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A Novel Watermarking using Multiresolution SVD

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***Abstract*—With the daily advancement of technology, copyright protection of all types of digital media has become an important issue. Thus to aid the copyright protection digital watermarking has emerged as solution to this problem. In this paper a new digital image watermarking scheme is proposed which combines Singular Value Decomposition (SVD) and its multiresolution variant. Tests have been undergone to check the proposed scheme for robustness and imperceptibility. The scheme has been compared with 3 previously standard schemes with respect to normalized correlation coefficient value of detected watermark.**

***Index Terms*— Image Watermarking, Singular Value Decomposition (SVD), Multiresolution-SVD.**

I. INTRODUCTION

Digital image watermarking is a process of embedding some secret information into an image (called as cover/host image) for the purpose of copyright protection. For an efficient image watermarking, the embedding of watermark should not degrade the visual quality of cover image and it must be robust to various types of malicious attacks by miscreants [1].

Digital watermarking schemes are usually based on either spatial or transform domain. In spatial domain based image watermarking, the watermark is embedded by directly modifying the pixel values of host image. While, in transform domain modification of frequency coefficient of image is done for embedding watermark. Generally, transform domain based watermarking schemes have more information embedding capacity and more robustness than their spatial counterpart. Discrete Cosine Transform (DCT), Discrete Wavelet Transform (DWT), Discrete Fourier Transform (DFT), and many other frequency modifying transform variants are commonly used for transform domain watermarking. In last few years the Singular Value Decomposition (SVD) based transform has been popularly used in watermarking [2] [3].

The SVD has some inherent properties in it which makes it popular to use stated as follows:

1. Singular Values (SVs) are stable i.e. any change to it doesn't affect the image quality.
2. SVs are able to represent inherent algebra properties of digital image.
3. SVD preserves both one-way and non-symmetric properties, which are not available using DCT or DFT transformations.
4. The size of matrices can be square or rectangular in SVD with ease in hardware implement-ability.
5. SVs are known to be invariant to some common attacks such as JPEG compression, noise addition, low pass filter (LPF), rotation, scaling and cropping.

Watermarking schemes based on SVD alone can't guarantee high robustness against attacks; therefore it is applied in combination with DCT, DFT or DWT due to their multiresolution capabilities.

Kakarala and Ogunbona [4] projected the idea of multiresolution form of the SVD (i.e. MR-SVD). Based on the analysis of MR-SVD it has been shown that this technique yields faster computation of larger data than the basic SVD operation [6-8]. A new image watermarking scheme is presented here, where SVD is combined with MR-SVD. The rest part of this paper is organized as follows. Section II implies basic concepts of SVD. Section III explains concepts of MR-SVD. Section IV illustrates the watermarking methodology. Section V provides experimental results, where the NC values of some attacks are compared with previous works of [9], [2] and [10] for showing the robustness of the proposed scheme in extension of our works [13][14]. Section VI concludes the paper.

II. SINGULAR VALUE DECOMPOSITION (SVD)

Singular Value Decomposition (SVD) is one of the popular mathematical tools for analysis of matrices. The SVD for square matrices was first introduced by Beltrami and Jordan in 1870 and then it was extended to rectangular matrices by Eckart and Young in 1936 [5].

Also SVD has shown its usefulness in variety of applications including image processing and watermarking. If A is an image of size *n*×*n*, then SVD of A is shown as below equation 1.

$$\text{SVD (A)} = USV^T \tag{1}$$

where U and V are orthogonal matrices whose columns are called as left and right singular vectors respectively. S is a diagonal matrix of singular values σ_i , i=1, 2…n arranged in decreasing order and elements of S matrix are zero except diagonal elements. Therefore:

$$\begin{pmatrix} U_{11}\cdots U_{1n} \\ U_{21}\cdots U_{2n} \\ \vdots \;\; \vdots \;\; \vdots \\ U_{n1}\cdots U_{nn} \end{pmatrix} \begin{pmatrix} \sigma_{11}\cdots \;0 \\ \vdots \;\; \ddots \;\; \vdots \\ 0 \;\;\cdots\sigma_{11} \end{pmatrix} \begin{pmatrix} V_{11}\cdots V_{1n} \\ V_{21}\cdots V_{2n} \\ \vdots \;\; \vdots \;\; \vdots \\ V_{n1}\cdots V_{nn} \end{pmatrix} = \sum_{i=1}^{r} \sigma_i u_i v_i^T \tag{2}$$

where r = rank of matrix A

u_i and v_i= left and right singular vectors

III. MULTIRESOLUTION SVD (MR-SVD)

MR-SVD process for digital image is similar to DWT of 2D signal [4] [7]. In case of DWT transform separate filtering of 2D signal are done by low and high pass filters and both the outputs are decimated by factor two; the decimation process is recursively repeated on the low pass output up to required level of decomposition. But in MR-SVD process the filtering of the outputs is replaced with the SVD operation at each level of approximation [4]. Both MR-SVD and SVD are matrix based operations and their combination avoids convolution function (as in case of DWT) which requires lots of resources.

In MR-SVD process the first level of decomposition proceeds as follows, the digital image (say X) is divided into non-overlapping 2 x 2 blocks and each block is arranged into a 4 x 1 vector by stacking columns to form the data matrix say X_1.This data matrix is centered by removing the mean in each row from elements of that row. Mathematically it can be shown as:

$$\overline{X}_1 = X_1 H_N \tag{3}$$

where $H_N = I_N - \frac{1}{N} e_N e_N^t$,

$I_N \rightarrow N \times N$ identity matrix,

and $e_N \rightarrow N \times 1$ vector containing all ones.

Then the Eigen decomposition of 4 x 4 matrix is computed by the equation (4) and then the SVD of scatter matrix (say T) is also computed:

$$T = \overline{X}_1 \overline{X}_1^T = USV^T \tag{4}$$

Since U and V are orthogonal matrices, letting:

$$\widehat{X}_1 = U^T \times \overline{X}_1 = S \times V^T \tag{5}$$

The SVD can also be written as $\overline{X}_1 = U^T \times \overline{H}_{X1}$. In this case, since U is the decorrelating matrix obtained from statistics of the input signal, $\widehat{X}_1$ contains the subband decomposition of the signal. The top row of the resulting matrix, $\left[\widehat{X}_1(1,:)\right]$, is rearranged to form an $M/2 \times N/2$ matrix ϕ that corresponds to the largest Eigen value and is considered as the smooth (approximation) components of the image. The remaining rows of $\widehat{X}_1$, i.e. $\left[\widehat{X}_1(2,:)\right]$, $\left[\widehat{X}_1(3,:)\right]$, and $\left[\widehat{X}_1(4,:)\right]$ contain the detail components, which denoted as φ_1, φ_2 and φ_3 respectively.

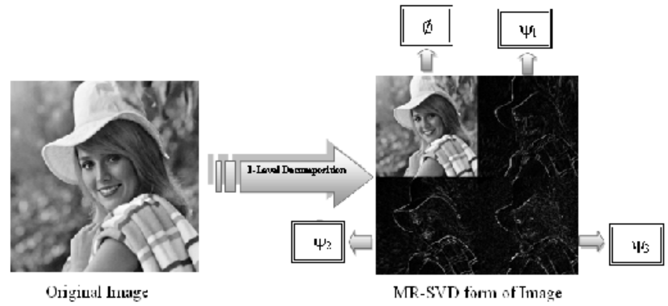


Fig. 1. Original ‘Elaine’ Image of 256x256 and its 1-level MR-SVD form

For the next level of transform, X is replaced by ϕ and the process is repeated as mentioned above. The complete transform can be represented as follows:

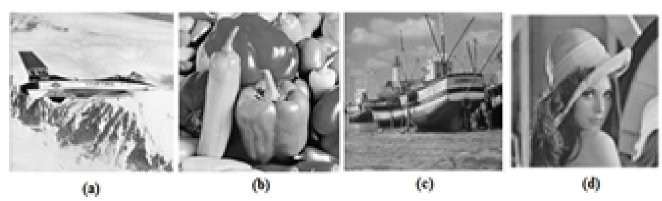


Fig. 2. (a) Plane, (b) Pepper, (c) Boat, (d) Lena.

$$X \rightarrow \left\{ \phi^L, \left\{ \varphi_1^l, \varphi_2^l, \varphi_3^l \right\}^{l=1,2,...L}, \{U^l\}^{l=1,2,...L}, \{\mu^l\}^{l=1,2,...L} \right\} \tag{6}$$

where L is the desired level of the decomposition and $\mu = \left(\frac{1}{N}\right) X_1 e_{N1}$, the mean vector.

The reverse process is just the opposite of above for L=1. The original image is reconstructed from $\left\{ \phi^L, \left\{ \varphi_1^l, \varphi_2^l, \varphi_3^l \right\}^{l=1,2,...L}, \{U^l\}^{l=1,2,...L}, \{\mu^l\}^{l=1,2,...L} \right\}$.

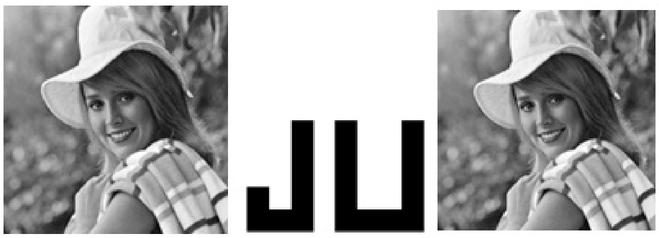
IV. WATERMARKING METHODOLOGY

In the proposed scheme a 256 x 256 gray scale image is taken as host image and a 16 x 16 binary logo as watermark. Here in figure only the ‘Elaine’ picture has been used, to provide the over view of the process.

A. Watermark Embedding

The watermark embedding steps are as under:

1. 1-Level MR-SVD decomposition applied on the 256×256 cover/host image to get smooth and detail components i.e. ϕ, φ_1, φ_2 and φ_3 with each of size 128 × 128.



(a) (b) (c)

Fig. 3. (a)Original Image (b) Watermark/Logo (c) Watermarked Image

2. The smooth component (i.e. ϕ) is taken and the SVD procedure is applied to it., i.e. $SVD(\phi) = U_\phi S_\phi V_\phi^T$
3. The binary logo is added to the diagonal of S_ϕ. Embedded Data = $S_\phi + \mu W$, with μ =scale factor and W =binary logo, to be watermarked/embedded.
4. SVD of the matrix Embed is obtained to get $U_{embedded}$, $S_{embedded}$ and $V_{embedded}$.

TABLE I PSNR AFTER WATERMARKING FOR DIFFERENT IMAGES

	Elaine	**Plane**	**Pepper**	**Boat**	**Lena**
PSNR(dB)	79.2463	79.3224	79.7072	79.8486	79.6683

U_ϕ and V_ϕ combined with $S_{embedded}$ to get watermarked smooth component ϕ_W. Then reverse MR-SVD is applied to ϕ_W along with detail components (i.e. φ_1, φ_2 and φ_3) to get the watermarked image which looks similarly as the original image.

A. Watermark Extraction

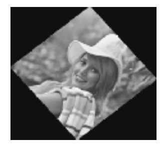
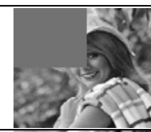
The watermark extraction steps are as under:

1. MR-SVD process is applied to the stego image to get the ϕ_{1W}, φ_{1W}, φ_{2W} and φ_{3W}.
2. SVD is applied to ϕ_{1W} (as watermark is embedded in this region) to extract the watermarked SVs i.e. S_{1W}.
3. The binary watermark is extracted as: $$Watermark = \frac{1}{\mu}\left(U_{embedded} S_{1W} V_{embedded}^T - S_\phi\right)$$

V. EXPERIMENTAL RESULTS

In this paper the standard image 'Elaine' of size 256 × 256 is taken as host image and a binary logo of size 16 × 16 is taken as watermark object. Here the scale factor μ is chosen as 9.

TABLE 2. THE DIFFERENT ATTACKS EMPLOYED ALONG WITH THE EXTRACTED WATERMARKS

Type	**Attacked Image**	**Extracted Watermark**
JPEG 90% Compression		
Resizing (256→64→256)		
Median [9×9] Filter		
50^0 Rotation		
Cropping		
Low Pass Filter		
Histogram Equalization		
Average Filter		

The proposed scheme also tested using images each of size 256× 256 named Plane, Pepper, Boat, and Lena as shown in figure 2.

PSNRs after applying the proposed scheme on the images is tabulated in Table I.

In figure 3 the image of original and watermarked image of 'Elaine' is shown. The watermarked image has PSNR of 79.2363dB. As shown in Table I the other images like 'Plane', 'Pepper', 'Boat' and 'Lena' too have similar PSNR of about 79 dB approximately. This implies that the method is rather logo/watermark's payload dependent and not image dependent. This is because for all different images of same size, the PSNR is approximately constant irrespective of the image. Moreover, even after embedding the watermark in the smooth component of MR-SVD (same as LL sub-band in case of DWT), it doesn't affect the image quality much. It is very unlikely in most DWT based watermarking algorithm image quality is significantly affected after embedding data in LL sub-band.

The proposed scheme is tested by various kinds of attacks, as in Table II. Some of the popular attacks employed are JPEG compression, resizing, median filtering, rotation, cropping, low pass filtering, histogram equalization and average filtering. The results of each attack i.e. NC values are shown in Table-III for three different images namely 'Eliane', 'Boat' and 'Lena'. The stego images after attacks and extracted watermark from the corrupted images are depicted in figures of Table II for one of the three standard images on which the different attacks have been tested. Table IV has the normalized correlation coefficient values of some attacks on the watermarked 'Lena' image are compared with previous watermarking schemes of Ganic and Eskicioglu [9]; Liu and Tan [2]; and Lai and Tsai, [10]. It is to show the robustness of the proposed scheme. The values of normalized correlation coefficients show that the proposed scheme is at par, if not better than the earlier schemes.

TABLE 3. NORMALIZED CORRELATION COEFFICIENT (NCC) FOR THE THREE STANDARD IMAGES FOR THE DIFFERENT ATTACKS.

ATTACKS		Normalized Correlation Coefficient		
		Elaine	Boat	Lena
JPEG Compression	(Q=40)	1	0.9999	1
	(Q=90)	0.9998	0.9997	0.9998
Resizing	(256→64→256)	0.9997	0.9995	0.9996
	(256→128→256)	0.9999	1	1
Median Filter	[3×3] window	1	0.9998	0.9998
	[9×9] window	0.9992	0.9979	0.9981
Average Filter [3×3] window		0.9999	0.9997	0.9999
Low Pass Filter		0.9999	0.9998	0.9998
Cropping		0.9703	0.9997	0.9974
Rotation	20 degree	0.9832	0.9588	0.9748
	50 degree	0.9684	0.8992	0.8945
Salt & Pepper Noise(0.3)		0.8154	0.771	0.8196
Histogram Equalization		0.9972	0.968	1

TABLE 4. NORMALIZED CORRELATION COEFFICIENT (NCC) FOR THE THREE STANDARD SCHEMES [9], [2] AND [10] WITH OUR SCHEME FOR THE DIFFERENT ATTACKS.

Attacks	Normalized Correlation Coefficient			
	Ganic and Eskicioglu	Liu and Tan	Lai and Tsai	Our Method
Cropping	0.7063	0.9578	0.9843	0.9917
Rotation	0.9091	0.9444	0.9897	0.9763
Averaging Filter	-0.7047	0.8978	0.9597	0.9401
JPEG Compression	0.9226	0.9554	0.9772	0.9971
Histogram Equalization	0.9700	0.9780	0.9890	0.9982
Contrast Adjustment	0.9989	0.9871	0.9994	0.9994

VI. CONCLUSION

In this paper SVD is combined with MR-SVD for the watermarking scheme. The watermark object had been embedded in the smooth component of MR-SVD of the original image like the popular DWT based schemes but yield better results. The algorithm has been tested by taking other images and also for different attacks for imperceptible and robustness. From overall observation it has been established that the proposed scheme yields better imperceptibility and robustness against various attacks which makes the proposed scheme suitable for some application. This has been supported by the comparision of NCC values with respect to other standard watermarking schemes. Moreover as the whole scheme is matrix based operation, so implementation of the algorithm is easier on FPGA unlike the popular DWT and DCT based schemes.

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