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Robust Watermarking Technique using Hybrid Wavelet Transform Generated from Kekre Transform and Discrete Cosine Transform

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Abstract- This paper presents a novel image watermarking technique using Kekre's algorithm to generate hybrid wavelet transform DKT_DCT from Kekre transform and Discrete Cosine Transform. In the proposed technique, 256x256 hybrid transform is generated using 16x16 Kekre transform and 16x16 DCT whereas, 128x128 hybrid wavelet transform is generated using 32x32 Kekre transform and 4x4 DCT matrix. Generated DKT_DCT transform is applied to host and watermark in three different ways: column wise, row wise and full transform. Performances of these three ways of applying transform are compared against various image processing attacks namely image cropping, image compression, adding noise and image resizing attacks. Column DKT_DCT transform is most robust for compression and resizing attack whereas row DKT_DCT wavelet transform is most robust for cropping, JPEG compression attack and binary distributed run length noise attack for increased run length. Column and row DKT_DCT transform show exceptionally better performance than full DKT_DCT wavelet transform. Also column DKT_DCT transform is observed to be better than column DCT wavelet transform for above mentioned attacks and row DKT_DCT wavelet is better than row DCT wavelet for binary distributed run length noise attack showing the strength of hybrid wavelet transform over wavelet transform generated from same component orthogonal transform matrices.

Index Terms- Binary distribution, column transform, Gaussian distribution, hybrid wavelet transform, image watermarking, Kekre transform, row transform, run length noise.

I. Introduction

Due to well-developed image processing tools, altering digital contents or claiming ownership of digital contents is not difficult. Digital image watermarking is very popular technique of protecting ownership of digital data in today's world. In digital watermarking, hidden information about owner of digital contents is stored in the contents to be transmitted. According to domain used for hiding the watermark in digital images, it can be distinguished as spatial domain and frequency domain watermarking. In spatial domain, modifications are introduced in pixel values of an image directly. Hence it is easy to implement but also more susceptible to common image processing attacks as direct changes in pixel values can be easily sensed by human visual system. In frequency domain watermarking, image is first transformed using underlying transform and then these frequency coefficients are altered in order to embed the watermark. Discrete Cosine Transform (DCT) based watermarking techniques are proposed by Wai Chu in [1], by Adrian G. Bors and Ioannis Pitas in [2], and by Rajesh Kannan Megalingam et. Al in [3]. Dr. B. Eswara Reddy et. Al in [4], Nagaraj V. Dharwadkar & B. B. Amberker in [5] and Yiwei Wang et. Al in[6] have presented Discrete Wavelet Transform (DWT) based image watermarking while Ruizhen Liu and Tieniu Tan in [7] and Bhagyshri Kapre et. Al in [8] have proposed Singular Value Decomposition (SVD) based watermarking. Mix of these transforms is also widely used in watermarking. While embedding watermark in transformed host images, normally low frequency coefficients are not selected because they carry maximum energy of an image and thus represent smoothness of image. Hence changes to these low frequency components can be easily detected by human visual system. On the other hand, changes to the frequency coefficients which correspond to texture and edges of an image are not easily detected by human visual system. Therefore, such high frequency coefficients are selected for watermark embedment. However these high frequency coefficients are easily eliminated under certain attacks like lossy compression performed on watermarked images. Hence in transform domain watermarking, the trend is to select middle frequency coefficients for embedding the watermark which makes the watermark invisible and also withstands various image processing attacks thereby making it robust.

In proposed method, the hybrid wavelet transform DKT_DCT, generated from Discrete Kekre Transform (DKT) [9] and DCT is used. 256x256 size and 128x128 size DKT_DCT transform matrix is generated from (16, 16) size and (32, 4) size DKT and DCT matrices respectively. Column wise, row wise and full transform of host and watermark images is taken. Middle frequency coefficients are selected to embed the watermark. To improve the imperceptibility, compressed watermark is embedded after normalizing and scaling. Robustness of proposed technique is tested against cropping, compression, resizing and noise addition attacks. Remaining paper is organized as follows. Section II gives review of related work in watermarking field. Section III briefly describes Kekre transform and Hybrid wavelet transform. Section IV presents proposed watermarking method. Section V comments on performance of proposed technique against various image processing attacks. Section VI ends the paper with conclusion.

II. RELATED WORK

Yan Dejun, Yang Rijing, Li Hongyan, and Zheng Jiangchao in [10] 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. In [11], Yan Dejun, Yang Rijing, Yu Yuhai and Xin Huijie proposed a blind image watermarking scheme based on intermediate significant bit and DWT. The DWT is used to embed the formatted watermark into the host image. In order to maintain the image quality and robustness, the watermark is embedded into the significant bit-plane of the LL sub band. While embedding watermark within the 8th bit-plane (Least significant bits) gives best image quality, embedding within the 1st bit-plane (Most significant bits) gives worst image quality. Through experiments, the 4th bit-plane of the LL sub band is selected to insert watermark, so that, the image quality is acceptable, and the bit in which the watermark is embedded will be kept after JPEG-2000 compression. A novel semi-fragile watermarking scheme in DWT domain for image authentication and tamper localization is proposed in [12] by Wei Wang, Aidong Men, Bo Yang. Watermark is generated from LL1 component of two level wavelet decomposed image. Image feature matrix is calculated using HL2, LH2 and HH2 sub-bands. Using this feature matrix and adaptive threshold, watermark is generated. Logistic map is used to encrypt the watermark. Middle frequency sub-bands are divided into 2x2 non-overlapping blocks. A secret key is used to determine the embedding positions in order to increase the security. To embed one bit of watermark relationship among two bits of 2x2 blocks is adjusted. By comparing extracted watermark and extracted feature matrix of an image this scheme was able to distinguish malicious attacks from non-malicious tampering of image contents. In [13], Olcay Duman and Olcay Akay presented watermark embedding and detecting method for blind and robust digital image watermarking. Host image is decomposed into four frequency bands using DWT. HL sub band is used for watermark embedding. HL band is divided into 8x8 blocks and Fractional Fourier Transform (FrFT) is applied to each block. The orders of FrFT are used as encryption keys in extraction process. Two separate pseudorandom sequences are generated according to standard normal distribution. Binary watermark is then inserted into host image by multiplying these sequences by gain factor and adding it to FrFT coefficients of HL2 band. In [14], a novel watermarking scheme for image authentication in DWT domain is presented by Chuanmu Li and Haiming Song. In this scheme, the binary watermark is generated by a chaotic map. Using a secret key, some perceptually significant coefficients from detail sub-bands of 3-level DWT of the host image are selected. The watermark is embedded by adjusting the values of ordered coefficients in different orientation. The scheme is invisible and robust against various image processing attacks. A robust multiwatermarking scheme was proposed by Yaxun Zhou, Wei Jin in [15]. According to their scheme, three independent binary watermarks are embedded in a grayscale digital image. To embed multi-watermarks simultaneously, to improve the quality of watermarked image and robustness of extracted watermarks, the three 2-D watermarks were first recombined into a 3-D watermarking sequence. The approximation sub image of the original digital image in the Discrete Wavelet Transform (DWT) domain was decomposed into non-overlapping blocks and the blocks with best abundant texture information were selected according to the size of binary watermark. Finally, the multi-watermark embedding was carried out by modifying the fractional part values of these selected block pixels based on the proposed discrete operation rule. It was observed that, one of multi-watermarks is robust enough against the common image processing such as noise addition, filtering, and JPEG compression, while the other two watermarks are immune to any image attacks. In [16], Bhagyshri Kapre and M. Y. Joshi proposed a DWT-SVD based watermarking scheme in YUV color space of image. In their proposed scheme, image is decomposed into RGB color space and then converted into YUV color space. Y components are then subjected to wavelet decomposition. Each band obtained after wavelet decomposition is subjected to SVD. These singular values are used to embed watermark. Image is converted to RGB color space after embedding watermark. Robustness is tested against attacks like salt and paper noise, cropping and histogram equalization. Kaushik Deb, Md. Sajib Al-Seraj, Md. Moshiul Hoque and Md. Iqbal Hasan Sarkar proposed combined DWT-DCT based watermarking technique for copyright protection in [17]. In the proposed method, watermark bits are embedded in the low frequency band of each DCT block of selected DWT sub-band. The weighted correction is also used to improve the imperceptibility. The extracting procedure is reverse of the embedding operations without the reference of the original image. A robust and geometric invariant digital watermarking scheme for gray-level images is proposed in [18] by Xiao-Chen Yuan and Chi-Man Pun. The scheme carries out watermark embedding and extraction based on histogram in DWT domain. For watermark embedding, the original image is decomposed into the approximation and details sub-bands. Pixels of the approximation sub-band are grouped into m blocks, each of which has the same number of intensity levels, thus the block histogram is generated; with the block histogram, pixels are moved to form a specific pattern in the intensity-level histogram distribution, indicating the watermark. For watermark extraction, the watermarked image is decomposed into the approximation and details sub-bands; then the pixels in the approximation sub-band are grouped into blocks in the similar manner. According to the histogram distribution in each block, the watermark is extracted.

H. B. Kekre, Tanuja Sarode, Shachi Natu presented a DWT-DCT-SVD based hybrid watermarking method for color images in [19]. In their method, robustness is achieved by applying DCT to specific wavelet sub-bands and then factorizing each quadrant of frequency sub-band using singular value decomposition. Watermark is embedded in host image by modifying singular values of host image. Performance of this technique is then compared by replacing DCT by Walsh in above combination. Walsh results in computationally faster method and acceptable performance. Imperceptibility of method is tested by embedding watermark in HL2, HH2 and HH1 frequency sub-bands. Embedding watermark in HH1 proves to be more robust and imperceptible than using HL2 and HH2 sub-bands. In [20] and [21] Kekre, Sarode, and Natu presented DCT wavelet and Walsh wavelet based watermarking techniques. In [20], DCT wavelet transform of size 256*256 is generated using existing well known orthogonal transform DCT of dimension 128*128 and 2*2. This DCT Wavelet transform is used in combination with the orthogonal transform DCT and SVD to increase the robustness of watermarking. HL2 sub-band is selected for watermark embedding. Performance of this proposed watermarking scheme is evaluated against various image processing attacks like contrast stretching, image cropping, resizing, histogram equalization and Gaussian noise. DCT wavelet transform performs better than their previously proposed DWT-DCT-SVD based watermarking scheme in [19] where Haar functions are used as basis functions for wavelet transform. In [21], Walsh wavelet transform is used that is derived from orthogonal Walsh transform matrices of different sizes. 256*256 Walsh wavelet is generated using 128*128 and 2*2 Walsh transform matrix and then using 64*64 and 4*4Walsh matrix which depicts the resolution of host image taken into consideration. It is supported by DCT and SVD to increase the robustness. Walsh wavelet based technique is then compared with DCT wavelet based method given in [20]. Performance of three techniques is compared against various attacks and they are found to be almost equivalent. However, computationally Walsh wavelet was found preferable over DCT wavelet. Also Walsh wavelet obtained by 64*64 and 4*4 is preferable over DCT wavelet and Walsh wavelet obtained from corresponding orthogonal transform matrix of size 128*128 and 2*2. In [22], other wavelet transforms like Hartley wavelet, Slant wavelet, Real Fourier wavelet and Kekre wavelet were explored by H. B. Kekre, Tanuja Sarode and Shachi Natu. Performance of Slant wavelet and Real Fourier wavelet were proved better for histogram Equalization and Resizing attack than DCT wavelet based watermarking in [20] and Walsh wavelet based watermarking presented in [21].

III. KEKRE TRANSFORM AND HYBRID WAVELET TRANSFORM

Now it is the time to articulate the research work with ideas gathered in above steps by adopting any of below suitable approaches:

A. Kekre Transform

Kekre's transform matrix [23] has the advantage that it need not be of size having integer power of 2. It can be of any size NxN. All diagonal and upper diagonal elements of Kekre transform are 1 whereas; all lower diagonal elements except the elements just below the diagonal are zero. Kekre transform matrix of size 5x5 is shown below for example.

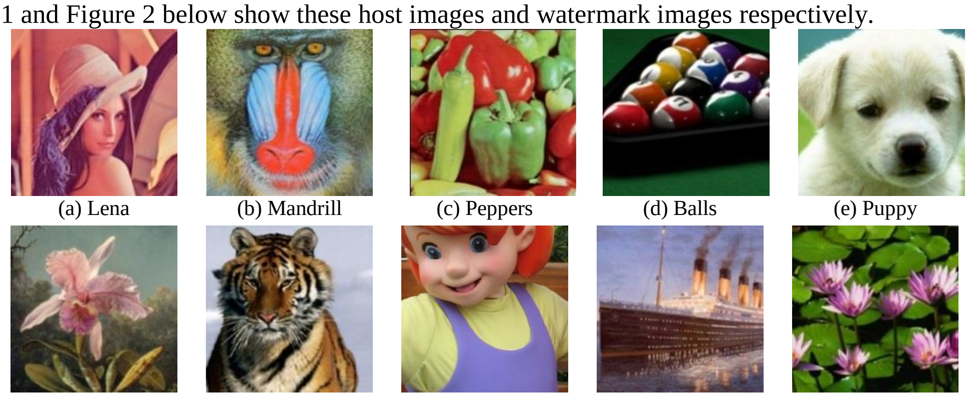
1	1	1	1	1
-4	1	1	1	1
0	-3	1	1	1
0	0	-2	1	1
0	0	0	-1	1

B. Hybrid Wavelet Transform

H. B. Kekre, Tanuja Sarode and Sudeep Thepade introduced the concept of hybrid wavelet transform in [24]. An idea behind use of hybrid wavelet transform is to explore the good properties of two different transforms by combining them into hybrid wavelet transform. Use of hybrid wavelet transforms generated from Discrete Cosine Transform, Discrete Walsh Transform, Discrete Hartley transform and Discrete Kekre transform have been explored by authors very successfully for image compression. Hybrid wavelet transform is also proved better in other image processing applications like image retrieval in [25] and biometrics applications like palm print identification in [26].

IV. PROPOSED TECHNIQUET

In the proposed technique, hybrid wavelet transform called Discrete Kekre Transform_Discrete Cosine Transform (DKT_DCT) is generated using Kekre transform and Discrete Cosine Transform as component orthogonal matrices. After trials for different combinations of DKT and DCT sizes, two combinations of DKT and DCT are selected for generation of DKT_DCT matrix. In order to generate 256x256 DKT_DCT transform matrix, both DKT and DCT of size 16x16 are chosen whereas, to generate 128x128 DKT_DCT matrix, DKT of size 32x32 and DCT of size 4x4 has been selected. Proposed technique has been experimented on ten 256x256 color bitmap images taken as host images and five 128x128 color bitmap images taken as watermarks. Figure 1 and Figure 2 below show these host images and watermark images respectively.



(a) Lena (b) Mandrill (c) Peppers (d) Balls (e) Puppy

(f) Flower (g) Tiger (h) Face (i) Titanic (j) Waterlili

Figure 1: Host images used for experimental work


(a)Austral (b) Bear (c) CCD (d) Logo (e)Nmims

Figure 2: Watermarks used for experimental work

A. Watermark Embedding Procedure:

Step 1. Separate the host image into its Red, Green and Blue channel and apply column DKT_DCT wavelet transform to each channel.

Step 2. Separate the watermark into its Red, Green and Blue channel and apply following steps to each channel and apply column DKT_DCT wavelet transform to each channel.

Step 3. Compress the watermark by compression ratio 2.67. This is maximum compression ratio for which image distortion is imperceptible.

Step 4. Normalize and then weight the watermark by suitable weight factor so as it increases the watermark strength and makes it visually imperceptible after embedment into host image. Weight factor selected in proposed method is 25.

Step 5. Embed this weighted normalized watermark in middle frequency band of corresponding channel of host image by replacing host image coefficients there.

Step 6. Take inverse column DKT_DCT wavelet to obtain watermarked image.

Step 7. Calculate average absolute pixel to pixel difference i.e. Mean Absolute Error (MAE) between host and watermarked image to measure the imperceptibility.

B. Watermark Extraction Procedure:

The reverse of embedding procedure is followed to recover the watermark from watermarked image. The watermarked image may also be subjected to image processing attack like cropping, compression, resizing or noise attack. Steps of extraction procedure are as follows:

Step 1. Separate the watermarked image into its Red, Green and Blue channel and apply following steps to each channel.

Step 2. Take column DKT_DCT wavelet transform of each channel of watermarked image.

Step 3. Extract the middle frequency coefficients of each plane of watermark from corresponding planes of watermarked image.

Step 4. Weight and then denormalize these coefficients using same weight factor and normalization coefficients used in embedding procedure.

Step 5. Take inverse column DKT_DCT transform of these extracted coefficients to recover the compressed watermark embedded in host image.

Step 6. Calculate average absolute pixel to pixel difference i.e. Mean Absolute Error (MAE) between embedded and extracted watermark to measure the robustness.

V. RESULTS OF PROPOSED TECHNIQUE

Figure 3 below shows watermarked images obtained by full, column and row DKT_DCT wavelet transform and watermarks extracted from them respectively. Various attacks are performed on watermarked images to test the robustness of proposed technique. It is observed that the MAE between original and compressed watermark in column DKT_DCT wavelet transform (MAE=15.40) is less than the MAE (MAE= 26.642) obtained when column DCT wavelet is used. This indicates that better compressed watermark is embedded in case of column DKT_DCT transform.

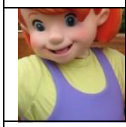
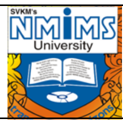
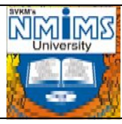
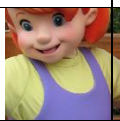
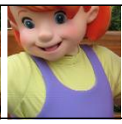
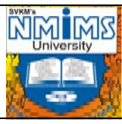
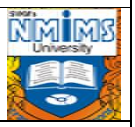
Host image	Original watermark	Compressed watermark	Watermarked images			Extracted watermark		
			Full transform	Column transform	Row transform	Full transform	Column transform	Row transform
								
MAE		15.40	1.131	1.317	1.322	close to 0	close to 0	close to 0

Figure 3: Original host and watermark images, compressed watermark and watermarked images and extracted watermarks using full, column and row DKT_DCT wavelet.

A. Attacks performed on watermarked images and their results:

Cropping:

Watermarked images are cropped at four corners with cropped portion of size 16x16 and 32x32. Also 32x32 size square is cropped at the center of watermarked image. Result images for host image 'face' and watermark 'nmims' are shown below for three types of cropping using full, column and row DKT_DCT wavelet transform. Figure 4 indicates that, row transform gives the smallest MAE value for extracted watermark. Also the MAE between watermarked and cropped watermarked image is smallest in case of row DKT_DCT wavelet which indicates better imperceptibility.

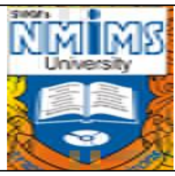
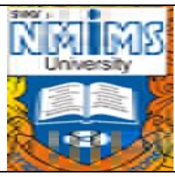
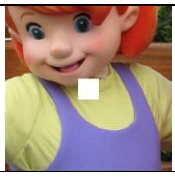
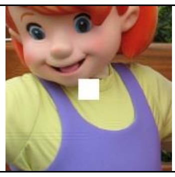
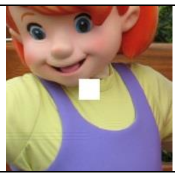
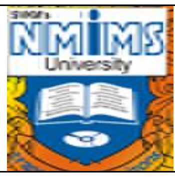
Attack	Watermarked image after attack			Extracted watermark from attacked watermarked image		
	Full transform	Column tr.	Row transform	Full transform	Column tr.	Row transform
Crop 16x16						
MAE	2.734	2.501	1.25	8.005	2.623	2.20
Crop 32x32						
MAE	5.75	5.75	5.75	18.53	9.716	8.291
Crop 32x32 at center						
MAE	2.087	2.087	2.087	2.341	0.681	0.333

Figure 4: Result images for 16x16, 32x32 cropping at corners and 32x32 cropping at center using Full DKT_DCT wavelet, column DKT_DCT wavelet and Row DKT_DCT wavelet.

Figure 5 shown below compares the full, column and row DKT_DCT wavelet under 16x16 cropping attack. It can be clearly seen from Figure 5 that, for all host images, row DKT_DCT wavelet gives least MAE value between embedded and extracted watermark. These values are almost four times less than the MAE value given by full DKT_DCT wavelet and 1.18 times less than column DKT_DCT wavelet. Thus for 16x16 cropping, row DKT_DCT wavelet performs best, whereas in DCT wavelet, column DCT wavelet performs best.

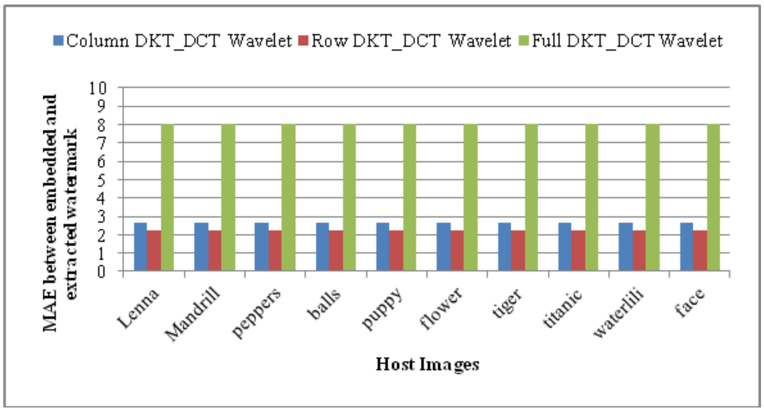


Figure 5: Comparison of MAE values between embedded and extracted watermark for cropping 16x16 square at corners using Full, Column and Row DKT_DCT wavelet

Figure 6 below shows the comparison of full, column and row DKT_DCT wavelet transform for 32x32 cropping done at corners of an image. Once again row DKT_DCT wavelet gives best performance among three. It gives twice better performance than full and 1.17 times better performance than column DKT_DCT wavelet transform.

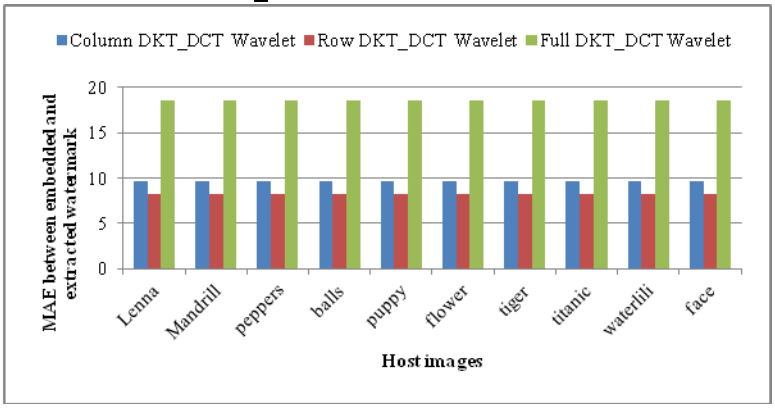


Figure 6: comparison of MAE values between embedded and extracted watermark for cropping 32x32 square at corners using Full, Column and Row DCT wavelet

Figure 7 shows the performance comparison of row, column and full DKT_DCT wavelet under cropping attack where 32x32 size portion of an image is cropped at the center of an image. Here also row transform shows highest robustness among the three. Robustness achieved by row DKT_DCT wavelet transform is twice better than column transform and approximately seven times better than full DKT_DCT wavelet transform.

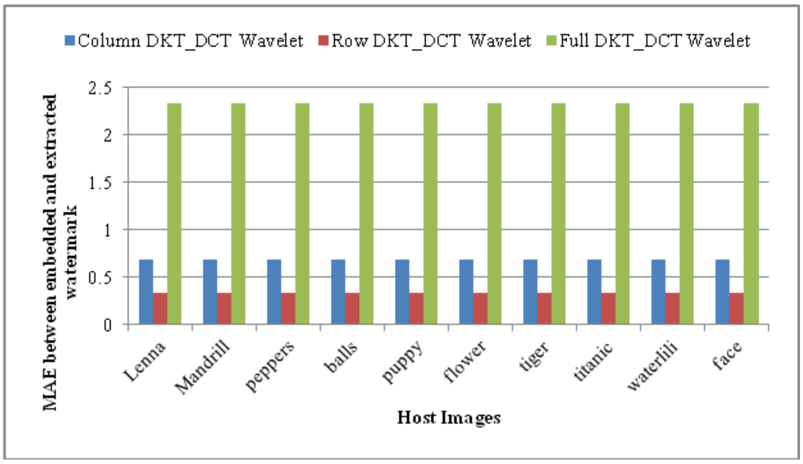


Figure 7: Comparison of MAE values between embedded and extracted watermark for cropping 32x32 square at center using Full, Column and Row DCT wavelet

Compression attack:

Watermarked images are compressed using orthogonal transforms DCT, DST, Walsh with compression ratio 1.14 and using DCT wavelet transform with compression ratio 1.95. Simulation results for compression attack are shown in Figure 8.

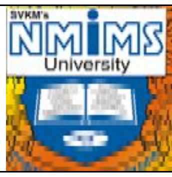
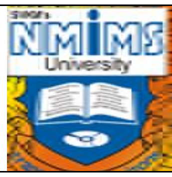
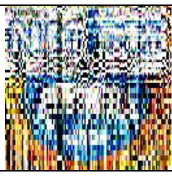
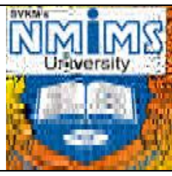
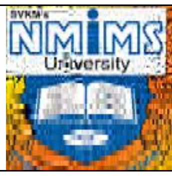
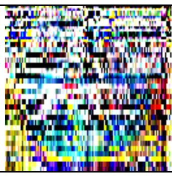
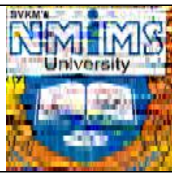
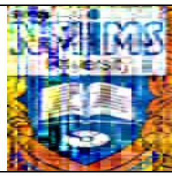
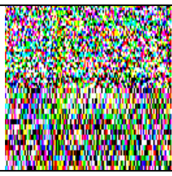
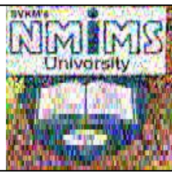
Transform used	Watermarked image after attack			Extracted watermark from attacked watermarked image		
	Full transform	Column tr.	Row transform	Full transform	Column tr.	Row transform
DCT wavelet						
MAE	2.191	1.564	1.544	27.202	0.783	1.958
DCT						
MAE	0.756	0.765	0.688	137.241	16.50	17.975
DST						
MAE	0.804	0.813	0.739	139.93	16.889	18.339
Walsh						
MAE	1.33	1.35	1.27	211.61	27.348	38.77
JPEG						
MAE	0.003	0.003	0.003	336.20	97.07	58.19

Figure 8: result images for compression using DCT wavelet, DCT, DST, Walsh and JPEG compression with MAE between host and watermarked image and MAE between embedded and extracted watermark.

Figure 9 shows performance comparison of full, column and row DKT_DCT wavelet under compression using DCT wavelet. Row transform gives 14 times better robustness whereas column transform gives 34 times better robustness than full transform.

Column transform also shows 2.5 times better performance than row DKT_DCT wavelet. Thus in all column DKT_DCT wavelet transform shows best performance in the form of robustness.

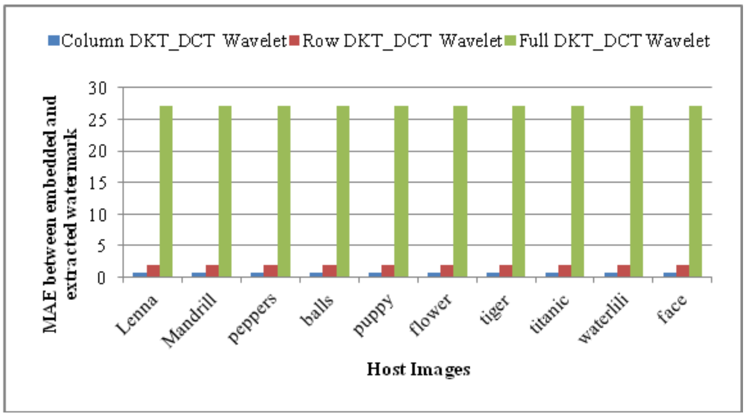


Figure 9: Performance comparison of column, row and full DKT_DCT wavelet transform under DCT wavelet based compression in terms of MAE between embedded and extracted watermark

Figure 10 below shows performance of full, column and row DKT_DCT wavelet under compression attack using DCT.

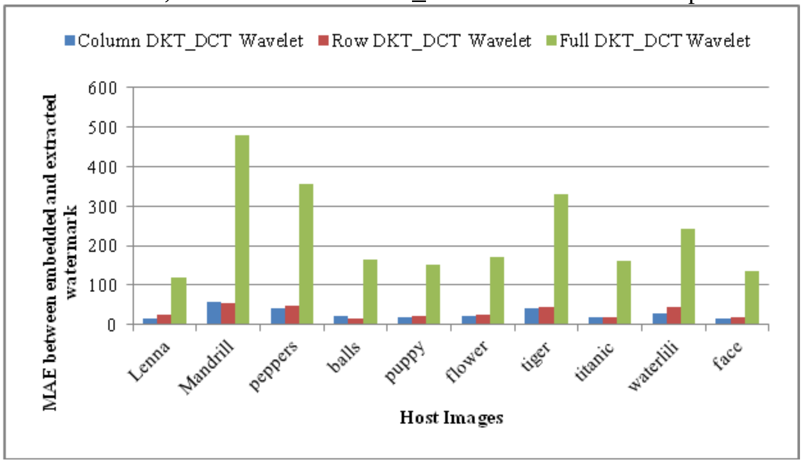


Figure 10: Performance comparison of full, row and column DKT_DCT wavelet for compression attack using DCT

From Figure 10 it can be observed that full DKT_DCT wavelet does not sustain against compression using DCT. Among row and column DKT_DCT wavelet transform, column DKT_DCT wavelet transform proves to be more robust.

Figure 11 shows the comparison of MAE values between embedded and extracted watermark under compression using DST. Column DKT_DCT wavelet once again proves better than row and full DKT_DCT wavelet. Full DKT_DCT wavelet does not withstand DST based compression attack.

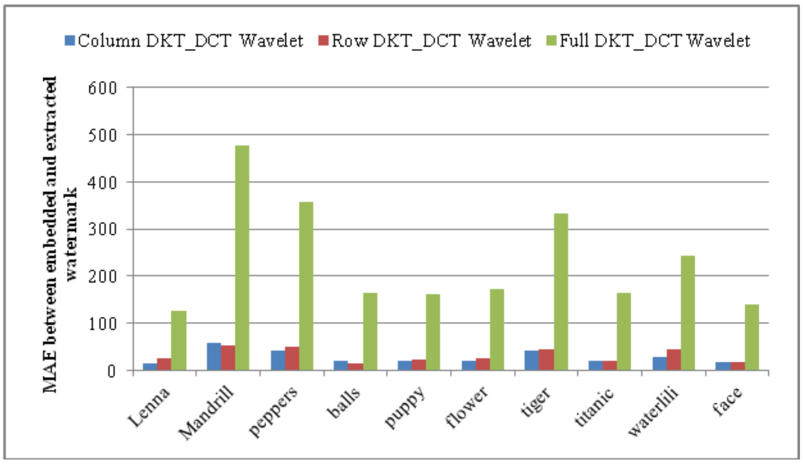


Figure 11: Performance comparison of full, row and column DKT_DCT wavelet for compression attack using DST

Figure 12 shows comparison of three approaches of applying DKT_DCT wavelet under compression using Walsh transform. Here also column DKT_DCT wavelet transform shows best performance in terms of robustness whereas, full DKT_DCT wavelet fails to sustain against Walsh based compression.

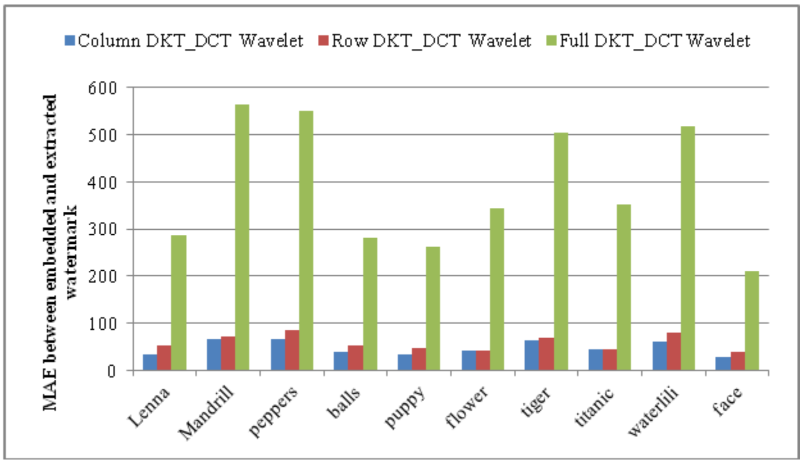


Figure 12: Performance comparison of full, row and column DKT_DCT wavelet for compression attack using Walsh

Resizing attack:

In resizing attack, watermarked images are manipulated by using bicubic interpolation. Two types of resizing attacks are performed. In the first type (Type 1), image is first increased in size by four times of its original size and then reduced back to its original size. In second type (Type 2), image is doubled in size and then reduced back to its original size. Watermarked images after resizing and watermarks extracted from them are shown in Figure 13 for full, column and row DKT_DCT wavelet along with corresponding MAE values below them.

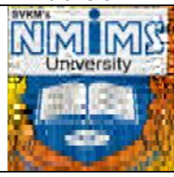
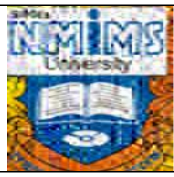
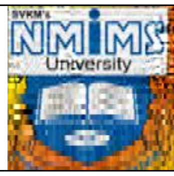
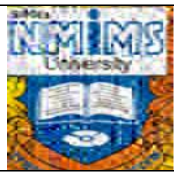
Attack	Watermarked image after attack			Extracted watermark from attacked watermarked image		
	Full transform	Column	Row transform	Full transform	Column transform	Row transform
Original-four times-original						
	0.769	0.777	0.773	128.670	19.818	21.292
Original-double-original						
	0.789	0.797	0.793	132.00	20.403	21.911

Figure13: watermarked images after resizing and watermarks extracted from them for full, column and row DKT_DCT wavelet with corresponding MAE values

Comparison of MAE values between embedded and extracted watermark for various host images under resizing attack of type 1 and type 2 are shown in Figure 14 and Figure 15 respectively.

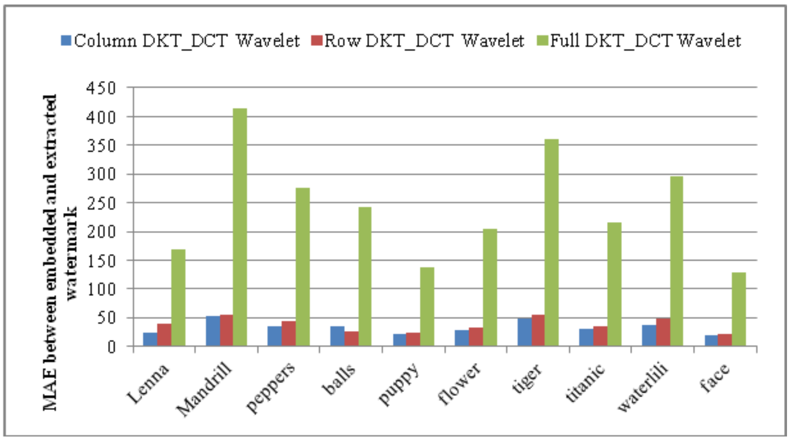


Figure 14: comparison of MAE values between embedded and extracted watermark in Type 1 resizing attack using column, row and full DKT_DCT wavelet transform.

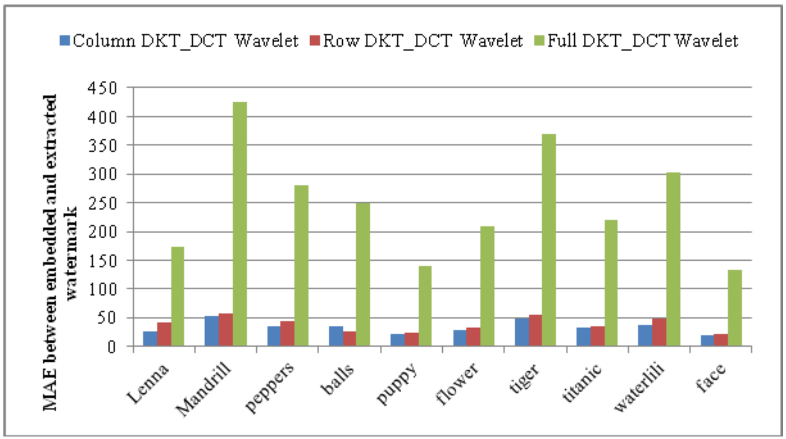


Figure 15: comparison of MAE values between embedded and extracted watermark in Type 2 resizing attack using column, row and full DKT_DCT wavelet transform.

From Figure 14 and Figure 15, it is clearly seen that for all host images except 'balls', column DKT_DCT wavelet gives the smallest MAE values i.e. best robustness. Also type 1 resizing shows slightly less MAE values than Type 2 resizing attack. Performance shown by full DKT_DCT wavelet transform is not acceptable.

Noise attack:

Two types of noises are generated namely binary distributed noise and Gaussian distributed noise and added to watermarked images to test their robustness. In binary distributed noise, magnitude is -1 or 1 while in Gaussian distributed noise, magnitude ranges between -2 to 2. In binary distributed noise, different run length i.e. run length 1 to 10, 5 to 50 (in multiples of 5) and 10 to 100 (in multiples of 10) are tried to check its effect on robustness. Figure 16 shows the watermarked image 'face' after adding these noises and watermark 'nmims' extracted from it with corresponding MAE values.

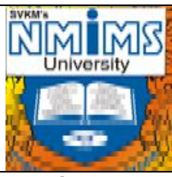
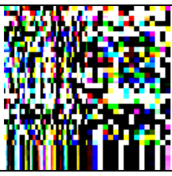
Attack	Watermarked image after attack			Extracted watermark from attacked watermarked image		
	Full transform	**Column transform**	**Row transform**	**Full transform**	**Column transform**	**Row transform**
Binary run length (run 1 to 10)						
	MAE=1	MAE=1	MAE=1	1198.62	Close to 0	15.505
Binary run length (run 5 to 50)						
	MAE=1	MAE=1	MAE=1	1200.692	43.27	9.677
Binary run length (run 10 to 100)						
	MAE=1	MAE=1	MAE=1	1200.468	50.30	5.634
Gaussian Run length						
	MAE=0.746	MAE=0.746	MAE=0.746	32.68	2.296	45.068

Figure 16: result images for 'face' watermarked image with 'nmims' watermark after adding binary distributed noise of different run length and Gaussian distributed run length noise and watermarks extracted from it

From Figure 16, it is observed that MAE values between embedded and extracted watermark for full DKT_DCT wavelet transform are exceptionally high for all types of run lengths of binary distributed noise. For column DKT_DCT wavelet, when run length of binary distributed noise is 1 to 10, MAE between embedded and extracted watermark is close to zero. As we increase run length, MAE is observed to be increased. However there is no specific trend observed in changes in MAE values. For some host images it is increased and for some images it falls with increased run length. However, for row DKT_DCT wavelet transform, a sharp decrease is observed with increase in run length of binary distributed noise. Thus for binary distributed noise, with run length between 10 to 100, row DKT_DCT transform gives highest robustness by showing least MAE between embedded end extracted watermark. Column DKT_DCT gives best performance for run length 1 to 10.

Figure 17 shows the graph comparing MAE values between embedded and extracted watermark for Gaussian distributed run length noise when full, column and row DKT_DCT wavelet transform is used.

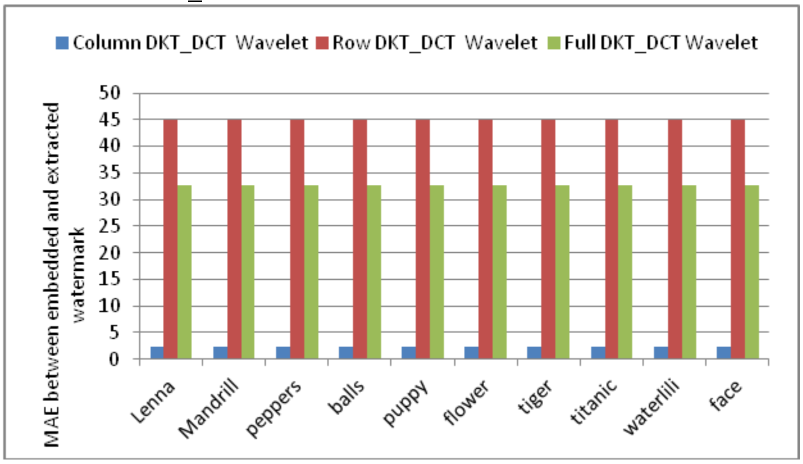
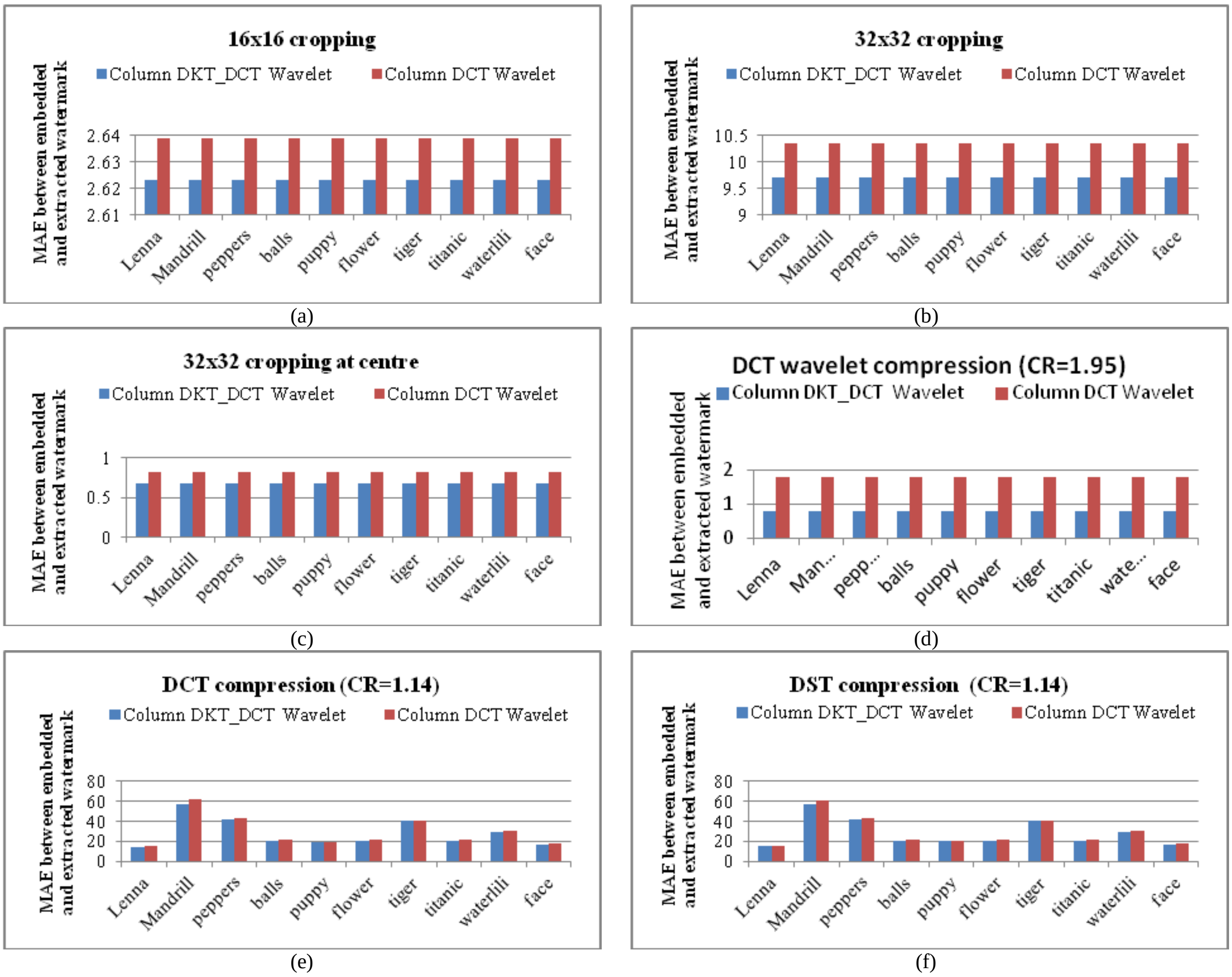
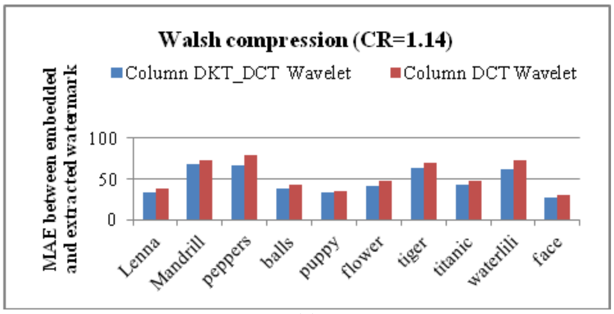


Figure 17: comparison of MAE values between embedded and extracted watermark by full column and row DKT_DCT wavelet under Gaussian distributed noise attack

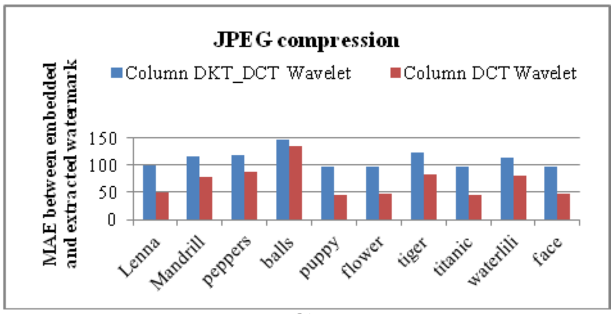
From Figure 17, it can be observed that for Gaussian distributed noise, column transform of DKT_DCT is most robust. It gives 20 times better performance than row DKT_DCT wavelet and 15 times better performance than full DKT_DCT wavelet transform.

When performance of column DKT_DCT wavelet is compared with column DCT wavelet for cropping, compression, resizing and Gaussian run length noise attacks, column DKT_DCT wavelet is found to be more robust than column DCT wavelet. For binary distributed run length noise with run from 5 to 50 and between 10 to 100, row DKT_DCT wavelet is more robust as compared to row DCT wavelet transform. These comparisons are shown in following Figure 18.

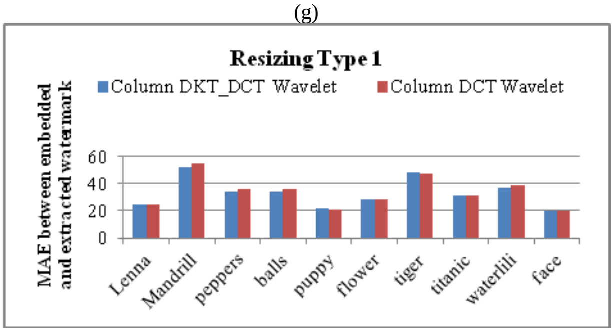




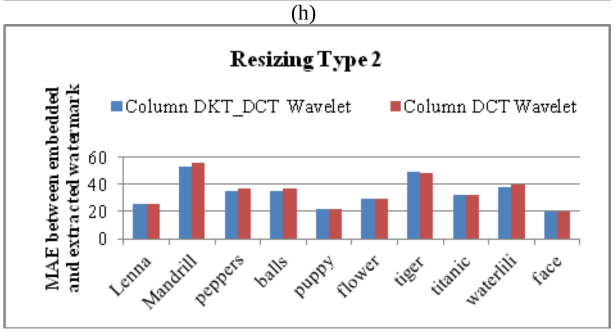
(g)



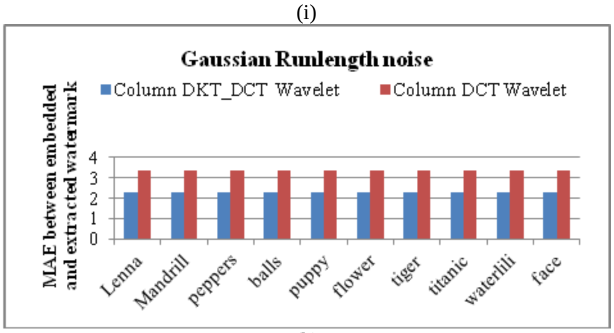
(h)



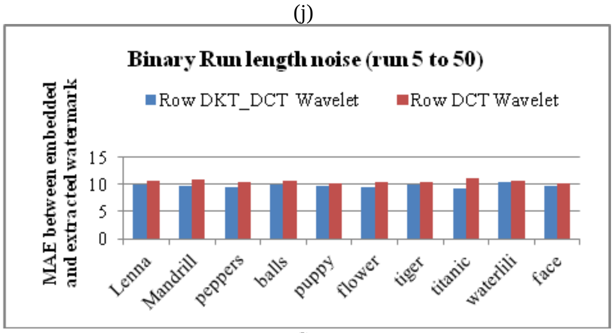
(i)



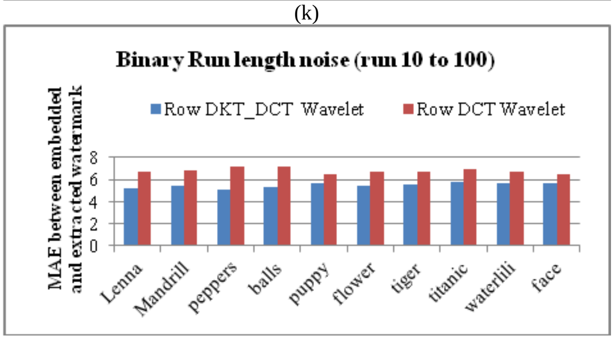
(j)



(k)



(l)



(m)

Figure 18: Performance comparison of column DKT_DCT hybrid wavelet and column DCT wavelet under (a) 16x16 cropping (b) 32x32 cropping (c) 32x32 cropping at center (d) Compression using DCT wavelet (e) compression using DCT (f) compression using DST (g) Compression using Walsh (h) JPEG compression (i) Resizing Type 1 (j) Resizing Type 2 (k) Gaussian Run length noise (l) Binary distributed run length noise (run 5 to 50) (m) Binary distributed run length noise (run 10 to 100)

VI. CONCLUSION

There is no specific trend observed for MAE between host and watermarked images for column, row and full DKT_DCT wavelet transform. Although it is image dependent, the variation in error is minimal for full, column and row transform. This MAE value corresponds to imperceptibility. Therefore the performance of column, row and full DKT_DCT wavelet is judged based on robustness i.e. their responses to various attacks on watermarked images. For majority of attacks tested in the proposed work, column and row DKT_DCT wavelet transforms give significantly better robustness than Full DKT_DCT wavelet transform.

For cropping attack, row DKT_DCT wavelet shows strong robustness as compared to column and full DKT_DCT wavelet. For cropping 16x16 size portion at four corners of watermarked image, row transform is four times more robust than full transform and 1.18 times more robust than column transform. For cropping 32x32 size portions at corners of image, row transform gives twice better performance than full and 1.17 times better performance than column DKT_DCT wavelet transform. For cropping 32x32 portions at center of an image, robustness achieved by row DKT_DCT wavelet transform is twice better than column transform and approximately seven times better than full DKT_DCT wavelet transform. Thus for cropping attack, performance of row DKT_DCT wavelet transform is best closely followed by column DKT_DCT wavelet transform.

For compression attack, DCT wavelet, DCT, DST and Walsh transforms are used to compress watermarked images. In case of compression using DCT wavelet, row transform gives 14 times better robustness whereas column transform gives 34 times better robustness than full transform. Column transform also shows 2.5 times better performance than row DKT_DCT wavelet. For compression using DCT, DST and Walsh, full DKT_DCT wavelet fails to sustain against the attack. However, row and column transforms show much better robustness. Among them column transform shows strong robustness for all above mentioned compressions. For JPEG compression with quality factor 100, though the performance is not very good, row DKT_DCT wavelet shows least MAE values among the three.

For resizing attack of type 1 and type2, column DKT_DCT wavelet has strong robustness. For binary distributed run length noise, column transform is most robust when run length from 1 to 10 is used. With increase in number of run length, performance of column transform degrades but it keeps on fluctuating without showing consistency in degradation. In contrast, row DKT_DCT wavelet shows consistent improvement in robustness with increase in length of run used in binary distributed noise. For Gaussian distributed noise, column transform gives 20 times better performance than row DKT_DCT wavelet and 15 times better performance than full DKT_DCT wavelet transform and hence most robustness.

Comparing the performance of DKT_DCT wavelet column transform with DCT_DCT wavelet column transform [27], it is observed that, performance of DKT_DCT wavelet is far better. A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

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