A Comparative Study of Well-known SVD-based Image Watermarking

Nour El-Houda Goléa, Rachid Seghir
Department of Computer Science
University of Batna, Algeria

Redha Benzid
Department of Electronics
University of M'Sila, Algeria

***Abstract*—The Singular Value Decomposition (SVD) is one of the most useful tools of linear algebra having several applications in image processing, and more recently in digital watermarking. In this paper, we compare between three different and well-known approaches using SVD transformation to embed a watermark in digital images. Experimental results show that these schemes maintain high quality watermarked images and robustness against several conventional attacks. We also pointed out some weaknesses of these methods and some solutions proposed by other researchers.**

Keywords: digital watermarking, Singular Value Decomposition, SVD-based image watermarking.

I. INTRODUCTION

The improvement of telecommunication and fast development of multimedia technology makes the process of storage and transmission of digital products easier. However, the ease of such manipulations may encourage the piracy of digital media without appropriate permissions. As a result, the protection of multimedia items becomes a great challenge.

Therefore, there is an urgent need for protecting the copyright of digital content against piracy and malicious manipulations [1].

In order to protect copyrighted material, two typical technologies have been developed. The first one is *cryptography technology*. Cryptography and encryption techniques enable the appropriate security during the transmission process, but once the encrypted data is decoded, the control of redistribution and its spread fails. To address the limitations of encryption, the main idea is to label a digital material with specific marks, which are called *digital watermarks*. Such technology can be used as ownership proof for distribution channel tracking and other applications in business and public domains [2, 3].

In [2], Juergen Seitz defines the concept of digital watermarking technology as:" means embedding information into digital material in such a way that it is imperceptible to a human observer but easily detected by computer algorithm. A digital watermark is a transparent, invisible information pattern that is inserted into a suitable component of the data source by using a specific computer

In order to detect the watermark information, *blind* and *non-blind* techniques are used. A watermark method is said *non-blind* if the detection of the digital watermark needs the original source document, and it is said *blind* if the original document is not required in the detection process [2, 3].

Current image watermarking techniques described in the literature can be grouped into two main classes. The first one includes the *spatial domain* techniques, in which the watermark is embedded by directly modifying the pixel values of the original image. An example of such techniques is the use of the LSB of an image to store watermarking information [4]. The second class includes the *transform domain* methods, which embed the watermark data into the frequency domain representation of the host image.

Although DCT [5] and DWT [6] are the mostly used transform methods, the SVD transform has been significantly used in recent watermarking schemes. The SVD mathematical technique provides an elegant way for extracting algebraic features from an image and it is widely applied to digital image processing [7].

In SVD-based image watermarking several approaches are possible. The SVD may be applied to the whole image or, alternatively, to small blocks of it.

Liu and Tan [7] proposed an SVD-based watermarking scheme in which the SVD of entire host image is firstly calculated. Then, the watermark matrix is multiplied by scaling factor and added to the diagonal matrix of *Singular Values* (SVs). The modified diagonal matrix is finally inserted back in the host image.

In addition, Chandra also proposed two SVD-based schemes [8]. The first one is a Global-based scheme, and the second one is Blocked-based scheme. In the first scheme the SVD of both the host image and the watermark is performed. The SVs of the watermark are multiplied by a scaling factor and added to the SVs of the host image. Whereas in the second scheme the host image is segmented into blocks and one bit of the watermark is embedded into the largest SV of each block.

In Liu and Chandra Global-SVD methods, the watermark extraction requires the knowledge of the watermark and the original image. In particular, the extraction of the watermark needs to store three matrices (S, U_w and V_w) whose size is the same as that of the original image. Whereas Chandra Block-SVD scheme requires only the original image to extract the watermark.

In this paper, we compare between three different manners to use the SVD transformation in digital image watermarking:

- Embedding the watermark by adding *the SVs of the watermark to the SVs* of the host image (Global-SVD of Chandra scheme).
- Embedding the watermark by adding it to the *largest SV* of the host image (Block-SVD of Chandra scheme).

Embedding the watermark *directly in S matrix* of the host image, and *perform SVD* on this new matrix (Liu scheme).

We are interested in these methods, since they are among the first watermarking methods using the SVD transformation and are generally effective in terms of imperceptibility and robustness. We also mention that they are among the most cited schemes[1] and several researchers [9, 10] usually compare effectiveness of their methods against those of Liu and Chandra.

The remainder of this paper is organized as follows: in Section 2, we give a brief description of the SVD principle. Section 3 presents the digital watermarking algorithm based on SVD. More precisely, we describe the three algorithms of Chandra and Liu. In Section 4, the experimental results are described and analyzed. Finally, we draw the conclusions in Section 5.

II. Singular Value Decomposition

Every real matrix A can be decomposed into a product of three matrices $A = USV^T$, where U and V are orthogonal matrices, $U^TU = I$, $V^TV = I$, and $S = diag(\lambda_1, \lambda_2, ..., \lambda_r)$.

The diagonal entries of S are called the *Singular Values* (SVs) of A, the columns of U are called the left singular vectors of A, and the columns of U are called the right singular vectors of A. This decomposition is known as the Singular Value Decomposition (SVD) of A, and can be written as:

$$A = \sum_{i=1}^{r} \lambda_i U_i V_i ,$$

Where r is the rank of matrix A.

The singular values of an image satisfy the relation: $\lambda_1 \geq \lambda_2 \geq ... \geq \lambda_r > 0$. Each one specifies the luminance of an image layer, while the corresponding pair of singular vectors specifies the geometry of the image. The SVs have a very good stability, i.e., when a small perturbation is added to an image, its SVs do not change significantly. Therefore, many watermarking algorithms [7, 8, 9, 10] use the SVs of an image to embed the watermark.

III. SVD-based Digital Watermarking Algorithms

In this section, we focus ourselves on the description of three well-known SVD-based watermarking algorithms.

A. *Chandra watermarking methods*

In [8], Chandra proposed two SVD-based methods: Global-SVD-based scheme, and Block-SVD scheme.

1) Chandra Global-SVD algorithm

Let *f* be the original image, and let *W* be the watermark. The digital watermarking process proposed by Chandra is described through the following steps:

- The SVD is performed on the original image (*f* matrix):

  $f = USV^T$, where λ_i are the SVs of *f*.

- The SVD is performed on the watermark (*W* matrix):

$W = U_w S_w V_w^T$, where λ_{wi} are the SVs of *W*.

- Add the watermark to the host image: $\lambda_{yi} = \lambda_i + \alpha\lambda_{wi}$; Where α is a scaling parameter chosen to maintain the quality of the watermarked image.
- Let S_y be the diagonal matrix whose diagonal elements are λ_{yi}.
- The watermarked image (f_w matrix) is obtained using the new SVs (S_y matrix).

  $f_w = US_yV^T$.

To extract the possibly corrupted watermark W^* from the possibly distorted watermarked image, given the U_w, S and V_w matrices and the possibly distorted image f_w^*, the above steps are reversed as follows*:*

- The SVD is performed on the watermarked image (f_w^* matrix):

  $f_w^* = U^*S^*V^{*T}$.

- The diagonal matrix S_w^* of the extracted watermark is computed as follows:

  $S_w^* = (S^* - S)/\alpha$.

- The watermark (W^* matrix) is obtained using the extracted SVs (S_w^* matrix).

[1] Liu scheme: cited 161 times, Chandra scheme: cited 56 times.

$W^* = U_w S_w^* V_w^T$.

2) Chandra Block-SVD algorithm

- Divide the original image into non-overlapping blocks X_B, whose size is *k x k*.
- For each block X_B

  - Perform the SVD of X_B

  $$X_B = U_X S_X V_X^T.$$

  - Embed the watermark bit W_B, into the largest singular value λ_1^B of the block as follows:

  $$\lambda_{y1}^B = \lambda_1^B + \alpha W_B$$

  Where, α is a scaling parameter chosen to maintain the quality of the watermarked image, and λ_{y1}^B is the largest SV of the watermarked block.

  -Let S_y be the diagonal matrix where the largest SVs is λ_{y1}^B.

  - Reconstruct the watermarked block**.**

  $$X_y = U_X S_y V_X.$$

- Reconstruct the watermarked image from the watermarked blocks.

To extract the possibly corrupted watermark W^* from the possibly distorted watermarked image f_w^*, given the original image *f* the above steps are reversed as follows:

- Divide f_w^* into non-overlapping blocks X_B^*, whose size is *k x k*.
- For each block X_B^*

  - Perform the SVD of X_B^*

  $$X_B^* = U_X^* S_X^* V_X^{*T}.$$

  - The watermark bit W_B^* is obtained by:

$$W_B^* = (\lambda_{y1}^{B^*} - \lambda_1^B) / \alpha.$$

  Where λ_1^B is the largest SV computed from the original block and $\lambda_{y1}^{B^*}$ is the largest SV of the S_X^*.

B. *Liu and Tan watermarking method*

Let f be the original image, and let W be the watermark. The digital watermarking process proposed by Liu et al. is described through the following steps:

- The SVD is performed on the original image (f matrix):

$f = USV^T$, where λ_i are the SVs of *f*.

- The watermark (*W* matrix) is added to the SVs of the original image (*S* matrix).

$$D = S + \alpha W.$$

Where, α is a scaling parameter chosen to maintain the quality of the watermarked image.

- The SVD is performed on the D matrix:

$$D = U_w S_w V_w.$$

- The watermarked image (f_w matrix) is obtained using the modified SVs (S_w matrix).

$$f_w = US_w V^T.$$

To extract the possibly corrupted watermark W^* from the possibly distorted watermarked image f_w^*, given the U_w, S and V_w matrices the above steps are reversed as follows:

- The SVD is performed on the possibly distorted watermarked image (f_w^* matrix).

$$f_w^* = U^* S^* V^{*T}.$$

- The matrix containing the watermark is computed using U_w and V_w as follows:

$$D^* = U_w S^* V_w^T.$$

- The possibly corrupted watermark is obtained.

$$W^* = (D^* - S) / \alpha.$$

IV. SIMULATION AND EXPERIMENTAL RESULTS

In this section, several experiments are carried out to compare between these three algorithms (Liu, Chandra Global-SVD, and Chandra Block-SVD).

We mainly demonstrate the imperceptibility and the robustness of each watermarking method. The experimental results reported here have been separated into two parts: the first one is for testing the imperceptibility property and the other one is for testing the robustness against some types of the most interesting and standard attacks.

A. *Imperceptibility property*

In order to test the imperceptibility property, several typical gray scale images with size 256 x 256 such as Lena, Baboon and Girl have been watermarked with “Map-flag of Algeria” image. Due to limited space, only “Lena” gray scale image with its watermarked image have been respectively shown in Figure 1.

In the Global-SVD and Liu methods, the watermarks used have the same size as the original image (256 x 256). But in Block-SVD, we chose the size of block 8 x 8; hence the watermark is of size 32 x 32.

The watermarked image and extracted watermark by Liu method and Chandra methods are respectively shown in Figures 2, 3 and 4, where the parameter α is set to: 0.05, 0.02, and 0.1 respectively.

To concretely estimate the quality imperceptibility property, we employed the Peak Signal-to-Noise Ratio (PSNR) to evaluate the distortion of the watermarked images.

After extracting the watermark, the Correlation Coefficient (CC) is computed using the original watermark and the extracted one. This coefficient allows us to judge the existence and the correctness of the extracted watermark. The CC can take any value between 0 and 1. In principle, if the CC value is closer to 1, the extracted watermark is getting more similar to the embedded one. The CC between the original watermark W and the extracted one W^* is defined by [3]:

$$CC = \frac{\sum_i \sum_j W(i,j) W^*(i,j)}{\sum_i \sum_j W(i,j)^2} g$$

Figure 1. Original image and original watermark

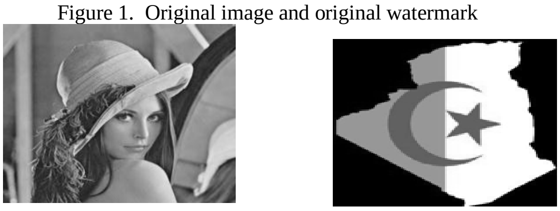

Figure 2. Watermarked image and extracted watermark by Liu method.

Figure 3. Watermarked image and extracted watermark by Chandra Global-SVD method.

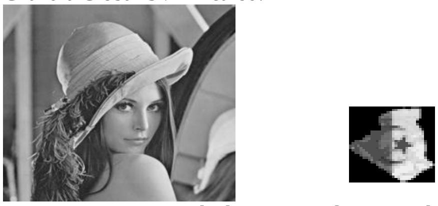

Figure 4. Watermarked image and extracted watermark by Chandra Block- SVD method.

Table 1 shows that, for our image and watermark, the PSNR obtained by Liu, Chandra Global-SVD and Block-SVD algorithms is not satisfactory when the parameter α is chosen as proposed by the authors. While Table 2 shows that the PSNR is significantly better when the parameter α is pragmatically[2] chosen (0.05, 0.02, and 0.1, respectively). For the CC, the gain is not much significant.

TABLE 1. PSNR AND CC OBTAINED BY LIU, CHANDRA GLOBAL-SVD, AND CHANDRA BLOCK-SVD WHEN THE PARAMETER α IS CHOSEN AS PROPOSED BY THE AUTHORS.

Liu		Global-SVD		Block-SVD	
PSNR	CC	PSNR	CC	PSNR	CC
26.9573	1.0000	18.5963	0.9996	37.2530	0.9974

From Tables 1 and 2, one can conclude that:

- When the parameter α is well-chosen, the distortion between the watermarked images and the original ones is imperceptible. We can also see that these three approaches are able to obtain extracted watermarks with a good CC value.
- When someone has to compare its own method against one of these three algorithms, he must not forget that α is a scaling parameter which determines the embedding strength and is chosen to maintain the quality of the watermarked image. Hence, the value of α has to be chosen so that it gives the best result (a good compromise between robustness and imperceptibility). Indeed, depending on original images and watermarks, the suitable value of α may not be the same as the one proposed by the authors.

The PSNR and the CC for different host images are listed in Table I.

[2] Because these values lead to better results for the image we used in the experiments.

	Liu		Global-SVD		Block-SVD	
Image	PSNR	CC	PSNR	CC	PSNR	CC
lena	42.7055	1.0000	39.4688	0.9966	43.7463	0.9850
Airplane	44.3353	1.0000	39.4259	0.9968	43.7934	0.9823
House	42.1967	1.0000	39.5609	0.9962	43.7142	0.9807
Peppers	43.5308	1.0000	39.4579	0.9974	43.6999	0.9851
Tree	44.6064	1.0000	39.4067	0.9955	43.7791	0.9863
Jellybeans	41.8295	1.0000	39.4837	0.9966	43.6964	0.9812
Sailboat	43.1169	1.0000	39.4993	0.9964	43.7692	0.9843
Splash	42.3736	1.0000	39.3937	0.9975	43.7185	0.9807
Tiffany	42.8319	1.0000	39.6742	0.9988	43.6424	0.9784

TABLE 3. PSNR AND CC FOR SEVERAL TYPICAL GRAY SCALE IMAGES.

We are also interested to vary the size of images. Table 4 shows that, for the three schemes, the variation of the size of image is not influenced to the CC and PSNR. But it influence on the time of insertion and extraction of the watermark.

TABLE 4. PSNR AND CC FOR DIFFERENTS SIZE OF HOST IMAGE.

	Liu		Global-SVD		Block-SVD	
size	PSNR	CC	PSNR	CC	PSNR	CC
128x128	42.8059	1.0000	39.5177	0.9967	44.0714	0.9857
256x256	42.7055	1.0000	39.4688	0.9966	43.7463	0.9850
512x512	42.7339	1.0000	39.4810	0.9966	43.5844	0.9817
1024x1024	42.6280	1.0000	39.4822	1.0000	43.4991	0.9782

B. Robustness property

An important property of the watermarking algorithms is that they should be robust against several kinds of attacks.

We are first interested in the JPEG attack, since it is one of the most popular image encoding schemes, and usually considered as a hard attack against image watermarking algorithms. Indeed, several methods are not robust against this type of attack. Table 5 shows that these schemes are robust against JPEG compression to a great extent.

TABLE 5. PERFORMANCE OF LIU, GLOBAL-SVD AND BLOCK-SVD METHODS AGAINST JPEG COMPRESSION.

Quality (%)	Liu	Global-SVD	Block-SVD
90	0.9994	0.9947	0.9822
80	0.9975	0.9903	0.9752
70	0.9960	0.9813	0.9578
60	0.9943	0.9690	0.9407
50	0.9932	0.9559	0.9098
40	0.9926	0.9434	0.8819
30	0.9903	0.9143	0.8140
20	0.9883	0.9001	0.6378
10	0.9812	0.8372	0.3187

From Table 5, one can see that:

- Liu scheme has strong robustness against JPEG compression.
- Chandra Global-SVD has good robustness against JPEG compression.
- Chandra Block-SVD has a good robustness against JPEG compression only when the ratio is greater than 20%.

We have also taken into account many other kinds of image watermarking attacks. Table 6 lists the results of the most interesting and standard attacks.

TABLE 6. PERFORMANCE AGAINST SEVERAL ATTACK.

Attacks	Parameters	Liu	Global -SVD	Block-SVD
Blurring	**0.1**	**1.0000**	**0.9966**	**0.9850**
	1	**0.9768**	**0.8225**	**0.8996**
Gaussian Noise	**M=0.;V=0.1**	**0.8669**	**0.3980**	**0.0129**
	M=0.01;V=0.001	**0.9886**	**0.8449**	**0.5860**
Gaussian Filter	**3x3 ; D=0.2**	**1.0000**	**0.9011**	**0.9850**
	3x3 ; D=1.0	**0.9669**	**0.9011**	**0.8437**
Media Filter	**3x3**	**0.9918**	**0.8547**	**0.8206**
	5x5	**0.9783**	**0.7988**	**0.6674**
Salt & Pepper	**D=0.001**	**0.9669**	**0.8984**	**0.9482**
	D=0.01	**0.9780**	**0.8319**	**0.6271**
Wiener Filter	**3x3**	**0.9933**	**0.8545**	**0.9119**
	5x5	**0.9884**	**0.8032**	**0.7046**
Average Filter	**3x3**	**0.9594**	**0.7823**	**0.8070**
	5x5	**0.9131**	**0.6803**	**0.5636**
Sharpen Filter	**1**	**0.9640**	**0.7835**	**0.4572**
	0	**0.9122**	**0.7429**	**0.4391**
Rotation	**Angle=10°**	**0.9920**	**0.8512**	**0.0497**
	Angle=20°	**0.9926**	**0.6554**	**0.0840**
	Angle=70°	**0.9859**	**0.6547**	**-0.033**
	Angle=180°	**1.0000**	**0.9011**	**-0.028**
Cropping	**X1=10, X2=20,Y1=10,Y2=20**	**0.9990**	**0.8994**	**0.9850**
	X1=10, X2=100,Y1=10,Y2=100	**0.9989**	**0.5820**	**0.9709**
Resize	**S=2**	**1.0000**	**0.9011**	**0.9850**
	S=0.5	**0.9816**	**0.8729**	**0.5362**
	S=0.25	**0.9321**	**0.7938**	**0.4147**
Flipping	**Horizontal**	**1.0000**	**0.9011**	**-0.040**
	Vertical	**1.0000**	**0.9011**	**0.1159**
	Horizontal + Vertical	**1.0000**	**0.9011**	**-0.028**

From Table 6, we can note that:

- In general, Liu method is very robust against most of the attacks.
- In most cases, Chandra Global -SVD is more robust than Block -SVD.
- Block-SVD is not robust to sharpen filter, rotation

V. CONCLUSION

In This work, we implemented and analyzed three well-known SVD-based watermarking algorithms. These methods maintain high quality watermarked images and robustness against several conventional attacks. However, the experiments we performed show that some weaknesses can be pointed out.

Liu method is improved in [11] by using a Block-based scheme. Indeed, the block-by-block watermark embedding makes the watermark more robust to the attacks and extracting the watermark from one block at least is enough to ensure the existence of the watermark.

Liu and Global-SVD of Chandra methods have also a problem of the ambiguity. In the detection process, the watermark is constructed by using original singular vectors. If the singular vectors of another image rather than the original watermark are used, that image is constructed as the embedded watermark, causing the false positive probability to be one. This problem is solved in [12] by embedding U_w or V_w matrices of the watermark as a control parameter.

In [13], another solution is proposed. The idea is to modify the relationship of the order of the SVs. In this method, the host image is divided into 8×8 sub-blocks, and then each block is decomposed by SVD. The second and third singular values of each block are exchanged if the watermark bit is 1, so the order of the SVs is not in the original descending order any more. This change of relationship of the order will be detected in the extracting process.

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