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Performance Comparison of Watermarking by Sorting and Without Sorting the Hybrid Wavelet Transforms Generated from Sinusoidal and Non-sinusoidal Orthogonal Transforms

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Abstract

In this paper a watermarking technique using hybrid wavelet transforms obtained from sinusoidal and non-sinusoidal component orthogonal transforms is proposed. Sinusoidal transform DCT and non-sinusoidal transforms Walsh, Haar and Discrete Kekre Transform are used to generate hybrid wavelet transforms namely DCT-Walsh, Walsh-DCT, DCT-Haar, Haar-DCT, DCT-DKT and DKT-DCT. Size of each component transform matrix is varied suitably from 4, 8, 16, 32, and 64 to generate hybrid wavelet transform matrix for host and watermark. The best size combination is further applied column wise and row wise to host and watermark and to embed the watermark middle frequency regions of host is selected. Embedding is first done without sorting the hybrid wavelet transform coefficients of host and watermark and then sorting is applied to observe the difference in the achieved robustness. Performance of proposed technique is evaluated against various attacks to decide whether sinusoidal transform when used as base transform matrix or local transform matrix is more robust.

Keywords: *Watermarking, Hybrid wavelet transform, Discrete Kekre Transform, DCT-DKT, DCT-Walsh*

1. Introduction

The immense popularity of World Wide Web opened a new gateway for transmission of multimedia contents over the network. However such transmission of digital contents over network has two serious problems. First, these contents are easily downloadable and can be easily reproduced. Second, because of powerful multimedia manipulation tools, credibility of multimedia data such as images, audios and videos is decreased. Thus copyright protection of digital contents is the driving force of research in digital watermarking. Digital watermarking is the process of inserting some signal in a multimedia content to preserve its copyright/ownership information.

Lot of work has been done in transform domain watermarking using DCT [1, 2, 3], wavelet transform [4, 5, 6] singular value decomposition [7, 8] and wavelet packet transform [9]. Methods are also proposed using combination of two or more transforms like DWT-DCT [10], DWT-SVD [11], DCT-SVD [12], and DWT-DCT-SVD [13]. 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.

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Remaining paper has been organized as follows: Section 2 gives review of related work done in the field of watermarking. Section 3 presents the brief discussion on hybrid wavelet transform. Section 4 discusses proposed method. Section 5 gives the discussion of various attacks and performance of proposed method against attacks. Section 6 concludes the paper.

2. Review of Related Work

Malihe Soleimani, Faezeh Sanaei Nezhad *et al.*, [14] have proposed a blind image watermarking based on spread spectrum in DCT domain. Image is first divided into 8*8 blocks. Then DCT is applied to each block. First two AC coefficients from each transformed block and the bias member which is zero is set. Watermark is coded in spread spectrum. For each watermark code, the nearest member of the collection which has not been selected is chosen. If the chosen number is not the bias number, AC coefficient in the transformed block is replaced by watermark. G. Bhatnagar, B. Raman and Q. M. J. Wu [15] have proposed a robust watermarking scheme using fractional wavelet packet transform. In their proposed technique, image is decomposed by means of fractional wavelet packet transform. Then positions of all frequency sub-bands at each level are changed with respect to some rule which is secret and known only to owner. Then inverse fractional wavelet transform is performed to obtain the reference image. For embedding, reference image is divided into non-overlapping blocks and then watermark is embedded in reference image by modifying its singular values. The size of blocks is same as size of watermark. K. Ramanjaneyulu and K. Rajarajeswari [16] have proposed a wavelet based image watermarking scheme using genetic algorithm. Here the cover image is subjected to three level DWT. Third and second level horizontal detail sub-band (LH2 and LH3) coefficients are grouped into different blocks. In each block first minimum and second minimum are identified and modified according to the watermark bit. After watermark insertion, inverse DWT is applied to the sub-bands with modified coefficients to obtain the watermarked image. A threshold based decoder is designed for extraction process. PSNR of watermarked image and Normalized Cross Correlation (NCC) of extracted watermark are the parameters used to measure the performance of this technique.

Emir Ganic and Ahmet Eskicioglu [17] have proposed wavelet and SVD based watermarking scheme in which image is first divided into four frequency bands using DWT. SVD of each sub-band is then calculated. SVD values of image are then modified using SVD values of watermark. Robustness in this scheme is achieved by embedding watermark in each frequency band. This scheme is claimed to be better than embedding watermark only using SVD scheme by authors. Say Wei Foo, Qi Dong [18] have proposed image normalization based watermarking scheme using SVD-DCT combination. Image is first normalized and divided into 4*4 size non-overlapping blocks. SVD is applied to each block. First singular values of each block are concatenated to form SV block. DCT is applied to SV block to get SVD-DCT block. Watermark is embedded in high frequency band of SVD-DCT blocks. Adaptive frequency mask is used to adjust the strength of watermarking. Liu Liang and Sun Qi [19] have suggested a composite watermarking method using SVD and DWT. In their proposed technique, watermark is embedded in high frequency image, *i.e.*, HH frequency sub-band of host image. SVD is applied to watermark and high frequency image. Then singular values of high frequency image are modified by adding scaled singular values of watermark. Using this modified high frequency sub-band watermarked image is obtained.

3. Hybrid Wavelet Transforms

Hybrid wavelet transform is generated from two different orthogonal transform matrices using Kekre's algorithm to generate hybrid wavelet transform [20]. This leads to achieving good characteristics of both component transforms. If transform matrix Ta is of size mxm and transform matrix Tb is of size nxn then resultant hybrid wavelet transform matrix is of size mn*mn. Thus for the proposed method, 256x256 size hybrid wavelet transform matrix is generated from orthogonal transforms of size 64x64 and 4x4 thus forming (64,4) as a pair of component matrix size. Similarly other pairs tried are (32, 8), (16, 16), (8, 32) and (4, 64). Also 128x128 size matrix is generated from pairs (32, 4), (16, 8), (8, 16) and (4, 32). In generation of hybrid wavelet transforms, first component matrix forms the base matrix and corresponds to the global properties of transform and second component matrix corresponds to local properties.

4. Proposed Method

In the proposed method, hybrid wavelet transform is generated from DCT, Walsh, Haar and Discrete Kekre Transform (DKT). DCT is either selected as base matrix or local matrix and the other transform selected is Walsh, Haar or DKT. Hence we get DCT-Walsh, Walsh-DCT, DCT-Haar, Haar-DCT and DCT-DKT and DKT_DCT. For host best pair for 256x256 size and for watermark, best pair for 128x128 size is selected. After applying the hybrid wavelet transform to host either columnwise or rowwise, middle frequency band is selected to embed the watermark. Two approaches are used to embed watermark into middle frequency band. In first approach, transform coefficients of selected middle frequency band of host image are replaced by transform coefficients of watermark to get watermarked image. In second approach, transform coefficients of middle frequency band of host and transform coefficients of watermark are sorted in the descending order of their energy values. After sorting, middle frequency coefficients of host are replaced by transform coefficients of watermark. While replacing, watermark transform coefficients are normalized and then using suitable weight factor their energy is made equal to the portion of host where they are to be replaced.

For recovery of watermark, column/row hybrid wavelet transform of watermarked image is obtained. From the middle frequency band selected for embedding, transform coefficients of watermark are extracted. If sorting is applied in the embedding process, these coefficients need to be rearranged at their appropriate positions. Scaling down and denormalization of these extracted watermark coefficients is performed and then inverse transform is taken to get the watermark. Extracted watermark is compared with embedded watermark for similarity and MAE between the two is used as similarity measure.

5. Performance Against Image Processing Attacks

Proposed method of watermarking is evaluated against various attacks. Without sorting the transform coefficients of host and watermark, comparison of performance is made by using DCT as base transform and as local transform. Thus DCT-Walsh and Walsh DCT performance is compared when embedding is done without sorting. Similarly performance of DCT-Walsh and Walsh-DCT is compared when embedding is done by sorting the coefficients. In the similar way, DCT-Haar and Haar-DCT performance is compared without sorting and with sorting of transform coefficients. Same thing applies for DCT-DKT and DKT-DCT hybrid wavelet transform too.

5.1. Compression attack

Watermarked images are compressed using three different techniques and performance of each technique is evaluated for above mentioned pair of transforms. First method of compression used is using transforms like DCT, DST, Walsh, Haar and DCT wavelet. Second is using JPEG compression and third is using vector quantization in which Kekre's Fast Codebook Generation (KFCG) algorithm [21] is used to generate 256 size codebook in order to compress the image. Recovered watermark from all these compression attacks are compared with embedded watermark using MAE as similarity measure.

Watermarked image after compression using Walsh and recovered watermark from it using DCT-Walsh and Walsh-DCT for embedding are shown in Figure 2.

1.441	0	1.568	15.917	1.441	0	1.421	3.90
DCT-Walsh column HWT(32,4)(64,4)		Walsh-DCT column HWT (32,4)(16,16)		DCT-Walsh column HWT (32,4)(64,4)		Walsh-DCT column HWT (32,4)(16,16)	
Without sorting				With sorting			

Figure 2. Result images for compression using Walsh when DCT-Walsh and Walsh-DCT column transforms are used for embedding without and with sorting of transform coefficients

From Figure 2 it is observed that DCT-Walsh hybrid wavelet transform performs better against Walsh compression attack than Walsh-DCT without sorting as well as with sorting of transform coefficients.

Figure 3 shows watermarked images compressed using Walsh transform and extracted watermark from it for DCT-Walsh row transform and Walsh-DCT row transform used in embedded and extraction process without sorting and with sorting transform coefficients of host and watermark.

2.171	0	2.284	17.474	2.171	0	2.168	6.109
DCT-Walsh row HWT(32,4)(64,4)		Walsh-DCT row HWT(32,4)(16,16)		DCT-Walsh row HWT (32,4)(64,4)		Walsh-DCT row HWT (32,4)(16,16)	
Without sorting				With sorting			

Figure 3. Result images for compression using Walsh when DCT-Walsh and Walsh-DCT row transforms are used for embedding without and with sorting of transform coefficients

From Figure 3 we can say that DCT-Walsh row transform performs better in Walsh compression attack than Walsh-DCT hybrid wavelet transform without and with sorting of transform coefficients.

Figure 4 (a)-(b) shows a graph in which performance of DCT-Walsh and Walsh-DCT column transform is compared against different types of compression attack when watermark

is embedded without sorting the transform coefficients and when sorting of transform coefficients is done. Since five different host images are used, graph shows average MAE for five watermarks extracted from these hosts. Figure 5 (a)-(b) shows the comparison of DCT-Walsh and Walsh-DCT row transform against compression attacks.

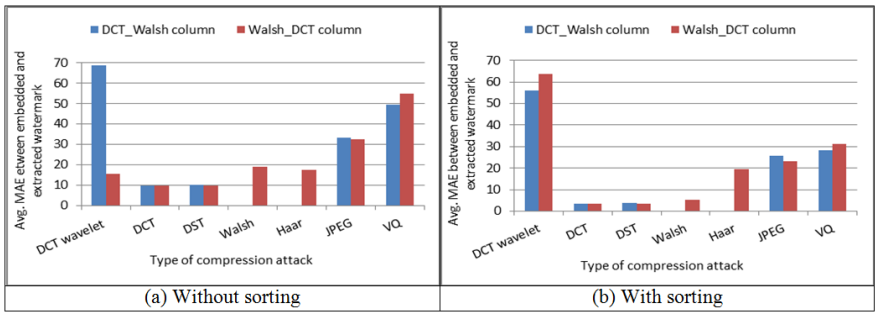


Figure 4. (a) Comparison of DCT-Walsh and Walsh-DCT column transform against compression attacks without sorting transform coefficients; (b) comparison of DCT-Walsh and Walsh-DCT column transforms against compression attacks with sorting of transform coefficients

From Figure 4 the following observations regarding performance of hybrid wavelet transform obtained from DCT and Walsh against compression attack are made. For DCT, DST and for JPEG compression, hybrid wavelet transform having DCT as its local component and Walsh as global component transform gives better robustness than having DCT as global component in both sorting and without sorting cases. For JPEG compression, without sorting transform coefficients, DCT as local transform proves more robust and when sorting is done during embedding, DCT as global component transform proves more robust. For Haar, Walsh and VQ based compression, DCT as global component transform gives better robustness irrespective of sorting during embedding.

Figure 5 (a)-(b) shows performance comparison of DCT-Walsh and Walsh-DCT hybrid wavelet transforms when applied row wise against compression attack without and with sorting of transform coefficients.

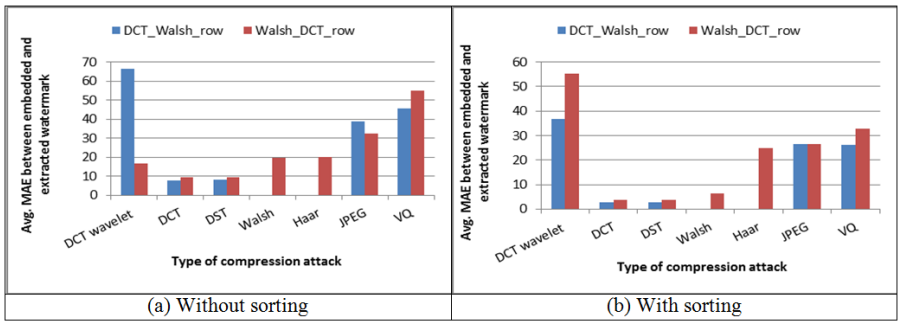


Figure 5. (a) Comparison of DCT-Walsh and Walsh-DCT row transform against compression attacks without sorting transform coefficients; (b) comparison of DCT-Walsh and Walsh-DCT row transforms against compression attacks with sorting of transform coefficients

As can be seen from Figure 5, except for compression using DCT wavelet and JPEG compression, DCT when used as global component in DCT-Walsh row transform, performs

better irrespective of sorting transform coefficients during embedding. For JPEG and DCT wavelet compression, when sorting is not applied during embedding of watermark, DCT as local component transform performs better and when sorting is applied, DCT as global component performs better when taken along with Walsh.

Figure 6(a)-(b) shows the graphs wherein DCT-Haar and Haar-DCT column hybrid wavelet transforms are compared against compression attack.

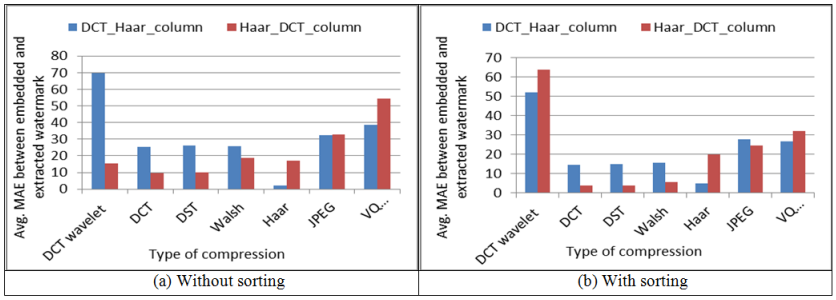


Figure 6. (a) Comparison of DCT-Haar and Haar-DCT column transform against compression attacks without sorting transform coefficients (b) comparison of DCT-Haar and Haar-DCT column transforms against compression attacks with sorting of transform coefficients

From Figure 6, it is concluded that, when watermark is embedded without sorting transform coefficients and compression using DCT, DST, Walsh and DCT wavelet is performed, DCT as a local component transform with Haar as global component transform is more robust. For compression using Haar, Haar as local and DCT as global transform gives better robustness and for JPEG compression, DCT as local or global component transform performs equally well. On the other hand when watermark is embedded by sorting the transform coefficients, Haar-DCT column wavelet is more robust than DCT-Haar column wavelet for compression using DCT, DST, Walsh and JPEG. DCT-Haar column wavelet is more robust for compression using DCT wavelet and Vector quantization.

Figure 7(a)-(b) shows the performance comparison of DCT-Haar and Haar-DCT row transforms against compression attack when embedding is done without sorting and by sorting transform coefficients of host and watermark.

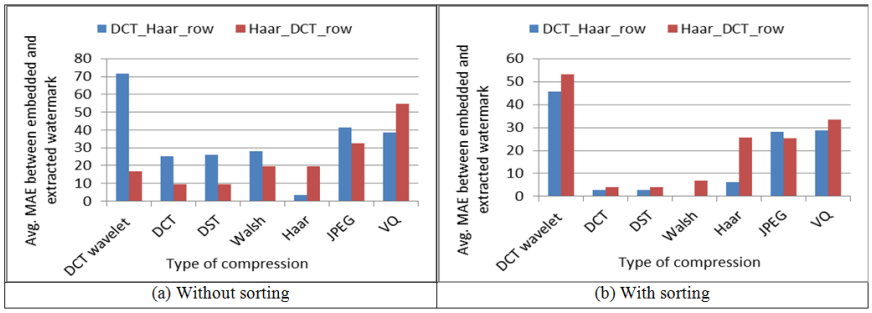


Figure 7. (a) Comparison of DCT-Haar and Haar-DCT row transform against compression attacks without sorting transform coefficients (b) comparison of DCT-Haar and Haar-DCT row transforms against compression attacks with sorting of transform coefficients

From Figure 7 (a) and (b), it is clear that MAE between embedded and extracted watermark reduces significantly when sorting of coefficients is applied during embedding process.

Further for embedding without sorting, Haar-DCT row wavelet transform consistently shows better robustness against compression attack except for Haar and VQ based compression. For embedding by sorting transform coefficients, DCT-Haar row wavelet is better than Haar-DCT row wavelet against all types of compression attacks performed except JPEG compression.

Figure 8 (a)-(b) shows performance comparison of DCT-DKT column hybrid wavelet transform with DKT-DCT column hybrid wavelet transform against compression attacks.

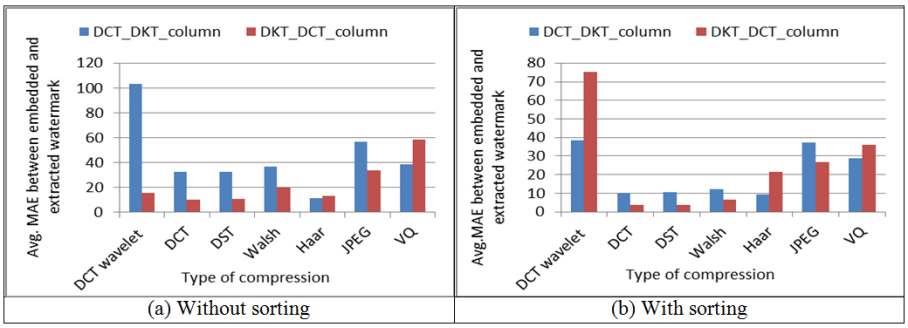


Figure 8. (a) Comparison of DCT-DKT and DKT-DCT column transform against compression attacks without sorting transform coefficients (b) comparison of DCT-DKT and DKT-DCT column transforms against compression attacks with sorting of transform coefficients

From Figure 8(a), it is observed that when embedding is done without sorting, DCT as local component transform along with DKT as global component transform is more robust for compression attacks except VQ based compression. Also for Haar based compression, using DCT as global component transform is closely followed by using DCT as local component transform with DKT as other transform in column version. When embedding is done by sorting, DKT-DCT column wavelet shows same observations as in case of without sorting except for DCT wavelet based compression.

Figure 9 (a)-(b) show the comparison of DCT-DKT and DKT-DCT row wavelet against compression attack. As can be seen from Figure 9(a)-(b), the range of MAE between embedded and extracted watermark is reduced when embedding is done using sorting of transform coefficients. Without sorting of transform coefficients, DKT-DCT row hybrid wavelet transform gives better robustness except in vector quantization based compression. For embedding using sorting, DKT-DCT is still better than DCT-DKT row hybrid wavelet transform except Haar and DCT wavelet based compression.

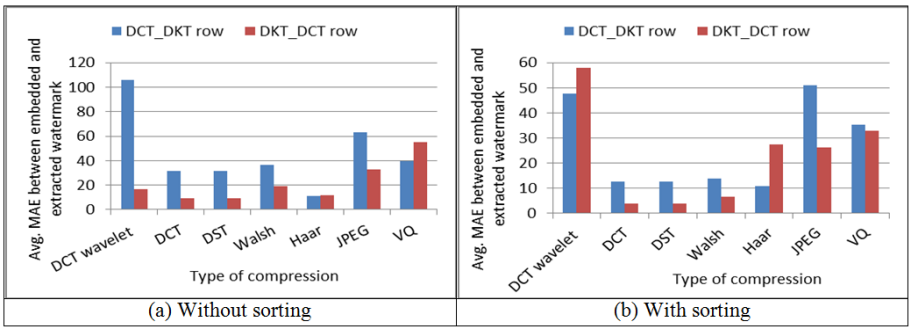


Figure 9. (a) Comparison of DCT-DKT and DKT-DCT row transform against compression attacks without sorting transform coefficients (b) comparison of DCT-DKT and DKT-DCT row transforms against compression attacks with sorting of transform coefficients

5.2. Cropping Attack

From watermarked images different amount of portions are cropped. This is done by cropping 16x16 size portion at four corners, 32x32 size portions at four corners and 32x32 portion at the middle of the image. Result images for one of these cropping attack where 32x32 portion of mage is removed from middle of an image are shown in following figures. Figure 10 shows cropped watermarked image and recovered watermark from it when DCT-Walsh and Walsh-DCT column wavelet transforms are used to embed the watermark without sorting transform coefficients of host. Figure 11 shows the results of DCT-Walsh and Walsh-DCT row transform.

1.782	0.382	1.781	2.297	1.781	2.424	1.781	12.240
DCT-Walsh column HWT(32,4)(64,4)		Walsh-DCT column HWT (32,4)(16,16)		DCT-Walsh column HWT (32,4)(64,4)		Walsh-DCT column HWT (32,4)(16,16)	
(a) Without sorting				(b) With sorting			

Figure 10. Result images for cropping 32x32 portion at the middle of image using DCT-Walsh and Walsh-DCT column hybrid wavelet transform

1.781	0.448	1.781	1.96	1.781	1.037	1.781	3.297
DCT-Walsh row HWT(32,4)(64,4)		Walsh-DCT row HWT (32,4)(16,16)		DCT-Walsh row HWT (32,4)(64,4)		Walsh-DCT row HWT (32,4)(16,16)	
(a) Without sorting				(b) With sorting			

Figure 11. Result images for cropping 32x32 portion at the middle of image using DCT-Walsh and Walsh-DCT row hybrid wavelet transform

Performance of column hybrid wavelet transform using DCT as global component transform with Walsh and DCT as local component transform with Walsh against different types of cropping attacks without and with sorting during embedding is compared and shown in Figure 12 (a)-(b) below.

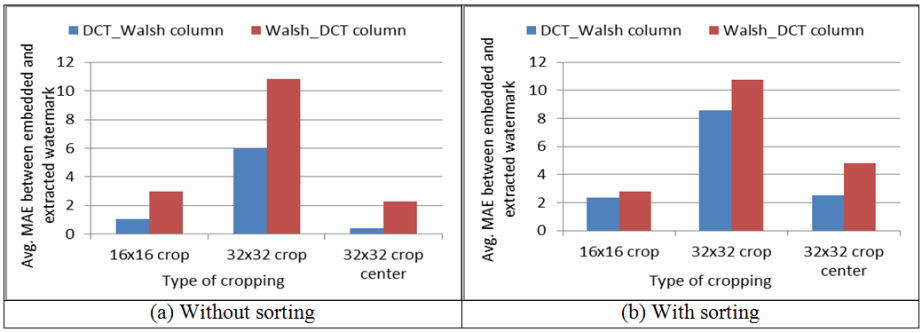


Figure 12. (a) Comparison of DCT-Walsh and Walsh-DCT column transform against compression attacks without sorting transform coefficients; (b) comparison of DCT-Walsh and Walsh-DCT column transforms against compression attacks with sorting of transform coefficients

For both sorting and non-sorting based embedding process, DCT-Walsh column transform shows better robustness over Walsh-DCT column transform. Among cropping 16x16 portions at corners and 32x32 portion at center where amount of information cropped from an image is same, cropping at center gives better robustness irrespective of DCT as global or local component when sorting is not applied during embedding process.

Figure 13 (a)-(b) shows comparison of DCT-Walsh and Walsh-DCT row wavelet transform against cropping attack. As an exceptional case, it can be seen that sorting during embedding process increases the MAE between embedded and extracted watermark.

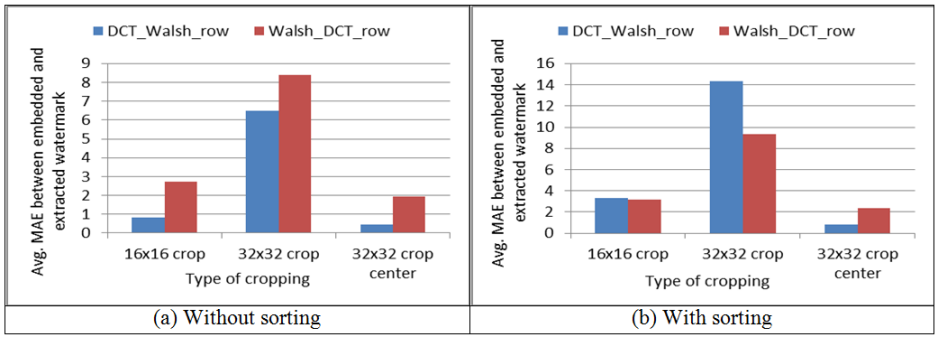


Figure 13. (a) Comparison of DCT-Walsh and Walsh-DCT row transform against compression attacks without sorting transform coefficients (b) comparison of DCT-Walsh and Walsh-DCT row transforms against compression attacks with sorting of transform coefficients

For 32x32 cropping at middle of an image, DCT-Walsh row transform is more robust than Walsh DCT row transform irrespective of sorting of coefficients is applied during embedding process. However, in contrast to other attacks, after sorting is applied, MAE between embedded and extracted watermark has been increased for cropping attack.

Performance of DCT as global and local component transform when used with Haar transform against cropping attack is shown graphically in Figure 14 (a)-(b). Similar to DCT-Walsh combination in row version, range of MAE between embedded and extracted watermark is increased after sorting the transform coefficients.

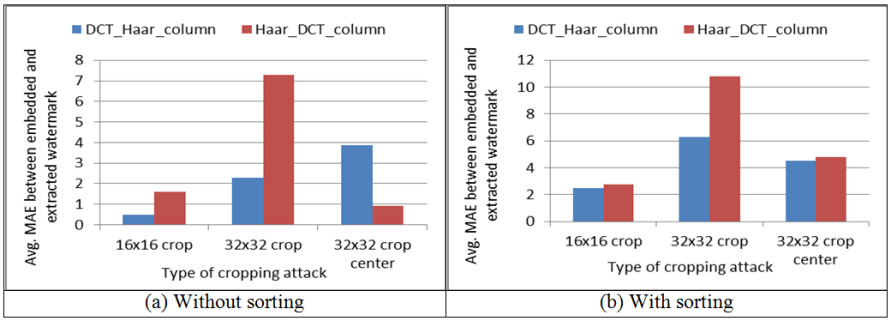


Figure 14. (a) Comparison of DCT-Haar and Haar-DCT column transform against cropping attacks without sorting transform coefficients (b) comparison of DCT-Haar and Haar-DCT row transforms against cropping attacks with sorting of transform coefficients

DCT-Haar column transform is better in robustness for all types of cropping except 32x32 cropping at center when watermark is embedded without sorting transform coefficients.

Performance of DCT-Haar and Haar-DCT row transform against cropping attack is shown in Figure 15 (a)-(b). Here also range of MAE values between embedded and extracted watermark is observed to be increased after sorting is applied in embedding process.

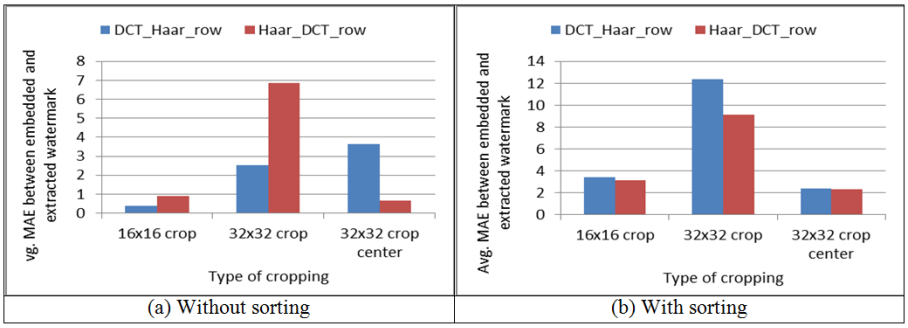


Figure 15. (a) Comparison of DCT-Haar and Haar-DCT row transform against cropping attacks without sorting transform coefficients (b) comparison of DCT-Haar and Haar-DCT row transforms against cropping attacks with sorting of transform coefficients

In embedding without sorting, for cropping at corners of an image, DCT-Haar row transform is more robust. In embedding with sorting, Haar-DCT row wavelet transform shows better robustness against cropping at corners of an image. In embedding without sorting, Haar-DCT row wavelet is superior over DCT-Haar row wavelet for cropping at center. In embedding with sorting, negligible difference is observed in DCT-Haar and Haar-DCT row wavelet performance against cropping at center attack.

Behavior of DCT-DKT and DKT-DCT column transform are shown in Figure 16 (a)-(b) graphically. From Figure 16, it can be observed that for 16x16 and 32x32 cropping at corners

of an image, DCT when used as a global component of hybrid wavelet transform in column version, gives better robustness irrespective of sorting the transform coefficients. However, performance of 32x32 cropping at the middle of an image is affected by sorting. Without sorting, DCT as local component of hybrid wavelet transform is more robust but when sorting of transform coefficients is done, DCT as global component in hybrid wavelet transform is more robust.

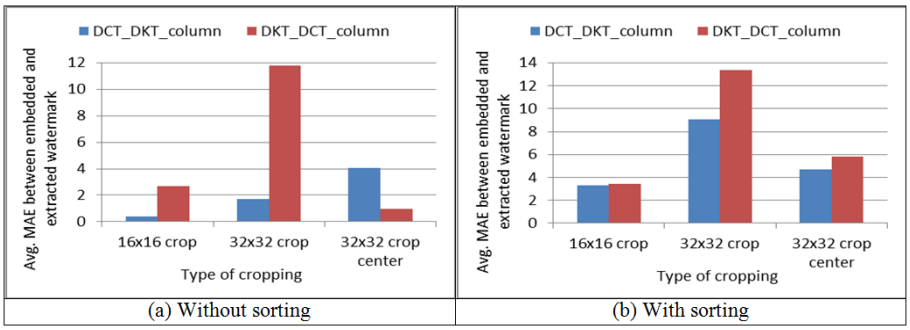


Figure 16. (a) Comparison of DCT-DKT and DKT-DCT column transform against cropping attacks without sorting transform coefficients; (b) comparison of DCT-DKT and DKT-DCT column transforms against cropping attacks with sorting of transform coefficients

Figure 17 shows the performance comparison of DCT-DKT and DKT-DCT row transform against cropping attack without and with sorting transform coefficients while embedding watermark. It is observed that for 32x32 cropping at middle of an image DKT-DCT row transform is more robust irrespective of sorting of transform coefficients and DCT-DKT is more robust for cropping at corners.

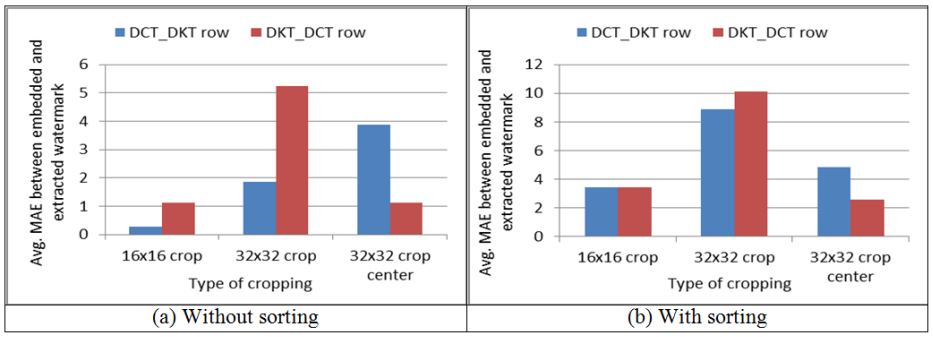


Figure 17. (a) Comparison of DCT-DKT and DKT-DCT row transform against cropping attacks without sorting transform coefficients; (b) comparison of DCT-DKT and DKT-DCT row transforms against cropping attacks with sorting of transform coefficients

5.3. Noise addition attack:

Binary distributed run length noise and Gaussian distributed run length noise are the two noises added to watermarked image. Binary distributed noise has discrete magnitude [-1, 1] and different run lengths as 1to10, 5 to 50 and 10 to 100. Gaussian distributed run length noise has discrete magnitude [-2, 2].

Performance of DCT as base and local component transform along with Walsh, Haar and DKT against these noises is summarized in following Figure 18 to Fig.

Figure 18 (a)-(b) shows MAE values between embedded and extracted watermark from these noise added watermarked image using DCT-Walsh and Walsh-DCT column transform when host and watermark transform coefficients are sorted and otherwise. In both sorting and non-sorting cases, DCT-Walsh and Walsh-DCT column transforms perform equally well with zero MAE. For higher run lengths, DCT-Walsh column transforms better than Walsh-DCT column transform with and without sorting host and watermark coefficients in embedding process. For Gaussian distributed run length noise also DCT-Walsh is marginally better than Walsh-DCT with and without sorting.

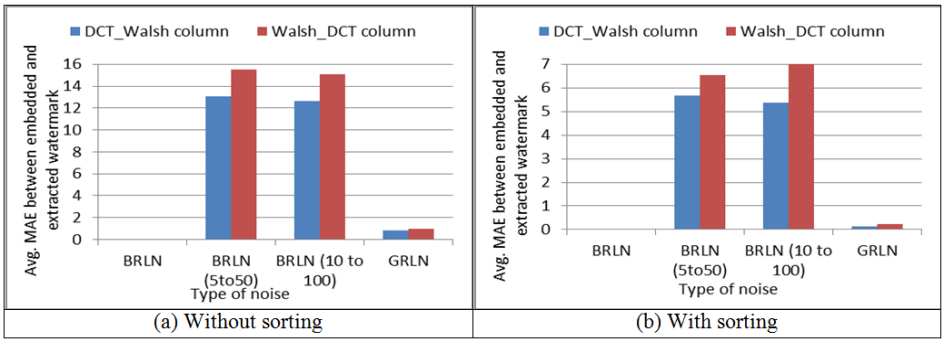


Figure 18. (a) Comparison of DCT-Walsh and Walsh-DCT column transform against noise addition attacks without sorting transform coefficients; (b) comparison of DCT-Walsh and Walsh-DCT column transform against noise addition attacks with sorting of transform coefficients

Figure 19 (a)-(b) shows the performance comparison of DCT-Walsh and Walsh-DCT row wavelet transform.

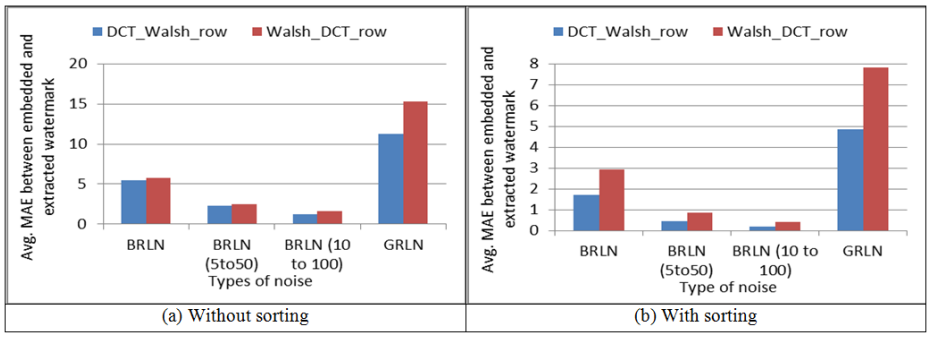
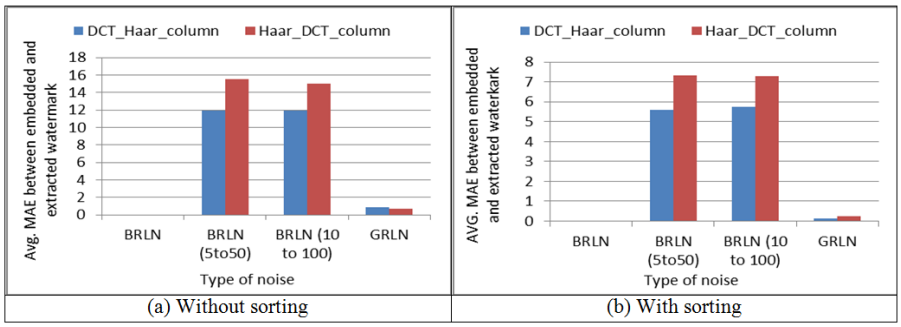


Figure 19. (a) Comparison of DCT-Walsh and Walsh-DCT row transform against noise addition attacks without sorting transform coefficients; (b) comparison of DCT-Walsh and Walsh-DCT row transform against noise addition attacks with sorting of transform coefficients

From Figure 19 (a) and (b), we can say that DCT-Walsh row wavelet transform is having slightly better robustness than Walsh-DCT column transform. For Gaussian distributed run length noise, DCT-Walsh is showing better performance.

Figure 20 (a)-(b) show graph of MAE between embedded and extracted watermark against noise addition attack when DCT is used as a global and local component transform along with

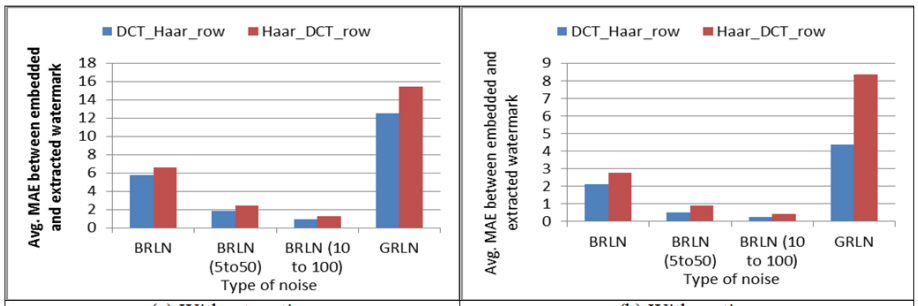
Haar (DCT-Haar and Haar-DCT respectively) in the form of column transform and without and with sorting of transform coefficients of host and watermark in embedding process. For smaller run length, both give zero MAE in case of embedding without sorting and with sorting. For higher run length of binary distributed run length noise, DCT-Haar gives better robustness than Haar-DCT irrespective of sorting the transform coefficients. Further, sorting improves (reduces) the range of MAE between embedded and extracted watermark thus showing better sustenance against attack.



(a) Without sorting (b) With sorting

Figure 20. (a) Comparison of DCT-Haar and Haar-DCT column transform against noise addition attacks without sorting transform coefficients; (b) comparison of DCT-Haar and Haar-DCT column transform against noise addition attacks with sorting of transform coefficients

Figure 21(a)-(b) shows the performance comparison of DCT-Haar row transform against noise addition attack. For both, without and with sorting of transform coefficients of host and watermark during embedding process, DCT-Haar is marginally better than Haar-DCT. Also sorting improves the performance of proposed method against noise addition attack by reducing the MAE range as can be seen from Figure 21.



(a) Without sorting (b) With sorting

Figure 21. (a) Comparison of DCT-Haar and Haar-DCT row transform against noise addition attacks without sorting transform coefficients; (b) comparison of DCT-Haar and Haar-DCT row transform against noise addition attacks with sorting of transform coefficients

Performance of DCT-DKT and DKT-DCT column wavelet transform against noise addition attack is compared in Figure 22 (a)-(b).

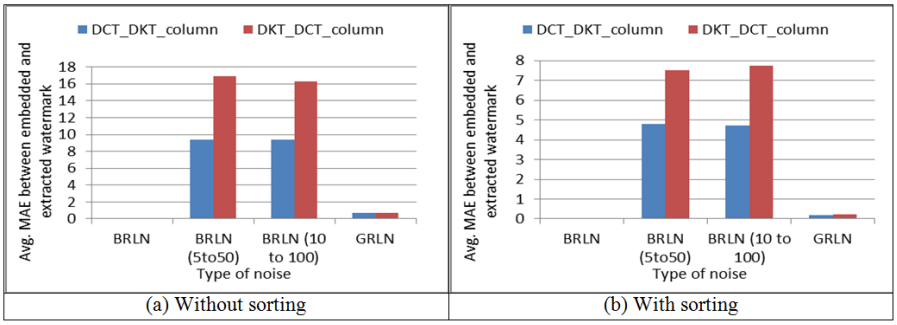


Figure 22. (a) Comparison of DCT-DKT and DKT-DCT column transform against noise addition attacks without sorting transform coefficients; (b) comparison of DCT-DKT and DKT-DCT column transform against noise addition attacks with sorting of transform coefficients

From Figure 22, once again it can be seen that DCT as a global component transform is more robust against noise addition attack.

Figure 23 compares the DCT-DKT and DKT-DCT row wavelet transform performance when noise is added to watermarked images.

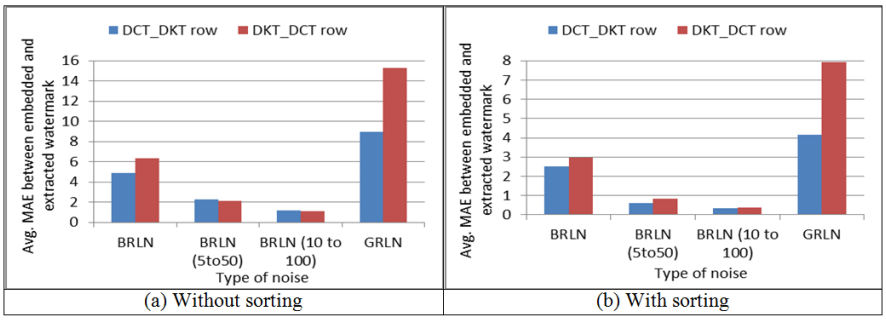


Figure 23. (a) Comparison of DCT-DKT and DKT-DCT row transform against noise addition attacks without sorting transform coefficients; (b) comparison of DCT-DKT and DKT-DCT row transform against noise addition attacks with sorting of transform coefficients

As can be seen from Figure 23, for binary distributed run length noise, DCT-DKT and DKT-DCT row wavelet transform are very close in performance without and with sorting of transform coefficients during embedding process. However, for Gaussian distributed run length noise, DCT-DKT row transform is better over DKT-DCT row wavelet transform.

5.4. Resizing attack:

Watermarked images are resized using three approaches. In resizing using bicubic interpolation, watermarked image is enlarged to four times its size and then reduced back to original size. This attack is shown by name Resize4 in Figure 24 and Figure 25. Also using bicubic interpolation, image is zoomed in to double its size and reduced back to original size. This is named as Resize2 in Figure 24 and Figure 25. In resizing using transform based zooming method [22], watermarked image is doubled in size and reduced back to original size using transforms like DFT, DCT, DST, Hartley and Real Fourier Transform. In the third approach, grid based resizing [23] is used to double the size of an image and then to reduce

back to original size. It has been observed that for transform based resizing attack, embedded and extracted watermark show zero MAE for all transforms used for resizing an image except DFT with very small MAE. Hence graphs in Figure 24 and Figure 25 show comparison for Resize4, Resize2, DFT based resizing and interpolation using grid based interpolation.

Figure 24(a)-(b) compares performance of DCT-Walsh and Walsh-DCT column wavelet transform against resizing attacks mentioned above. As can be seen from Figure 24(a), Walsh-DCT column is more robust than DCT-Walsh when sorting is not applied during embedding process. For DFT based resizing attack DCT-Walsh is better but with negligible performance difference. When sorting is used in embedding process, DCT-Walsh is more robust than Walsh-DCT except for grid based resizing. However, MAE between embedded and extracted watermark has been increased after sorting for resizing using bicubic interpolation and using DFT.

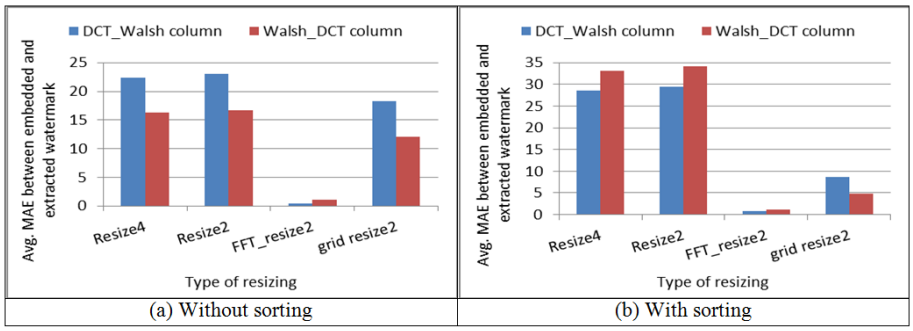


Figure 24. (a) Comparison of DCT-Walsh and Walsh-DCT column transform against resizing attack without sorting transform coefficients; (b) comparison of DCT-Walsh and Walsh-DCT column transform against resizing attack with sorting of transform coefficients

Figure 25 (a)-(b) show the performance comparison of DCT-Walsh and Walsh-DCT row wavelet transform against image resizing attack. From Figure 25(a) it is observed that Walsh-DCT is more robust than DCT-Walsh for bicubic interpolation attack without applying sorting during embedding. When sorting is used for embedding, DCT-Walsh shows more robustness than Walsh-DCT as shown in Figure 25(b). For DFT based resizing DCT-Walsh and Walsh-DCT are very close in robustness without and with sorting in embedding process. For grid based resizing, DCT-Walsh is more robust than Walsh-DCT in case of sorting and without sorting.

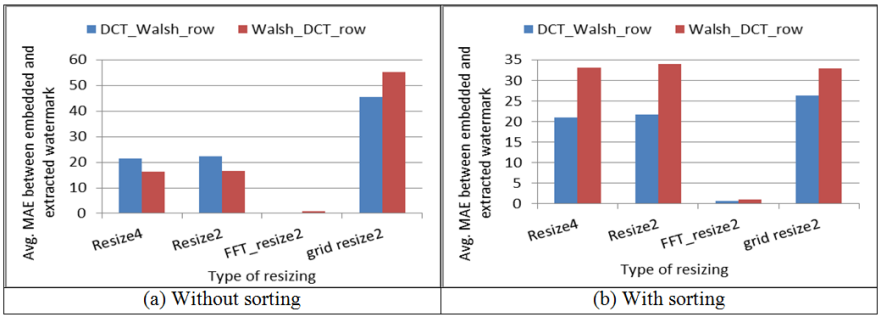
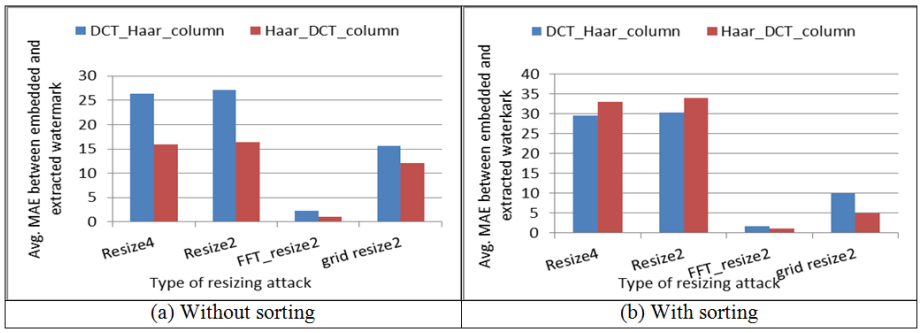


Figure 25. (a) Comparison of DCT-Walsh and Walsh-DCT row transform against resizing attack without sorting transform coefficients; (b) comparison of DCT-

Walsh and Walsh-DCT row transform against resizing attack with sorting of transform coefficients

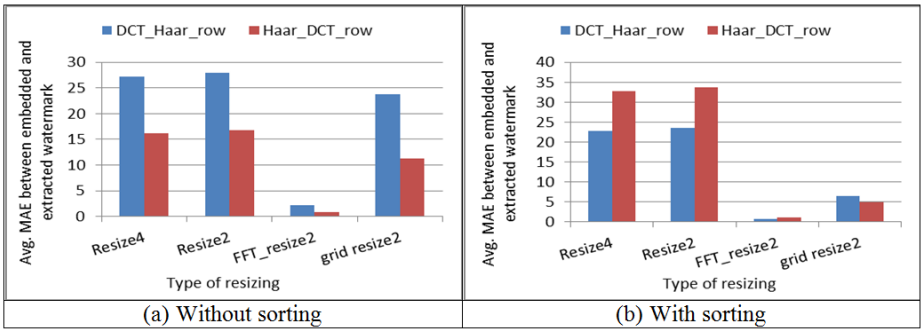
Performance of DCT as global and local component transform in DCT-Haar and Haar-DCT column wavelet transform against resizing attack is compared in Figure 26(a)-(b). Without applying sorting in embedding process, DCT as a local component is more robust than as a global component transform for all types of resizing. When sorting is applied to embed the watermark, DCT as global component transform proves to be slightly better for resizing using bicubic interpolation. For DFT based resizing and grid based interpolation resizing, DCT as a local component transform continues to be better in robustness.



(a) Without sorting (b) With sorting

Figure 26. (a) Comparison of DCT-Haar and Haar-DCT column transform against resizing attack without sorting transform coefficients; (b) comparison of DCT-Haar and Haar-DCT column transform against resizing attack with sorting of transform coefficients

Performance of DCT-Haar and Haar-DCT row wavelet transform against resizing attack is compared in Figure 27(a)-(b). DCT-Haar gives better robustness against all types of resizing when embedding is done without sorting. When embedding is done with sorting, DCT as a local component along with Haar shows better robustness except grid based resizing where it marginally lags the performance.



(a) Without sorting (b) With sorting

Figure 27. (a) Comparison of DCT-Haar and Haar-DCT row transform against resizing attack without sorting transform coefficients; (b) comparison of DCT-Haar and Haar-DCT row transform against resizing attack with sorting of transform coefficients

Figure 28(a)-(b) shows the performance comparison of DCT-DKT and DKT-DCT column wavelet transform for resizing attack. DKT-DCT shows distinctly shows better robustness

when embedding is done without sorting the transform coefficients. In contrast, DCT-DKT gives better robustness against resizing using bicubic interpolation based resizing when embedding is done with sorting.

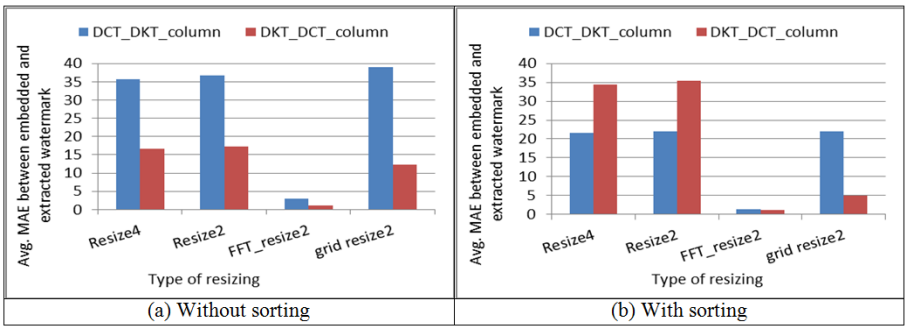


Figure 28. (a) Comparison of DCT-DKT and DKT-DCT column transform against resizing attack without sorting transform coefficients; (b) comparison of DCT-DKT and DKT-DCT column transform against resizing attack with sorting of transform coefficients

Figure 29(a)-(b) show the performance comparison of DCT-DKT and DKT-DCT row wavelet transform against resizing when embedding is done without and with sorting. DKT-DCT shows better robustness again when embedding is done without sorting and continues to be better when embedding is done with sorting except for bicubic interpolation based resizing.

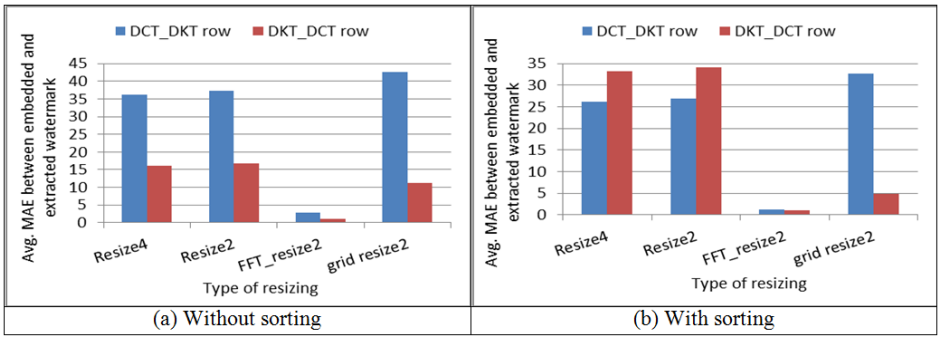


Figure 29. (a) Comparison of DCT-DKT and DKT-DCT row transform against resizing attack without sorting transform coefficients; (b) comparison of DCT-DKT and DKT-DCT row transform against resizing attack with sorting of transform coefficients

6. Conclusion:

The proposed method uses hybrid wavelet transform in column and row form generated from DCT as global/local component transform along with Walsh, Haar and DKT. Performance of these hybrid wavelet transforms is evaluated against various attacks in two situations-when embedding of watermark is done without sorting transform coefficients of host and watermark, embedding is done by sorting transform coefficients.

In embedding without sorting and when column/row wavelet transform is used, for compression using DCT, DST, DCT wavelet and JPEG compression, DCT as local

component of hybrid wavelet transform is more robust. For compression using VQ and Haar, DCT when used as global component, gives better robustness. When column wavelet transform is used for embedding by sorting transform coefficients, DCT as a global transform performs better except for JPEG, DCT and DST compression. When row wavelet transform is used for embedding by sorting transform coefficients, DCT as a local transform performs better except for JPEG compression.

In embedding without sorting and column wavelet transform, for cropping attack, DCT gives superior performance when used as global component transform and continues to perform better when sorting is applied during embedding. For row wavelet transform and embedding without sorting, DCT as a global component transform gives higher robustness when cropping is done at corners. For embedding with sorting DCT as local transform is better performer when applied row wise. For cropping is done at center, DCT as local component transform with others as global gives better robustness irrespective of sorting.

For different types of noises added to watermarked images, irrespective of sorting and column/row transform, DCT as global component transform is most robust.

For resizing attack, and embedding without sorting, irrespective of column and row transform DCT when used as local component transform is more robust. When embedding is done by sorting, for grid based and DFT based resizing using DCT as local component is more robust. For resizing using bicubic interpolation based resizing, using DCT as global component proves more robust.

References

[1] W. Chu, "DCT-Based Image Watermarking Using Subsampling", IEEE transactions on multimedia, vol. 5, no. 1, **(2003)**, pp. 34-38.
[2] A. G. Bors and I. Pitas, "Image watermarking using block site selection and DCT domain constraints", Optics Express, vol. 3, no. 12, **(1998)**, pp. 512-523.
[3] R. K. Megalingam, M. M. Nair, R. Srikumar, V. K. Balasubramanian and V. S. V. Sarma, "A Comparative Study on Performance of Novel, Robust Spatial Domain Digital Image Watermarking with DCT Based Watermarking", International Journal of Computer Theory and Engineering, vol. 2, no. 4, **(2010)**, pp. 647-653.
[4] B. E. Reddy, P. Harini, S. M. Perumal and V. V. Kumar, "A New Wavelet Based Digital Watermarking Method for Authenticated Mobile Signals", International Journal of Image Processing, vol. 5, Issue 1, **(2011)**, pp. 13-24.
[5] N. V. Dharwadkar and B. B. Amberker, "Determining the Efficient Sub band Coefficients of Biorthogonal Wavelet for Grey level Image watermarking", International Journal of Image Processing, vol. 4, Issue 2, **(2010)**, pp. 89-105.
[6] Y. Wang, J. Doherty and R. V. Dyck, "A wavelet-based watermarking algorithm for ownership verification of digital images", IEEE transactions on image processing, vol. 11, no. 2, **(2002)**, pp. 77-88.
[7] R. Liu and T. Tan, "An SVD-Based Watermarking Scheme for Protecting Rightful Ownership", IEEE transactions on multimedia, vol. 4, no. 1, **(2002)**, pp. 121-128.
[8] K. Bhagyashri and M. Y. Joshi, "Robust image watermarking based on singular value decomposition and discrete wavelet transform", Proceedings of IEEE International Conference on Computer Science and Information Technology, vol. 3, no. 5, **(2010)**, pp. 337-341.
[9] G. Bhatnagar, B. Raman and Q. M. J. Wu, "Robust watermarking using fractional wavelet packet transform", IET Image Processing, vol. 6, issue 4, **(2012)**, pp. 386-397.
[10] A. Abdulfetah, X. Sun, H. Yang and N. Mohammad, "Robust adaptive image watermarking using visual models in DWT and DCT domain", Information Technology journal, vol. 9, no. 3, **(2010)**, pp. 460-466.
[11] M. K. Khorasani, M. M. Sheikholeslami, "A DWT-SVD Based Digital Image Watermarking Using a Novel Wavelet Analysis Function", Fourth International Conference on Computational Intelligence, Communication Systems and Networks, **(2012)**, pp. 254-256.
[12] A. Sverdlov, S. Dexter and A. M. Eskicioglu, "Robust DCT-SVD domain image watermarking for copyright protection: Embedding data in all frequencies", in proc. of Multimedia and Security Workshop, ACM press **(2004)**, pp. 166-174.

[13] Navas K. A. Ajay M. C., M. Lakshmi, T. S. Archana and M. Sasikumar, "DWT-DCT-SVD based watermarking", Third International conference on Communication Systems Software and Middleware and Workshops **(2008)**, pp. 271-274.
[14] M. Soleimani and F. S. Nezhad, "A robust digital blind image watermarking based on spread spectrum in DCT domain", Science Academy Transactions on Computer and Communication Network, vol. 2, no. 2, **(2012)**, pp. 122-126.
[15] G. Bhatnagar, B. Raman and Q. M. J. Wu, "Robust watermarking using fractional wavelet packet transform", IET Image Processing **(2012)**, vol. 6, issue 4, pp. 386-397.
[16] K. Ramanjaneyulu and K. Rajarajeswari, "Wavelet-based oblivious image watermarking scheme using genetic algorithm", IET Image Processing, vol. 6, issue 4, **(2012)**, pp. 364-373.
[17] E. Ganic and A. M. Eskicioglu, "Robust Embedding of visual watermarks using DWT-SVD", Journal of electronic imaging, vol. 14, issue 4, pp. 1-13.
[18] S. W. Foo and Q. Dong, "A Normalization-based Robust Image Watermarking Scheme Using SVD and DCT", International Journal of Information and Communication Engineering, vol. 6, no. 4, **(2010)**, pp. 6-4.
[19] L. Liang and S. Qi, "A new SVD-DWT composite watermarking", In Proc. of IEEE International Conference on Signal Processing, **(2006)**.
[20] H. B. Kekre, T. Sarode and S. Thepade, "Inception of Hybrid Wavelet Transform using Two Orthogonal Transforms and its use for Image Compression", International Journal of Computer Science and Information Security, vol. 9, no. 6, **(2011)**, pp. 80-87.
[21] Kekre, H. B., and T. K. Sarode, "Fast Codebook Generation Algorithm for Color Images using Vector Quantization", International Journal of Computer Science and Information Technology, vol. 1, no. 1, **(2009)**, pp. 7-12.
[22] H. B. Kekre, T. Sarode and S. Natu, "Image Zooming using Sinusoidal Transforms like Hartley, DFT, DCT, DST and Real Fourier Transform", International journal of computer science and information security, vol. 12, no. 7, **(2014)**, pp. 11-16.
[23] H. B. Kekre, T. Sarode and S. Thepade, "Grid based image scaling technique", International Journal of Computer Science and Applications, vol. 1, no. 2, **(2008)**, pp. 95-98.

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