



Research Article

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A Novel Dual Image Watermarking Technique Using Homomorphic Transform and DWT

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Abstract: In this paper a new technique of dual image watermarking is proposed for protection of ownership rights which utilizes salient properties of homomorphic transform (HT), discrete wavelet transform (DWT), singular value decomposition (SVD) and Arnold transform (AT). In embedding algorithm host image is splitted into reflectance and illumination components using HT, DWT is further applied to the reflectance component resulting in frequency subbands (HL and LH) which are transformed by SVD. Two image watermarks are selected for embedding process whereas security of proposed algorithm is strengthen by performing scrambling of second watermark through AT. Both watermarks are transformed with DWT and SVD. Singular values (SVs) of both transformed watermark are embedded into SVs of host image. Simulation results clearly signifies for high robustness and imperceptibility of proposed algorithm as it is examined under various attacks. Superiority of proposed technique is illustrated by comparing it with other reported methods.

Keywords: Dual image watermarking, security, HT, DWT, SVD

2010 Mathematics Subject Classification: 94A08; 68P20

1 Introduction

With progressive development of communication technologies over the years made accessibility of multimedia data such as audio, text and images in an easy way. By virtue of this accessibility, one individual can easily exchange their information contents with other individuals in an efficient manner. Nowadays confidentiality and integrity of these data needs to be protected from illegitimate activities attempted by unauthorized users such as manipulation of information. So, researchers have drawn their attention to resolve such issues in a suitable manner. Digital image watermarking is a well renowned method for retaining confidentiality of multimedia data [1, 2]. In this methodology a secondary signal in form of an image generally which bears meaningful information is concealed into a host image. Image watermarking methods can be broadly classified in spatial and transform domain. In spatial domain approach, embedding take place just by altering pixel values of images whereas in transform domain numerous transforms are being employed such as discrete cosine transform (DCT), DWT, Karhunen – Loeve transform (KLT) [3–12] for embedding of watermark. Out of these two transform domain method is widely preferred as they exhibit better robustness.

Significant features of a watermarking technique are imperceptibility, robustness, security and capacity. Imperceptibility accounts for visual similarity among original and watermarked images whereas robustness describes ability of algorithm to resist against attacks. Security is a vital parameter which protect watermark from unauthorized users whereas number of bits to be embedded are defined by capacity. There always exist a trade-off among robustness and imperceptibility. For maintaining balance between these properties hybrid

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watermarking techniques are designed such as DWT – SVD, DCT – SVD [10, 13–15]. In single image watermark embedding embedded watermark may get distorted or manipulated easily due to undesirable reasons and the copyright information can easily be revealed. So, this scenario really motivates us to develop a dual image watermarking technique with aid of various transforms so that this major concern can be resolved. Recently multiple watermarking techniques are widely used in practices as; they offer better resilience from unethical users which means even if first watermark is infringed by the attacker then second watermark can deliver meaningful information required for copyright protection. On the other hand these approaches reduces storage requirement of several multimedia data in the form of multiple watermarks that can be transmitted at once. These all merits accounts for good efficiency of multiple image watermarking.

Lai *et al.* [16] reported a method which utilizes combination of DWT and SVD in which host image is decomposed using DWT in numerous subbands from which middle frequencies subbands (LH and HL) are chosen whereas watermark is being divided in two halves. Each halves of watermark are directly embedded into SVs of HL and LH subbands. The main advantage of this method is that developed scheme is blind. Image watermarking technique using HT is investigated in [17] where HT of cover image is performed resulting in reflectance and illumination components further SVs of reflectance component are varied with watermark directly. The same idea is also extended by authors to block level for achieving better immunity but it seems method does not achieves satisfactory results. Another method using HT is suggested by Khare *et al.* [18] in which reflectance component of host image is processed with DWT and watermark is directly added to SVs of reflectance component of LL subband. It appears that this reported method attains better robustness and imperceptibility due to use of DWT which provides subband analysis of reflectance component. Dual image watermarking methodology is proposed in [19] where two watermarks are simultaneously embedded inside a medical host image. In this approach host image is decomposed upto IIIrd level DWT, followed by DCT and SVD. Similarly both watermarks are also processed by DCT and SVD. SVs of first watermark are embedded into SVs of LH₂ subband of host image whereas SVs of second watermark are altered with SVs of LL₃ subband. To enhance robustness of algorithm back propagation neural network (BPNN) is applied. In [20] similar approach using BPNN is reported in which single image watermark along with two text watermarks are embedded into a host image for different values of scaling factors.

Bhatnagar *et al.* [21] proposed multiple watermarking of two images using DWT. In this methodology secondary watermark is embedded inside a primary watermark, afterwards SVs of new primary watermark are inserted into SVs of cover image. However, this method does not yield sufficient value of correlation coefficient. Another similar method is investigated in [22]. Major difference lying in both schemes is use of image transforms. In this approach redundant discrete wavelet transform (RDWT) is employed whereas in [21] DWT is used for decomposing the cover image. Assini *et al.* [23] also developed multiple image watermarking method using fusion of DWT – fast Walsh – Hadamard – SVD. SVs of various watermarks were embedded into SVs of host image in this scheme. A fire fly optimized multiple watermarking algorithm is developed in [24]. In this procedure different watermarks are embedded into a host image with aim of maximizing certain objective function, so that scheme can become more robust and imperceptible. A DWT- KLT method of watermarking is reported by Sharma *et al.* [25] where cover image is decomposed with help of DWT, followed by KL transform on chosen subband, similarly watermark is also processed with DWT and embedding of wavelets coefficients of watermark is done in KL transformed subband. Khare *et al.* [26] developed a non – blind method of image watermarking using RDWT- DCT- SVD. High degree of robustness is attained in this method due to RDWT.

Kannammal *et al.* [27] suggested a watermarking technique using non – tensor wavelet transform where embedding of watermark is done in LH subband using least significant bit (LSB) method. Singh *et al.* [28] presented a multiple watermarking technique using DWT- DCT- SVD in which DWT of host medical image is performed, then DCT and SVD. Similarly watermark image is also processed by DCT- SVD, another text watermark is also encrypted and SVs of image watermark are embedded into SVs of host image. Encrypted text watermark is also embedded in HH₂ subband coefficients of the host image. Singh *et al.* [29] suggested a new watermarking technique for medical purposes in which a medical image is decomposed into various subbands using IInd level of DWT decomposition, whereas two watermarks are used in this algorithm. First one is image watermark and second is text watermark. Text watermark consist of medical information about a patient which is being encrypted with error correcting codes, image watermark is splitted in two halves. Each

watermark part is embedded with SVs of original medical image; similarly text watermark is also embedded by same procedure. This technique presented a new way for securing health information of patients. A multiple image watermarking technique for color images is discussed in [30] where two image watermarks are concurrently embedded inside a color host image. In this approach, a RGB colored host image is transformed into YCbCr color space. Further 'Y' component is decomposed upto IInd level using lifting wavelet transform (LWT) where LL₂ and LH₂ subbands are further transformed by DCT. DCT is also applied on both the watermarks, out of which first watermark is encrypted through AT. Finally these DCT transformed watermarks are embedded into host image.

Ray *et al.* [31] introduced a watermarking methodology which basically uses Rivest – Shamir – Adleman (RSA) algorithm. In this scheme, different frequency subbands of host image are obtained using 1st level DWT whereas SVs of watermark are attained which are further encrypted with help of RSA algorithm. These encrypted SVs of watermark image are embedded into SVs of transformed host image. Though it appears that developed scheme attains low imperceptibility but since it uses RSA algorithm which increases security of the developed scheme. In [32] a watermarking technique is discussed where two watermarks are simultaneously embedded inside a medical host image by using combination of non-subsampled contourlet transform (NSCT) - RDWT - SVD transforms. For providing more security to the technique chaotic encryption is employed. Kaur *et al.* [33] established a new approach of watermarking with the help of dual tree complex wavelet transform (DTCWT) and AT. A host image is decomposed into various subplanes using DTCWT whereas encrypted watermark image is also decomposed in a similar manner using DTCWT while encryption of watermark is done through AT. Further embedding process is performed for all subplanes distinctively whereas inverse DTCWT leads to generation of watermarked image. However, the developed scheme turns out to be a non-blind scheme which requires original host image for recovery of watermark. A multiple image watermarking approach is proposed in [34] where LWT along with DCT is employed. In this methodology a colored host image is converted from RGB to YIQ color space. Further 'Y' component is chosen for embedding of watermark while two encrypted watermarks are embedded concurrently inside the host image. Developed technique seems to be robust against numerous attacks and provides adequate security to the watermarks. Briefly several watermarking techniques are elaborated in [35], where authors have highlighted the salient features of numerous watermarking techniques. This actually helps researchers in providing roadmap for developing new watermarking methodologies. Researchers have proposed a novel dual image watermarking technique in [36] where RDWT, NSCT, AT and SVD transforms are effectively used. Dual image watermarks are embedded in this methodology whereas set partitioning in hierarchical tree (SPIHT) algorithm is employed successfully for compressing the watermarked image.

Layout of remaining paper is structured as: Section 2 highlights main significance of the proposed work whereas Section 3 elaborates basic concepts of HT, DWT, SVD and AT. In Section 4 proposed watermarking technique is presented. Section 5 deals with simulation results whereas conclusions are illustrated in Section 6.

2 Main Significance of the Proposed Work

A new approach of dual image watermarking is presented in this paper. Use of this technique leads to various advantages such as storage reduction, security and bandwidth requirements. In proposed methodology HT on host image is performed which results in illumination and reflectance components. Out of these two components reflectance component is preferred for embedding of watermark since it bears key features of image, so embedding in this part can lead to better immunity against attacks whereas perceptual invisibility is also increased simultaneously as this component varies very rapidly hence watermark becomes invisible to human perception easily. DWT is used to decompose reflectance component into numerous subbands [9, 14]. Use of DWT provides multiresolution analysis which strengthens imperceptibility. Choice of HL and LH subbands for embedding ensures that robustness and imperceptibility are achieved concurrently whereas use of SVD [5–7] increases robustness of algorithm as SVs are not much affected by various signal processing at-

tacks. Usage of DWT increases computational complexity of the technique. Therefore, in order to overcome this short coming of DWT various other transforms such as RDWT [37, 38], NSCT [32, 36, 39] which possess shift invariance property can be used to reduce the computational complexity. However, false positive problem which tends to occur with usage of SVD transform needs to be eliminated. Shuffled SVD (SSVD) [40] is one of the possible methods which can be applied for the removal of false positive problem. In proposed method image watermark 1 is transformed by DWT resulting in HL subband whose SVs are computed using SVD. Similarly image watermark 2 is scrambled through AT and then DWT is applied on this scrambled watermark. Further SVs of LH subband of image watermark 2 are evaluated and SVs of HL and LH subbands of host image are modified with SVs of both watermarks. ‘EC’ logo is used as image watermark 1 whereas ‘MNNIT’ logo is used as image watermark 2 which ensures that privacy of information content is maintained even if one logo is tampered other logo delivers correct information. Therefore main significant features of proposed work are:

- In [19] DCT is used for the processing of two image watermarks whereas in proposed approach we have utilized DWT. Use of DWT enhances perceptual invisibility in comparison to DCT which suffers from blocking artifacts. So, the proposed scheme becomes more imperceptible by embedding two watermarks in suitable frequency subbands.
- Security is increased upto large extent as image watermark 2 ‘MNNIT’ logo is scrambled through AT and embedding two watermarks concurrently in a single host image reduces unethical activities carried out by unlawful users.
- Reflectance component promises to deliver excellent robustness and perceptual invisibility therefore it is chosen for embedding of both watermarks as depicted in Tables 1-5.
- Bandwidth requirement is also decreased as two watermark images are concurrently transmitted inside a single cover image.

3 Basic Concepts

This section throws light on basic concepts regarding HT, DWT, SVD and AT in brief.

3.1 Homomorphic Transform

An image $z(p_1, p_2)$ can be considered as product of illumination component $i(p_1, p_2)$ and reflectance $r(p_1, p_2)$ component [18, 41, 42], where (p_1, p_2) represents spatial coordinates.

$$z(p_1, p_2) = i(p_1, p_2)r(p_1, p_2) \quad (1)$$

Above Eq. (1) is made separable using logarithm function as:

$$\ln(z(p_1, p_2)) = \ln(i(p_1, p_2)) + \ln(r(p_1, p_2)) \quad (2)$$

This Eq. (2) is transformed in frequency domain by using fast fourier transform.

$$Z(u, v) = Z_i(u, v) + Z_r(u, v) \quad (3)$$

For extraction of ‘ $Z_r(u, v)$ ’ from Eq. (3) it is passed through a high pass filter ‘ $H(u, v)$ ’.

$$F(u, v) = Z_i(u, v)H(u, v) + Z_r(u, v)H(u, v) \quad (4)$$

Inverse transformation of Eq. (4) is done for yielding reflectance component. This component comprises of vital image features with a low energy hence embedding watermark in this component will improve imperceptibility and robustness of proposed scheme as embedded watermark will be difficult to be perceived by human perception and greater noise immunity will be attained. Diagrammatic representation of HT decomposition of an image is depicted in Figure 1.

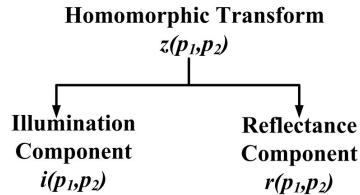


Figure 1: Illumination and Reflectance Component of an Image.

3.2 Discrete Wavelet Transform

DWT is a transformation used for frequency domain analysis of image. Basically it consists of a filter system which decomposes a given image into numerous subbands as: A (approximation), H (horizontal), V (vertical) and D (diagonal) [43–45]. Approximation is a low frequency subband while other three remaining are high frequency subbands. These subbands contain coarse and fine details of image which are closely related to human visual system. This decomposition can be increased to multiple times for higher subbands decomposition. The key feature of DWT is it exhibits good frequency localization which improves imperceptibility as watermark can be embedded into any desired subband.

3.3 Singular Value Decomposition

A real matrix ‘B’ is decomposed into three matrices U , D and V using SVD where U , V are left and right orthogonal matrices and ‘ D ’ is a diagonal matrix which consists of SVs [46, 47]. Mathematically it is formulated as:

$$B = U_1 D_1 V_1^T + U_2 D_2 V_2^T + \dots \dots \dots U_R D_R V_R^T \quad (5)$$

Here ‘ R ’ denotes rank of matrix ‘ B ’. In watermarking techniques SVD is very frequently used as SVs demonstrates excellent stability towards various changes made in image under several attacks. Hence resistance of watermarking schemes is increased with usage of SVD.

3.4 Arnold Transform

Protection of ownership is a challenging task so that information can be protected from malicious attacks. Therefore scrambling of image are performed using AT. Scrambling is performed for fixed number of iterations whereas after applying inverse AT original image is recovered back [48–50]. Mathematically AT is formulated as:

$$\begin{pmatrix} l'_1 \\ l'_2 \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 1 & 2 \end{pmatrix} \begin{pmatrix} l_1 \\ l_2 \end{pmatrix} \bmod P \quad (6)$$

where $\begin{pmatrix} l'_1 \\ l'_2 \end{pmatrix}$ and $\begin{pmatrix} l_1 \\ l_2 \end{pmatrix}$ represents image pixels after and before AT whereas ‘ P ’ is size of image. This transform is periodic which means after finite iterations original image is retrieved back.

4 Proposed Algorithm

This section discusses about the proposed algorithm regarding watermark embedding and its extraction from noisy watermarked image. Embedding algorithm make use of HT, DWT, SVD along with AT to enhance the security. Embedding of watermark in reflectance component ensures that imperceptibility and robustness are simultaneously attained which is a prime requirement for any watermarking algorithm. The steps for these

algorithms are discussed below. Figure 2A and B depicts embedding and extraction algorithms to distinctly define the flow of the proposed technique.

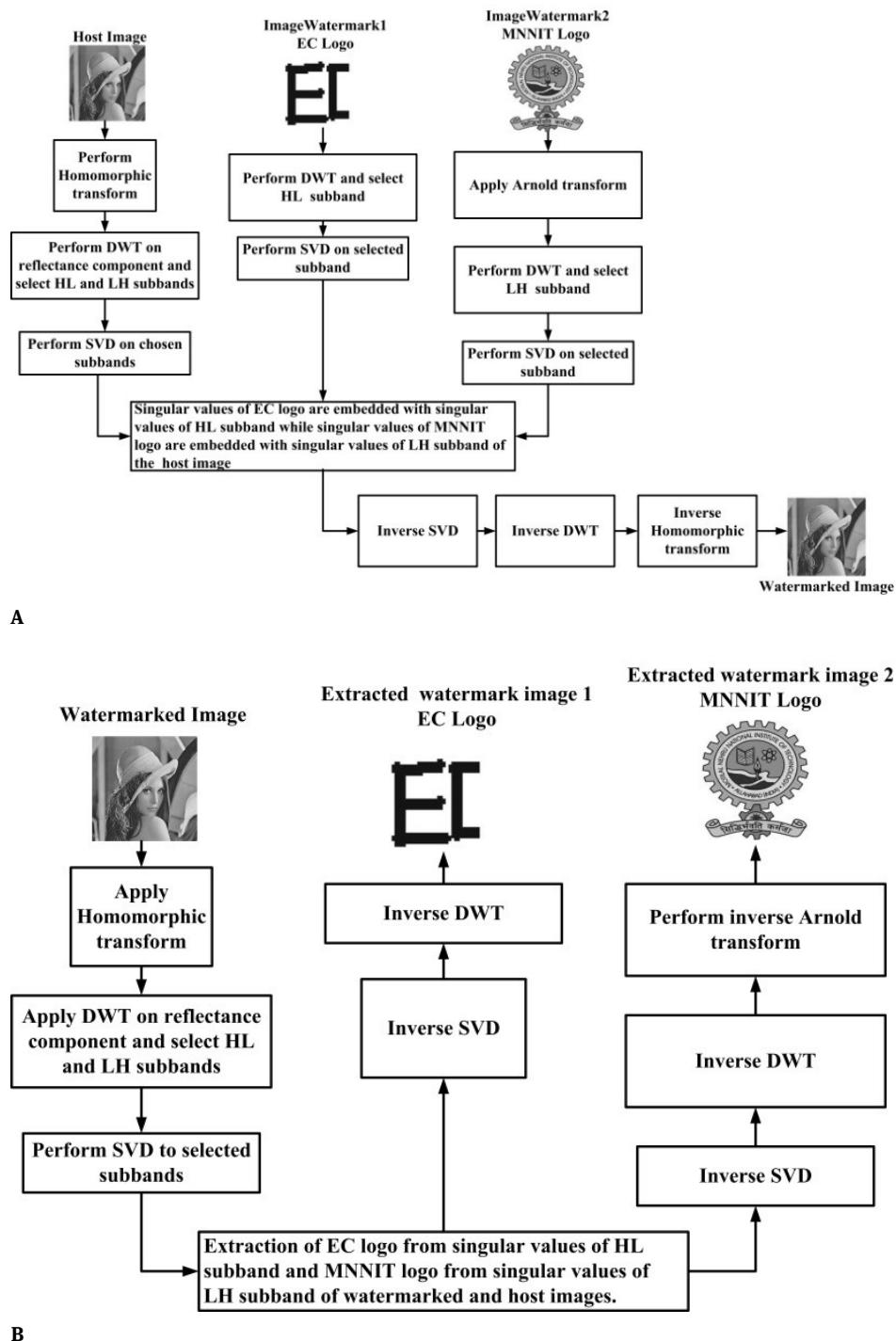


Figure 2: (A) Embedding Algorithm (B) Extraction Algorithm.

4.1 Embedding Algorithm

- Illumination ‘ I ’ and reflectance ‘ R ’ components of host image ‘ Y ’ are computed using HT.
- Apply DWT on ‘ R ’ resulting in HL and LH subbands, further apply SVD to these selected subbands.

$$SVD(R_{HL}) = U_{HL} S_{HL} V_{HL}^T \quad (7)$$

$$SVD(R_{LH}) = U_{LH} S_{LH} V_{LH}^T \quad (8)$$

- Apply DWT on EC logo and select HL subband whose SVs are computed using SVD.

$$SVD(W_{EC}) = U_{WEC} S_{WEC} V_{WEC}^T \quad (9)$$

- AT of MNNIT watermark is performed, afterwards LH subband of scrambled watermark is obtained by one level DWT of it and then SVD of selected subband is done.

$$SVD(W_{MNNIT}) = U_{WMNNIT} S_{WMNNIT} V_{WMNNIT}^T \quad (10)$$

- EC and MNNIT watermarks are embedded into the host image according to following Eqs. (11) and (12)

$$S_{w1} = S_{HL} + \alpha * S_{WEC} \quad (11)$$

$$S_{w2} = S_{LH} + \alpha * S_{WMNNIT} \quad (12)$$

here α is a scaling parameter whose value is set to 0.005.

- Now inverse SVD is applied on obtained modified coefficients ‘ S_{w1} ’ and ‘ S_{w2} ’, followed by inverse DWT.
- Inverse HT is successively performed for obtaining watermarked image ‘ Y_{WM} ’.

4.2 Extraction Algorithm

- HT of watermarked image ‘ Y_{WM} ’ is performed for separating out illumination and reflectance components.
- Apply one level DWT to reflectance component and then apply SVD to HL and LH subbands.

$$SVD(R_{WMHL}) = U_{WMHL} S_{WMHL} V_{WMHL}^T \quad (13)$$

$$SVD(R_{WMLH}) = U_{WMLH} S_{WMLH} V_{WMLH}^T \quad (14)$$

- Modified SVD coefficients for both image watermarks are recovered using Eqs. (15) and (16) respectively.

$$S_{\text{Recov}EC} = (S_{WMHL} - S_{HL})/\alpha \quad (15)$$

$$S_{\text{Recov}MNNIT} = (S_{WMLH} - S_{LH})/\alpha \quad (16)$$

- Inverse SVD is distinctively applied on $S_{\text{Recov}EC}$ and $S_{\text{Recov}MNNIT}$ for obtaining modified wavelet coefficients of EC and MNNIT logos.
- Inverse DWT is performed for recovery of EC logo whereas inverse DWT followed by inverse AT is done to decrypt MNNIT logo.

5 Simulation Results and its Analysis

Several experiments were performed comprehensively for evaluating effectiveness of proposed algorithm. Six standard gray scale images namely, Goldhill, Couple, Lena, Peppers, Aerial and Clock are taken as host images of size 512×512 as depicted in Figure 3A-F whereas EC and MNNIT logos of size 512×512 are used as image watermarks presented in Figure 4A and B. All simulation results are computed using MATLAB software. Figure 5A-D illustrates original Goldhill image, watermarked Goldhill image and both image watermarks recovered after applying extraction algorithm.

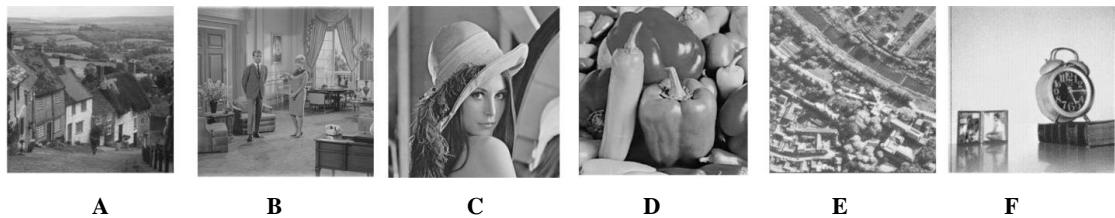


Figure 3: Various Host Images taken (A) Goldhill (B) Couple (C) Lena (D) Peppers (E) Aerial (F) Clock.

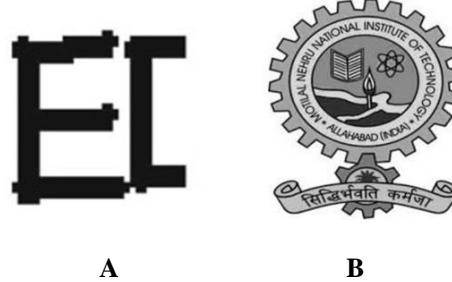


Figure 4: Image Watermarks used (A) EC Logo (B) MNNIT Logo.

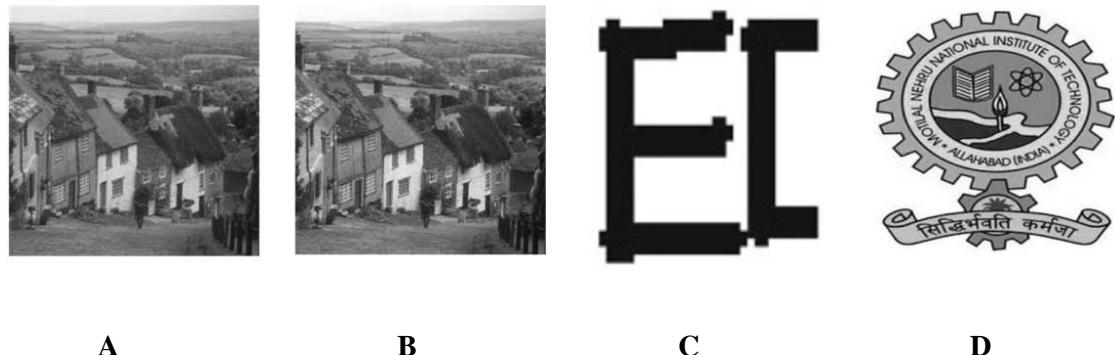


Figure 5: (A) Original Goldhill Image (B) Watermarked Image (C) Recovered EC Logo (D) Recovered MNNIT Logo.

Mean squared error (MSE), peak signal to noise ratio (PSNR), normalized correlation (NC) [51], structural similarity index [52] and weighted PSNR (WPSNR) [53, 54] are the parameters which are employed for evaluating performance of the proposed technique. Table 1 tabulates MSE, PSNR, WPSNR, NC and SSIM values

for the proposed algorithm under no attacks. Maximum PSNR and WPSNR is obtained for Peppers image of 60.2320 dB and 77.4798 dB whereas NC for recovered EC logo (NC_1) is 1.00 and for MNNIT logo (NC_2) is 1.00 for all host images respectively while highest SSIM of 0.9999 is attained for Lena image. Thus excellent values of PSNR, WPSNR, NC and SSIM are achieved for the proposed scheme.

Table 1: Performance Metrics for Proposed Technique under No Attacks.

Images	MSE	PSNR (dB)	WPSNR (dB)	NC ₁	NC ₂	SSIM
Goldhill	9.8474×10^{-7}	60.0668	76.9511	1.00	1.00	0.9998
Peppers	9.4798×10^{-7}	60.2320	77.4798	1.00	1.00	0.9998
Couple	1.0608×10^{-6}	59.7436	76.4922	1.00	1.00	0.9998
Lena	1.0035×10^{-6}	59.9850	76.8346	1.00	1.00	0.9999
Clock	1.2108×10^{-6}	59.1692	76.2251	1.00	1.00	0.9997
Aerial	1.2323×10^{-6}	59.0929	76.3081	1.00	1.00	0.9998

Table 2: Measuring Performance of the proposed technique Under Various Sizes of Watermarks.

Size of watermark images	Image	PSNR (dB)	SSIM	NC ₁	NC ₂
256×256	Goldhill	58.1871	0.9994	1.00	1.00
	Peppers	56.4652	0.9989	1.00	1.00
	Couple	49.1298	0.9949	1.00	1.00
	Lena	48.4964	0.9927	1.00	1.00
	Clock	62.2569	0.9998	1.00	1.00
	Aerial	52.6356	0.9986	1.00	1.00
128×128	Goldhill	46.7389	0.9920	1.00	1.00
	Peppers	45.5398	0.9883	1.00	1.00
	Couple	41.0958	0.9765	1.00	1.00
	Lena	40.5402	0.9692	1.00	1.00
	Clock	53.0098	0.9971	1.00	1.00
	Aerial	41.4954	0.9836	1.00	1.00

Table 2 evaluates the variations in size of image watermarks for the proposed technique. For varying size of watermark images again performance parameters are evaluated and it is observed that they yield satisfactory results. Hence on changing the size of watermark images our proposed technique exhibits good robustness and perceptual invisibility.

In Figure 6 imperceptibility analysis for proposed technique is carried out in which PSNR is computed for various host images under influence of various attacks. It is observed from Figure 6 that highest PSNR of 57.1796 dB is attained for JPEG compression (100) attack for Lena image whereas lowest PSNR value of 10.8908 dB is obtained for Clock image under rotation (3°) attack. For majority of attacks PSNR values are well above 30 dB which signifies high perceptual invisibility of the proposed scheme. SSIM values are also evaluated for the proposed technique under influence of numerous attacks as demonstrated graphically in Figure 7. This metric values accounts for remarkable perceptual invisibility of the proposed approach for majority of attacks except for rotation (3°) attack where SSIM values are low.

Table 3 presents NC values for both recovered watermark images when several watermarked images are subjected to different attacks. On observing Table 3 it appears that NC values for both watermarks are well above 0.9 for most of the attacks.

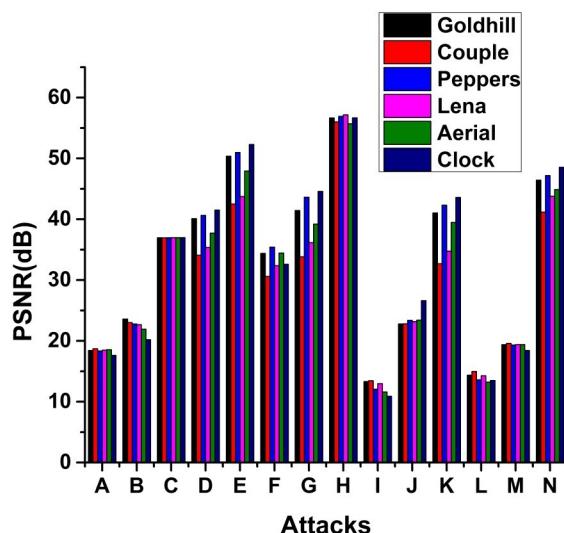


Figure 6: Imperceptibility Analysis for Proposed Scheme under Several Attacks (A) Salt & pepper Noise (0.05) (B) Speckle Noise (0.02) (C) Gaussian Noise (0, 0.0002) (D) Sharpening (E) Gaussian Filter (3×3) (F) Average Filter (3×3) (G) Median Filter (3×3) (H) JPEG Compression (100) (I) Rotation (3°) (J) Gamma Correction (0.8) (K) Scaling (0.5, 2) (L) Translation [10 10] + Salt & pepper Noise (0.001) (M) JPEG Compression (60) + Salt & pepper Noise (0.04) (N) JPEG Compression (80) + Scaling (2,0.5).

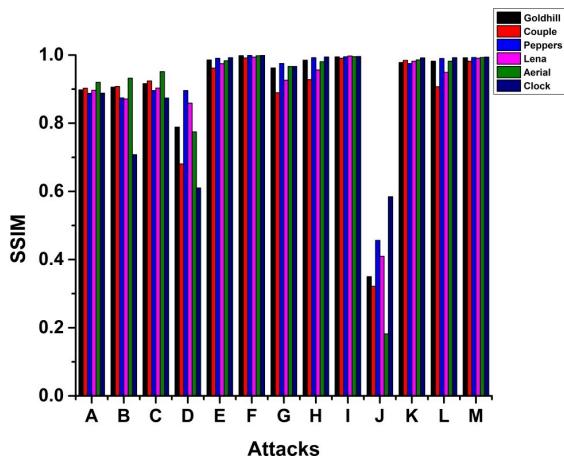


Figure 7: SSIM Values Evaluated for Proposed Technique under Several Attacks (A) Salt & pepper Noise (0.004) (B) Speckle Noise (0.001) (C) Gaussian Noise (0, 0.0002) (D) Histogram equalization (E) Sharpening (F) Gaussian Filter (3×3) (G) Average Filter (3×3) (H) Median Filter (3×3) (I) JPEG Compression (90) (J) Rotation (3°) (K) Gamma Correction (0.8) (L) Scaling (0.5, 2) (M) JPEG Compression (80) + Scaling (2,0.5).

Numerous hybrid attacks such as JPEG compression (80) + scaling (2, 0.5), gamma correction (0.9) + JPEG compression (70), Translation [10 10] + Salt & pepper noise (0.0002) are also applied to the proposed technique for examining its robustness as tabulated in Table 4. So from Tables 3 and 4 it can easily be concluded that proposed methodology offers good amount of robustness against numerous attacks as NC values for recovered watermarks are lying close to 1.

Table 5 presents imperceptibility comparison among different schemes as reported in [19, 21, 30, 31] and [33] with our proposed approach and it is found that our developed scheme outperforms all remaining schemes in terms of imperceptibility with a high value of PSNR of 60.2320 (dB).

In Figure 8 given below graphical comparison of NC values for both image watermarks has been performed among proposed scheme and scheme reported in [30]. It is found that NC₁ and NC₂ of proposed scheme are much higher than the values obtained in [30] for same set of attacks.

Table 3: NC Values for Extracted Watermark Logos under Attacks.

Attacks	Goldhill		Couple		Peppers		Lena		Clock		Aerial	
	NC ₁	NC ₂										
Salt & pepper noise (0.04)	0.9995	0.8385	0.9996	0.9074	0.9994	0.8161	0.9994	0.8680	0.9994	0.7845	0.9996	0.8145
Speckle noise (0.02)	0.9998	0.9664	0.9998	0.9759	0.9998	0.9542	0.9997	0.9710	0.9997	0.9295	0.9998	0.9327
Gaussian noise (0, 0.005)	0.9997	0.9480	0.9998	0.9721	0.9997	0.9463	0.9997	0.9645	0.9998	0.9647	0.9998	0.9454
Histogram equalization	0.9998	0.9221	0.9995	0.7414	0.9999	0.9925	0.9998	0.9492	0.9999	0.9518	0.9995	0.9388
Sharpening	0.9999	0.9895	0.9998	0.9340	0.9999	0.9937	0.9999	0.9642	0.9999	0.9919	0.9999	0.9443
Gaussian filter (3×3)	1.00	0.9997	1.00	0.9904	1.00	0.9996	1.00	0.9946	1.00	0.9999	1.00	0.9994
Averaging filter (3×3)	0.9996	0.9954	0.9997	0.9589	0.9996	0.9930	0.9997	0.9849	0.9995	0.9928	0.9998	0.9927
Median filter (3×3)	1.00	0.9988	1.00	0.9770	1.00	0.9995	1.00	0.9897	1.00	0.9988	1.00	0.9983
JPEG compression (50)	1.00	1.00	1.00	1.00	1.00	1.00	0.9999	0.9925	1.00	0.9981	1.00	0.9990
Rotation (3°)	0.9996	1.00	0.9997	1.00	0.9997	0.9898	0.9997	0.9952	0.9996	0.9269	0.9999	0.9760
Gamma correction (0.8)	1.00	1.00	1.00	0.9979	1.00	0.9993	1.00	0.9986	1.00	1.00	1.00	0.9980
Translation [30:20]	0.9998	0.9994	0.9999	0.9997	0.9999	0.9979	0.9999	1.00	0.9998	0.9929	1.00	0.9964

Table 4: Robustness Evaluation for Proposed Technique under Hybrid Attacks.

Attacks	Goldhill		Couple		Peppers		Lena		Clock		Aerial	
	NC ₁	NC ₂										
Gamma correction (0.9) + JPEG compression (70)	1.00	1.00	1.00	1.00	1.00	0.9996	1.00	0.9999	1.00	1.00	1.00	0.9990
Translation [10:10] + Salt & pepper noise (0.0002)	0.9999	0.9997	0.9999	0.9998	1.00	0.9995	1.00	1.00	0.9999	0.9952	1.00	0.9993
JPEG compression (80) + Scaling (2, 0.5)	1.00	0.9999	1.00	0.9965	1.00	1.00	0.9969	1.00	0.9995	1.00	0.9995	1.00

Table 5: PSNR (dB) Comparison among Various Schemes.

[19]	[21]	[30]	[31]	[33]	[34]	Proposed method
30.99	43.2093	34.5164	27.3823	56.2135	60.2320	

Table 6: Comparison of Proposed Technique with Other Reported Methods.

Attacks	[19] ^a		[19] ^b		[21]		[22]		Proposed scheme	
	NC ₁	NC ₂	NC ₁	NC ₂	NC ₁	NC ₂	NC ₁	NC ₂	NC ₁	NC ₂
JPEG compression (50)	*	*	*	*	0.9887	0.7393	0.6963	0.5998	1.00	0.9990
Gaussian noise (0, 0.001)	0.8939	0.9901	0.9515	0.9908	*	*	*	*	*	1.00
Salt & pepper noise (0.05)	0.6287	0.6596	0.8405	0.6828	*	*	*	*	*	0.9966
Median (3×3)	0.8457	0.9833	0.8657	0.9861	*	*	*	*	*	0.7706
filter (11×11)	*	*	*	*	-0.5432	0.3314	*	*	*	1.00
Average filter (3×3)	0.6709	0.9809	0.7348	0.9863	*	*	*	*	*	0.9983
filter (11×11)	*	*	*	*	-0.5394	0.3170	*	*	*	1.00
Rotation (5°)	0.5798	0.7843	0.7912	0.9806	*	*	*	*	*	0.9645
Gamma correction	0.9249	0.9200	0.9650	0.9668	*	*	*	*	*	0.9830
Scaling	0.9206	0.9825	0.9626	0.9879	*	*	0.6365	0.5783	1.00	0.9945

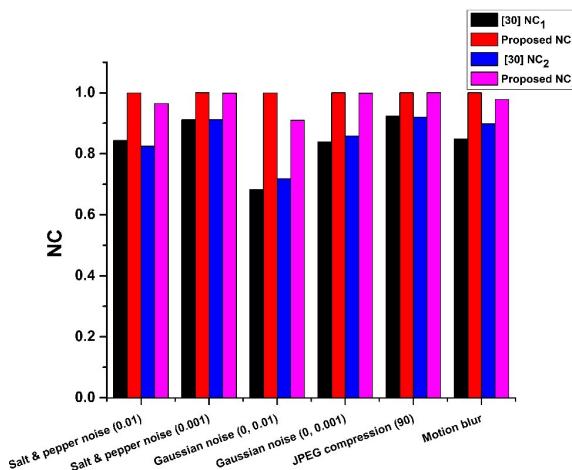


Figure 8: NC Values Comparison among Proposed Scheme and Scheme Reported in [30].

Table 6 emphasizes the efficacy of proposed algorithm by comparing it with other reported techniques such as [19]^a, [19]^b, [21] and [22] where [19]^a signifies technique without BPNN and [19]^b denotes technique using BPNN. Symbol '*' means NC values were not reported for these attacks. On observing Table 6 it can be easily interpreted that proposed scheme is superior as it offers better robustness in comparison to other reported techniques. NC values are quite high for proposed technique as they are ranging from 0.7706 to 1.00 which is quite remarkable.

6 Conclusions

In this paper a novel dual image watermarking technique is proposed which uses fusion of HT, DWT, SVD and AT. HT decomposition of image gives reflectance component in which embedding of two image watermarks is performed. Embedding is performed in reflectance component due to its characteristics which exhibits better robustness and imperceptibility whereas DWT also provides better perceptual invisibility by embedding these watermarks in high frequency subbands. SVD enhances robustness of proposed method against geometrical attacks, while AT strengthens security of algorithm. Embedding of dual watermarks inside a single host image reduces risk of tampering and storage requirements simultaneously. Simulation results clearly accounts for high robustness and imperceptibility of proposed scheme under numerous attacks as well as its superiority is illustrated by comparing it with other existing methods such as [19]^a, [19]^b, [21, 22, 30, 31] and [33]. Hence a reliable and secure dual image watermarking technique is developed in this paper. The proposed watermarking technique finds its potential application in the field of medical health care where a patient record bearing vital information can be transmitted as watermark along with medical image watermark. Secondly, applying proposed technique for color image watermarking can be an interesting area of research.

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