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Three Dimensional Discrete Wavelet Transform Based Robust Multiple Watermarking Algorithm for Spectral Images

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Abstract - Three Dimensional (3-D) imaging is a fast growing technology in the areas of computer graphics, robotics, metrology, medicine and cultural heritage etc. With the development of internet, 3-D contents are easily manipulated, transmitted and widely distributed. Watermarking has been proved to be an efficient technology in copyright protection of multimedia information. In this paper, a novel blind multiple watermarking algorithm for copyright protection of spectral images is presented. Watermarking is based on 3-D Discrete Wavelet Transform (DWT). Dual binary watermarks are proposed to embed in the mid frequency bands of cover image. One level 3-D DWT is applied to the original spectral image and one level 2-D DWT is applied on two binary watermarks. Eigen values of selected subbands of spectral image are modified by the eigen values of selected subbands of two binary watermarks. Inverse SVD (Singular Value Decomposition) and Inverse 3-D DWT is taken on the modified subbands to obtain the watermarked image. During extraction process, two binary watermarks are recovered from the test image with the help of a secret key. An experimental result shows that, the proposed algorithm produces very high imperceptibility and robustness against various types of attacks like low pass filtering, median Filtering, JPEG compression, histogram equalization, cropping, various angles of rotation and addition of noise like Gaussian, Salt &Pepper, Speckle, Poisson etc.

Keywords : *DWT, 3-D DWT, SVD and Multiple Watermarking.*

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THREE DIMENSIONAL DISCRETE WAVELET TRANSFORM BASED ROBUST MULTIPLE WATERMARKING ALGORITHM FOR SPECTRAL IMAGES

Strictly as per the compliance and regulations of :

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S.Maheswari[α], K.Rameshwaran[Ω]

Abstract - Three Dimensional (3-D) imaging is a fast growing technology in the areas of computer graphics, robotics, metrology, medicine and cultural heritage etc. With the development of internet, 3-D contents are easily manipulated, transmitted and widely distributed. Watermarking has been proved to be an efficient technology in copyright protection of multimedia information. In this paper, a novel blind multiple watermarking algorithm for copyright protection of spectral images is presented. Watermarking is based on 3-D Discrete Wavelet Transform (DWT). Dual binary watermarks are proposed to embed in the mid frequency bands of cover image. One level 3-D DWT is applied to the original spectral image and one level 2-D DWT is applied on two binary watermarks. Eigen values of selected subbands of spectral image are modified by the eigen values of selected subbands of two binary watermarks. Inverse SVD (Singular Value Decomposition) and Inverse 3-D DWT is taken on the modified subbands to obtain the watermarked image. During extraction process, two binary watermarks are recovered from the test image with the help of a secret key. An experimental result shows that, the proposed algorithm produces very high imperceptibility and robustness against various types of attacks like low pass filtering, median Filtering, JPEG compression, histogram equalization, cropping, various angles of rotation and addition of noise like Gaussian, Salt &Pepper, Speckle, Poisson etc.

Keywords : DWT, 3-D DWT, SVD and Multiple Watermarking.

I. Introduction

Digital watermarking and steganography techniques are used to address digital rights management, protect information, and conceal secrets. During the last decade, 3-D meshes have been widely used in industrial, medical and entertainment applications. Since 3-D watermarking has also become an active research topic to protect 3-D information, we present a new frame work for copyright protection of 3-D spectral images in this paper. Spectral imaging is a practical tool for various applications like medical imaging, industrial quality control, digital commerce and maintenance of cultural heritage in digital museums etc [1]. In spectral color imaging, color of an object can be represented more accurately as compared to traditional three channel RGB images.

Three conflicting requirements of watermarking systems are robustness, imperceptibility and capacity [2]. Any watermarking system should allow embedding large number of secret information. Embedding of secret message should not degrade the quality of image; it should withstand in the image; for all kinds of attacks like JPEG compression, low pass filtering, median filtering, noise addition, histogram equalization, rotation, scaling, cropping etc. Embedding of multiple watermarks enhances the robustness property. Embedding of multiple watermarks, instead of a single one into one cover image improves the robustness of watermarking scheme [3].

Transform domain technique offers very high robustness as compared to spatial domain technique; but it needs more computational complexity because input images are converted into transform coefficients by using various image transforms like DCT [4-5], DFT and DWT [6-9] etc. 3-D watermarking techniques are classified into two types [10], similar to that of 2-D watermarking, spatial domain technique [10] and spectral domain technique [4-9]. Spatial domain techniques are further classified into two types. They are Geometry modification technique and Topology modification technique. In spectral method; information can be embedded in one of the mesh transform domains like mesh spectral decomposition, wavelet transform or spherical transform.

The use of wavelets in image and video coding has increased significantly over the years, mainly due to the superior energy compaction property of wavelets compared with the traditional transforms like DCT [11]. In this paper, we have proposed a method to embed the watermark in wavelet transform domain. The 3-D object is processed for obtaining 2-D slices, so that each 3-D objects are represented by a set of 2-D slices. A 3-D DWT domain, obtained by performing a 2-D spatial wavelet transform and then a temporal 1-D wavelet transform [12]. The Haar Wavelet Transform consistently outperforms the more complex ones when using non-coloured watermark [13]. Therefore, we propose 3-D Haar Wavelet Transform based watermarking scheme. Eigen values of mid frequency subbands of a cover image and two binary watermarks are obtained by

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Singular Value Decomposition (SVD)[1, 8]. Eigen values of mid frequency subbands are modified by the Eigen values of dual binary watermarks. Section (2) deals with 3-D DWT. Section (3) discusses about the proposed embedding and extraction algorithm, Section (4) gives the experimental results of proposed scheme, followed by conclusion in section (5).

II. Three Dimensional DWT

A 3-D DWT performs wavelet transform in the three directions x, y and z on the image. A 3-D image is an extension of 2-D image along with time axis. To use the wavelet transform for 3-D images, we must implement a 3-D version of analysis and synthesis filter banks [12]. Figure 1 shows the decomposition structure of one level 3D-DWT.

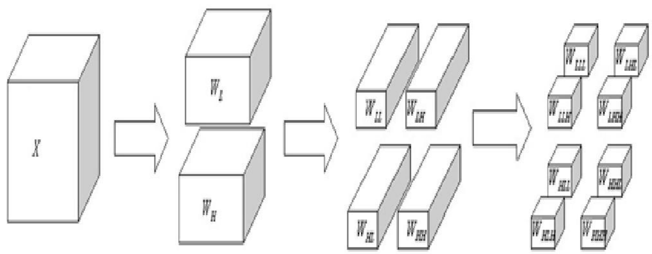

Fig.1: One Level 3-D DWT

If the data is of the size of npixels. The steps of the 3-D Discrete Wavelet Transform are defined as follows. n_1, n_2 and n_3. After applying DWT in one dimension, we obtain two subbands of the size of $n_1/2$, n_2 and n_3. After applying DWT in second dimension, we obtain four subbands of the size of $n_1/2$, $n_2/2$ and n_3. After applying third dimension, we obtain the eight subbands of the size of $n_1/2$, $n_2/2$ and $n_3/2$ [11]. Let X is an image of size $m \times n \times l$ pixels. The steps of the 3-D Discrete Wavelet Transform are defined as follows.

Step 1 : In the horizontal direction, the original image x (m,n,l) is filtered by the filters $H_0(n)$ and $H_1(n)$respectively. $Twoimages\ x_0(m,n,l) and x_1(m,n,l)$ are produced.

Step 2 : In the vertical direction, the two images $x_0(m,n,l)\ and\ x_1(m,n,l)$ are filtered by the filters $H_0(n)$ and $H_1(n)$ respectively. This gives four images $x_{00}(m,n,l), x_{01}(m,n,l)$, $x_{10}(m,n,l) and\ x_{11}(m,n,l)$.

Step 3 : In the temporal direction, the four images, $x_{ij}(m,n,l)$, $0 \le i \le 2, 0 \le j \le 2$ are filtered by the filters $H_0(n)$ and $H_1(n)$ respectively. This gives eight images $x_{000}(m,n,l), x_{001}(m,n,l)$, $x_{010}(m,n,l), \ldots x_{ijk}(m,n,l)$ where $0 \le i \le 2, 0 \le j \le 2\ and\ 0 \le k \le 2$.

Step 4 : Steps 1 to 3 can be repeated on the subimage $x_{ijk}(m,n,l)$ so as to get the other subimages for the next scale.

Figures 2 and 3 show the analysis and synthesis filter banks of 3-D DWT.

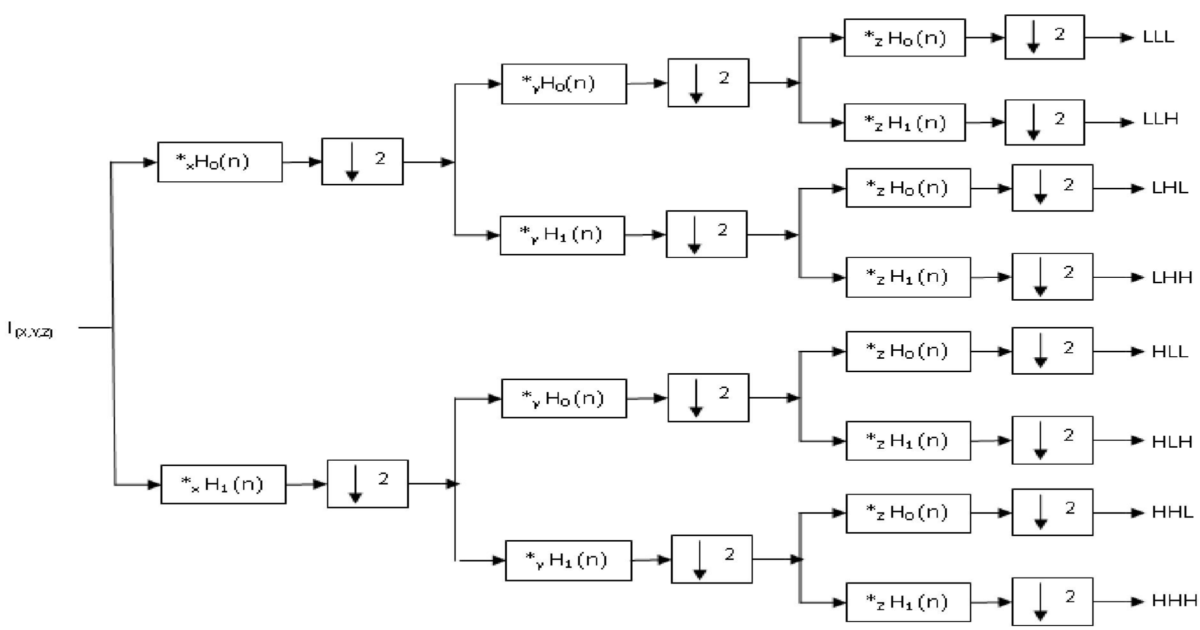

Fig. 2 : Analysis Filter Bank of 3-D DWTFig.3 Synthesis Filter Bank of 3-D DWT

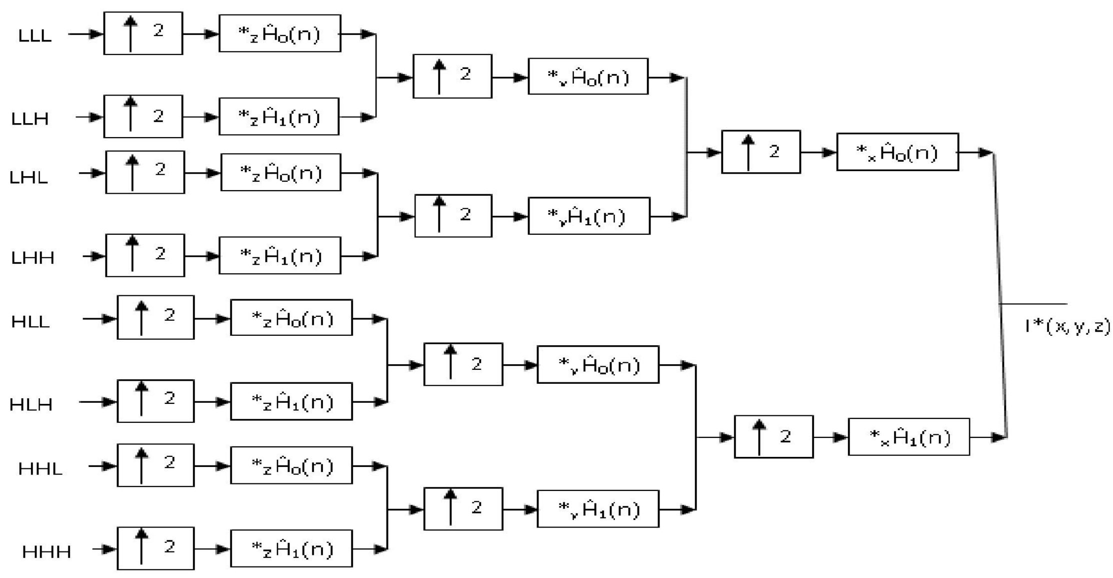

Fig.3 : Synthesis Filter Bank of 3-D DWT

III. Proposed Method

In recent years, several 3-D watermarking techniques have been proposed for gray scale and colour images for authentication, copyright protection, finger printing and ownership assertion. Here, we propse a novel blind watermarking scheme based on wavelet transform for spectral images. Designing of blind watermarking i.e. extracting the watermark without original image and original watermark is a very difficult task [9]. In this paper, blind watermarking scheme has been employed. Watermark is extracted with the help of a secret key.Mid frequency bands are selected to embed the secret message in order to compromise between imperceptibility and robustness. Watermark embedding and extraction processes are explained in the following sections.

a) Embedding Algorithm

One level 3-D DWT is applied on the spectral image (X). It decomposes the cover image into eight subbands ($X_{lll,}$ $X_{llh,}$ $X_{lhl,}$ $X_{lhh,}$ $X_{hll,}$ $X_{hlh,}$ $X_{hhl,}$ X_{hhh}). One level 2-DDWT is applied on the dual binary watermark (W_1 & W_2). It decomposes each watermark into four subbands($W_{ll,}$ W_{lh} W_{hl} W_{hh}).Singular Value Decomposition (SVD) is applied on the selected mid frequency subbandsof a cover image ($X_{llh,}$ $X_{lhl,}$ $X_{hlh,}$ X_{hhl}) and watermark image ($W_{lh1,}$ $W_{hl1,}$ $W_{lh2,}$ W_{hl2}). Eigen valuesof the selectedsubband (σ_{llh}, σ_{lhl}, σ_{hlh}, σ_{hhl}) is modified with the Eigen values of mid frequency subbands of binary watermark ($\sigma_{lhw1,}$ $\sigma_{hlw1,}$ $\sigma_{lhw2,}$ σ_{hlw2}) which is multiplied with appropriate strength factor (α). Inverse SVD is applied on the new Eigen values (σ^*_{llh}, σ^*_{lhl}, σ^*_{hlh}, σ^*_{hhl}) to obtain the modified subbands(X^*_{llh}, X^*_{lhl}, X^*_{hlh}, X^*_{hhl}) and inverse 3D-DWT is applied on the modified subbands to obtain the watermarked image (X^*). PSNR value is calculated for the watermarked image. Watermark embedding scheme has been shown in Figure 4.

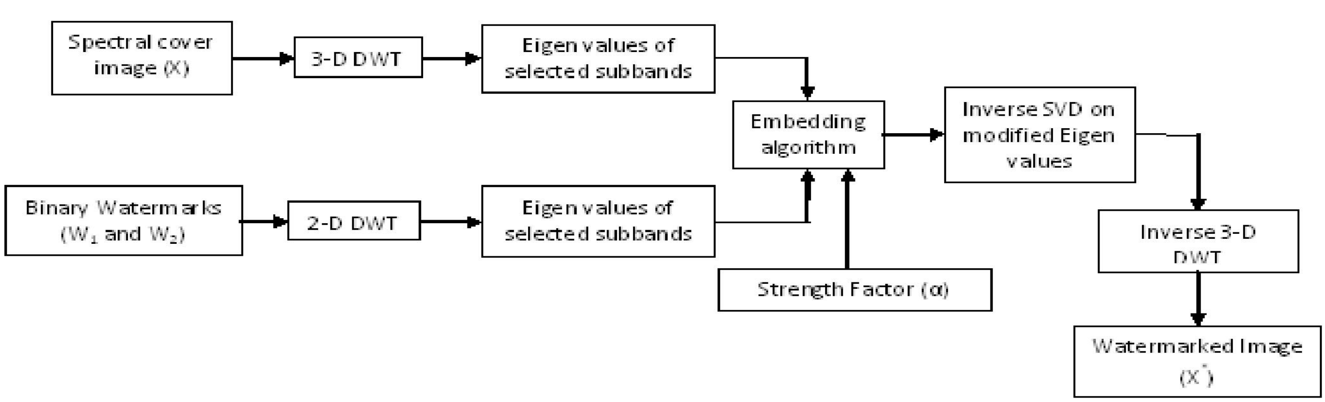

Fig.4 : Watermark Embedding Algorithm

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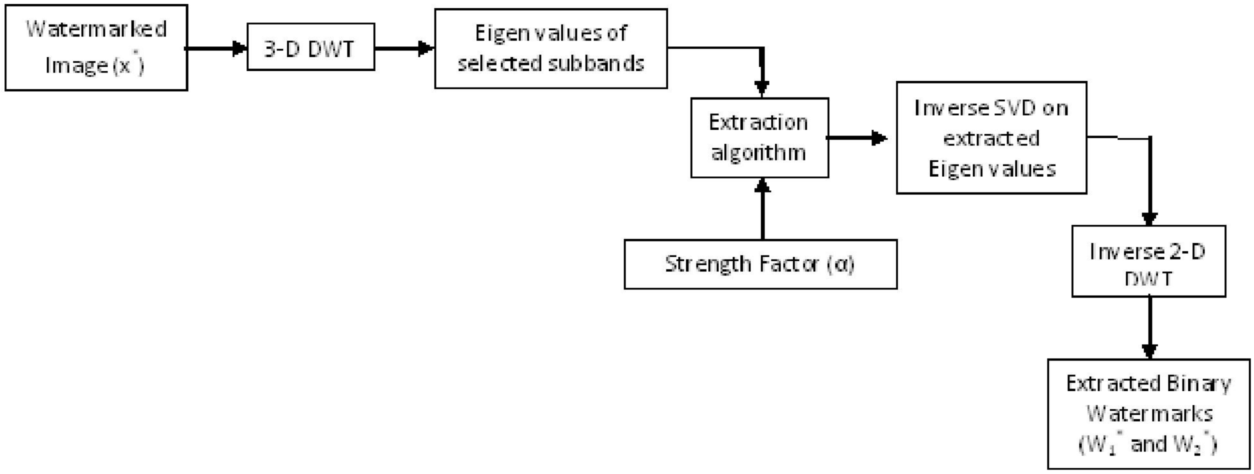

Fig.5 : Watermark Extraction Algorithm

b) Extraction Algorithm

One level 3-D DWT is applied on the Test image (X^*). It decomposes the cover image into eight subbands ($X^*_{lll}, X^*_{llh}, X^*_{lhl}, X^*_{lhh}, X^*_{hll}, X^*_{hlh}, X^*_{hhl}, X^*_{hhh}$). Singular Value Decomposition (SVD) is applied on the selected mid frequency subbands of a test image ($X^*_{llh}, X^*_{lhl}, X^*_{hlh}, X^*_{hhl}$). Eigen values of mid frequency subbands of binary watermark ($\sigma^*_{lhw1}, \sigma^*_{hlw1}, \sigma^*_{lhw2}, \sigma^*_{hlw2}$) is recovered from the Eigen values ($\sigma^*_{llh}, \sigma^*_{lhl}, \sigma^*_{hlh}, \sigma^*_{hhl}$) of selected subband($X^*_{llh}, X^*_{lhl}, X^*_{hlh}, X^*_{hhl}$) of test image with the help of strength factor (α). Inverse SVD is applied on the obtained Eigen values ($\sigma^*_{lhw1}, \sigma^*_{hlw1}, \sigma^*_{lhw2}, \sigma^*_{hlw2}$) to Recover the subbands and inverse 2D-DWT is applied to reconstruct the watermark (W^*). Normalised Correlation of recovered watermark is calculated on comparing with original watermark. Watermark extraction scheme has been shown in Figure 5.

IV. Experimental Results

The experiments were performed on two different hyperspectral natural images [14]. Natural image of the size 256x256x30 and two binary watermarks of size 32x32 were taken to evaluate the proposed algorithm. A single level 3-D DWT was taken on the host image and single level 2-D DWT was taken on the two binary watermarks. Eigen values of selected mid frequency subbands ($\sigma_{llh}, \sigma_{lhl}, \sigma_{hlh}, \sigma_{hhl}$) of the original image and two binary watermarks ($\sigma_{lhw1}, \sigma_{hlw1}, \sigma_{lhw2}, \sigma_{hlw2}$) were obtained by applying SVD. Eigen values of binary watermarks were multiplied with the strength factor (α=10 for scene2) and modified with the Eigen values of selected subbands. Watermarked image was obtained by applying inverse SVD and inverse 3-D DWT to the modified sub bands. Figure 6 illustrate the Host image, Original watermarks w_1 and w_2, Watermarked image and recovered watermarks w_1^*, w_2^*.

Figure 6 : (a) Host image (b) Original Watermark (c) Watermarked Image (d) Extracted Watermark

PSNR value of the watermarked image is calculated by using the equations (1) and (2).

$$PSNR = 10\log\frac{255^2}{MSE} \qquad (1)$$

$$MSE = \frac{1}{m*n*l}\sum_{x=1}^{m}\sum_{y=1}^{n}\sum_{z=1}^{l}\left(f(x,y) - \hat{f}(x,y)\right)^2 \qquad (2)$$

where m, n, and l are dimensions of the image $f(x,y)$ and $\hat{f}(x,y)$ are the pixel values of the original and watermarked image. Normalized Correlation (NC) between original watermark and extracted watermark from the test image is calculated by using the equation (3).

$$NC = \frac{\sum_i\sum_j\sum_k p_{ijk}\,p^*_{ijk}}{\sum_i\sum_j\sum_k (p_{ijk})^2} \qquad (3)$$

PSNR value of the watermarked image and Normalised Correlation of recovered watermark are shown in Table 1.

Table 1: PSNR Value of Watermarked Image and NC

	PSNR Value in dB	Normalised correlation	
		W_1^*	W_2^*
Natural Image I	69.7494	1	1
Natural Image II	57.7162	1	1

Any watermarking system should be robust against various image processing attacks. It should not be removable by unauthorized users and it should not degrade the quality of the images. There are many attacks against which image watermarking system could be judged. The attacks include JPEG compression, Histogram equalization, various filtering operations like, average filtering, median filtering, addition of noise like Salt and Pepper noise, Gaussian noise, speckle noise and Poisson noise, cropping, various angles of rotation and so on. These attacks are applied to the watermarked images to evaluate recovery process. Table 2, 3 and 4 shows the PSNR value and NC under various attacks. Table 5 shows the extracted watermark image under various attacks from Natural Image I.

Table 2 : PSNR Value of Watermarked Image Under various Attacks.

Image Type	PSNR in db of Watermarked image under various Attacks					
Histogram equalization						
Natural Image I	50.247					
Natural Image II	51.778					
JPEG Compression						
Natural Image I	36.0904					
Natural Image II	36.0912					
Low pass filtering						
	3x3	5x5	7x7	9x9	11x11	15x15
Natural Image I	72.0312	72.3203	72.4340	72.5012	72.5499	72.6231
Natural Image II	58.4857	58.5827	58.6308	58.6664	58.6968	58.75
Median filtering						
	3x3	5x5	7x7	9x9	11x11	15x15
Natural Image I	71.61	72.2512	72.4937	72.6184	72.9642	72.7934
Natural Image II	58.3489	58.5241	58.6099	58.6576	58.6923	58.7413
Angle of rotation						
	15	30	45	60	75	90
Natural Image I	71.2821	71.6741	71.7716	71.7003	71.2946	69.7760
Natural Image II	58.4666	58.8021	58.9701	58.8654	58.6201	57.7558
Addition of noise						
	Gaussian	Salt&Pepper	Speckle		Poisson	
Natural Image I	69.5155	67.5837	75.1603		75.1603	
Natural Image II	64.2688	63.0395	63.9917		64.0872	

Table 3 : Normalised Correlation of Recovered Watermark (W_1) under various Attacks.

Image Type	Normalised Correlation of Recovered Watermark (W_1) under various Attacks					
Histogram equalization						
Natural Image I	0.9864					
Natural Image II	0.9653					
Cropping						
Natural Image I	0.9855					
Natural Image II	0.9716					
JPEG Compression						
Natural Image I	0.9307					
Natural Image II	0.9307					
Low pass filtering						
	3x3	5x5	7x7	9x9	11x11	15x15
Natural Image I	0.9582	0.9473	0.9429	0.9399	0.9378	0.9355
Natural Image II	0.9598	0.9486	0.9416	0.9389	0.9374	0.9359
Median filtering						
	3x3	5x5	7x7	9x9	11x11	15x15
Natural Image I	0.9697	0.9548	0.9471	0.9418	0.9382	0.9349
Natural Image II	0.9706	0.9579	0.9470	0.9420	0.9393	0.9365
Angle of rotation						
	15°	30°	45°	60°	75°	90°
Natural Image I	0.9531	0.9473	0.9471	0.9417	0.9382	0.9443
Natural Image II	0.9594	0.9546	0.9481	0.9428	0.9406	0.9443
Addition of noise						
	Gaussian	Salt&Pepper	Speckle	Poisson		
Natural Image I	0.9757	0.9771	0.9782	0.9782		
Natural Image II	0.9658	0.9672	0.9664	0.9680		

Table 4 : Normalised Correlation of Recovered Watermark (W_2) under various Attacks.

Image Type	Normalised Correlation of Recovered Watermark (W_2) under various Attacks					
Histogram equalization						
Natural Image I	0.9864					
Natural Image II	0.9653					
Cropping						
Natural Image I	0.9843					
Natural Image II	0.9698					
JPEG Compression						
Natural Image I	0.9307					
Natural Image II	0.9307					
Low pass filtering						
	3x3	5x5	7x7	9x9	11x11	15x15
Natural Image I	0.9576	0.9477	0.9429	0.9401	0.9378	0.9355
Natural Image II	0.9590	0.9493	0.9413	0.9394	0.9374	0.9360
Median filtering						
	3x3	5x5	7x7	9x9	11x11	15x15
Natural Image I	0.9697	0.9550	0.9472	0.9418	0.9383	0.9350
Natural Image II	0.9704	0.9583	0.9469	0.9423	0.9393	0.9365
Angle of rotation						

	15°	30°	45°	60°	75°	90°
Natural Image I	0.9531	0.9473	0.9467	0.9415	0.9383	0.9443
Natural Image II	0.9594	0.9544	0.9479	0.9428	0.9404	0.9443
Addition of noise						
	Gaussian	Salt&Pepper	Speckle	Poisson		
Natural Image I	0.9759	0.9772	0.9782	0.9782		
Natural Image II	0.9659	0.9672	0.9664	0.9680		

Table 5 : Image Results of Recovered watermarks from Natural Image I

Addition of Noise				JPEG Compression	Histogram Equalization
Gaussian	Salt and Pepper	Poisson	Speckle	QF=10	
0.9757,0.9759	0.9771,0.9772	0.9795,0.9795	0.9782,0.9782	NC=0.9307	0.9864,0.9864
Low Pass Filtering					
3x3	5x5	7x7	9x9	11x11	15x15
0.9582,0.9576	0.9473,0.9477	0.9429,0.9429	0.9399,0.9401	0.9378,0.9378	0.9355,0.9355
Median Filtering					
3x3	5x5	7x7	9x9	11x11	15x15
0.9697,0.9697	0.9548,0.9550	0.9471,0.9472	0.9418,0.9418	0.9382,0.9383	0.9349,0.9350
Rotation					
α=0.25	α=0.5	α=0.75	α=1	α=15	α=30
0.9843,0.9845	0.979,0.9782	0.9711,0.9709	0.9857,0.9857	0.9531,0.9531	0.9473,0.9473
α=45	α=60	α=90	α=180	α=270	Cropping
0.9471,0.9461	0.9417,0.9415	0.9443,0.9443	1,1	0.9443,0.9443	0.9855,0.9843

The proposed watermarking scheme is compared with existing recently published papers by Arto Kaarna *et al* [15], Long Mal et[16],the results are shown in Tables 6 and 7.

Table 6 : Comparison of PSNR value of Watermarked Image in Proposed method and existing methods

Methods	PSNR in dB
Arto Kaarna et al	38.95
Long Mal et al	48.74
Proposed method	69.74

Table 7 : Comparison of Proposed Method and Existing Methods under Image Processing Attacks

LPF	Arto Kaarna et al	Long Mal et al	Proposed method	
			W_1	W_2
3 * 3	0.66	0.73	0.9582	0.9576
5 * 5	0.43	0.56	0.9473	0.9477
7 * 7	0.30	0.43	0.9429	0.9429

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V. Conclusion

Three Dimensional mesh watermarking is an interesting and promising research area. In this paper, a novel blind multiple watermarking algorithm based on 3-D DWT for copyright protection of spectral images has been proposed. Dual binary watermarks have been proposed to embed in mid frequency bands to increase the robustness against attacks and to improve imperceptibility. Extracting the secret message without the help of original image and original watermark is a very difficult task. We extracted dual binary watermarks with the help of details of subband selection and strength factor only. Experimental result shows that the proposed scheme achieves very high imperceptibility and robustness against various image processing attacks like LPF, Median Filtering, JPEG Compression, histogram equalization, cropping, various angle of rotation and addition of noise like Gaussian, Salt & Pepper, Speckle, Poisson etc.

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