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Effect of Varying Embedding Energy and Energy wise Sorting on Watermarking using Wavelet Transforms of Orthogonal Transforms DCT, Walsh and Haar

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***Abstract*— This paper proposes a robust watermarking technique using wavelets of well-known transforms DCT, Walsh and Haar. HL and LH bands are separately selected for watermark insertion. While inserting watermark, its energy is varied with 40% margin to original energy of region of host selected for insertion of watermark to study effect on robustness. Performance of proposed technique is evaluated against cropping, compression, noise addition, image resizing and histogram equalization attacks and compared for varying embedding energy. Increasing embedding energy leads to improved robustness as well as sometimes marginal improvement in imperceptibility when various attacks are performed on watermarked image. This performance is also found to be better than use of orthogonal transforms DCT, Walsh and Haar as proposed in our previous work and use of wavelets without energy-wise sorting of middle frequency coefficients.**

***Keywords*— Watermarking, DCT, Walsh, Haar, wavelet transforms.**

I. INTRODUCTION

Copyright protection of digital contents is a major issue faced due to proliferation of internet technology for their transmission. Apart from this, many tools are available for copying or altering the digital contents. Many solutions have been found in literature to avoid copyright abuse of digital contents. Watermarking of digital contents is one of the popular solutions. Some information of owner known as watermark is inserted secretly in digital contents called as host. This watermark can be recovered and can be used to identify owner. Three important aspects of watermarking need to be taken care of for good watermarking. First is that perceptual quality of host should not reveal existence of hidden watermark i.e. imperceptibility. Second, watermark should not be removable from host except the owner and should resist common attacks performed on host. If watermark survives various attacks performed on host, it is known to be robust. Third, watermark should be extractable without need of original host and watermark. In the proposed technique, a blind watermarking for digital images has been proposed using wavelet transforms obtained from popular orthogonal transforms DCT, Walsh and Haar. Watermark insertion is carried out in HL and LH region separately to compare their performance against various attacks. While inserting watermark, its energy is varied in the range of ±40% of HL and LH region of host to observe its effect on robustness. This performance is also compared with orthogonal transforms DCT, Walsh and Haar and with wavelets of the same without sorting the HL and LH region energy-wise. Organization of this paper as follows: Section II presents review of related work in digital image watermarking. Section III describes proposed method. Section IV shows results of proposed method against various attacks. Section V shows comparison with wavelets itself but without energy-wise sorting of HL and LH region while embedding. Section VI presents conclusion.

II. REVIEW OF RELATED WORK

Watermarking on digital images can be performed by directly changing the pixel values of image known as spatial domain watermarking. Spatial domain watermarking is easy to perform but is at high risk of altering watermark or getting it detected. On the other hand in transform domain watermarking image is first transformed in frequency domain by using appropriate transform and these transformed coefficients are altered appropriately to insert watermark. Transformed domain techniques are more robust than spatial domain techniques because after inserting watermark in frequency coefficients and taking inverse transform, watermark is irregularly spread all over the image. Thus it becomes difficult for an attacker to detect or modify watermark. in literature, watermarking using Discrete Cosine Transform [1-4], Discrete Fourier Transform [5-8], Discrete Wavelet Transform [9-12] are available. Singular Value Decomposition (SVD) is yet another popular transformation technique used in inserting watermark into host. In [13, 14], watermarking using SVD is proposed. From literature, it has been observed that instead of using any single transform when they are used together, give better robustness.

In [15] a multiband wavelet transformation based watermarking is proposed. Depending on number of passes different bands are selected for watermarking together. Third level decomposition using wavelets and HL and LH bands was observed to be good performance-wise. Watermarking using two dimensional Walsh coding is proposed in [16]. Watermark is coded using two dimensional Walsh functions and is then embedded in low frequency coefficients in DCT of host image. In [17], watermarking using DCT and DWT is proposed. DCT coefficients of watermark are inserted into high frequency wavelet coefficients of host. In [18], another joint DCT-DWT watermarking approach is proposed. A binary watermark is scrambled using Arnold transform and is embedded in 3-level wavelet transform of host. DCT of each DWT sub-band is computed and PN sequence of watermark is embedded in middle frequency coefficients of DCT block. This method is observed to be robust against image enhancement and noise addition attacks. A dual digital image watermarking is proposed by Maha Sharkas et. al in [19]. A watermarking technique incorporates two watermarks in a host image for improved protection and robustness. A watermark, in form of a PN sequence called the secondary watermark, is embedded in the wavelet domain of a primary watermark before being embedded in the host image. Singh, Rawat and Agarwal proposed yet another DCT-DWT watermarking technique for colour and grayscale images [20]. Host image is decomposed up to 3rd level of wavelet decomposition and passed through chaotic encryption process. Watermark is embedded in the form of DCT with special coefficient shifting algorithm.

III. Proposed Method

Method proposed in this paper is extension of our previous work in [21]. In proposed method instead of using traditional Haar wavelet or any other popular wavelet transform, wavelet transforms generated from DCT, Walsh and Haar are used to embed watermark into host. These wavelet transforms are obtained using Kekre's algorithm to generate wavelet transforms [22]. For simulation, set of five color bitmap host images of size 256x256 and a color bitmap watermark of size 128x128 is used. These images are shown in Fig. 1.

(a)Lenna | (b)Mandrill | (c)peppers | (d)face | (e)puppy | (f)NMIMS

Fig. 1 (a)-(e) Host images and (f) watermark image used for simulation

As proposed in [22], a wavelet transform matrix of size MNxMN can be generated using same component orthogonal transform matrix with different sizes, MxM and NxN respectively or by usig two different component transform matrices of size MxM and NxN respectively. Thus for example, 256x256 size DCT wavelet matrix can be generated using two DCT matrices of size 128x128 and 2x2 or 64x64 and 4x4 or 32x32 and 8x8 etc. for the proposed method wavelet transform matrices of size 256x256 for host and of size 128x128 for watermark are required. So there are pairs of various possible combinations for host and watermark such as {(64, 4), (32, 4)} which means 256x256 size wavelet matrix of DCT/ Walsh/ Haar for host using component matrix of size 64x64 and 4x4 and 128x128 size wavelet matrix of DCT/ Walsh/ Haar for watermark using component matrix of size 32x32 and 4x4. Other possible pairs are {(64,4), (16,8)}, {(64,4), (8,16)}, {(64,4), (4,32)}, {(32,8), (32,4)}, {(32,8), (16,8)}, {(32,8), (8,32)}, … and so on. All such possible pairs for each wavelet transform have been tested and the pair which gives higher robustness for maximum number of attacks performed is selected. Steps for embedding are listed below.

1. Separate Red, Green and Blue channels of host image and watermark image and apply the selected pair of wavelet transform on them.
2. Sort the HL/LH band coefficients of host and all coefficients watermark in descending order of their energy values.
3. To bring the watermark coefficients in the uniform range of 0 to 1, they are normalized.
4. To bridge the energy gap between HL/LH band of host and watermark, watermark coefficients are scaled using suitable scaling factor such that energy of watermark is equal to the energy of HL/LH band of host.
5. Such normalized, scaled and sorted coefficients are now placed at the place of sorted coefficients of host.
6. Inverse wavelet transform is applied to transformed coefficients of host to get watermarked image.

To study the effect of varying embedding energy, scaling factor is adjusted such that it makes the energy of embedded watermark is less (60%) than that of HL/LH band of host image and greater (140%) than that of HL/LH band of host image.

For extraction of watermark, reverse procedure is followed.

1. Apply wavelet transform on watermarked image.
2. From HL/LH band extract watermark coefficients from the positions where they were embedded.
3. Scale up the watermark coefficients using the same scaling factor used in embedding process to get them in their original energy form followed by denormalization.
4. Take inverse wavelet transform to get the watermark.

Fig. 2 below shows Lena host image after inserting watermark and extracted watermark from it from HL and LH band before any attack is performed. Below each image corresponding MAE is displayed. Also the best size combination for which these results are obtained is given for HL and LH band.

Obtained watermarked images are subjected to various attacks and performance is evaluated for robustness. Description of these attacks and their results is given in following section.

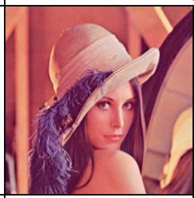
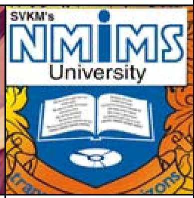
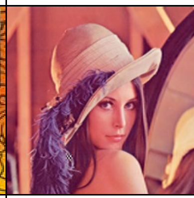
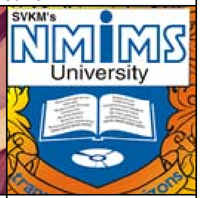
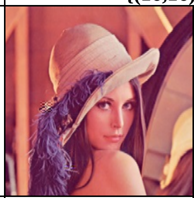
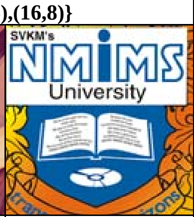
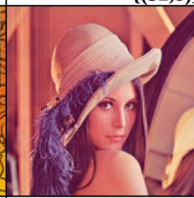
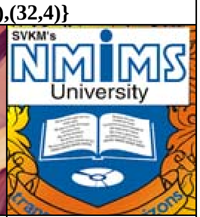
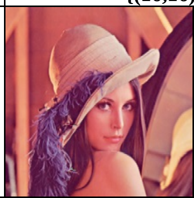
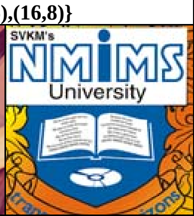
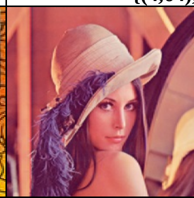
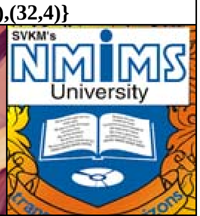
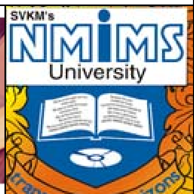
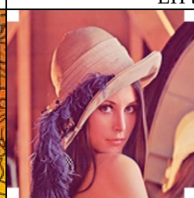
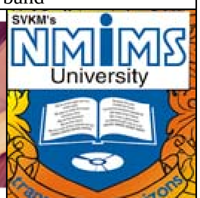
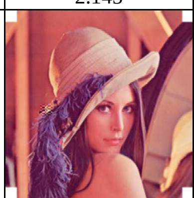
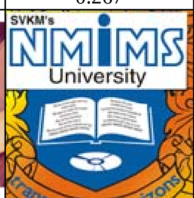
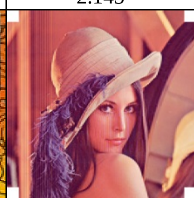
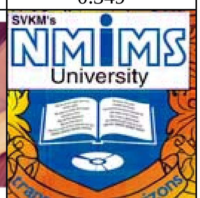
Transform used for embedding watermark	**Watermarked image**	**Extracted Watermark**	**Watermarked image**	**Extracted Watermark**
	HL band		LH band	
DCT wavelet				
MAE	1.366	0	2.048	0
Size combination	**{(16,16),(16,8)}**		**{(32,8),(32,4)}**	
Walsh wavelet				
MAE	2.052	0	4.809	0
Size combination	**{(16,16),(16,8)}**		**{(4,64),(32,4)}**	
Haar wavelet				
MAE	1.861	0	2.902	0
Size combination	**{(16,16),(16,8)}**		**{(32,8),(32,4)}**	

Fig. 2 Watermarked image Lena and extracted watermark from it using DCT wavelet, Walsh wavelet and Haar wavelet from HL and LH band when energy of watermark is matched (100%) with energy of HL and LH band of wavelet transformed host

IV. RESULTS OF PROPOSED METHOD AGAINST VARIOUS ATTACKS:

A. Cropping of watermarked image

Watermarked images are cut at corners such that 16x16 size portion is removed from each corner. Variations to this attack are done in two ways, by increasing the cropped information from watermarked image and by keeping the amount of cropped information same but changing the position of cropped portion. To see the impact of increased amount of cropping, 32x32 size portion is cropped at corners. to observe the effect of cropping other than at corners, but keeping the amount of cropped information same, 32x32 size portion is cropped at centre of watermarked image. Representative example of Lena image when subjected to 16x16 cropping at corners and watermark recovered from it is shown in Fig. 3. These results are for DCT wavelet, Walsh wavelet and Haar wavelet using HL and LH band for embedding.

Transform used for embedding watermark	**Cropped Watermarked image**	**Extracted Watermark**	**Cropped Watermarked image**	**Extracted Watermark**
	HL band		LH band	
DCT wavelet				
MAE	2.145	0.267	2.145	0.349
Walsh wavelet				
MAE	2.145	0.690	2.145	5.765

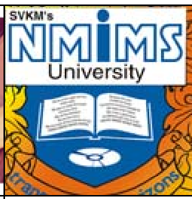
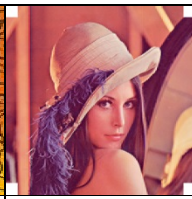
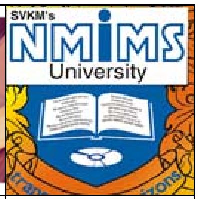
Haar wavelet				
MAE	2.145	0.542	2.145	1.219

Fig. 3 Result images for 16x16 cropping at corners when watermark is embedded into HL and LH band using DCT wavelet, Walsh wavelet and Haar wavelet

Overall performance for cropping attack is shown in Fig. 4 graphically where average of MAE between embedded and extracted watermark from five different hosts is considered to judge the performance. For other attacks also average MAE between embedded and extracted watermark is considered.

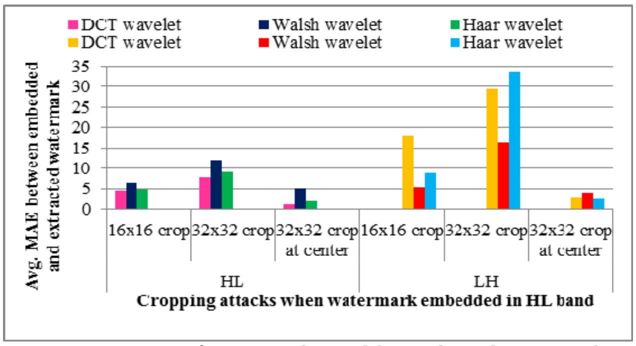


Fig. 4 Comparison of DCT wavelet, Walsh wavelet and Haar wavelet against cropping attack when HL and LH band is used to embed watermark

From Fig. 4 it is observed that embedding watermark in HL band leads to better robustness than using LH band for DCT wavelet and Haar wavelet. This is applicable to Walsh wavelet also but only for 32x32 cropping at corners. For 16x16 cropping at corners and 32x32 cropping at centre, LH band used for embedding shows better robustness.

B. Compression of watermarked image

The most obvious attack possible while the digital contents are exchanged over network is compression of data. For still images used in the simulation work, compression of images is performed in variety of ways namely compression using transformation techniques, compression using JPEG (quality factor 100%) and compression using vector quantization. For Vector quantization Kekre's Fast Codebook Generation algorithm [23] is used and image is compressed using codebook of size 256.

In compression attack using transforms, different orthogonal transforms like DCT, DST, Walsh, Haar and DCT wavelet are used to compress the watermarked image. Result images for Lena when subjected to JPEG compression and VQ compression are shown in Fig. 5 and Fig. 6 respectively.

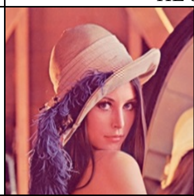
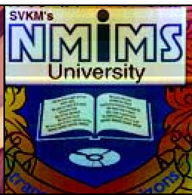
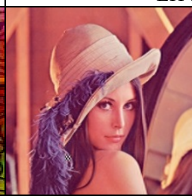
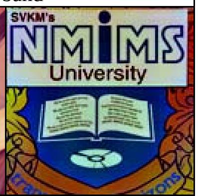
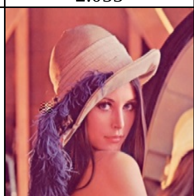
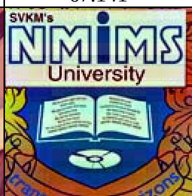
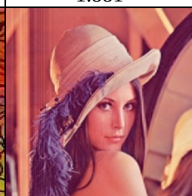
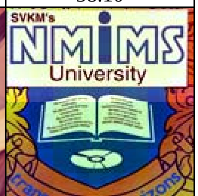
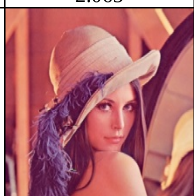
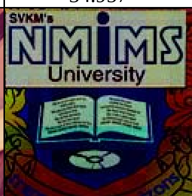
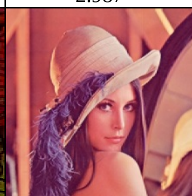
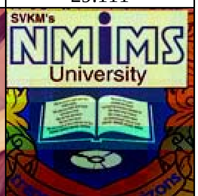
Transform used for embedding watermark	**JPEG compressed Watermarked image**	**Extracted Watermark**	**JPEG compressed Watermarked image**	**Extracted Watermark**
	HL band		LH band	
DCT wavelet				
MAE	2.055	67.141	1.881	58.10
Walsh wavelet				
MAE	2.065	34.957	2.987	29.111
Haar wavelet				
MAE	1.958	108.415	2.387	64.487

Fig. 5 watermarked image Lena after JPEG compression and extracted watermark from it when watermark is embedded in HL and LH band using DCT wavelet, Walsh wavelet and Haar wavelet

From Fig. 5, it is observed that MAE between embedded and extracted watermark is quite high but it does not correspond to distortion of extracted watermark but due to changes taking place in pixel intensity values. Also, as compared to HL band, LH band when used to embed watermark gives less MAE value for extracted watermark.

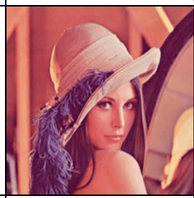
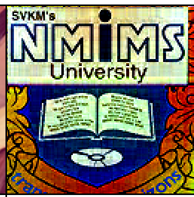
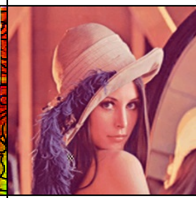
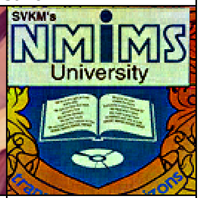
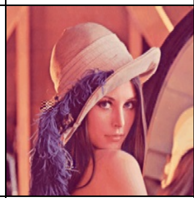
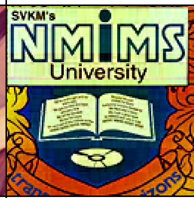
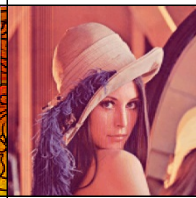
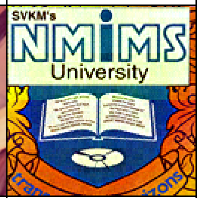
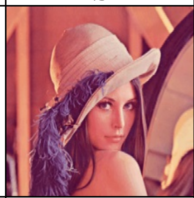
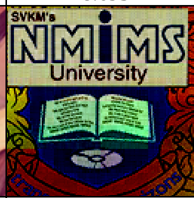
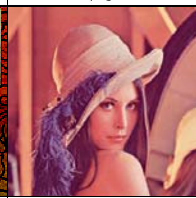
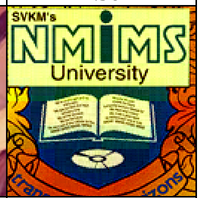
Transform used for embedding watermark	**VQ compressed Watermarked image**	**Extracted Watermark**	**VQ compressed Watermarked image**	**Extracted Watermark**
	HL band		LH band	
DCT wavelet				
MAE	2.519	64.841	2.465	49.112
Walsh wavelet				
MAE	2.54	48.693	2.792	24.961
Haar wavelet				
MAE	2.493	103.823	2.650	48.656

Fig. 6 Watermarked image Lena when subjected to VQ based compression and watermark recovered from it using DCT wavelet, Walsh wavelet and Haar wavelet for embedding watermark in HL and LH band of host.

From Fig. 6, it can be noted that for Lena image, MAE between embedded and extracted watermark is less when watermark is embedded in LH band instead of HL band for the wavelet transforms explored in proposed technique. Further Walsh wavelet with HL/LH band used for embedding watermark proves more robust against compression using Vector Quantization than DCT wavelet and Haar wavelet.

Fig. 7 (a) shows the performance comparison of three wavelet transforms against compression using various transforms and Fig. 7 (b) shows the comparison against compression using DCT wavelet, JPEG compression and VQ.

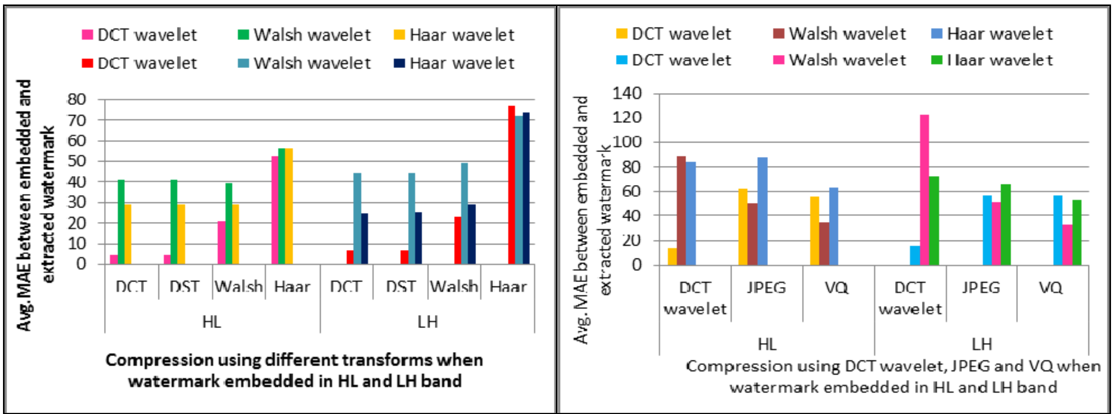


Fig. 7 (a) Performance comparison of DCT wavelet, Walsh wavelet and Haar wavelet against compression using DCT, DST, Walsh and Haar when watermark is embedded in HL and LH band (b) Performance comparison of DCT wavelet, Walsh wavelet and Haar wavelet against compression using DCT wavelet, JPEG and VQ when watermark is embedded in HL and LH band

C. Noise addition to watermarked images:

Another common attack watermarked image is addition of noise to it. In the proposed technique binary distributed random run length noise and Gaussian distributed run length noise is added to watermarked image. In case of binary distributed run length noise run length is increased from range 1-10 to 5-50 and 10-100. Fig. 8 shows watermarked image Lena using various wavelet transforms after adding binary distributed run length noise with run length in the range of 10 to 100 and extracted watermark.

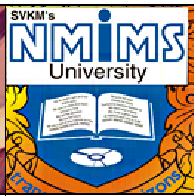
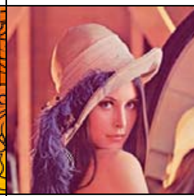
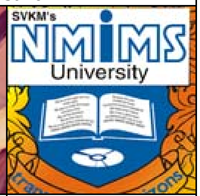
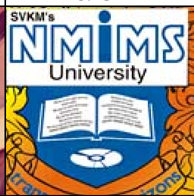
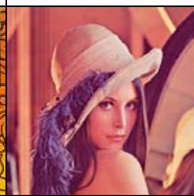
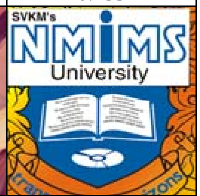
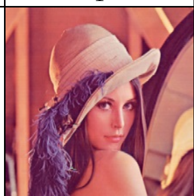
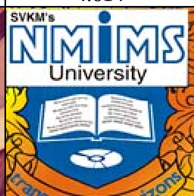
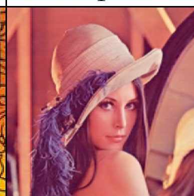
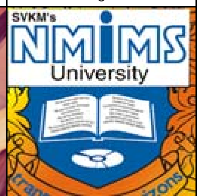
Transform used for embedding watermark	Watermarked image after adding Binary distributed run length noise (10-100)	Extracted Watermark	Watermarked image after adding Binary distributed run length noise (10-100)	Extracted Watermark
	HL band		LH band	
DCT wavelet				
MAE	1	8.797	1	0.255
Walsh wavelet				
MAE	1	4.614	1	0
Haar wavelet				
MAE	1	4.659	1	0

Fig. 8 Watermarked image Lena after adding binary distributed run length noise with run length 10-100 and watermark extracted from it when embedding is done HL and LH band using DCT wavelet, Walsh wavelet and Haar wavelet transform

Fig. 8 shows that embedding watermark in LH band is more robust than embedding in HL band against binary distributed run length noise of run length 10-100. Among the three wavelet transforms used, Walsh wavelet and Haar wavelet show highest robustness with their LH band used for embedding immediately followed by DCT wavelet.

Fig. 9 shows comparison of DCT wavelet, Walsh wavelet and Haar wavelet when their HL and LH bands are used to embed watermark against noise addition attack.

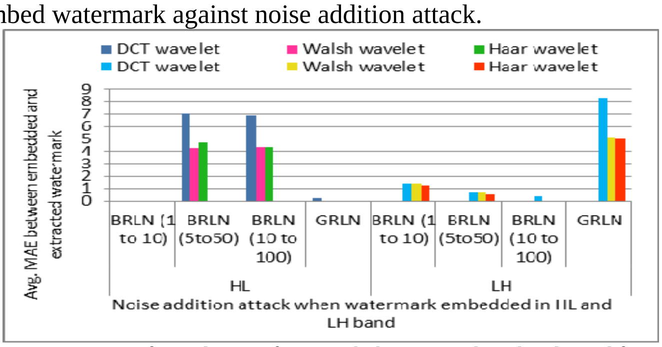


Fig. 9 comparison of wavelet transforms with their HL and LH bands used for embedding watermark against noise addition attack (BRLN=Binary distributed run length noise and numbers in bracket specify run length, GRLN=Gaussian distributed run length noise)

From Fig. 9 it is observed that, for binary run length noise of less run length i. e. 1 to 10, embedding watermark in HL band shows strong robustness with MAE between embedded and extracted watermark zero. For increased run length, embedding watermark in LH band shows better robustness. Also for increased run length, Haar wavelet consistently shows very good robustness closely followed by Walsh wavelet and then DCT wavelet in LH band. In HL band, for increased run length of binary distributed run length noise, Walsh wavelet is closely followed by Haar wavelet in robustness. For Gaussian distributed run length noise, performance of HL band of all three wavelets is exceptionally good when compared to LH band. In LH band, once again Walsh and Haar wavelets show equally well performance.

D. Resizing of watermarked image:

In this type of attack, watermarked image is doubled in size and then reduced back to its original size. From such zoomed-reduced watermarked image, watermark is recovered. Different techniques used to perform zooming and reducing of watermarked images are, bicubic interpolation, image zooming using orthogonal transforms [24] and grid based resizing [25]. Fig. 10 shows zoomed-reduced watermarked image using grid based resizing.

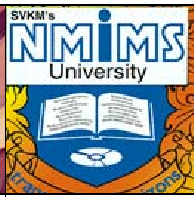
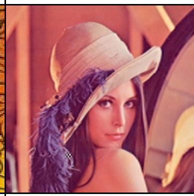
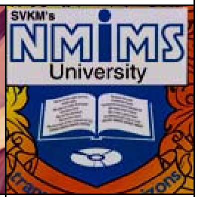
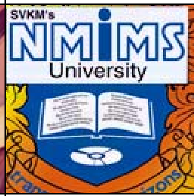
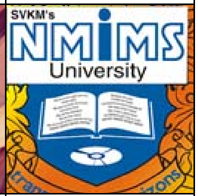
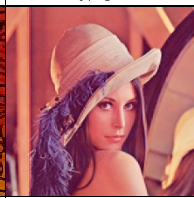
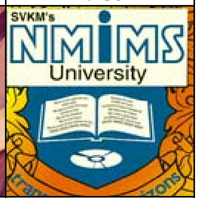
Transform used for embedding watermark	Zoomed reduced Watermarked image using grid based resizing	Extracted Watermark	Zoomed reduced Watermarked image using grid based resizing	Extracted Watermark
	HL band		LH band	
DCT wavelet				
MAE	0.250	4.171	0.291	52.448
Walsh wavelet				
MAE	0.265	11.545	0.251	1.750
Haar wavelet				
MAE	0.286	68.616	0.269	10.855

Fig. 10 Watermarked image Lena zoomed and reduced using Grid based resizing and extracted watermark when HL and LH bands are used to embed watermark using DCT wavelet, Walsh wavelet and Haar wavelet

From Fig. 10 it can be said that for Lena image, when DCT wavelet is used to embed watermark, selection of HL band gives higher robustness than LH band. For Walsh wavelet and Haar wavelet, embedding watermark in LH band gives significantly better robustness over HL band. Among the three wavelet transforms, Walsh wavelet with LH band used for embedding is observed to be more robust against resizing attack. Performance of three wavelets in HL and LH band against resizing attack for five different host images is compared in the graph shown in Fig. 11.

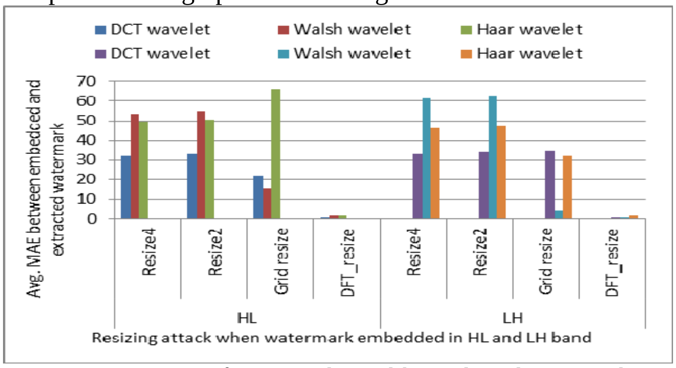


Fig. 11 Comparison of DCT wavelet, Walsh wavelet and Haar wavelet against resizing using bicubic interpolation, grid based interpolation and using DFT

From Fig. 11 following observations are made. For bicubic interpolation based resizing, DCT wavelet performs better than Walsh wavelet and Haar wavelet. Performance of DCT wavelet against resizing using bicubic interpolation is almost same in HL and LH band and for grid based resizing it is more robust when embedding of watermark is done in HL band than in LH band. For grid based resizing, Walsh wavelet is more robust than DCT wavelet and Haar wavelet and when compared between HL and LH band, LH band shows better robustness. For DCT wavelet, embedding watermark in HL band and for Haar wavelet, embedding in LH band leads to robust watermarking against grid based resizing. For zooming-reducing using Discrete Fourier Transform (DFT), both HL and LH band selection for embedding watermark in all three wavelets proves to be exceptionally robust with minimum MAE. Moreover, for other transforms used for zooming-reducing watermarked images, gives zero MAE between embedded and extracted watermark.

V. PERFORMANCE COMPARISON WITH WAVELETS ITSELF BUT WITHOUT ENERGY-WISE SORTING

Proposed technique is compared with our previous work wherein watermark is inserted in host image's HL and LH band without sorting coefficients of host as well as watermark.

A. *Cropping attack*

Table I-III show comparison of MAE values between embedded and extracted watermark obtained against cropping attack using sorting for embedding and without using sorting for embedding for DCT wavelet, Walsh wavelet and Haar wavelet. (Note: EE= Embedding Energy).

From Table I, it can be seen that for embedding in HL/LH band, by sorting of host and watermark coefficients, performance against cropping at corners is significantly improved with reduced MAE values. Performance against cropping at centre is also improved in terms of robustness. However, change in embedding energy does not change the MAE values between embedded and extracted watermark.

TABLE I COMPARISON OF DCT WAVELET AGAINST CROPPING ATTACK WHEN EMBEDDING IS DONE WITHOUT SORTING THE TRANSFORM COEFFICIENTS AND USING SORTING IN HL AND LH BANDS FOR VARYING EMBEDDING ENERGY (60%, 100%, 140%)

	DCT wavelet (HL)						DCT wavelet (LH)					
	60% EE		100% EE		140% EE		60% EE		100% EE		140% EE	
	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting
16x16 crop	17.385	4.578	17.385	4.578	17.385	4.578	19.628	17.759	19.628	17.759	19.628	17.759
32x32 crop	36.393	7.959	36.393	7.959	36.393	7.959	38.480	29.478	38.480	29.478	38.480	29.478
32x32 crop center	2.241	1.246	2.241	1.246	2.241	1.246	1.290	3.074	1.290	3.074	1.290	3.074

TABLE II COMPARISON OF WALSH WAVELET AGAINST CROPPING ATTACK WHEN EMBEDDING IS DONE WITHOUT SORTING THE TRANSFORM COEFFICIENTS AND USING SORTING IN HL AND LH BANDS FOR VARYING EMBEDDING ENERGY (60%, 100%, 140%)

	Walsh wavelet (HL)						Walsh wavelet (LH)					
	60% EE		100% EE		140% EE		60% EE		100% EE		140% EE	
	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting
16x16 crop	17.381	6.535	17.381	6.535	17.381	6.535	11.657	5.313	11.657	5.313	11.657	5.313
32x32 crop	36.099	11.928	36.099	11.928	36.099	11.928	36.738	16.379	36.738	16.379	36.738	16.379
32x32 crop center	3.676	5.130	3.676	5.130	3.676	5.130	5.466	3.892	5.466	3.892	5.466	3.892

From Table II, we can conclude that for Walsh wavelet and HL/LH band used for embedding watermark, sorting of coefficients improves robustness against cropping at corners. However, for cropping done at the centre of an image, MAE values are observed to be slightly increased irrespective of embedding energy.

TABLE III COMPARISON OF HAAR WAVELET AGAINST CROPPING ATTACK WHEN EMBEDDING IS DONE WITHOUT SORTING THE TRANSFORM COEFFICIENTS AND USING SORTING IN HL AND LH BANDS FOR VARYING EMBEDDING ENERGY (60%, 100%, 140%)

	Haar wavelet (HL)						Haar wavelet (LH)					
	60% EE		100% EE		140% EE		60% EE		100% EE		140% EE	
	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting
16x16 crop	17.385	**4.879**	17.385	**4.879**	17.385	**4.879**	19.62783	**6.858**	19.62783	**6.858**	19.62783	**6.858**
32x32 crop	36.110	**9.216**	36.110	**9.216**	36.110	**9.216**	38.47501	**33.627**	38.47501	**33.627**	38.47501	**33.627**
32x32 crop center	2.200	**2.027**	2.200	**2.027**	2.200	**2.027**	1.112732	**2.566**	1.112732	**2.566**	1.112732	**2.566**

Table III shows that when Haar wavelet and HL/LH band is used for embedding, sorting improves robustness against cropping image at corners. For cropping at centre, performance of sorting and without sorting is almost same for embedding in HL band. For LH band, performance of cropping at centre is slightly better when coefficients of host and watermark are not sorted.

B. Compression attack

Table IV-VI show comparison of MAE values between embedded and extracted watermark obtained against compression attack using sorting for embedding and without using sorting for embedding for DCT wavelet, Walsh wavelet and Haar wavelet.

From Table IV, it can be seen that after sorting the transform coefficients during embedding in HL band, MAE between embedded and extracted watermark is reduced for compression using DCT, DST, Walsh, Haar and VQ for all variations of embedding energy. For compression using DCT wavelet, almost same performance is observed with and without sorting. For JPEG compression, sorting does not improve the robustness. Similar observations are noted for embedding in LH band also except that for DCT wavelet compression, significant improvement in robustness is noted.

TABLE IV COMPARISON OF DCT WAVELET AGAINST COMPRESSION ATTACK WHEN EMBEDDING IS DONE WITHOUT SORTING THE TRANSFORM COEFFICIENTS AND USING SORTING IN HL AND LH BANDS FOR VARYING EMBEDDING ENERGY (60%, 100%, 140%)

Compression Technique	DCT wavelet (HL)						DCT wavelet (LH)					
	60% EE		100% EE		140% EE		60% EE		100% EE		140% EE	
	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting
DCT	17.734	**5.727**	14.920	**4.562**	13.487	**4.111**	26.185	**9.152**	21.753	**6.863**	19.476	**5.931**
DST	18.275	**5.869**	15.161	**4.644**	13.587	**4.162**	25.509	**9.334**	21.006	**6.946**	18.712	**5.965**
Walsh	54.786	**31.365**	42.733	**21.011**	36.342	**16.104**	59.417	**33.720**	46.295	**22.941**	39.337	**17.805**
Haar	83.591	**60.023**	76.349	**53.025**	72.718	**50.560**	84.275	**79.810**	76.606	77.020	72.782	76.152
DCT wavelet	14.364	14.456	14.364	14.456	14.364	14.456	43.250	**18.048**	37.845	**16.141**	35.127	**15.855**
JPEG	43.197	58.400	41.961	61.996	41.497	64.907	44.921	50.279	42.892	57.444	42.180	63.111
VQ	69.696	**59.958**	56.478	**55.300**	49.150	53.557	71.806	**62.612**	57.720	**56.783**	50.480	53.682

TABLE V COMPARISON OF WALSH WAVELET AGAINST COMPRESSION ATTACK WHEN EMBEDDING IS DONE WITHOUT SORTING THE TRANSFORM COEFFICIENTS AND USING SORTING IN HL AND LH BANDS FOR VARYING EMBEDDING ENERGY (60%, 100%, 140%)

Compression Technique	Walsh wavelet (HL)						Walsh wavelet (LH)					
	60% EE		100% EE		140% EE		60% EE		100% EE		140% EE	
	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting
DCT	42.285	42.450	33.460	40.769	28.843	40.203	42.490	44.874	35.449	44.341	30.394	44.278
DST	42.369	42.563	33.448	40.873	28.786	40.308	42.825	44.959	35.752	44.335	30.662	44.191
Walsh	6.298	39.665	6.298	39.665	6.298	39.665	4.181	49.346	4.181	49.346	4.181	49.346
Haar	60.512	**56.521**	60.512	**56.521**	60.512	**56.521**	59.208	72.183	59.208	72.183	59.208	72.183
DCT wavelet	73.117	95.591	58.039	89.156	50.122	86.508	94.484	124.229	79.869	122.983	68.476	122.855
JPEG	50.013	**47.896**	47.092	50.699	45.790	53.776	54.389	**51.624**	50.193	51.287	47.643	51.385
VQ	53.791	**39.822**	44.567	**35.217**	39.428	**33.036**	55.063	**40.829**	47.015	**33.503**	41.593	**29.452**

TABLE VI COMPARISON OF HAAR WAVELET AGAINST COMPRESSION ATTACK WHEN EMBEDDING IS DONE WITHOUT SORTING THE TRANSFORM COEFFICIENTS AND USING SORTING IN HL AND LH BANDS FOR VARYING EMBEDDING ENERGY (60%, 100%, 140%)

Compression Technique	Haar wavelet (HL)						Haar wavelet (LH)					
	60% EE		100% EE		140% EE		60% EE		100% EE		140% EE	
	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting
DCT	48.579	**33.035**	41.182	**29.126**	37.468	**27.651**	49.486	**29.670**	40.329	**25.225**	35.613	**23.756**
DST	49.903	**33.289**	42.435	**29.325**	38.683	**27.824**	51.038	**29.840**	41.817	**25.273**	37.072	**23.760**
Walsh	38.292	**29.270**	38.292	**29.269**	38.292	**29.269**	39.406	**29.063**	39.406	**29.063**	39.406	**29.063**
Haar	55.878	56.426	55.878	56.426	55.878	56.426	56.360	73.981	56.360	73.981	56.360	73.981
DCT wavelet	104.641	**91.016**	90.751	**84.371**	83.776	**82.698**	112.725	**82.995**	96.395	**72.823**	88.207	**69.542**
JPEG	53.160	79.503	51.217	87.037	51.498	92.406	56.8704	62.799	55.133	66.040	55.776	69.903
VQ	53.866	64.499	44.503	63.357	39.734	65.954	54.479	54.471	44.855	53.175	39.929	53.144

From Table V, it is seen that Walsh wavelet leads to more robustness after sorting only for JPEG and VQ compression attack in both HL and LH band and to some extent for Haar compression in HL band.

Table VI shows that when Haar wavelet is used to embed watermark either in HL or LH band, sorting leads to improved robustness for compression using DCT, DST, Walsh and DCT wavelet. For Walsh and Haar compression, increased embedding energy also improves robustness.

C. Noise addition attack

Table VII-IX show the comparison of embedding watermark with and without sorting transform coefficients of DCT wavelet transformed host and watermark when watermark is embedded in HL and LH band and different types of noises are added to it.

Table VII shows that sorting of host and watermark coefficients, improves robustness of noise addition attack. For smaller run length (1 to 10) of binary distributed run length noise, embedding in HL band with and without sorting is highly robust with zero MAE.

From Fig. VIII, we can conclude that, Walsh wavelet performs best against smaller run length of binary distributed run length noise attack and for Gaussian run length noise in HL band. Other run length noise when added row wise and column wise, robustness is improved. When watermark is embedded in LH band, proposed method shows strong robustness against increased run length of binary distributed run length.

TABLE VII COMPARISON OF DCT WAVELET AGAINST NOISE ADDITION ATTACK WHEN EMBEDDING IS DONE WITHOUT SORTING THE TRANSFORM COEFFICIENTS AND USING SORTING IN HL AND LH BANDS FOR VARYING EMBEDDING ENERGY (60%, 100%, 140%)

	DCT wavelet (HL)						**DCT wavelet (LH)**					
Noise type	**60% EE**		**100% EE**		**140% EE**		**60% EE**		**100% EE**		**140% EE**	
	No sorting	**Sorting**	**No sorting**	**Sorting**	**No sorting**	**Sorting**	**No sorting**	**Sorting**	**No sorting**	**Sorting**	**No sorting**	**Sorting**
BRLN (1-10)	0.000	**0.000**	0.000	**0.000**	0.000	**0.000**	10.187	**2.017**	8.031	**1.409**	6.546	**1.121**
BRLN (5-50)	29.926	**10.801**	23.541	**6.993**	20.176	**5.412**	2.995	**0.958**	2.352	**0.712**	2.023	**0.605**
BRLN (10-100)	31.447	**10.320**	23.829	**6.892**	20.210	**5.280**	0.911	**0.451**	0.686	**0.351**	0.565	**0.286**
GRLN	0.733	**0.277**	0.568	**0.216**	0.480	**0.185**	33.992	**12.464**	26.338	**8.280**	22.261	**6.308**

TABLE VIII COMPARISON OF WALSH WAVELET AGAINST NOISE ADDITION ATTACK WHEN EMBEDDING IS DONE WITHOUT SORTING THE TRANSFORM COEFFICIENTS AND USING SORTING IN HL AND LH BANDS FOR VARYING EMBEDDING ENERGY (60%, 100%, 140%)

	Walsh wavelet (HL)						**Walsh wavelet (LH)**					
Noise type	**60% EE**		**100% EE**		**140% EE**		**60% EE**		**100% EE**		**140% EE**	
	No sorting	**Sorting**	**No sorting**	**Sorting**	**No sorting**	**Sorting**	**No sorting**	**Sorting**	**No sorting**	**Sorting**	**No sorting**	**Sorting**
BRLN (1-10)	0.000	**0.000**	0.000	**0.000**	0.000	**0.000**	7.824	**2.229**	7.663	**1.385**	6.287	**1.083**
BRLN (5-50)	22.839	**6.530**	17.679	**4.293**	14.988	**3.389**	2.940	**0.908**	2.390	**0.705**	1.994	**0.595**
BRLN (10-100)	23.340	**6.419**	17.714	**4.348**	15.002	**3.242**	0.000	**0.000**	0.000	**0.000**	0.000	**0.000**
GRLN	0.000	**0.000**	0.000	**0.000**	0.000	**0.000**	23.070	**7.485**	18.909	**5.167**	15.978	**4.087**

TABLE IX COMPARISON OF HAAR WAVELET AGAINST NOISE ADDITION ATTACK WHEN EMBEDDING IS DONE WITHOUT SORTING THE TRANSFORM COEFFICIENTS AND USING SORTING IN HL AND LH BANDS FOR VARYING EMBEDDING ENERGY (60%, 100%, 140%)

	Haar wavelet (HL)						**Haar wavelet (LH)**					
Noise type	**60% EE**		**100% EE**		**140% EE**		**60% EE**		**100% EE**		**140% EE**	
	No sorting	**Sorting**	**No sorting**	**Sorting**	**No sorting**	**Sorting**	**No sorting**	**Sorting**	**No sorting**	**Sorting**	**No sorting**	**Sorting**
BRLN (1-10)	0.000	**0.000**	0.000	**0.000**	0.000	**0.000**	8.235	**2.027**	5.740	**1.228**	4.625	**0.838**
BRLN (5-50)	22.774	**6.848**	17.708	**4.692**	15.042	**3.598**	1.569	**0.777**	1.190	**0.601**	1.022	**0.508**
BRLN (10-100)	23.283	**6.294**	17.842	**4.349**	15.151	**3.565**	0.000	**0.000**	0.000	**0.000**	0.000	**0.000**
GRLN	0.000	**0.000**	0.000	**0.000**	0.000	**0.000**	24.693	**7.580**	19.131	**5.061**	16.168	**3.897**

From Table IX, it is noted that using Haar wavelet and HL band shows strong robustness without sorting as well as with sorting for run length 1 to 10 and for Gaussian distributed run length noise. In LH band, higher run length (10-100) of binary distributed run length noise leads to strong robustness with and without sorting.

D. Resizing attack

Table X-XII show comparison of three wavelet transforms against resizing attacks when embedding is done with or without sorting in both in HL band and LH band.

TABLE X COMPARISON OF DCT WAVELET AGAINST RESIZING ATTACK WHEN EMBEDDING IS DONE WITHOUT SORTING THE TRANSFORM COEFFICIENTS AND USING SORTING IN HL AND LH BANDS FOR VARYING EMBEDDING ENERGY (60%, 100%, 140%)

	DCT wavelet (HL)						**DCT wavelet (LH)**					
Compression Technique	**60% EE**		**100% EE**		**140% EE**		**60% EE**		**100% EE**		**140% EE**	
	No sorting	**Sorting**	**No sorting**	**Sorting**	**No sorting**	**Sorting**	**No sorting**	**Sorting**	**No sorting**	**Sorting**	**No sorting**	**Sorting**
Resize4	25.674	31.848	24.626	32.115	24.135	32.279	32.310	32.719	30.067	32.895	29.040	33.030
Resize 2	26.458	32.821	25.393	33.093	24.894	33.260	33.207	33.688	30.923	33.870	29.878	34.007
DFT_resize	4.479	**0.707**	3.494	**0.580**	2.971	**0.527**	4.437	**0.985**	3.450	**0.780**	2.927	**0.682**
Grid based	9.800	14.873	9.626	22.237	9.883	28.252	9.121	23.966	8.961	34.305	9.355	41.685

From Table X, it is observed that for DFT based resizing, sorting results in improved robustness. However, for bicubic interpolation and grid based resizing, embedding without sorting is better than embedding with sorting. Another notable thing is for transform based zooming other than DFT, MAE between embedded and extracted watermark is zero irrespective of embedding energy, frequency band used for embedding and transform used for embedding.

From Table XI, it is concluded that when embedding is done in HL band using Walsh wavelet, sorting does not improve robustness. But when used in LH band, for all types of resizing attack, sorting proves to be more robust.

TABLE XI COMPARISON OF WALSH WAVELET AGAINST RESIZING ATTACK WHEN EMBEDDING IS DONE WITHOUT SORTING THE TRANSFORM COEFFICIENTS AND USING SORTING IN HL AND LH BANDS FOR VARYING EMBEDDING ENERGY (60%, 100%, 140%)

Compression Technique	DCT wavelet (HL)						DCT wavelet (LH)					
	60% EE		100% EE		140% EE		60% EE		100% EE		140% EE	
	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting
Resize4	43.543	53.842	37.198	53.402	34.020	53.504	7.824	**2.229**	7.663	**1.385**	6.287	**1.083**
Resize 2	44.719	55.257	38.230	54.804	34.981	54.909	2.940	**0.908**	2.390	**0.705**	1.994	**0.595**
DFT_resize	0.489	1.906	0.489	1.906	0.489	1.906	0.000	**0.000**	0.000	**0.000**	0.000	**0.000**
Grid based	12.900	**10.092**	12.278	15.438	12.336	20.203	23.070	**7.485**	18.909	**5.167**	15.978	**4.087**

TABLE XII COMPARISON OF HAAR WAVELET AGAINST RESIZING ATTACK WHEN EMBEDDING IS DONE WITHOUT SORTING THE TRANSFORM COEFFICIENTS AND USING SORTING IN HL AND LH BANDS FOR VARYING EMBEDDING ENERGY (60%, 100%, 140%)

Compression Technique	Haar wavelet (HL)						Haar wavelet (LH)					
	60% EE		100% EE		140% EE		60% EE		100% EE		140% EE	
	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting	No sorting	Sorting
Resize4	61.117	**50.220**	55.143	**49.429**	52.256	**49.371**	63.882	**47.257**	57.043	**46.133**	53.770	**46.098**
Resize 2	62.617	**51.541**	56.494	**50.727**	53.534	**50.668**	65.448	**48.508**	58.438	**47.349**	55.082	**47.312**
DFT-resize	9.588	**1.552**	9.588	**1.552**	9.588	**1.552**	6.725	**1.621**	6.725	**1.621**	6.725	**1.621**
Grid based	18.498	52.259	21.205	66.052	24.564	75.381	18.458	23.007	22.350	32.049	26.105	39.450

From Table XII, we can conclude that except grid based resizing, for all other resizing attacks, sorting leads to better robustness especially for DFT based resizing in HL and LH band.

VI. CONCLUSIONS

Conclusion regarding frequency band (HL/LH) of DCT wavelet, Walsh wavelet and Haar wavelet that shows better robustness against various attacks is shown in Table XIII.

TABLE XIII WAVELET TRANSFORMS OF DCT, WALSH AND HAAR WITH THEIR HL/LH BAND SHOWING ROBUSTNESS AGAINST ATTACKS

Attack	DCT wavelet	Walsh wavelet	Haar wavelet
Cropping	HL	HL, LH	HL
Transform based compression	HL, LH	HL	HL
JPEG	LH	HL, LH	LH
VQ	HL, LH	HL, LH	LH
BRLN 1-10, GRLN	HL, LH	HL, LH	HL, LH
BRLN 5-50, 10-100	LH	LH	LH
Bicubic interpolation resizing	HL, LH	HL	LH
Grid based resizing	HL	LH	LH

Apart from this, sorting improves the performance of all wavelet transforms tested in proposed technique against cropping and noise addition attack. Sorting improves the performance of Haar wavelet against resizing attack. Against compression attack, sorting leads to improved robustness of DCT wavelet and Haar wavelet to some extent. For majority of attacks except JPEG and VQ compression and grid based resizing, increased embedding energy leads to better robustness.

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