DWT and SVD based Image Watermarking Scheme using Noise Visibility and Contrast Sensitivity

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***Abstract* —This paper presents a robust and imperceptible methodology of watermark embedding in the transform domain using Discrete Wavelet Transform (DWT). The robustness is brought about by hiding the watermark in the Eigen values after computing the Singular Value Decomposition (SVD) on low frequency sub-band after DWT. While for the imperceptibility the Contrast Sensitivity Function (CSF) has been employed here along with the Noise Visibility Function (NVF). Human beings are sensitive to visual contrasts so CSF is used to take care of that while NVF characterizes the local image properties of texture, edge and smoothness to determine the optimal watermark locations and strength at the wavelet sub-bands for watermark embedding. The algorithm has been tested on 16 metrics out of which 10 are for imperceptibility and 6 for robustness for some popular attacks and the result has been found encouraging.**

***Keywords*—Watermarking, Singular Value Decomposition (SVD), Discrete Wavelet Transform (DWT), Contrast Sensitivity Function (CSF) , Noise Visibility Function (NVF).**

I. INTRODUCTION

Digital watermarking is one of the popular solutions to copyright protection of multimedia data like image, audio, video, etc. This will help out the content integrity authentication and piracy avoidance to some extent [1] [2]. The digital watermarking done should satisfy two main properties of imperceptibility and robustness [3]. This is because the quality of the original media should appear unaffected visually and the watermark has to survive compression and noise which are unavoidable [4] [5].

Singular value decomposition (SVD), is a generalization of the Eigen-value decomposition, is used to analyze rectangular matrices (the Eigen-value decomposition is defined only for squared matrices). It has been used widely in field of image compression and watermarking either individually or in hybrid form with other popular transforms like discrete cosine transform (DCT), discrete wavelet transform (DWT), and many more. The main idea of the SVD is to decompose a rectangular matrix into three simple matrices (two orthogonal matrices and one diagonal matrix) [6] [7].

In this paper, a DWT and SVD based watermarking technique is presented using noise visibility function (NVF) and contrast sensitivity function (CSF). Here the DWT and SVD techniques employed takes care of the robustness part while the NVF and CSF takes care of the imperceptibility part of the digital watermarking technique. Till date a lot of work has been done using HVS, NVF, and CSF but most have been used with different wavelet based transforms or along with DCT. But novelty of the work here lies in the fact that SVD has been used here along with CDF9/7 wavelets, NVF and CSF. Moreover the usage of CDF and SVD helps in easier hardware implementation of algorithm.

The algorithm has been tested for imperceptibility based on calculation of ten popular metrics and for robustness based on six popular metrics. So for imperceptibility Peak Signal to Noise Ratio (PSNR), Signal to Noise Ratio (SNR), Mean Square Error (MSE), Image Fidelity (IF), Maximum Difference (MD), Average Absolute Difference (AD), Normalized Average Absolute Difference (NAD), Normalized Mean Square Error (NMSE), Laplacian Mean Square Error (LMSE) and Structural Content (SC) values have been calculated. And for robustness Normalized Cross Correlation (NC), Correlation Quality (CQ), Pearson Correlation Coefficient (PCC), Correlation Factor (CF), Watermark To Document Ratio (WDR) and Correlation (CR) have been calculated for some popular attacks [24] [25].

II. NVF AND CSF

Human vision system (HVS) pays more attention to the flat regions than textured or edge regions. Thus small changes in smooth area are highly visible. So it is un-reasonable to embed the watermark in the smoother pastures of the host image. A solution to this problem is the usage of the NVF based on a non-stationary Gaussian model in [8] [9] to analyze the local image properties and to identify the textured and edge regions where more secret bits should be embedded. There by as per the local variance detecting the less attention-getting regions where the watermark bits can be embedded. The NVF is defined by equation (1) as under:

$$NVF(i,j) = \frac{1}{1+\theta\sigma_x^2(i,j)}, \quad \theta = \frac{D}{\max[\sigma_x^2]} \tag{1}$$

where $\sigma_x^2(i,j)$ is the local variance of the window of size $x \times x$ centered at (i,j), θ is the turning parameter which varies image to image (thus bringing in the HVS criteria), and $\max[\sigma_x^2]$ is the maximum local variance and $D \in [50,100]$

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is an experimentally determined constant. In Figure 1 D=75 for the 'Lena' image. As NVF approaches 1 the smoother regions, and approaches 0 in the regions that alter intensively [10] [11].

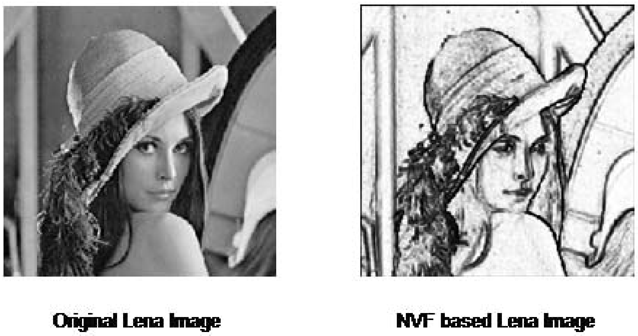

Figure 1: Original 'Lena' Image and noise visibility function image of 'Lena'

At a given spatial frequency how well the HVS perceives a contrast is quantified by the contrast sensitivity function (CSF) i.e. the function sets the contrast perception with respect to the spatial frequency [12] [13]. As per CSF the spatial frequency response is modeled approximately by:

$$S(\omega) = \frac{3}{2} e^{\frac{-\sigma^2 \omega^2}{2}} - e^{-2\sigma^2 \omega^2}, \tag{2}$$

where

$$\sigma = 2, \omega = \frac{2\pi f}{60}, \; f = \sqrt{u^2 + v^2} \tag{3}$$

and u and v are the horizontal and vertical spatial frequencies respectively in cycles per degree. As compared to the CSF modeled for instance in [14] the response of equation (2) gives more weight to low frequencies, which is critical to the reproduction of edges [15]. High frequencies also need to be attenuated as compared the measured CSF of human vision to account for the transfer function [12][19] [20]. For maximum frequency +20 and minimum frequency -20 the CSF matrix plot for frequency sampling based FIR filter design for applying CSF to the image is given in figure 2.

At higher spatial frequencies the frequency response is anisotropic [16], [17] so that a better model [18] is given by:

$$S_a(u,v) = S(\omega) O(\omega, \theta), \tag{4}$$

with

$$O(\omega, \theta) = \frac{1 + e^{\beta(\omega - \omega_0)} \cos^4 2\theta}{1 + e^{\beta(\omega - \omega_0)}}, \tag{5}$$

where $\theta = \tan^{-1}(u/v)$ is the angle with respect to the horizontal axis.

$$\beta = 8, \; f_o = 11.13 \text{ cycles/degree} \tag{6}$$

and $O(\omega, \theta)$, blends in a $\cos^4 2\theta$ anisotropy fairly quickly for frequencies $f > f_o$. The frequency weighted error $e_w(m,n)$, then is just the contrast adjusted error filtered with $S_a(u,v)$ [12]. In figure 2 the 41x41 plot for the maximum and minimum frequencies being +20 and -20 is taken using the frequency sampling technique. Based on this the two-dimensional (2D) FIR filter is obtained using frequency sampling method of filter design. This 2D FIR filter is applied on the original Image to get the HVS based CSF applied image [21-23].

III. WATERMARKING METHODOLOGY

The 256 x 256 'Lena' image has been used here as the host image and the logo to be watermarked is 32 x 32 and has the initials 'S' four times. The wavelet used is Cohen-Daubechies-Feauveau (CDF) 9/7 wavelet, which is the name 'cdf97'. Though other wavelets could be used, this wavelet is preferred due to its ease of implementation in lifting based technology for hardware applications in near future. Here the host image undergoes two levels of wavelet transform based decomposition. The first level provides the CA_1, CH_1, CV_1 and CD_1, which are the approximate, horizontal, vertical and diagonal coefficients. The CA_1 again undergoes another similar decomposition to yield CA_2, CH_2, CV_2 and CD_2.

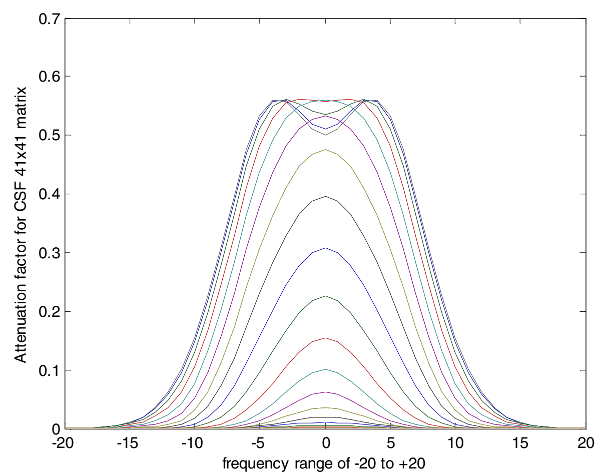

Figure 2: For f_{max}= +20 and f_{min}= -20 the CSF matrix plot for frequency sampling based FIR filter design for applying CSF to the image.

As shown in the figure 3 above, watermarking is done in 3 sub bands only; CH_1 and CV_1 in the first level and CH_2 in the second level. In CH_2 the watermarking is done by first undergoing singular value decomposition (SVD) on it to get the two orthogonal matrices and the diagonal Eigen value matrix as in equation (7).

$$SVD[CH_2] = \begin{cases} U_{CH2} \\ S_{CH2} \equiv \text{Diagonal Eigen value matrix} \\ V_{CH2} \end{cases} \tag{7}$$

The 32x32 intensity reduced logo (by multiplying it with K<1) is embedded in the S_{CH2} to obtain S_{CH2}^{L} where 'L' on the prefix denotes the embedded logo. This undergoes another SVD operation to yield new set of Eigen value matrix S_{CH2}^{W}.

$$S_{CH2}^{L} = S_{CH2} + \mathrm{K} \times \mathrm{LOGO}, \quad SVD\left[S_{CH2}^{L}\right] = \begin{cases} U_{CH2}^{W} \\ S_{CH2}^{W} \\ V_{CH2}^{W} \end{cases} \tag{8}$$

Now interchanging the Eigen value matrices of equation (7) and (8) and combining, the watermarked image CHI_W and the key image CHI_K (for logo detection) are obtained.

$$CHI_W = U_{CH2} \times S_{CH2}^{W} \times \left[V_{CH2}\right]^T \tag{9}$$

$$CHI_K = U_{CH2}^{W} \times S_{CH2} \times \left[V_{CH2}^{W}\right]^T \tag{10}$$

This CHI_W replaces the previous CH_2, and along with CA_2, CV_2 and CD_2 undergoes inverse discrete wavelet transform (IDWT) to obtain CA_1^W instead of CA_1 as shown in figure 3.

$$\mathbf{DWT_{2D}}\left[CA_1\right] = \begin{cases} CA_2 \Rightarrow CA_2 & \Rightarrow \\ CH_2 \Rightarrow SVD\left[CH_2\right] \oplus \boxed{\text{Logo}} & \Rightarrow \\ CV_2 \Rightarrow CV_2 & \Rightarrow \\ CD_2 \Rightarrow CD_2 & \Rightarrow \end{cases} \begin{bmatrix} CA_2 \\ CHI_w \\ CV_2 \\ CD_2 \end{bmatrix} \mathbf{IDWT_{2D}} \Big\} CA_1^W$$

Figure 3: The SVD based embedding procedure in CH_2 sub-band in 2nd level.

$$\mathbf{DWT_{2D}}[I] = \begin{cases} CA_1 \Rightarrow \underset{\text{embedding}}{SVD} \quad \text{2nd Level DWT} & \text{Logo} \Rightarrow \\ CH_1 \Rightarrow CSF + NVF\left[CH_1\right] \oplus \boxed{\text{Logo}} & \Rightarrow \\ CV_1 \Rightarrow CSF + NVF\left[CV_1\right] \oplus \boxed{\text{Logo}} & \Rightarrow \\ CD_1 \Rightarrow CD_1 & \text{Logo} \Rightarrow \end{cases} \begin{bmatrix} CA_1^W \\ CH_1^W \\ CV_1^W \\ CD_1 \end{bmatrix} \mathbf{IDWT_{2D}} \Big\} \left[I_W\right]$$

Figure 4: The CSF+NVF based embedding procedure in CH_1 and CV_1 sub-band in 1st level of 2D DWT operation.

The process of embedding the watermarking in CH_1 and CV_1 are similar. The contrast sensitivity function (CSF) is applied on the sub-band image with a two dimensional FIR filter designed by frequency sampling method for maximum and minimum frequency being ±3. After applying CSF the noise visibility function is applied with D=75. The earlier 32x32 binary ([0,1]) logo is converted to [1,-1] format binary logo with a lowered intensity (by multiplying $K_1 < 1$) and embedded in the sub-band image positions based on the obtained NVF of the sub-band image. So CH_1 and CV_1 are replaced by CH_1^W and CV_1^W. Therefore the combination of CA_1^W of previous stage in figure 3, along with CH_1^W and CV_1^W after CSF and NVF operation and the unchanged CD_1 containing the row and column wise high frequency components produces the watermarked image I_W for original 256x256 'Lena' image I. This operation is represented in figure 4 and the overall watermarking operation of embedding the 32x32 logo three times in the figure 5.

The peak signal to noise ratio (PSNR) of the watermarked image I_W after embedding the 32x32 logo three times with original image I is 41.72dB. In case watermarking is done in CA_2 or an extra set of watermark in CV_2 reduces the image PSNR to less than 40dB. Therefore in this embedding operation the watermark has been embedded three times only to keep the quality of the image.

The watermark extracting methodology requires the two intensity reducing key values K_1 and K for the CSF+NVF operation and the SVD based operation respectively. Other than these the predefined value of NVF threshold for the CSF+NVF operation and the key image CHI_K for SVD based operation are required in the receiver end. These may be predefined or can be transmitted through a secure channel.

In the receiver end instead of the transmitted watermarked image I_W normally the image I_{WN} is obtained as the stego image. This I_{WN} is the noisy version of I_W due to noise, channel distortion or malicious attacks on it. The watermark is extracted by firstly undergoing the 2 level DWT operation using the Cohen-Daubechies-Feauveau (CDF) 9/7 wavelet. Here the CH_1^{NW} and CV_1^{NW} of the first level and the CHI_{NW} of the second level are taken for detection. The steps are just the reverse of the previous embedding procedure. There by three logos are obtained. The best of the three logos is considered as the detected logo. The watermark detection operation is shown in figure 6.

IV. Results and Discussion

The 'Lena' host image of size 256x256 watermarked using the DWT and SVD along with noise visibility and contrast sensitivity functions. Here 32x32 logo used is embedded 3 times out of which after detection the best detected logo is considered as the detected logo. The image has been attacked 4 times here with four very common attacks. They are firstly 'salt and pepper' noise attack, compressing the image to 25% actual size and resizing using bicubic interpolation, image sharpening using 3x3 image mask and image crop attack. So for all these four attacks the metrics for checking imperceptibility and robustness have been calculated and provided in Table I and Table II, respectively. Therefore as it can be seen from the 16 different metrics, the performance is good under these type of commonly feasible attacks.

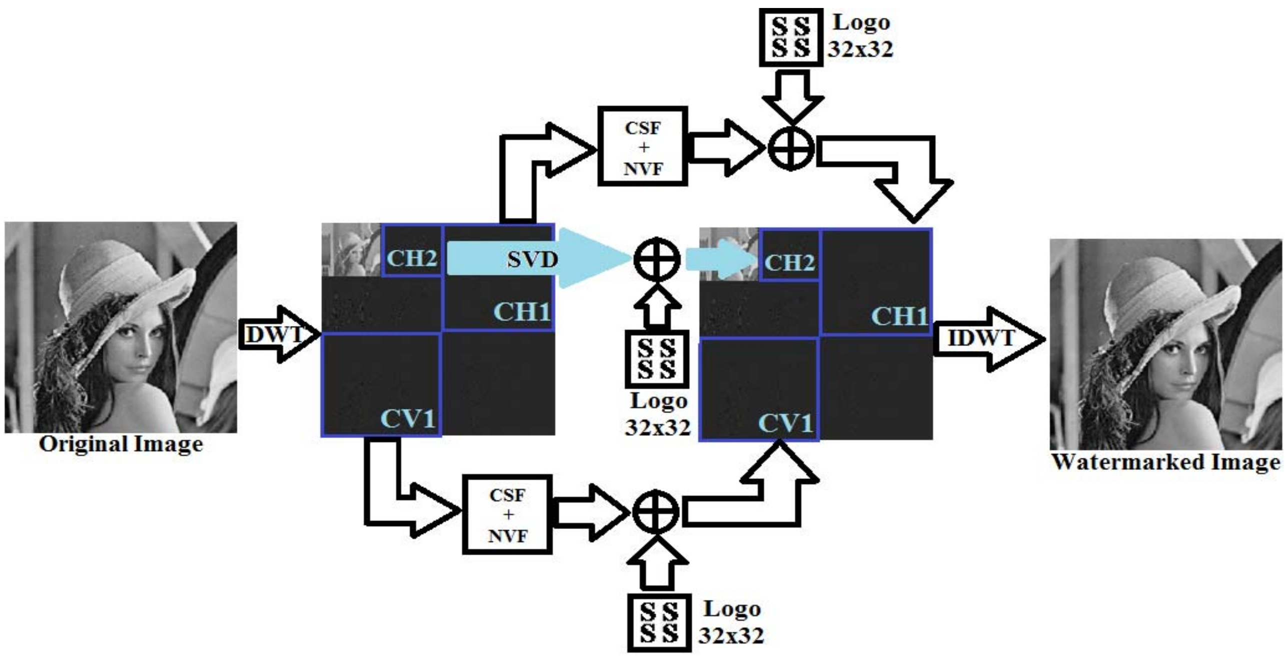

Figure 5: Over all watermark embedding procedure in CH_1, CV_1 and CH_2.

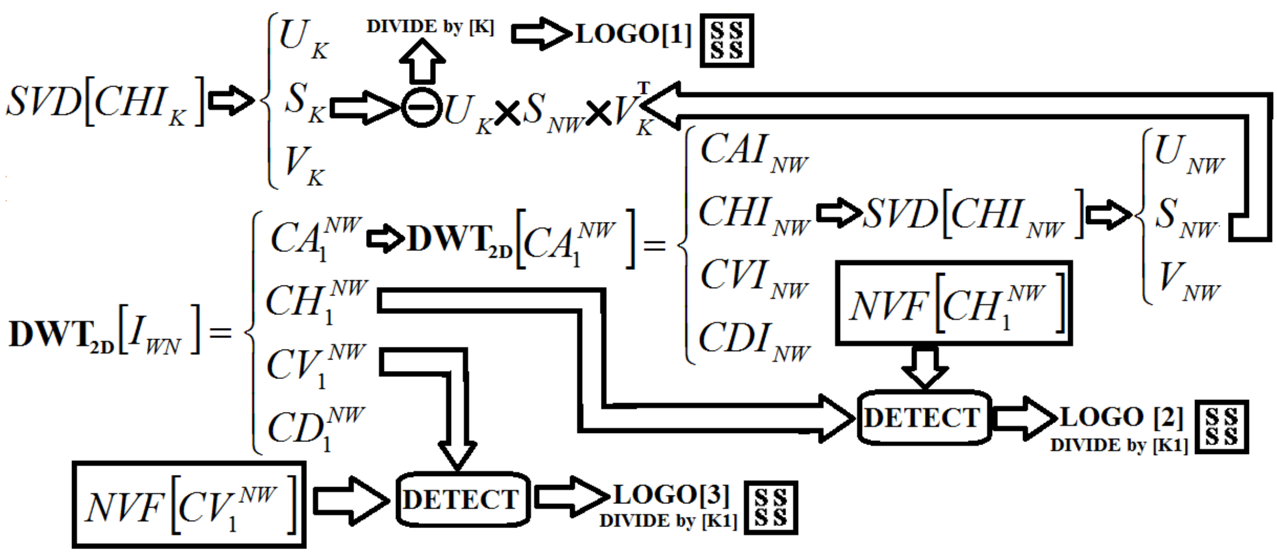

Figure 6: Over all watermark extraction procedure.

TABLE I. IMPERCEPTIBILITY MEASURE FOR DIFFERENT ATTACKS

Sl. No.	Metric	'salt and pepper' noise attack	25% Compression and resizing using bicubic interpolation	image sharpening using 3x3 image mask	image crop
1	PSNR	42.46 dB	34.77dB	39.48 dB	42.08932
2	SNR	32.03 dB	16.66 dB	29.79 dB	26.00976
3	MSE	11.073	381.34	91.0729	234.34267
4	IF	0.99937	0.97842	0.9294141	0.988895
5	MD	43.0466	242	40.033338	166.7233
6	AD	1.9194	4.3936	1.785042	3.59586
7	NAD	0.015477	0.035429	0.0201201	0.0289959
8	NMSE	0.000627	0.021584	0.00081475	0.0132638
9	LMSE	0.10101	5.075	0.131313	3.095505
10	SC	1.0021	0.9864	0.9860664	1.09289

TABLE II. ROBUSTNESS MEASURE FOR DIFFERENT ATTACKS

Sl. No.	Metric	'salt and pepper' noise attack	25% Compression and resizing using bicubic interpolation	image sharpening using 3x3 image mask	image crop
1	NC	0.99861	0.9961	0.997355	0.9886239
2	CQ	142.27	141.91	142.13	142.09
3	PCC	0.9976	0.92199	0.987624	0.959795
4	CF	0.99969	0.9893	0.9995901	0.994495
5	WDR(-)	32.0292	16.6586	30.42774	26.00976
6	CR	0.99969	0.9893	0.99469155	0.994495

V. Conclusion

In this paper a novel hybrid watermarking scheme is presented with the logo embedded in the DWT based transform domain along with SVD, NVF and CSF. The algorithm has been tested for a set of attcks under which the respective metrics were measured to compare the imperceptibility and the robustness of the algorithm. The future work to be included is to check its robustness and imperceptibility for a lot of other available attacks & include more metrics to justify that.

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