavelet transforms in column and row version with DCT base, against noise addition attack is shown in Figure 8 (a)-(b). Here watermark is embedded in low frequency region.



(a) Column transform (b) Row transform

Figure 9 (a) Performance against noise addition attack when watermark is embedded in low frequency band using column hybrid wavelet transform with DCT as base (b)) Performance against noise addition attack when watermark is embedded in low frequency band using row hybrid wavelet transform with DCT as base

From Figure 9 (a), we can see that all three column hybrid wavelet transform show outstanding robustness. Among them column DCT-Haar and column DCT-Walsh are better with negligible difference in MAE value. Similar observations are noted for row hybrid wavelet transforms from Figure 9 (b). Best performance can be marked for row hybrid wavelet transforms against Gaussian distributed run length noise.



(a) Column transform	(b) Row transform

Figure 10 (a) Performance against noise addition attack when watermark is embedded in middle frequency band using column hybrid wavelet transform with DCT as base (b)) Performance against noise addition attack when watermark is embedded in middle frequency band using row hybrid wavelet transform with DCT as base

When column hybrid wavelets are used to embed watermark in middle frequency band, it shows excellent robustness against binary distributed run length noise of run length 1 to 10 and for Gaussian distributed run length noise. For row wavelet transforms, all three transforms show outstanding robustness for binary distributed run length noise for increased run length 5 to 50 and 10 to 100. For lower run length, DCT-Haar and for Gaussian distributed run length noise, DCT-DKT is better.

5.4. Resizing Attack

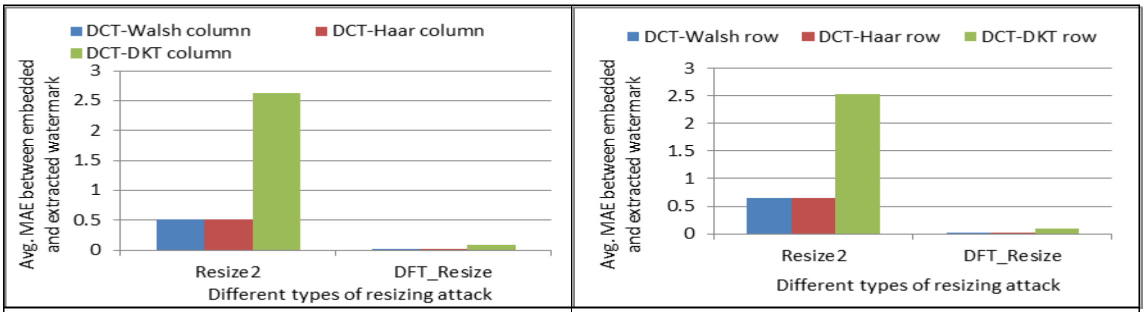
In image resizing attack, a watermarked image is enlarged to twice of its original size and the reduced back to its original size. From such enlarged-reduced watermarked image, watermark is extracted. Quality of extracted watermark is compared with embedded watermark by calculating MAE between them. This resizing is performed in three different ways: using bicubic interpolation, using grid based interpolation [26] and using transform based zooming [27].

Figure 11 shows such enlarged-reduced watermarked image Lena using bicubic interpolation and watermark extracted from it using DCT-Walsh, DCT-Haar and DCT-DKT column wavelet transform. These result images are for watermark embedded in low frequency band.

1.247	0.369	1.247	0.369	1.247	0.727
DCT-Walsh Column transform		DCT-Haar Column transform		DCT-DKT column transform	

Figure 11 Watermarked Lena after resizing attack and watermark extracted from it when low frequency band is used for embedding

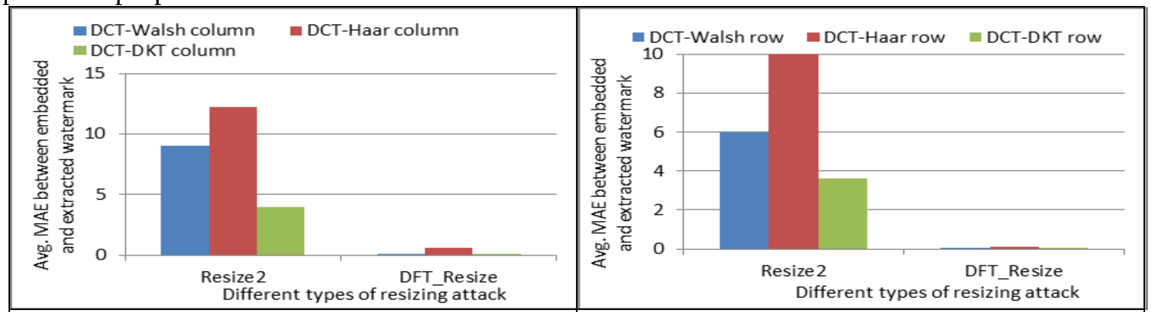
From Figure 11 proposed method is observed to be highly robust against resizing attack. Performance of proposed method against resizing attack by considering average MAE values over five host images is shown graphically in Figure 12 and Figure 13. In graph resizing using bicubic interpolation and using DFT is shown. For other transform based resizing (DCT, DST, Hartley, and Real Fourier Transform) embedded and extracted watermarks are found to be same with zero MAE. For grid based resizing also proposed method gives zero MAE irrespective of frequency band and wavelet transform used for embedding.



(a) Column transform	(b) Row transform

Figure 12 (a) Performance against resizing attack when watermark is embedded in low frequency band using column hybrid wavelet transform with DCT as base (b) Performance against resizing attack when watermark is embedded in low frequency band using row hybrid wavelet transform with DCT as base

From Figure 12 we can conclude that DCT-Walsh and DCT-Haar column hybrid wavelet transform when used to embed watermark in low frequency band show high robustness against resizing attack using bicubic interpolation. DCT-DKT column wavelet is also showing strong robustness but with slightly higher MAE values. Same observations are noted for row wavelet transform also. Strong robustness is also observed for resizing using DFT by all three column and row wavelet transforms explored in proposed method.



(a) Column transform	(b) Row transform

Figure 13 (a) Performance against noise addition attack when watermark is embedded in middle frequency band using column hybrid wavelet transform with DCT as base (b)) Performance against noise addition attack when watermark is embedded in middle frequency band using row hybrid wavelet transform with DCT as base

As shown in Figure 13 (a), DCT-DKT shows better robustness over DCT-Walsh and DCT-Haar column / row wavelet transform against resizing using bicubic interpolation. For resizing using DFT, all wavelet transforms explored show high robustness. Among them DCT-DKT shows marginally higher MAE values.

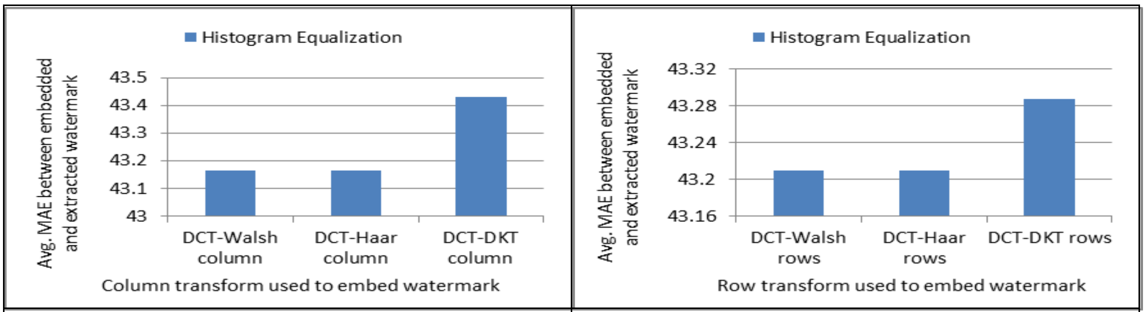
5.5. Histogram Equalization Attack

Watermarked image Lena after equalizing histogram and watermark extracted from it are shown in Figure 14 where watermark is embedded in low frequency band using DCT-Walsh, DCT-Haar and DCT-DKT column wavelet transforms.

DCT-Walsh Column transform	DCT-Haar Column transform	DCT-DKT column transform

Figure 14 Watermarked Lena after Histogram equalization attack and watermark extracted from it when low frequency band is used for embedding

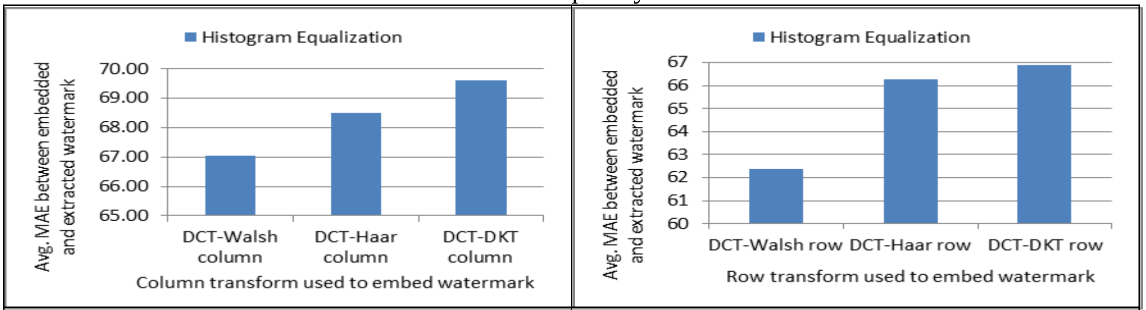
Figure 15 (a)-(b) shows performance of DCT-Walsh, DCT-Haar and DCT-DKT column and row wavelet transform respectively when low frequency band is used to hide the watermark. Similarly Figure 16 shows performance of DCT-Walsh, DCT-Haar and DCT-DKT column and row wavelet transform respectively when watermark is embedded in middle frequency band.



(a) Column transform	(b) Row transform

Figure 15 (a) Performance against Histogram equalization attack when watermark is embedded in low frequency band using column hybrid wavelet transform with DCT as base (b)) Performance against noise addition attack when watermark is embedded in low frequency band using row hybrid wavelet transform with DCT as base

With higher MAE values between embedded and extracted watermark, performance of column wavelet and row wavelet is almost same for histogram equalization attack. DCT-Walsh and DCT-Haar column wavelet transform show negligibly better robustness over DCT-DKT column wavelet transform when watermark is embedded in low frequency band.



(a) Column transform	(b) Row transform

Figure 16 (a) Performance against Histogram equalization attack when watermark is embedded in middle frequency band using column hybrid wavelet transform with DCT as base (b)) Performance against noise addition attack when watermark is embedded in middle frequency band using row hybrid wavelet transform with DCT as base

As can be seen from Figure 16, when middle frequency band is used to embed the watermark, performance of proposed method against histogram equalization degrades. Thus for histogram equalization, low frequency region is found to be suitable for embedding. Order of better performance is DCT-Walsh, DCT-Haar and DCT-DKT.

VI. CONCLUSION

Proposed method shows outstanding robustness against all attacks tested in simulation work except histogram equalization. For compression, noise addition and resizing attack, low frequency band when used to embed watermark gives promising robustness as compared to middle frequency band. However to survive against cropping attack, middle frequency band is more suitable candidate to embed watermark. DCT-Walsh and DCT-Haar give more or less similar and better robustness than DCT-DKT wavelet transform in low frequency band. In middle frequency band, DCT-DKT wavelet transform gives better robustness in compression, resizing, noise addition and cropping attack.

VII. FUTURE WORK

Future work includes using more than two transforms to generate hybrid wavelet transform. Also it can be extended to multilevel wavelet transforms along with SVD.

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AUTHORS

H. B. Kekre has received B.E. (Hons.) in Telecomm. 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.

Tanuja K. Sarode 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 14 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. She has more than 150 papers in National /International Conferences/journal to her credit.

Shachi Natu has received M.E. (Computer Engineering) degree from Mumbai University in 2010. Currently pursuing Ph.D. from NMIMS University. She has 10 years of experience in teaching. Currently working as Assistant Professor in Department of Information Technology at Thadomal Shahani Engineering College, Mumbai. Her areas of interest are Image Processing, Database Management Systems and Operating Systems. She has 27 papers in International Conferences/journal to her credit.