Optimized, Robust and Secure Digital Image Watermarking Technique based on Modified Periodic and Smooth Decomposition

Khushi Yadav, Sunil Joshi, Navneet Agrawal

College of Technology and Engineering, Udaipur (313001), Rajasthan, India

khushi7050@gmail.com, suniljoshi7@rediffmail.com, navneetctae@gmail.com

Abstract

Optimized, Robust and Secure Digital Image Watermarking technique based on Modified Periodic and Smooth Decomposition is proposed. This proposed technique based on Periodic and Smooth Decomposition (PPSD), Discrete Wavelet Transform (DWT) and Singular Value Decomposition (SVD). The host and watermark image is decomposed into a smooth and periodic component. The smooth component decomposed into its frequency sub-bands through 2nd level DWT. Later by SVD, the watermark singular matrix is combined with the singular matrix of the transformed image. The watermarked image has been obtained by using the inverse of DWT. Through the proposed technique we improved the different parameters like PSNR is 92.9075, SSIM watermarked 0.8039, SSIM extracted watermark 0.9924, NCC 0.9929. The experimental result displays that the proposed technique is imperceptible and robust to different attacks. By using SVD we faced false positive problem but we solved this problem by adopting a digital signature. Digital signature gives authentication before extracting watermark image.

Indexing terms/Keywords: Digital Image Watermarking; Discrete wavelet transform; Periodic Plus Smooth Decomposition; Singular Value Decomposition; Peak Signal to Noise Ratio; Structural Similarity Index Measurement; Normalized Correlation Coefficient;

1. Introduction

The Internet and communication technologies rapidly develop, which makes the multimedia data can simply be copied, distributed, accessed and used illegally. Thus, the security of the multimedia data is truly important. All watermarking system should have robustness, imperceptibility, and security. Robustness refers to the scheme's resistance against several attacks. Imperceptibility is the similarity between the host and watermarked image. The peak signal-to-noise ratio (PSNR) is a metric that is used to evaluate imperceptibility performance. A higher PSNR indicates a higher imperceptibility. The PPSD image is well based on DFT, and it has been shown that the DFT based images watermarking schemes are highly robust against attacks [1]. DWT decompose an image (2D) into four bands HH (high-frequency band), HL (horizontal mid-frequency band), LH (vertical mid-frequency band), LL (low-frequency band). SVD is widely used in applications, such as noise reduction, image watermarking, image hiding and image compression. SVD is also used for reliable watermarking but false positive problem generally faced by SVD based watermarking techniques. So the digital signature authentication mechanism help to solve the false positive problem which is one important problem in the watermarking area [2]. Today, digital watermarking is developing quickly due to increased attention on copyright issues [3]. Digital signature typically sensitive to single bit changes, which offers stronger security [4]. So study of digital watermarking is incomplete without secure data transfer, copyright protection, image authentication and to design the efficient algorithm to improve the PSNR, SSIM, correlation coefficient and robustness of watermark against attacks.

A new image watermarking technique based on Periodic Plus Smooth Decomposition (PPSD) [1]. The PPSD can simply deal with periodization artifacts arising from the use of the DFT transform on 2-D images. It decompose the discrete image into a periodic component and smooth component where periodic component collects most of the image information but escapes periodization artifacts, and a smooth (harmonic) component presents very sluggish variations inside the image. The experiments indicate that our developed PPSD technique can achieve high imperceptibility while showing good robustness to various kinds of attacks, including geometrical distortions.

A watermarking algorithm based on chirp z-transform, DWT and SVD [6] which involved increasing attention and give copyright protection and content authentication. This type of problem is addressed in multimedia technology. Initially, the host image is decomposed into its frequency sub-bands by using 1-level DWT. Now, the decomposed sub-band 'HH' is transformed into z-domain by using CZT. At last, the watermark image's singular matrix is added to the singular matrix of the transformed image and we get a new singular matrix. By the new singular matrix we generate a new frequency band HH2 . At last, we inverse the CZT and DWT and get the watermarked image

A new robust and secure digital image watermarking scheme based on the IWT and SVD [2] which give a security and robustness. This scheme can give the effectiveness in term of capacity, robustness and imperceptibility due to the combination of some technique like IWT and SVD. By the usages of IWT, SVD and Digital Signature it make an optimized algorithm with security.

In this study, we have proposed Modified Periodic and Smooth Decomposition technique for robust and secure digital image watermarking which is based on PPSD, DWT, SVD and Digital Signature. This algorithm can help satisfy the robustness, imperceptibility and security characteristics of a good watermarking algorithm by greatly improving the visual quality of the watermarked image and being robust against common signal processing operation and attacks.

2. Proposed Technique

The paper propose an optimized technique which is based on PPSD-DWT-SVD to improve the imperceptibility, robustness, and security.

2.1. Periodic Plus Smooth Decomposition (PPSD)

PPSD can simply deal with periodization artifacts. It decompose the discrete image into two component [1]

- Periodic component- This image is well analysed by the DFT and most image visually very similar to discrete image.
- Smooth component- This image has very smooth variation except at the border of the image.

The proposed technique is based on the PPSD. Our main contribution consists of decomposing the host image and watermark image into its periodic and smooth components, which shown in Fig. 1 and then embedding the watermark in the smooth component (s) of the host image in order to provide more transparency and robustness to the embedded watermark. The PPSD image is well based on the DFT. The DFT-based images watermarking schemes are highly robust against geometric attacks. By using of PPSD the image 'u' is decomposed into two images: an image 'p' that is called "periodic component" and 's' that is called "smooth component" which shown in eq. (1)

$$E(p,s) = \sum_{\substack{\mathbf{x}\in\Omega,\mathbf{y}\in\mathbb{Z}^2\setminus\Omega,\\ |\mathbf{x}-\mathbf{y}|=1}} \left(p(\mathbf{x}) - p(\dot{\mathbf{y}})\right)^2 + \sum_{\substack{\mathbf{x}\in\Omega,\mathbf{y}\in\Omega,\\ |\mathbf{x}-\mathbf{y}|=1}} \left(s(\mathbf{x}) - s(\mathbf{y})\right)^2 \tag{1}$$

The equation shows that 'u = p + s', and the mean shown in eq. (2)

$$\mathrm{mean}(s) = \frac{1}{|\Omega|}\sum_{\mathbf{x}\in\Omega} s(\mathbf{x}). \tag{2}$$

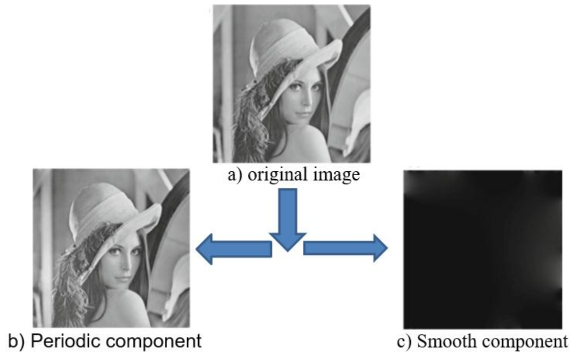


Fig.1: PPSD decomposition of 'Lena' image into its components: a) original image b) periodic component c) smooth component

2.2. Discrete Wavelet Transform (DWT)

The DWT is a wavelet transform. The main work is to decomposed an image into frequency sub-bands. [5-8] The sub-bands are LL, LH, HL and HH. The sub-bands are one-fourth of the size of the original 2D image. As we know the image is in 2D and we decomposed the image with the help of filter band and the filter band is 1D so we apply 1D filter band along row of the image and then column of the image or vice-versa as well. We apply down sample by 2 on LPF and HPF. In Fig.2 we see the demostration of DWT [12-14] image and we get four frequency sub-band at two level of filter bands. For LL band we filtered the image two time from LPF. Thus we can get maximum information in this sub-band or we can say maximum energy or high magnitude. The LL band in DWT represents low resolution band and it is the lowest frequency band which represent the most coarse part i.e. high energy density whereas the other components are representation of the finer details in the image. The LH sub-band shows the horizontal edges, HL sub-band shows the vertical edges and HH sub-band shows the diagonal edges[15]. The information is less in LH, HL and HH band because the HPF has been used.

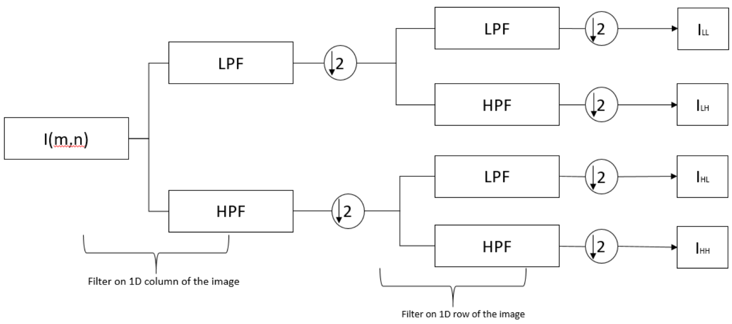


Fig. 2: Demonstration of DWT image

Furthermore clearance we can see the Fig.3 , the LL band of host image is visible because the magnitude of DWT coefficient is high but in other bands the magnitude of DWT coefficient is low. Embedding in the low frequency sub-bands could increase the robustness significantly.

→ HH (high frequency band): It mean high horizontal and high vertical

→ HL (horizontal mid-frequency band): It mean high horizontal and low vertical

→ LH (vertical mid-frequency band): It mean low horizontal and high vertical

→ LL (low frequency band): It mean low horizontal and low vertical

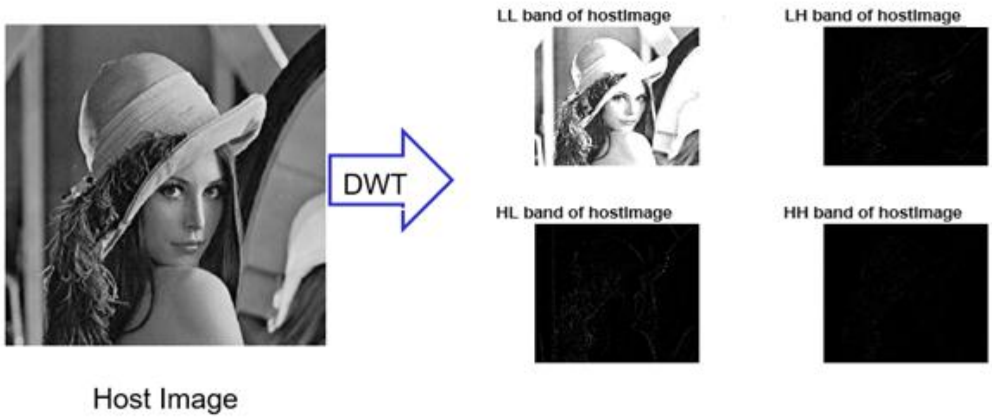


Fig. 3: DWT basic work

The DWT is also decomposed in levels i.e. single level decomposition, 2nd level decomposition, 3rd level decomposition [5-6]. We use 2nd level decomposition in proposed technique so the diagram is shown in Fig. 4

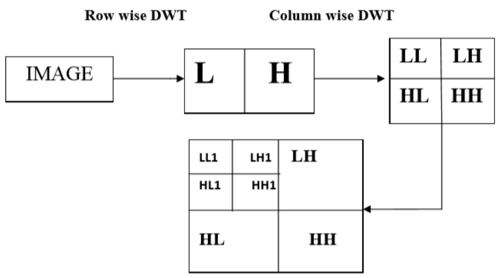


Fig. 4: 2nd level decomposition of DWT

2.3. Singular value decomposition (SVD)

The singular value decomposition scheme was firstly announced by Beltrami and Jordan in 1870. The singular value decomposition (SVD) is based on numerical analysis and linear algebra technique. [6-10] It makes calculations easy because of the singular matrix. Presently, the SVD used in applications, for example image compression, watermarking, hiding and noise reduction. Here we consider an image as matrix '*A*' of real/complex *N*×*N* with rank *r*, *A*(*r*<*N*). Using SVD, matrix *A* can be represented as follows eq. (3,4,5,6):

$$A = U_A S_A V_A^T = \sum_{i=1}^{r} u_i * s_i * v_i^T \quad (3)$$

$$U_A = [u_1, u_2 \ldots, u_N] \quad (4)$$

$$V_A = [v_1, v_2 \ldots, v_N] \quad (5)$$

$$S_A = \begin{pmatrix} S_1 & & \\ & S_2 & \\ & & . \end{pmatrix} \quad (6)$$

.

S_N

U_A and V_A are the orthogonal matrix of M x M and $N \times N$ respectively, represent their column vectors, where, as the S_A *is the* diagonal matrix of the N x N which include the singular values S_i in a decreasing order. The Fig. 5 shows the basic work of SVD. The SVD gives advantages in digital image watermarking process [10], which are given below:

Advantage-

- When small perturbation is added to image, its singular value do not change significantly due to stability property of the singular value.
- Achieve better transparency and robustness since minor variation in the singular value, it doesn't disturb the visual perception of the cover image.

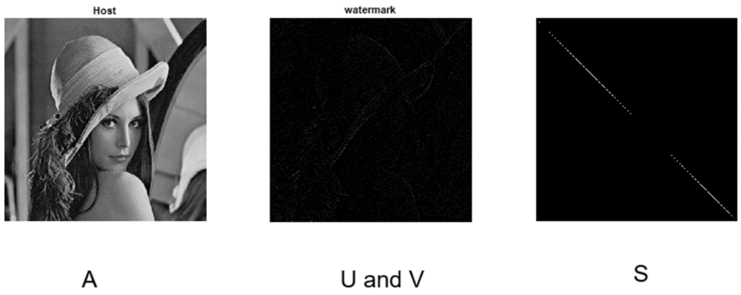


Fig. 5: SVD Basic work

2.4. Digital Signature

A signature-based authentication mechanism for the periodic component is proposed to overcome such drawbacks. The authentication process is performed into two stages: signature generation and embedding. Signature is produced within the watermark embedding process. This all goes parallel; the decoder extracts the embedded signature first and matches it with the signature that is generated at the user side based on the received key *(*periodic component). [11] If key match, then they are authenticated, and the watermark extraction process is continued. Otherwise extraction process is not possible. It stops to work further. These all steps show its strength and security.

3. Embedding and Extraction process of proposed approach:

Here PPSD-DWT-SVD technique is presented. It follows two procedures for watermark embedding and extracting as given in step wise.

3.1. The embedding procedure: The Block diagram of embedding process shows in Fig. 6:

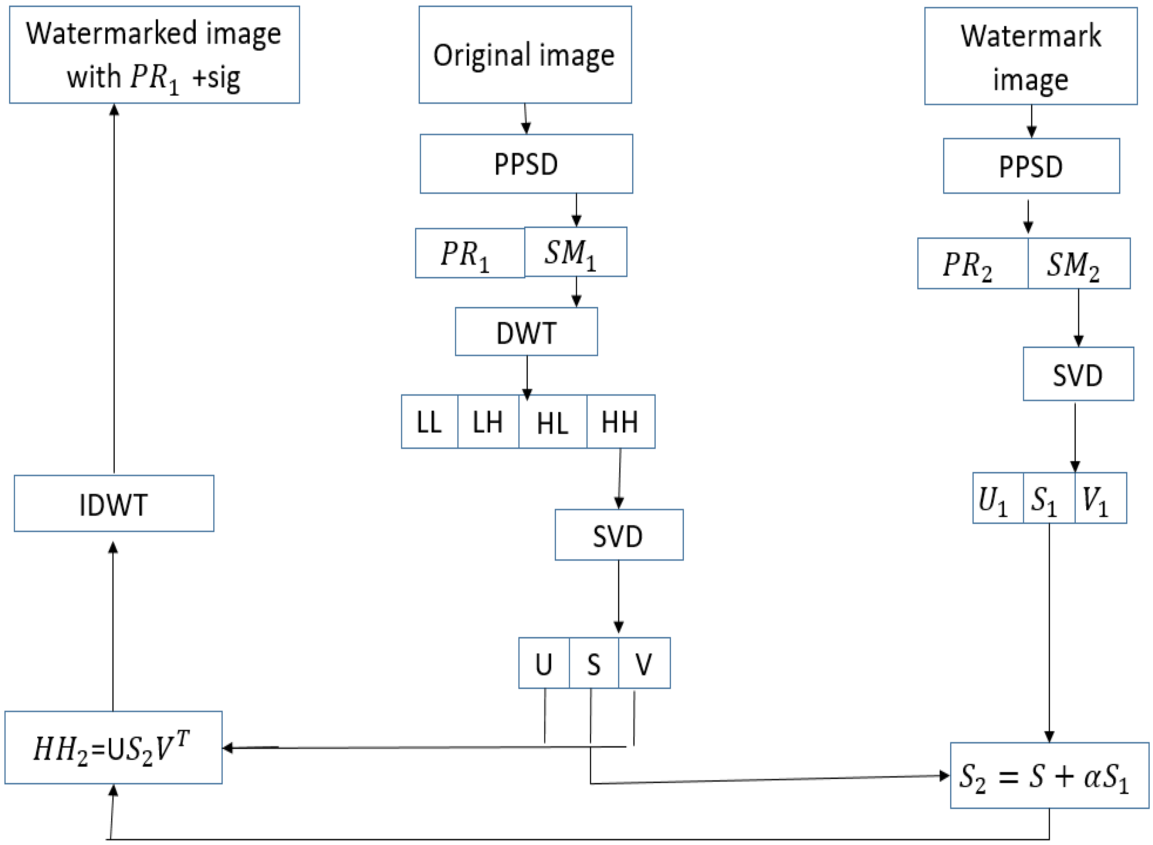


Fig. 6: Block diagram of embedding process of proposed technique

The Proposed technique embedding procedure steps are given below:

1. Put on PPSD at original image 'I' which is decompose in periodic component (PR_1)) and smooth component (SM_1)).

$$[PR_1\ SM_1] = \text{PPSD (I)}$$

2. Put on DWT to smooth component (SM_1)) to decompose it in four sub bands as specified

$$\text{LL LH HL HH=DWT } (SM_1))$$

3. Put on SVD to HH sub-band to decompose it as monitors

$$[\text{U S V}^T] = \text{SVD (HH)}$$

Wherever U and V is the orthogonal matrix of N x N and S is the diagonal matrix.

4. Put on PPSD to watermark image 'W' which is decompose in two component PR_2 and SM_2

$$[PR_2\ SM_2] = \text{PPSD (W)}$$

5. Put on SVD to SM_1 to decompose it in three matrix

$$[U_1 S_1 V_1] = SVD(SM_2)$$

6. Now we add the singular value of the host image and the watermark image by using a scaling factor (∝) .

$$S_2 = S + \propto S_1$$

7. Combine the orthogonal matrix of the decomposed original image with modified singular value matrix

$$HH_2 = US_2V^T$$

8. Put on the inverse DWT to the HH_2 sub-bands which is in place of HH and the other sub-bands is not change

$$W_m = \text{IDWT (LL LH HL } HH_2)$$

9. After that, we combine the PR_1 in the watermarked image 'W_m'.

$$W_m + PR_1$$

10. At last we add up a digital signature in the watermarked image. Here as a signature we used periodic component of watermark image (PR_2). It is used for authentication purpose

$$W_m + PR_1 + \text{sig}$$

3.2. The extracting procedure: The extraction process of block diagram shown in Fig. 7:

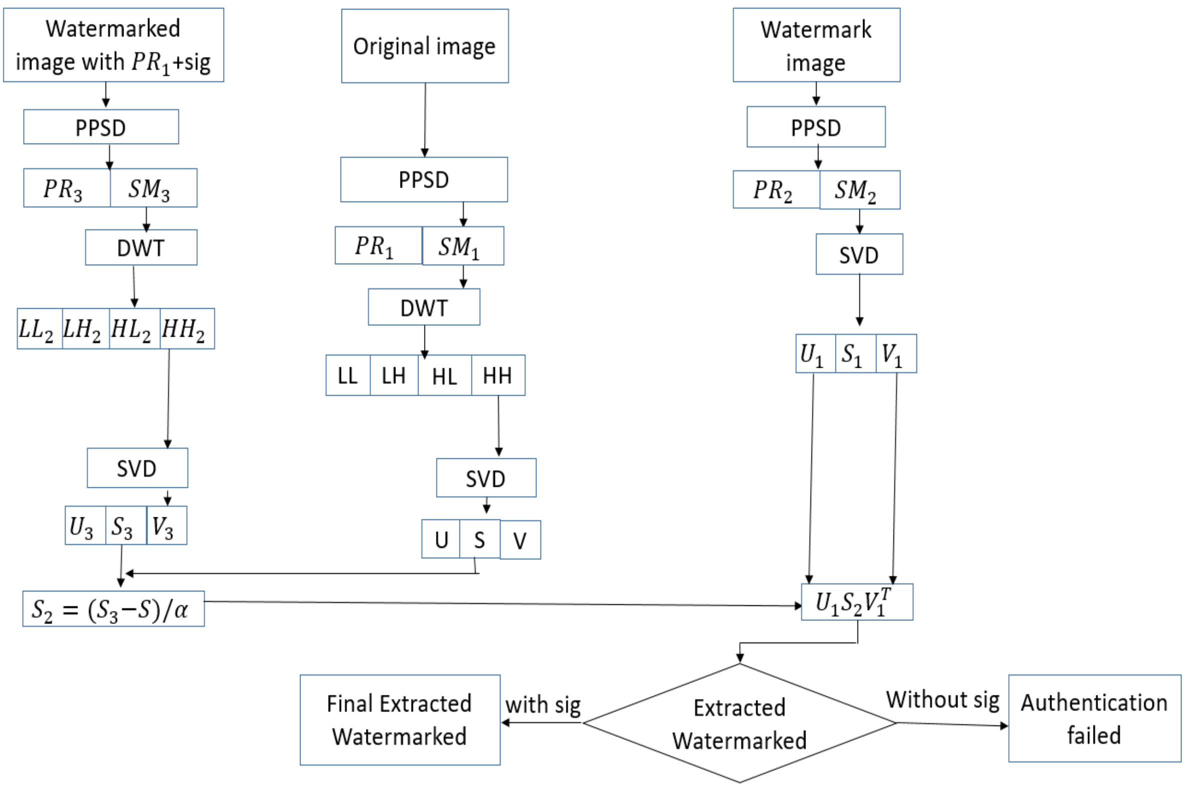


Fig. 7: Block diagram of extraction process of proposed technique

There is a safety test before extracting the watermark. This will help to remove the false positive problem. With the help of the secret key, authentication is done. Watermark extracting procedure will be continued if digital signature (the periodic component of watermark image) is added to the watermarked image. Finally, embedded watermarks were extracted.

The watermark extraction procedure steps are given below:-

1. Put on PPSD at the original image 'I' which is decompose in two component; the periodic (PR_1) and smooth (SM_1)

   a. $[\,PR_1 \;\; SM_1] = \text{PPSD (I)}$

2. Put on DWT to smooth image (SM_1) so it decompose in four frequency sub-bands which given below:

a. LL LH HL HH=DWT (SM_1)

3. Put on PPSD to the watermarked image 'W_m' which decompose it two component periodic (PR_3) and smooth (SM_3)
   a. [PR_3 SM_3] = PPSD (W_m)
4. Put on DWT to SM_3 to decompose in sub-bands as shown

$$LL_2 LH_2 HL_2 HH_2 = DWT(SM_3)$$

5. Put on SVD to HH sub-band which decompose the image in as given
   a. [U S V]=SVD (HH)
6. Put on SVD to HH_2 sub-band which decompose an image into three matrix is as given

$$[U_3 S_3 V_3] = SVD(HH_2)$$

1. Put on PPSD to 'W'. where 'W' is a watermarked image which decompose in two component; periodic (PR_2) and smooth (SM_2)
   i. [PR_2 SM_2] = PPSD (W)
2. Put on SVD to SM_2 which is decomposed as given
   i. $[U_1 S_1 V_1] = SVD(SM_2)$
3. Now, we subtract the singular value of the host image from the watermarked image and divide the scaling factor(∝). By this we get a new singular matrix is as follow
   a. $S_2 = (S_3 - S)/ \propto$
4. After that, we combine the orthogonal matrixes $U_1 and\ V_1^T$ and the obtained S_2 is given to the extracted image 'W_W'. This is shown below
   i. $W_W = U_1 S_2 V_1^T$
5. For the authentication purpose we put on the Digital signature (sig) with the extracted watermark image (W_W) and we are now at the final stage.
   a. [Final extracted watermark image] = (W_W+ sign.)
6. At, the last if digital signature is not matched or given then the authentication is failed.
   a. [Authentication failed] = (W_W+ sign.)

4. Results and Discussion:

Watermarking algorithms are usually evaluated with respect to imperceptibility, robustness and security.

- **Imperceptibility:**

For imperceptible capability, we measure the peak signal to noise ratio (PSNR). The unit of the PSNR is decibel (dB). The PSNR can defines the resemblance between an original image I(s) and the watermarked image W(s). The PSNR in decibel (dB) of the host and watermarked image can be calculated using eq. (7)

$$PSNR_{dB} = 10\log(\frac{MAX^2}{MSE}) \quad (7)$$

In the formula a 'log' is a logarithm base 10. Where 'MAX' is the maximum possible pixel value of the image, 'MSE' is the mean square error. For a gray scale with eight bit pixel MAX= 255. The average of the pixel difference between two images is called MSE. The MSE calculated using eq. (8)

$$MSE = \frac{1}{S}\sum_1^S (I(S) - W(S))^2 \quad (8)$$

Where I(S) is the 'original image' and the W(S) is 'watermarked image

Table 1 *Imperceptibility comparison values using PSNR (dB) for Lena image of* Aherrahrou et. al. [1], Makbol et al. [2], Agoyi et al. [6] and *proposed technique*

Agoyi et al. technique [6]	Aherrahrou et. al. technique [1] (avg. of 100 images)	Makbol et al. technique [2]	Proposed technique
29.41	74.1501 (Max-87.9687 & min-60.3316)	43.6769	92.9075

- **Robustness:**

To measure the robustness capability, we measure the the different parameters at different attacks. The SSIM watermarked, SSIM extracted watermark and normalized correlation coefficient (N.C) can measure at different attacks. A robust watermark must be capable to repel the attacks like AWGN, gamma correction, sharpening, additive histogram equalization, contrast enhancement, flipping and blurring. The SSIM can be measured using eq. (9)

$$\text{SSIM(x,y)} = \frac{(2\mu_x\mu_y+C_1)(2\sigma_{xy}+C_2)}{(\mu_x^2+\mu_y^2+C_1)(\sigma_x^2+\sigma_y^2+C_2)} \qquad (9)$$

In this the universal image quality index resemble to the case of $C_1 = C_2 = 0$.

$\mu_X = mean\ of\ x$, $\mu_y = mean\ of\ y$, $\sigma_x = standard\ deviation\ of\ x$,

$\sigma_y = standard\ deviation\ of y$, $\sigma_{xy} = cross\ correlation$.

Normalized correlation coefficient can be measured using eq. (10)-

$$\rho(W,K) = \frac{\sum_{i-1}^{n} W_i K_i}{\sqrt{\sum_{i-1}^{n} W_{i^2}}\sqrt{\sum_{i-1}^{n} K_{i^2}}} \qquad (10)$$

Where W=correlation factor of watermark image;

K=correlation factor of extracted image

The different attacks like histogram equalization, sharpening, flipping, blurring, contrast enhancement, gamma correction and AGWN apply to host image 'Lena' then the attacks effect the watermarked image which is shown in Fig. 8

Fig. 8: Watermarked image 'Lena' with different attacks (a) Original image. (b) Histogram equalization attack. (c) Sharpening attack (d) Flipping attack (e) Blurring attack (f) Contrast adjustment attack (g) Gamma correction attack (h) AWGN attack.

Table 2 *The robustness test w.r.t SSIM watermarked and SSIM extracted*

parameters	SSIM watermarked		SSIM extracted	
technique / Attacks	**Agoi et al. technique [6]**	**Proposed technique**	**Agoi et al. technique [6]**	**Proposed technique**
Histogram equalization	0.7255	0.7750	0.4823	0.9924
Sharpening	0.4561	0.8569	0.1136	0.9924
Flipping	0.2258	0.8572	1.0000	0.9924
Blurring	0.6373	0.8603	-0.0896	0.9924
Contrast adjustment	0.8195	0.7915	0.6439	0.9924
Gamma correction	0.6061	0.8176	0.6881	0.9924
AWGN	0.1960	0.8421	0.1725	0.9924

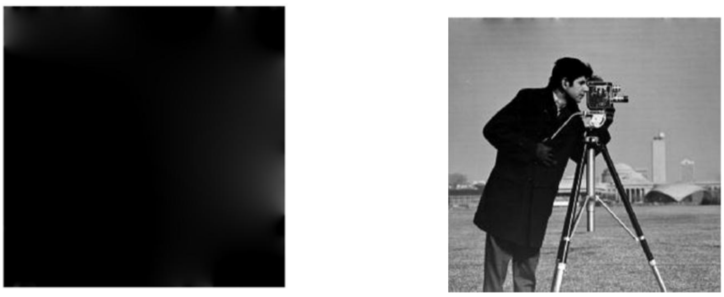
Table 3 *The robustness test w.r.t N.C coefficient*

techniques / Attacks	**Agoi et al. technique [6]**	**Proposed technique**
Histogram equalization	0.9776	0.9929
Sharpening	0.9791	0.9929
Flipping	1.0000	0.9929
Blurring	-0.6533	0.9929
Contrast adjustment	0.9916	0.9929
Gamma correction	0.9810	0.9929
AWGN	0.6362	0.9929

In 'Table 2' and 'Table 3' we can see that in proposed technique, attacks impact is very less on the parameters like SSIM watermarked, SSIM extracted and N.C coefficient, so we can say that proposed technique is robust against different attacks.

- **Security:**

The security test can check the authentication of the process, in this the watermark can leaves security on the image; it is the subordinate image which is enclosed on the host image. This is just like a digital signature, which offers a sense of ownership and authenticity to the image. If signature or key is not given at extracted side then we can't get the extracted watermark image. We simply understand in Fig. 9 The digital signature authentication mechanism give benefits like to solve the false positive problem, security, authentication and copyright protection which is one of the important problem in watermarking area.



(a) *(b)*

Fig. 9. *Extracted watermark image (a) without key (b) with key*

Discussion:

We have presented PPSD-DWT-SVD based technique. It follows two procedure watermark embedding and extraction process. The experimental result of the proposed technique is illustrated in this result section. The original 256 x 256 grayscale image of "Lena" was used as the cover image. The experiments were conducted using 128*128 watermark image. In the proposed technique we apply PPSD at host and watermark image while in Aherrahrou et. al. technique [1] PPSD apply at host image only, Thus the visual quality of the watermark image of the proposed technique is better. The PSNR values in dB are given in 'Table 1'. Now for robustness test different kind of attacks were applied on the watermarked image like histogram equalization, sharpening, flipping, blurring, contrast enhancement, gamma correction and AWGN on Lena image and the results are given in 'Table 2' ,'Table 3' and the security test is shown in 'Fig.9'.

5. Conclusions

The crucial features of the proposed technique are:

- The imperceptibility is increase which is measure by PSNR and the PSNR=92.9075 dB of the image. If the PSNR is increase mean the imperceptibility is increase. So our new result show the better result.
- Image should be robust against different attacks like AWGN, gamma correction, contrast enhancement, blurring, flipping, sharpening and histogram equalization and we check three parameters for robustness i.e. SSIM Watermarked, SSIM extracted watermark and NCC.
- The false positive problem is solved by digital signature authentication mechanism. For the authentication purpose we apply a digital signature in embedding process and check the authentication at extraction process. By this we get security from copyright protection, illegal duplication.

To define the efficiency of the proposed technique we compared our new results with Agoyi et al., technique 2014, Makbol et al., 2014, and Aherrabrou et al.,2017 techniques. We might show that the proposed technique deliver the best compromise among invisibility, robustness and security.

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