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Robust Watermarking Technique using Singular Values of Watermark Embedded in Single Mid-row of Column Transformed Host using DCT/DKT-DCT Wavel

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Abstract

A robust watermarking technique using wavelet transform/hybrid wavelet transform and SVD is proposed in the paper. Singular values of watermark are embedded in mid-frequency transform coefficients of host located in a single row. Selection of single row makes only 256 transform coefficients available where watermark singular values can be embedded. By using the compression property of Singular Value Decomposition, only few singular values are embedded in the host row. Transform coefficients of host are sorted in descending order and their index positions are used to embed singular values. Scaling factor is also adaptively selected based on highest transform coefficient in the selected host row and highest singular value of watermark. Selection of single row makes it difficult to predict the location where watermark is embedded thus making it more robust over selecting multiple rows for embedding. Adaptive scaling factor adds to the robustness by adjusting the strength of watermark according to the highest singular value of watermark and host row selected for embedding. This technique proves better in terms of robustness against various attacks than embedding singular values of watermark in multiple rows of host proposed in our previous work.

Keywords: *Watermarking, DCT wavelet, DKT-DCT wavelet, Singular Value Decomposition*

1. Introduction

Watermarking is the popular way of protecting digital contents like images, audios, videos from unauthorized claiming. Successful watermarking is one which makes it difficult to realize existence of watermark into host i.e. the one which is imperceptible. Also it makes removal or alteration of embedded watermark difficult by any intentional or unintentional attacks performed on digital contents after inserting watermark into it. This property is called as robustness. Where both imperceptibility and robustness are desired, they never go hand in hand. Higher imperceptibility normally leads to less robust watermarking and for highly robust watermarking we may need to compromise imperceptibility. Hence focus of our work presented in the paper is to achieve both with minimum compromise.

Since wavelet transforms are widely used nowadays for many image processing applications, watermarking is also not an exception. Further to add strength to the watermarking techniques, wavelets are accompanied by other transforms like DCT, DFT and Singular Value Decomposition. In this paper also a wavelet/hybrid wavelet

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transform is combined with Singular Value Decomposition to make the technique robust. Instead of using routine wavelet transforms obtained from Haar basis functions and other, DCT wavelet transform and DKT-DCT hybrid wavelet transforms are used. DCT wavelet is generated from two DCT matrices of appropriate sizes using algorithm in [1] and DKT-DCT wavelet is obtained from Discrete Kekre Transform proposed by Kekre *et. al.*, [2] and Discrete Cosine Transform. These transforms are applied to host images and SVD is applied to watermark. Singular values of watermark are inserted into a single mid-frequency row of transformed host. Sorting and adaptive derivation of scaling factor makes it hard to damage the watermark. Performance of proposed technique is evaluated with respect to two transforms used on host as well as with respect to single and multiple rows of host selected for embedding against various image processing attacks.

Contents of paper are organized as follows. Section 2 reviews the literature, section 3 gives discussion of proposed method of watermarking. Performance of proposed technique against attacks like cropping, compression using various orthogonal transforms, noise addition to watermarked images, resizing and histogram equalization is evaluated in section 4. In section 5, this performance is compared with our technique in which singular values of watermark are embedded in multiple mid frequency rows of host image. Section 6 ends the paper with conclusion.

2. Related Work

In literature, many researchers have proposed watermarking schemes using multiple transformation techniques. Soumya Mukherjee and Arup Kumar Pal [3] proposed a DCT-SVD based watermarking scheme for grayscale images. In their proposed technique, grayscale host image is transformed block wise using DCT. From each DCT transformed block middle frequency elements are selected and reduced transformed image is formed. Singular values of watermark are embedded in this reduced transformed image after scaling down it. By taking inverse transformation, watermarked image is obtained. Another singular value decomposition based watermarking technique is proposed by Priyanka Singh and Suneeta Agarwal [4]. Authors have proposed a region based watermarking approach where region of interest (ROI) are selected using quad tree based approach and watermark is embedded in these ROI. Quad tree based segmentation splits image into regions based on intensities of the pixels in image. When intensities are uniform, large regions are formed whereas when non-uniform intensities are there, small regions are obtained. These small regions represent critical information present in the image and hence are good place for embedding the watermark. Blocks of size 4x4 are selected using quad tree segmentation. SVD is applied to each of these blocks. Third singular value of each of these blocks is used to embed the watermark converted to binary image. Another watermarking scheme based on selection of region of interest from host image and creation of compound watermark is given by Saraju Mohanty and Bharat K. Bhargava [5]. Perceptually important region from host is determined and used as area for embedding watermark. A compound watermark is generated from user watermark and attributes of the host image.

A novel logo watermarking scheme is proposed based on wavelet frame transform, singular value decomposition and automatic thresholding by Gaurav Bhatnagar, Q. M. Jonathan Wu, and Pradeep K. Atrey [6]. The proposed scheme essentially rectifies the ambiguity problem in the SVD-based watermarking. The core idea is to randomly upscale the size of host image using reversible random extension transform followed by the embedding of logo watermark in the wavelet frame domain. After embedding, a verification phase is casted with the help of a binary watermark and total automorphism. A SVD based watermarking is proposed by Kazuo Ohzeki and Masaru

Sakurai [7]. It is based on reduction of rank of singular value matrix by using Quasi-one-way operation.

A watermarking technique using DWT and SVD is proposed by Musrrat Ali and Chang Wook Ahn [8]. Authors have also used Differential Evolution (DE) algorithm to find optimal multiple scaling factors. The host image is wavelet transformed up to first level and four frequency sub bands namely LL, LH, HL and HH are obtained. Watermark is divided into two halves horizontally. Singular values of HL and LH band are used to embed two halves of watermark. Scaling factor used for scaling down the watermark are obtained using DE algorithm as mentioned earlier. Modified HL and LH bands are replaced at their positions and inverse wavelet transform is taken to get the watermarked image. Multiple scaling factors gives better robustness than single scaling factor. One more DWT-SVD based watermarking algorithm is proposed by Erkan Yavuz and Ziya Telatar. In their method [9], third level decomposition of host image is obtained. LL and HL sub bands obtained through this decomposition are used to embed singular values of watermark. In addition, components of U matrix of watermark are embedded into LH and HH sub band. While extracting, first the similarity of extracted U components are checked with the original one. If they are found similar, watermark is constructed by using extracted singular values and original U and V matrices of the watermark.

Abdallah Al-Tahan Al-Nu'aimi [10] proposed watermarking technique for color images using gray watermark in YCbCr color space. Color image is converted into YCbCr space and watermark is embedded in Luminance component only. Gray watermark is divided into slices where each slice represents binary image. Before embedding, pixels of watermark are scrambled using certain key. Certain block is chosen corresponding to every bit. This selection is done using another key. Pixels of host image are arranged in ascending order. Depending on the value of watermark pixel either intensity values of first and third quadrant of host are increased or intensity values in second and fourth quadrant are decreased.

Kekre, Tanuja and Shachi presented a DWT-DCT-SVD based hybrid watermarking method for color images in [11]. 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 [12] and [13] Kekre, Sarode, and Natu presented DCT wavelet and Walsh wavelet based watermarking techniques. In [12], 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 [11] where Haar functions are used as basis functions for wavelet transform. In [13] 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*4 Walsh 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 [12].

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 [14], other wavelet transforms like Hartley wavelet, Slant wavelet, Real Fourier wavelet and Kekre wavelet were explored by Kekre, Tanuja and Shachi. Performance of Slant wavelet and Real Fourier wavelet were proved better for histogram Equalization and Resizing attack than DCT wavelet based watermarking in [12] and Walsh wavelet based watermarking presented in [13].

Kekre *et. al.*, [15] presented a DCT wavelet transform based watermarking technique. Here DCT wavelet is generated from orthogonal DCT using algorithm of wavelet generation from orthogonal transforms given by Dr. Kekre in [16]. Watermark is compressed before embedding in host image. Various compression ratios are tried for compression of watermark so that watermark image quality is maintained with acceptable loss of information from image. Embedding compressed image also reduces the payload of information embedded in host image and thus causes good imperceptibility of watermarked image. Performance of the technique is evaluated under attacks like binary run length noise, Gaussian distributed run length noise and cropping. The watermarking technique by Kekre *et. al.*, in [15] was extended in [16] for other attacks like resizing and compression. Also the compressed watermark is obtained using compression ratio 2.67 and strength of compressed normalized watermark is further increased using suitable scaling factor which was not done in [15]. Performance of full, column and row transform using DCT wavelet and DKT_DCT hybrid wavelet against various attacks is explored by Kekre *et. al.*, in [17] and [18] respectively. Column transform was proved better performance wise as well as computational efficiency wise in both the cases. Further, DKT_DCT column wavelet was observed better than DCT column wavelet. Effect of embedding the watermark by maintaining its energy in some proportion of the host energy is proposed in [19] by Kekre *et.al*.

3. Proposed Method

The proposed method has been implemented using set of five host images and a watermark image shown in Figure 1.

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

Figure 1. Five Host Images and a Watermark Image used for Experimental Work

This work is an extension of our previous work in which multiple rows in mid-frequency of host are chosen for embedding singular values of watermark. Column wavelet transforms namely DCT wavelet and DKT-DCT wavelet have been explored for performance comparison purpose. Steps of embedding algorithm are given below:

Embedding Algorithm

1. Read host image of size 256x256 and separate its red, green and blue channels.

2. Generate DCT wavelet transform matrix of size same as image size using pair of DCT matrices of size 64x64 and 4x4. (write about DKT-DCT size)
3. Apply DCT/DKT-DCT wavelet transform on each plane of host image column wise.
4. Select a single row from mid-frequency region of transformed channels of host image. In proposed method we have tried each single row in the range of row 108 to row 117 of transformed host.
5. Read watermark image of size 128x128 and separate its red, green and blue channels.
6. Apply Singular value Decomposition to each channel. We get 128 singular values for each plane of watermark.
7. Select first few singular values of each plane for embedding in single row of host such that selected singular values will cause minimum loss in the information from watermark. The results have been simulated by selecting first 30, 50, 70, 90, 110 and all 128 singular values.
8. Sort the transform coefficients from single row of host selected in step 4 in descending order and record their index positions.
9. Scaling factor is obtained by dividing the first singular value by highest coefficient of host obtained in step 8.
10. Using the scaling factor from step 9, scale down the singular values of watermark.
11. These values are embedded at the index positions of sorted transform coefficients obtained in step 8 such that first singular value occupies the index position of highest transform coefficient. To embed second singular value, the position of smallest transform coefficient from set of coefficients higher than singular value is chosen. All next singular values are placed in consecutive index positions following the index position of this smallest higher transform coefficient of host.
12. After embedding all selected singular values, host transform coefficients are rearranged at their positions and inverse column DCT wavelet transforms of each plane of host is taken to get watermarked image.
13. Mean Absolute Error between host and watermarked image is calculated to measure the imperceptibility.

Extraction Algorithm

1. Read the watermarked image.
2. Separate red, green and blue channels of it and apply column DCT/DKT-DCT wavelet transform to each channel.
3. Select the row from each channel of transformed watermarked image in which watermark SVD values were embedded.
4. Extract the coefficients from the positions recorded in embedding procedure for each plane. These correspond to the singular values embedded in host.
5. Scale up these singular values and take singular value decomposition of each channel using these values to get extracted watermark.
6. Calculate Mean Absolute Error between embedded and extracted watermark.

Result Images

Results of embedding and extraction procedure are shown in Figure 2. These results are obtained when watermark is compressed using 30 singular values only and embedded into 108th row Lena image using DCT wavelet and DKT-DCT wavelet for host image.

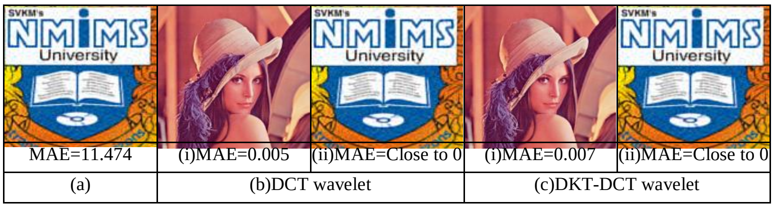


Figure 2. (a) Watermark Obtained from 30 Singular Values (b) (i) Watermarked Image using Watermark in (a) and DCT Wavelet, (ii) Extracted Watermark from Watermarked Image (b) (i), (c) (i) Watermarked Image obtained using Watermark in (a) and DKT-DCT Wavelet, (ii) Extracted Watermark from (c) (i)

From Figure 2 it can be seen that when no attack is performed on watermarked image, extracted watermark is same as that of embedded watermark with MAE between them zero. Also when DKT-DCT wavelet is used for embedding the watermark, MAE between host and watermarked image is marginally higher than when DCT wavelet is used.

4. Performance Evaluation against Various Attacks for Robustness

In order to test the robustness of proposed method, watermarked images obtained using DCT wavelet and DKT-DCT wavelet are subjected to various attacks like cropping, Compression using orthogonal transforms, JPEG compression, Histogram Equalization, noise addition and resizing. Results and observations for each of these attacks are discussed below.

Cropping attack: In cropping attack, squares of sizes 16x16 and 32x32 are cropped at the corners of an image. Also, square of size 32x32 is cropped at the centre of an image. Comparison of MAE between embedded and extracted watermark using DCT wavelet and DKT-DCT wavelet from these cropped images is shown below in Figure 3.

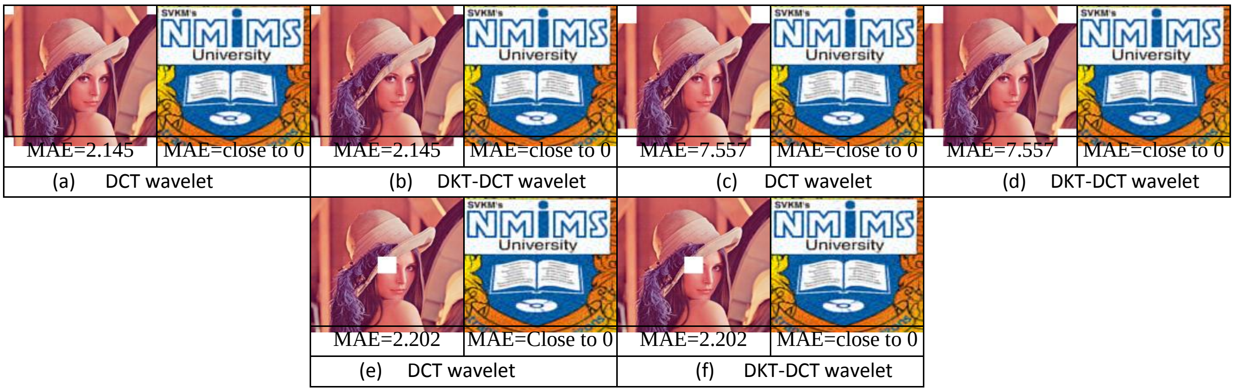


Figure 3. (a) 16x16 Corners Cropped from Watermarked Image and Extracted Watermark using DCT Wavelet for Embedding (b) 16x16 Corners Cropped from Watermarked Image and Extracted Watermark using DKT-DCT Wavelet for Embedding (c) 32x32 Corners Cropped from Watermarked Image and Extracted Watermark using DCT Wavelet for Embedding (d) 32x32 Corners Cropped from Watermarked Image and Extracted Watermark using DKT-DCT Wavelet for Embedding (e) 32x32 Square Cropped at Center from Watermarked Image and Extracted Watermark using DCT Wavelet for Embedding (f) 32x32 Square Cropped at Center from Watermarked Image and Extracted Watermark using DKT-DCT Wavelet for Embedding

From Figure 3 it can be observed that for both DCT wavelet and DKT-DCT wavelet used in embedding process, extracted watermarks from cropped watermarked images are closest to embedded watermark with MAE zero. However when we compare this to embedding singular values of watermark into multiple mid-frequency rows of host instead of single row, these results show an improvement in the quality of extracted watermark. In multiple rows of host and SVD of watermark approach as proposed in our previous work, MAE between embedded and extracted watermark goes on increasing as we embed more number of singular values of watermark into host. It holds true when we select lower host row for embedding the watermark. However for single row of host and singular values of watermark approach, though we increase number of singular values embedded in host row, MAE between embedded and extracted watermark remains almost zero irrespective of shift of host row selected for embedding.

Compression attack: In compression attack, watermarked image is compressed using orthogonal transforms DCT, DST, Walsh and Haar with compression ratio 1.14 and using DCT wavelet transform with compression ratio 2.67. JPEG compression is also performed with quality factor 100.

Result images for DCT and DST based compression using DCT wavelet and DKT-DCT wavelet for embedding are shown in Figure 4.

MAE=0.638	MAE=6.158	MAE=0.638	MAE=7.057	MAE=0.715	MAE=6.232	MAE=0.714	MAE=7.057
(i) DCT wavelet		(ii) DKT-DCT wavelet		(iii) DCT wavelet		(iv) DKT-DCT wavelet	
(a) Compression using DCT				(b) Compression using DST			

Figure 4. (a) Compression of Watermarked Image using DCT and Watermark Extracted from it: (i) using DCT Wavelet on Host (ii) using DKT-DCT Wavelet on Host (b) Compression of Watermarked Image using DST and Watermark Extracted from it: (iii) using DCT Wavelet on Host (iv)using DKT-DCT Wavelet on Host

From Figure 4, it can be seen that, MAE between embedded and extracted watermark are less for DCT wavelet as compared to DKT-DCT wavelet for embedding. Thus DCT wavelet proves more robust than DKT-DCT wavelet. Also, DCT wavelet shows better robustness when it is compared to embedding singular values of watermark in multiple host rows. Shifting the host row used for embedding downwards results in fluctuations in MAE initially and then shows continuous decrease in MAE between embedded and extracted watermark for both single and multiple rows of host using DCT wavelet. But, embedding in single row of host is always more robust. For DKT-DCT wavelet used in embedding, it is observed that as we go on embedding more number of singular values, use of single host row gives better robustness than multiple host rows used for embedding the watermark.

Figure 5 shows results of compression attack using Walsh and Haar transform.

MAE=1.440	MAE=9.742	MAE=1.440	MAE=18.537	MAE=0.810	MAE=close to 0	MAE=0.810	MAE=close to 0
(i) DCT wavelet		(ii) DKT-DCT wavelet		(iii) DCT wavelet		(iv) DKT-DCT wavelet	
(a) Compression using Walsh				(b) Compression using Haar			

Figure 5. (a) Compression of Watermarked Image using Walsh and Watermark Extracted from it: (i) using DCT Wavelet on Host (ii) using DKT-DCT Wavelet on Host (b) Compression of Watermarked Image using Haar and Watermark Extracted from it: (iii) using DCT Wavelet on Host (iv)using DKT-DCT Wavelet on Host

For compression using Walsh, it has been observed that when DCT wavelet is used for embedding, and singular values embedded in single row (row number 108), robustness is much better as compared to DKT-DCT wavelet for different number of singular values and for shifting the host rows downwards. Also robustness is better than in case of multiple rows selected for embedding singular values. When we select lower row for embedding singular values of watermark, single row performance degrades as compared to multiple rows performance. For DKT-DCT wavelet, embedding more singular values gives better robustness.

For Haar based compression, observations for DCT wavelet are as follows. When we move towards lower row for embedding watermark from row 108 to row 112, extracted watermark is almost same as the one embedded with MAE between them zero irrespective of number of singular values embedded in host row. Thus use of single row of host is better than multiple rows of host selected for embedding. From row 113 to row 117, there is sudden degradation in robustness of single row technique. When DKT-DCT wavelet is used for embedding, irrespective of number of singular values embedded and the lower row selected for embedding them, extracted watermark is always closest to embedded watermark with MAE between the two as zero. Thus single row technique is more robust with DKT-DCT wavelet for Haar based compression.

Figure 6 shows result images for DCT wavelet based compression and JPEG compression attack.

MAE=2.66	MAE=Close to 0	MAE=2.659	MAE=62.867	MAE=0.012	MAE=37.469	MAE=0.011	MAE=52.455
(j) DCT wavelet		(ii) DKT-DCT wavelet		(iii) DCT wavelet		(iv)DKT-DCT wavelet	
(a) Compression using DCT wavelet				(b) JPEG Compression			

Figure 6. (a) Compression of Watermarked Image using DCT Wavelet and Watermark Extracted from it: (i) using DCT Wavelet on Host (ii) using DKT-DCT Wavelet on Host (b) JPEG Compression of Watermarked Image and Watermark Extracted from it: (iii) using DCT Wavelet on Host (iv)using DKT-DCT Wavelet on Host

From Figure 6 we can see that DCT wavelet is better in robustness than DKT-DCT wavelet for DCT wavelet based compression and JPEG compression. However when we compare the single row technique with multiple row technique, both DCT wavelet and DKT-DCT wavelet improved in robustness in single row technique irrespective of host row selected and number of singular values selected for embedding.

Noise Addition Attack: Two types of noises are added. Binary distributed run length noise with discrete magnitude between 1 and -1 and Gaussian distributed run length noise with discrete magnitude between 2 and -2. Also different run lengths of binary distributed run length noise are tried i.e. run length 1 to 10, 5 to 50 and 10 to 100. Figure 7 shows the result images for binary run length noise (with run length 1 to 10 and 5 to 50) added to watermarked images and extracted watermarks from them.

MAE=1	MAE=Close to 0	MAE=1	MAE=Close to 0	MAE=1	MAE=6.333	MAE=1	MAE=4.511
(i) DCT wavelet		(ii) DKT-DCT wavelet		(iii) DCT wavelet		(iv) DKT-DCT wavelet	
(a) Binary distributed run length noise run length 1-10				(b) Binary distributed run length noise run length 5-50			

Figure 7. (a)Watermarked Image after Adding Binary Distributed Run Length Noise (with run length between 1 to 10) (b) Watermarked Image after Adding Binary Distributed Run Length Noise (with Run Length between 5 to 50)

From Figure 7 we can observe that for run length 1 to 10 of binary distributed run length noise, both DCT wavelet and DKT-DCT wavelet show zero MAE between embedded and extracted watermark for different number of singular values embedded into it and for varying the host row towards lower end. For run length 5 to 50, both DCT wavelet as well as DKT-DCT wavelet show increased MAE between embedded and extracted watermark. Also, they show fluctuating performance for increased number of singular values and shift in position of embedding the watermark.

Figure 8 shows the watermarked images and extracted watermark for binary distributed run length noise with run length 10 to 100 and Gaussian distributed run length noise added to watermarked image.

MAE=1	MAE=9.995	MAE=1	MAE=7.416	MAE=0.746	MAE=Close to 0	MAE=0.746	MAE=close to 0
(i) DCT wavelet		(ii) DKT-DCT wavelet		(iii) DCT wavelet		(iv) DKT-DCT wavelet	
(a) Binary distributed run length noise run length 10-100				(b) Gaussian distributed run length noise			

Figure 8. (a) Watermarked Image after Adding Binary Distributed Run Length Noise (with Run Length in the range 10 to 100) (b) Watermarked Image after Adding Gaussian Distributed Run Length Noise

From Figure 8 it is clearly observed that DKT-DCT wavelet gives better robustness than DCT wavelet for binary distributed run length noise. For Gaussian distributed run length noise, though the MAE between embedded and extracted watermark is zero for both the transforms, for other number of singular values, it is seen that DCT wavelet is more robust than DKT-DCT wavelet.

Histogram Equalization Attack: Figure 9 below shows the watermarked images after performing histogram equalization attack and watermark extracted from it using DCT wavelet and DKT-DCT wavelet in embedding process.

MAE=41.551	MAE=117.93	MAE=41.548	MAE=133.934
(a) DCT Wavelet		(b)DKT-DCT wavelet	

Figure 9. Histogram Equalized Watermarked Image and Watermark Extracted from it using (a) DCT Wavelet and (b) DKT-DCT Wavelet while Embedding

From Figure 9 it can be seen that both DCT wavelet and DKT-DCT wavelet are not able to sustain against histogram equalization attack. However among the two, DCT wavelet is better. Also embedding singular values of watermark in multiple rows of host as proposed in previous work, is better than embedding in single row of host.

Resizing Attack: Performance of proposed technique for resizing attack using bicubic interpolation is shown in Figure 10.

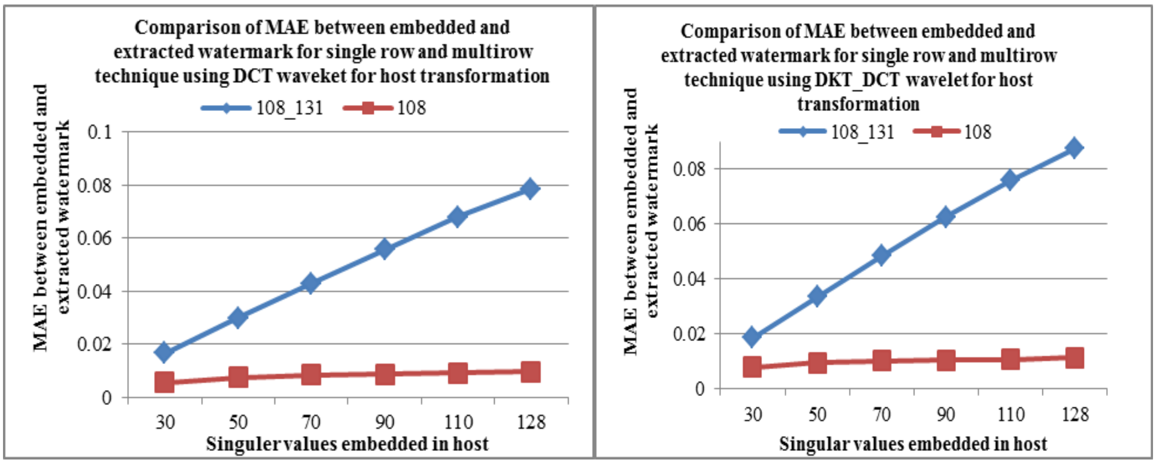
MAE=1.247	MAE=33.61	MAE=1.247	MAE=25.997	MAE=1.215	MAE=32.702	MAE=1.214	MAE=25.226
(i)DCT wavelet		(ii)DKT-DCT wavelet		(iii)DCT wavelet		(iv)DKT-DCT wavelet	
(a) Resizing by doubling and then to original size				(b) Resizing by increasing size four times and then to original size			

Figure 10. Resized Watermarked Images and Extracted Watermark using DCT Wavelet and DKT-DCT Wavelet in Embedding (a) for Doubling the Image and then Bringing Back to Original Size (b) by Increasing the Image Size Four Times and then Bringing to Original Size

From Figure 10 it is observed that for both types of resizing, DKT-DCT wavelet gives better robustness than DCT wavelet. As we move down in host rows, initially for less number of singular values, single row of host may give more MAE values between embedded and extracted watermark. But, as we increase the number of singular values embedded, using single row of host for embedding proves to be more robust. For DCT wavelet also, when 30 values are embedded in single row of host, resizing attack seems to be less robust. But for all the rest of singular values and moving down in the host row for embedding reduces the MAE between embedded and extracted watermark as compared to multiple rows of host used for embedding.

5. Comparison of Proposed Technique with Multirow Technique

In this section, performance of proposed technique is compared with our previously proposed technique in which singular values of watermark are embedded in multiple middle frequency rows of transformed host against various attacks wherever applicable. Figure11 below shows the MAE between embedded and extracted watermark without any attack performed for single and multirow technique using DCT wavelet and DKT-DCT wavelet for host transformation. Single row selected for embedding is row number 108 and multiple rows selected are rows 108-131. Singular values ranging from 30 to 128 are embedded in host.

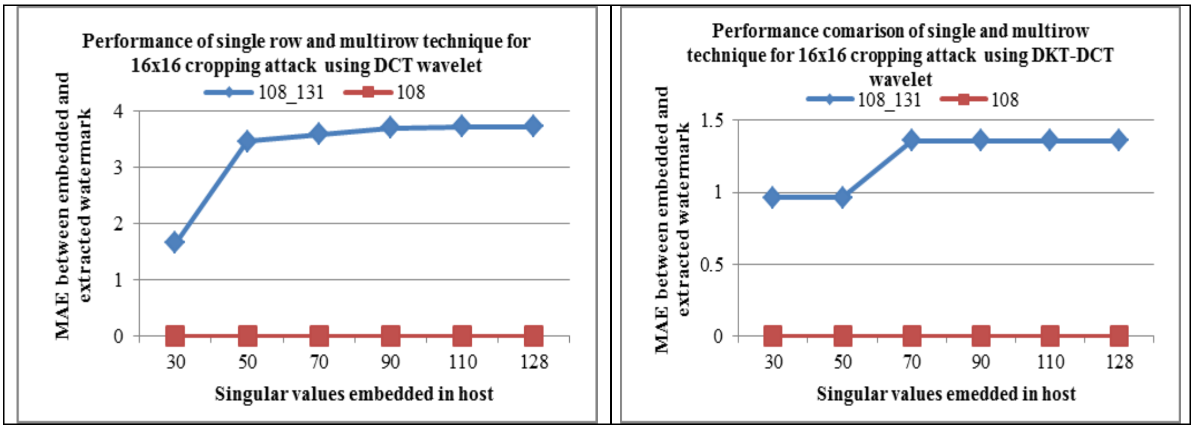


(a) (b)

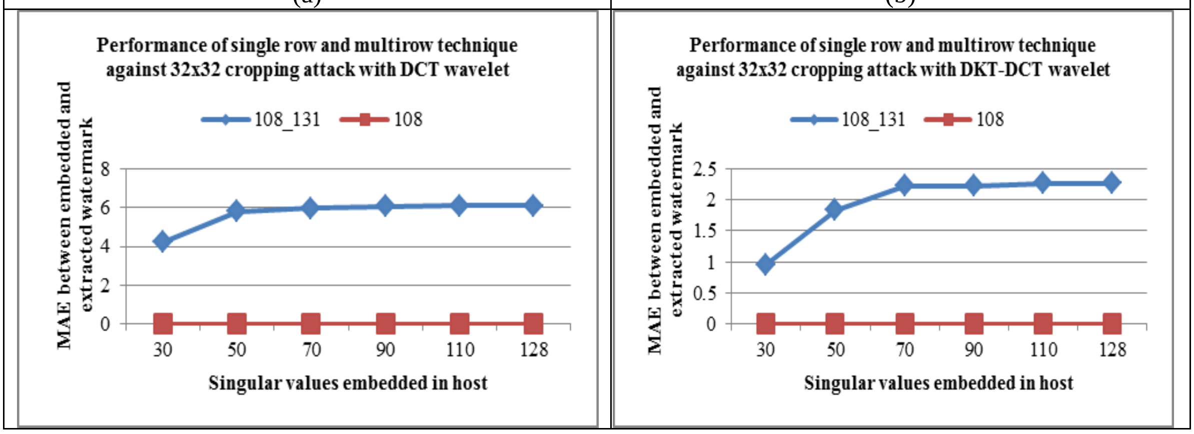
Figure 11. (a)Comparison of MAE between Embedded and Extracted Watermark for Single and Multirow Technique when DCT Wavelet is used for Host Transformation (b) Comparison of MAE between Embedded and Extracted Watermark for Single and Multirow Technique when DKT-DCT Wavelet is used for Host Transformation

From Figure 11(a) and (b) it is observed that when single row of host is used for embedding watermark singular values, MAE between inserted and recovered watermark is reduced for various singular values. Thus imperceptibility is better when we use single row for embedding.

Figure 12 below shows the performance comparison of single row vs. multirow technique for cropping attack.



(a) (b)



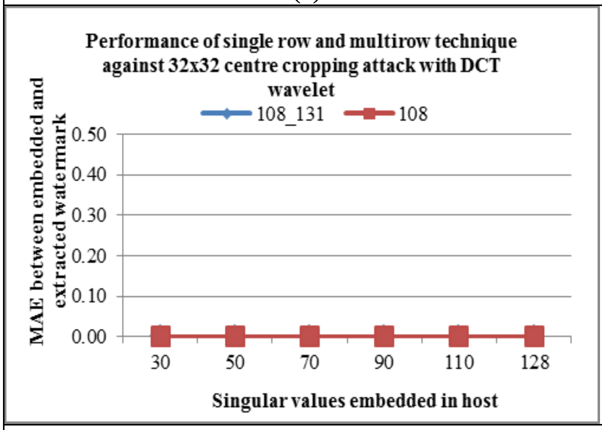
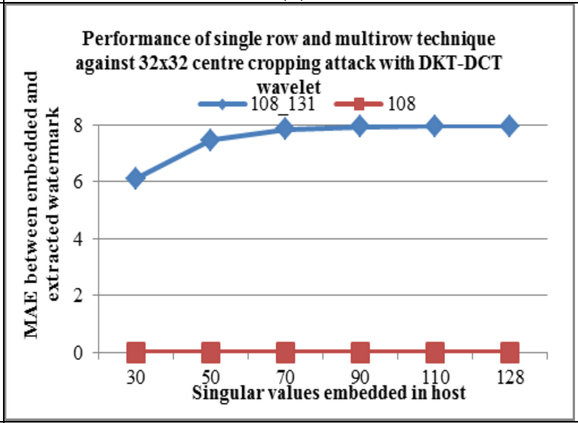
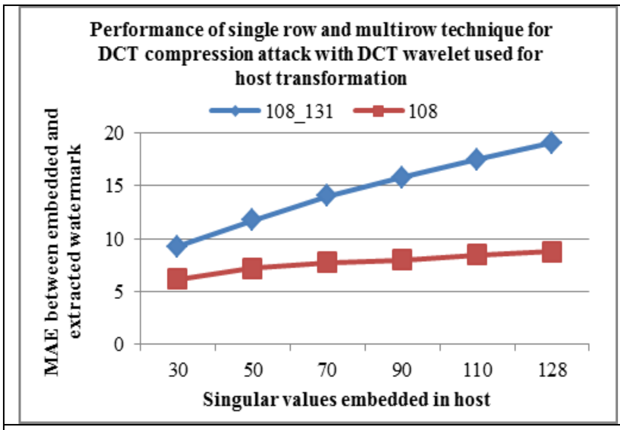
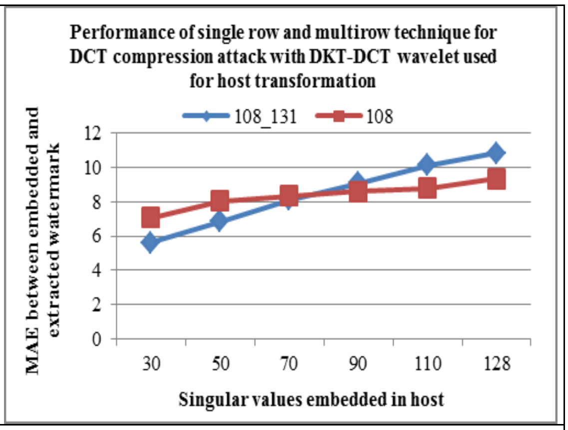
(c)	(d)
	
(e)	(f)

Figure 12. Comparison of MAE between Embedded and Extracted Watermark using Single and Multirow Technique. (a) 16x16 Cropping and DCT Wavelet for Host Transformation (b) x16 Cropping and DKT-DCT Wavelet for Host Transformation (c) 32x32 Cropping and DCT Wavelet for Host Transformation (d) 32x32 Cropping and DKT-DCT Wavelet for Host Transformation (e) 32x32 Cropping at Center and DCT Wavelet for Host Transformation (f) 32x32 Cropping at Center and DKT-DCT Wavelet for Host Transformation

From Figure 12 it is observed that, whether it is DCT wavelet or DKT-DCT wavelet, using single row for embedding singular values of watermark improves the performance of cropping attack by showing MAE value zero.

Figure 13 shows the performance comparison of single row and multi row technique for compression attack with DCT wavelet and DKT-DCT wavelet used for transformation of host while embedding the watermark.

	
(a)	(b)

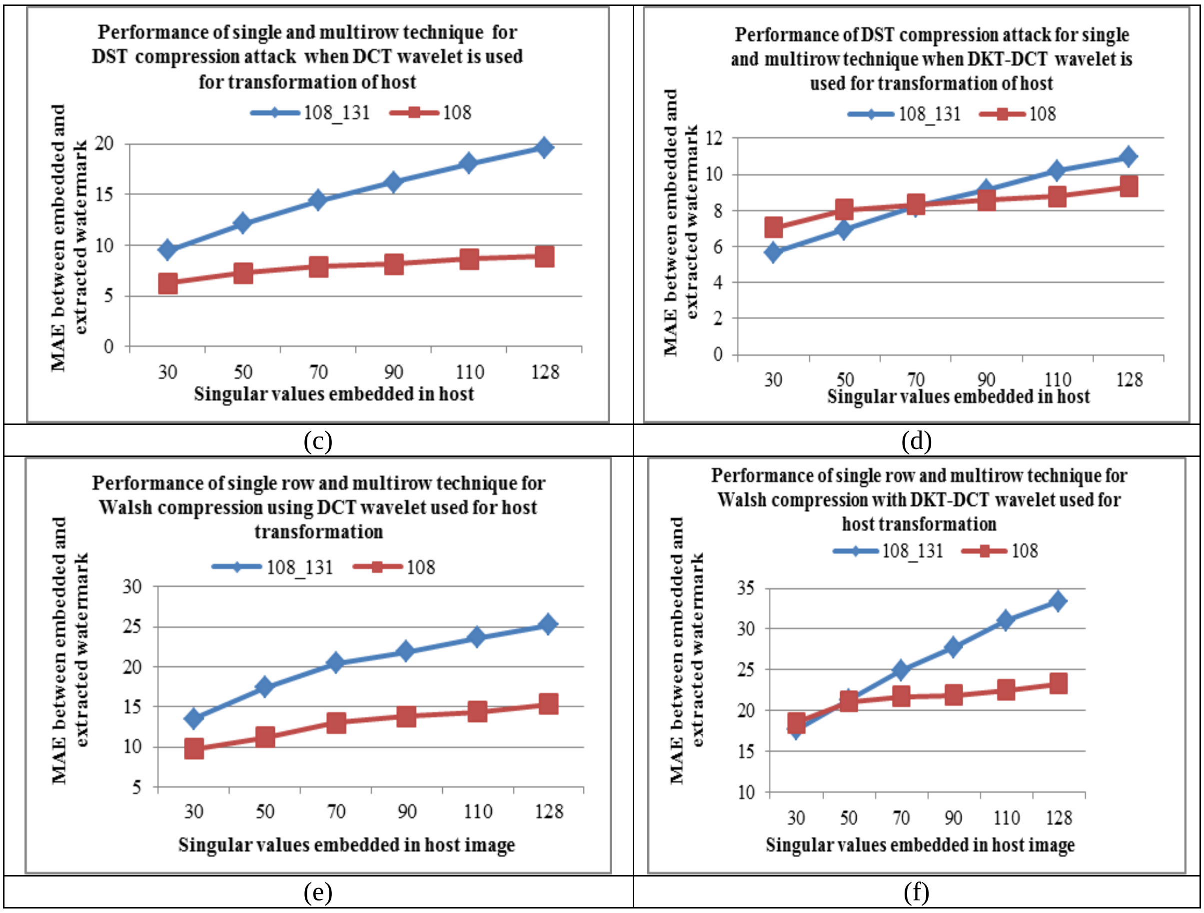


Figure 13. Comparison of MAE between Embedded and Extracted Watermark using Single and Multirow Technique. (a) DCT Compression with DCT Wavelet for Host Transformation (b) DCT Compression with DKT-DCT Wavelet for Host Transformation (c) DST Compression with DCT Wavelet for Host Transformation (d) DST Compression with DKT-DCT Wavelet for Host Transformation (e) Walsh Compression with DCT Wavelet for Host Transformation (f) Walsh Compression with DKT-DCT Wavelet for Host Transformation

From Figure13 (a), (c) and (e), it is seen that for DCT wavelet used in embedding process, compression using DCT, DST and Walsh compression give smaller MAE values for single row technique than in multirow technique for various singular values embedded in host image.

From Figure 13 (b), (d) and (f) it can be observed that in case of DKT-DCT wavelet used for host transformation, for lesser number of singular values, single row technique gives slightly higher MAE value for DCT and DST and equivalent performance for Walsh compression attack. But, as we increase number of singular values embedded in host image, single row technique performs better with smaller MAE value.

From Figure 13 (a), (b), (c) and (d) another observation can be clearly made is that range of MAE values for DKT-DCT wavelet is smaller as compared to DCT wavelet for DCT and DST compression attack and higher for Walsh compression attack. Thus, DKT-DCT wavelet is more robust for DCT and DST compression attack.

Figure 14 shows the performance comparison of Haar, JPEG and DCT wavelet based compression attack using single row and multirow technique for DCT wavelet and DKT-DCT wavelet used in host transformation.

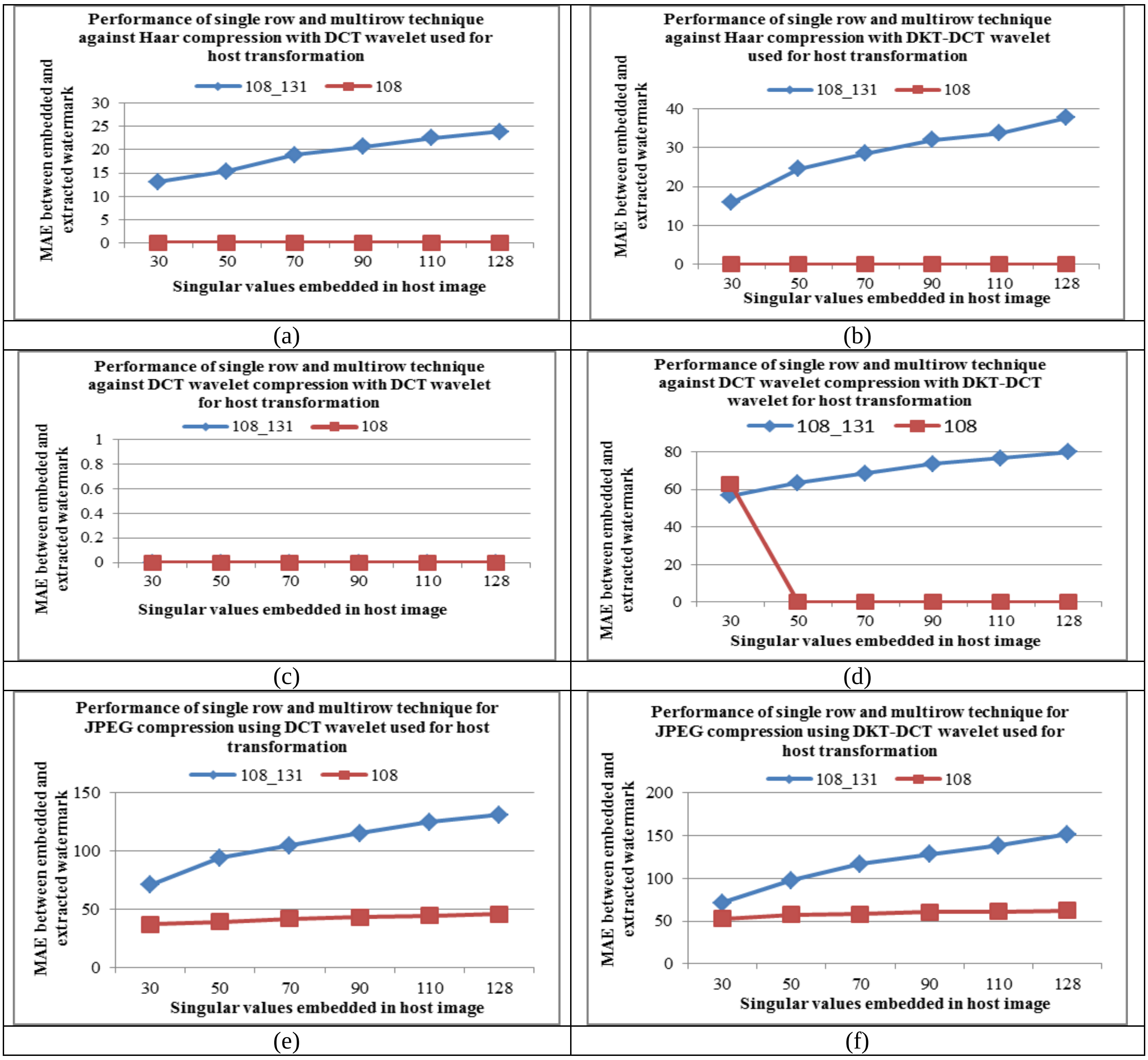


Figure 14. Comparison of MAE between Embedded and Extracted Watermark using Single and Multirow Technique (a) Haar Compression with DCT Wavelet for Host Transformation (b) Haar Compression with DKT-DCT Wavelet for Host Transformation (c)DCT Wavelet Compression with DCT Wavelet for Host Transformation (d) DCT Wavelet Compression with DKT-DCT Wavelet for Host Transformation (e) JPEG Compression with DCT Wavelet for Host Transformation (f) JPEG Compression with DKT-DCT Wavelet for Host Transformation

From Figure 14 (a) and (c) it can be seen that in case of DCT wavelet used for embedding, single row technique proves more robust against Haar and DCT wavelet compression with zero MAE for various singular values. For JPEG compression also, single row technique shows increased robustness for various singular values as seen in Figure 14(e).

As observed from Figure 14 (b), in case of DKT-DCT wavelet used for embedding, single row technique is more robust irrespective of number of singular values embedded in host. For DCT wavelet compression, when 30 singular values embedded in host, MAE between embedded and extracted watermark using single row technique and multirow technique are very close as can be seen from Figure 14 (d). Afterwards, for increased singular values embedded in host, single row technique shows improved robustness. For JPEG compression using DKT-DCT wavelet for embedding also single row technique shows better robustness for various singular values embedded in host.

Figure 15 shows performance comparison of single row and multirow technique for noise addition attack with DCT wavelet and DKT-DCT wavelet transform used in embedding process.

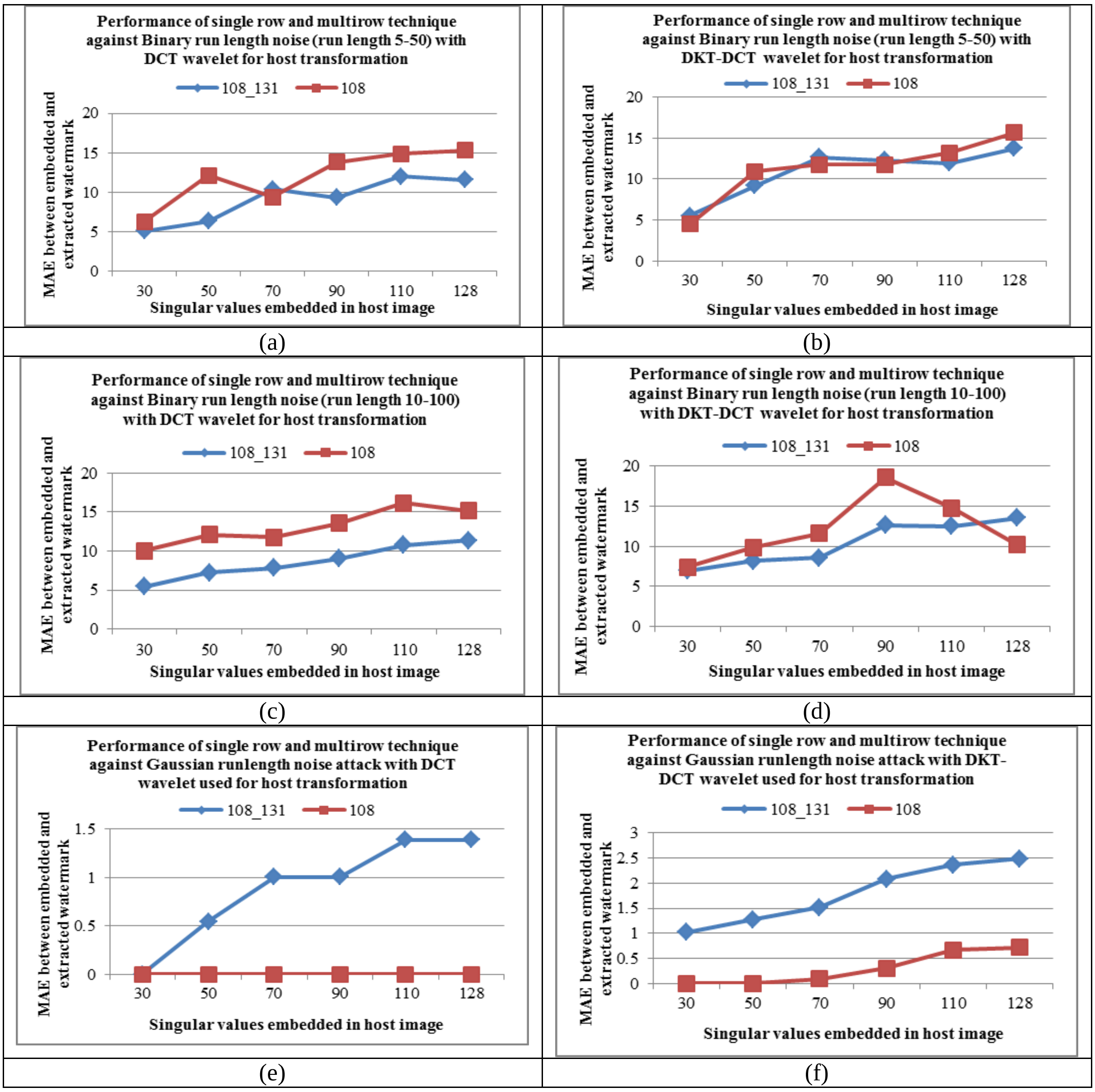


Figure 15. Comparison of MAE between Embedded and Extracted Watermark using Single and Multirow Technique (a) Binary Run Length Noise Attack (Run Length 5-50) with DCT Wavelet for Host Transformation (b) Binary Run Length Noise Attack (Run Length 5-50) with DKT-DCT Wavelet for Host Transformation (c) Binary Run Length Noise Attack (Run Length 10-100) with DCT Wavelet for Host Transformation (d) Binary Run Length Noise Attack (Run Length 10-100) with DKT-DCT Wavelet for Host Transformation (e) Gaussian Run Length Noise Attack with DCT Wavelet for Host Transformation (f) Gaussian Run Length Noise Attack with DKT-DCT Wavelet for Host Transformation

Figure 15 (a) highlights that multirow technique is more robust for Binary distributed run length noise with run length 5 to 50 except for 70 singular values embedded in host. Figure 15 (c) also shows that multirow technique better sustains the Binary run length noise when run length is further increased to the range of 10-100. For Gaussian distributed run length noise however, single row technique shows better sustenance than multirow technique as shown in Figure 15 (e) with zero MAE.

Figure 15 (b) shows that in case of DKT-DCT wavelet, single row and multirow technique show very little difference in robustness for Binary distributed run length noise when run length 5-50 is added to watermarked image. For increased run length multirow technique shows better robustness over single row technique except when all singular values of watermark are embedded in host as shown in Figure 15 (d). For Gaussian noise run length attack in case of DKT-DCT wavelet transform, single row technique shows higher robustness than multirow technique as can be seen from Figure 15 (f).

Figure 16 shows performance comparison of single row and multirow technique for histogram equalization and resizing attack.

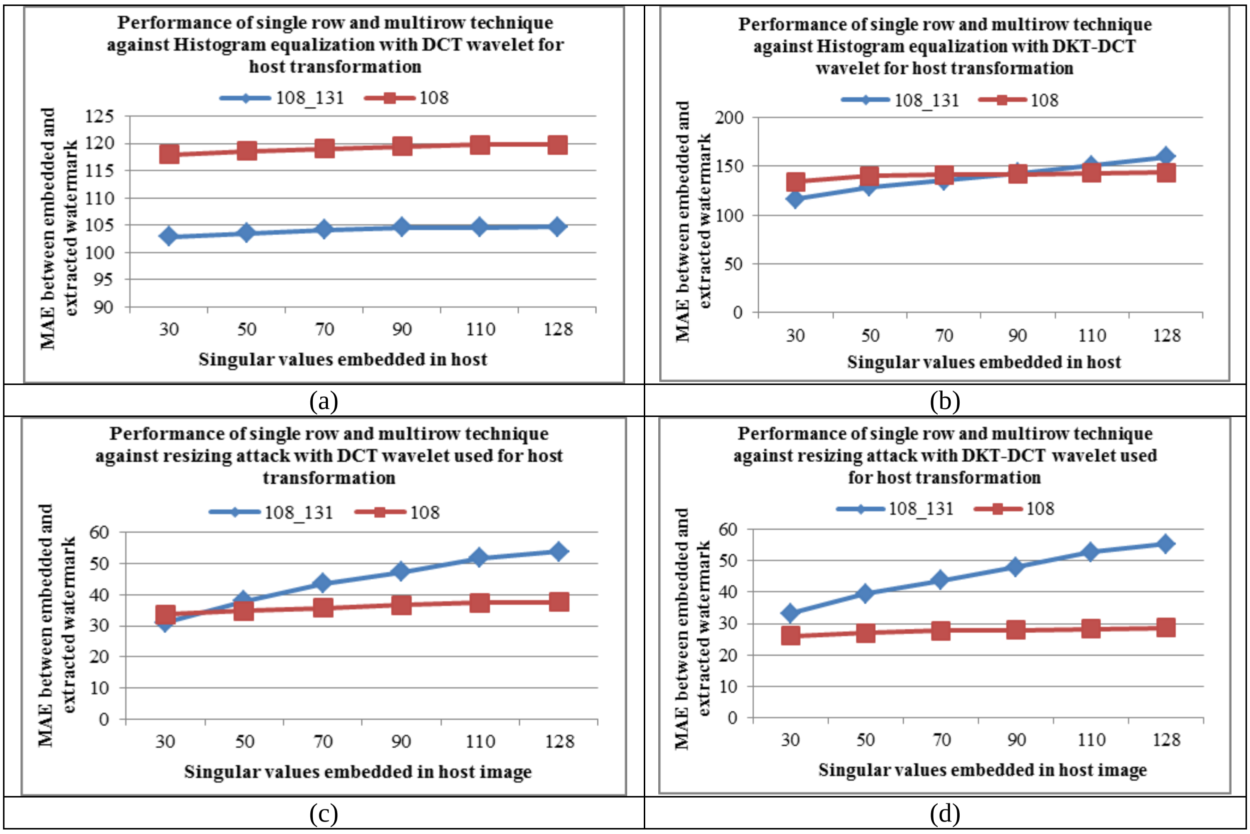


Figure 16. Comparison of MAE between Embedded and Extracted Watermark using Single and Multirow Technique (a) Histogram Equalization Attack with DCT Wavelet for Host Transformation (b) Histogram Equalization attack with DKT-DCT wavelet for Host Transformation (c) Resizing Attack (Doubling the Image in Size and Reducing to Original Size) with DCT Wavelet for Host transformation (d) Resizing Attack (Doubling the Image in Size and Reducing to Original Size) with DKT-DCT Wavelet for Host Transformation

Figure 16 (a) clearly shows that for histogram equalization attack, when DCT wavelet transform is used in embedding process, multirow technique is superior in terms of robustness than single row technique though the MAE values for this attack are much higher as compared to other attacks. For DKT-DCT wavelet, higher number of singular values embedded in host image lead to better robustness. For less number of singular values embedded in host, multirow technique gives better robustness.

From Figure 16 (c), we can say that, initially for lower number of singular values (*i.e.*, 30 values), performance of single row technique is slightly poorer than multirow technique against resizing attack. As more singular values are used for embedding, single row technique shows significant improvement in robustness.

When DKT-DCT wavelet transform is used for host transformation, robustness of single row technique is observed to be better for different number of singular values embedded in host as shown in Figure 16 (d). Similar observations are noted for another type of resizing attack also.

6. Conclusions

A Robust watermarking technique in which singular values of watermark are embedded in transform coefficients of host is proposed. By using the property of energy compaction of singular value decomposition, instead of all singular values, embedding only few values is tried such that it will not cause much loss of information embedded in host. These singular values are embedded in a single mid frequency row of transformed host image. Two transforms namely DCT wavelet and DKT-DCT wavelet are used for transforming host. Performance comparison of these two transforms against various attacks shows that for attacks like cropping, compression and histogram equalization DCT wavelet is more robust than DKT-DCT wavelet against whereas DKT-DCT wavelet is robust over DCT wavelet for noise addition attack and resizing attack. The proposed technique is also observed to be more robust against various attacks like cropping, compression etc. than our previous technique in which multiple mid-frequency rows of host were selected for embedding singular values of watermark.

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