

Optimal Image Watermark Technique Using Singular Value Decomposition with PCA

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Abstract—Image watermarking is very important phenomenon in modern society where intellectual property right of information is necessary. Considering this impending problem, there are many image watermarking methods exist in the literature each of having some key advantages and disadvantages. After summarising state-of-the-art literature survey, an optimum digital watermark technique using singular value decomposition with principle component analysis (PCA) is proposed and verified. Basically, the host image is compressed using PCA which reduces multi-dimensional data to effective low-dimensional information. In this scheme, the watermark is embedded using the discrete wavelet transformation-singular value decomposition approach. Simulation results show that the proposed method improves the system performance compared with the existing method in terms of the watermark embedding, and extraction time. Therefore, this work is valuable for image watermarking in modern life such as tracing copyright infringements and banknote authentication.

Index Terms—Image watermarking, peak signal-to-noise ratio, principal component analysis, singular value decomposition, and wavelet transformation.

I. INTRODUCTION

Generally speaking, image watermarking is a very important part of modern life where intellectual property rights for digital medias (image, video, and audio) are reserved by watermarking [1]. Many works have been done in this field so far [2], [3], [4]. Most of the color image watermarking techniques are pseudo-random sequence, binary or greyscale image and only few watermarking schemes used the color image as watermark [10-18]. First of all, FindIk et al. [5] proposal was to embed the binary image of size 32x32 to the blue component of color image with size 510x510 by artificial immune recognition system, and this method has good performances of the watermark. Moreover, Niu et al. [6] proposed for a resisting geometric color image watermarking method, which was based on support vector regression and non-subsampled contour transform, in which the binary image of size 32x32 was embedded into the green component of color host image and the embedded strength was decided by human visual system (HVS) [7]. To summarise, Table I shows the first part of state-of-the-art literature review in the context of image watermarking.

Furthermore, Vahedi et al. [8] proposed a new wavelet-based watermarking approach for color images. It uses bio-inspired optimization principles, and the binary logo of size 64x64 was embedded into the color image of size 512x512. Also, Wang et al. [9] proposed a robust blind color image watermarking in quaternion Fourier transform domain to embed the binary image of size 64x64 into the color image of size 256x256, where the running time of the method was increased by training least squares support vector machine. In these aforementioned methods, the embedded watermarks are binary images. Interesting, the watermarks are greyscale images in [10], [11]. Chou and Wu [12] proposed to embed the color image watermarks into the color host image, in which the computational complexity was very low but its robustness needs to be improved.

Moreover, some watermarking methods based on matrix decomposition have been proposed [13]. Among them, Lai [13] designed a novel watermarking method based on human visual system (HVS) and singular value decomposition (SVD), in which the binary watermark was embedded into greyscale image of size 512x512 by modifying the certain elements of the unitary matrix U . This method has better performance of resisting adding noise, cropping and median filtering, but is worse in the aspect of resisting the rotation and scaling. Table II illustrates the remaining state-of-the-art literature review in the context of image watermarking. From this table in can be seen that Golea et al. [14] proposed an SVD-based color image watermarking scheme to embed color watermark image into color host image, but its invisibility is bad because one or more singular values of embedding block must be modified to keep the order of singular values. Bhatnagar and Raman [1] embedded the greyscale watermark of size 256x256 into the greyscale image of size 512x512. This method is non-blind watermarking method and has the false-positive detection problem.

Basically, Naderahmadian and Hosseini-Khayat [15] proposed a greyscale image watermarking algorithm based on QR decomposition. It was found that this method has lower computing complexity and better watermark performance, but

the embedded watermark was binary logo of size 32x32. Yashar and Saied [16] proposed a novel watermarking scheme based on QR decomposition, in which the watermark bit is embedded into all elements of the first row of R matrix of every 8x8 block. In [17], the watermark is embedded into Q matrix of QR decomposition. It was noted that the embedded watermark was binary image in [15] or [17].

Finally, the greyscale image of size 64x64 was embedded into greyscale image of size 256x256 based on Hessenberg decomposition, which belongs to non-blind method [18]. Seddik et al. [19] proposed a blind watermarking method that applies the mathematical Hessenberg transformation to the original image and further tests the effect of the different zones of the Hessenberg matrix on the image perception. The embedding technique was applied to the transformed image in a non-sensitive zone which has no effect on the image quality after the inverse transformation was applied. Although this method belongs to blind watermarking, the original binary image watermark has little information and the host image was greyscale image.

TABLE I: State-of-the-art literature first part.

Approach	Advantage	Disadvantage	Ref.
Embedding the binary image of size 32x32 to the blue component of color image with size 510x510 by artificial immune recognition system.	This method has good performance of the watermark.	Only blue component is used.	[20]
Resisting geometric color image watermarking method based on support vector regression and non-subsampled contour transform.	Embedding strength is decided by human visual system.	Provides inconsistent results.	[6]
Wavelet-based watermarking approach for color images.	Bio-inspired optimization principles are used.	Have to choose proper wavelet.	[8]
A robust blind color image watermarking in quaternion Fourier transform domain.	Robust to various attacks and does not need host image information for extraction.	Running time of the method is increased by training least squares support vector machine.	[9]
Embed the color image watermarks into the color host image.	Computational complexity is very low.	Robustness needs to be improved.	[12]

Driven by this motivation, this paper proposes an optimum digital watermark technique using singular value decomposition with PCA. The key contributions of this paper are as follows:

- An optimum digital watermark technique using singular value decomposition with PCA is proposed in this paper. First of all, the host image is compressed using PCA process. Afterwards, the watermark is embedded using the discrete wavelet transformation-singular value decomposition approach.
- Extensive simulation results show that the proposed method provides significant performance improvement compared with the existing approach. Consequently, this

TABLE II: State-of-the-art literature remaining part.

Approach	Advantage	Disadvantage	Ref.
A novel watermarking method based on Human visual system (HVS) and singular value decomposition (SVD), in which the binary watermark is embedded into greyscale image by modifying the certain elements of the unitary matrix U.	Better performance of resisting adding noise, cropping and median filtering.	Worse in the aspect of resisting the rotation and scaling.	[13]
SVD-based color image watermarking scheme to embed color watermark image into color host image.	More capacity required due to color image.	Invisibility is bad.	[14]
Greyscale watermark of size 256x256 was embedded into the greyscale image of size 512 x 512 by non-blind watermarking method.	Better performance and low complexity.	False-positive detection problem arises.	[1]
Greyscale image watermarking algorithm based on QR decomposition.	Lower computing complexity and better watermark performance	Low robustness.	[15]
Novel watermarking scheme based on QR decomposition.	Watermark bit is embedded into all elements of the first row of R matrix.	Computational complexity high due to using all elements.	[16]
Blind watermarking method that applies the mathematical Hessenberg transformation to the original image.	Tests the effect of the different zones of the Hessenberg matrix on the image perception.	New domain for image representation is introduced.	[19]
Digital watermark technique using singular value decomposition with PCA.	Provides better performances.	The quality of host image degrades.	This work

framework and analysis is valuable in image watermarking community such as tracing copyright infringements and banknote authentication.

II. PROPOSED IMAGE WATERMARK SCHEME

The proposed scheme is developed using the DWT-SVD watermarking scheme with PCA compression of the host image. In this process, the first step is to compress the host image with PCA compression method. Basically, the watermark scheme is performed for color images. This means the host image and the watermark image both are color images. To process RGB color images, at first it needs to be divided into three components: red, green and blue. Then all these three components are processed separately. Afterwards, the PCA image is watermarked using DWT-SVD. Finally, using DWT-SVD scheme watermark is extracted. All these three steps are described in the followings.

A. Step 1: PCA compression on the host image

Fig. 1 shows the flow chart of PCA image compression of the host image. First of all, the RGB color host image is taken

and which is divided into red, green and blue components [14]. Afterwards, we have converted these components into double precision. After that we have computed row mean of the matrices [1]. Now we subtract the row mean from the R, G, B component matrices to get another matrix and also calculate their the covariance matrix. The singular value decomposition is performed on these matrices to get the U, S, V components [21] [13]. Then we simply calculate variances of S matrices and also calculate the sum of variances of these matrices.

Now we can take as much principal components as we want. If we take less principal components, then the compression will be high and quality will degrade. If we take more principal components, then the compression will be low and quality will not degrade that much. After taking the first few principal components of V matrices, it is projected the data into these principal components and convert back to original basis. After that we add the row means back. Then we combine three matrices to get back the host image. This is the process of compressing the color host image using PCA image compression method. By applying PCA compression on the host image, the dimension reduction has been done and complexity of the host image is reduced. So, the watermark will now be done on less complex dimension because of PCA compressed image. The watermark is embedded into the PCA compressed image which describes in the following.

B. Step 2: Watermark embedding scheme

Fig. 2 illustrates the flow chart of watermark embedding scheme using DWT-SVD. To begin with, the watermark is embedded into the PCA compressed image using discrete wavelet transform and singular value decomposition. After taking aforementioned PCA compressed image, the embedding strength is set [10]. Generally speaking, the higher the value of embedding strength is, the more the watermark is embedded and visibility gets high. Therefore, an optimum value of embedding strength is generally taken. Basically, the PCA compresses image is divided into R, G, B components and DWT is performed on these to get the LL matrix. Then SVD is performed on the LL matrix to obtain U, S, V matrices. In this way, the watermark image is read. Next the grayscale of the watermark image is taken and it is resized to the LL matrix. The SVD is performed on the watermark image to get U_w, S_w, V_w matrices. Now we calculate the new Sigma matrix, $S_{new} = S + (\alpha * S_w)$ and new LL matrix: $LL_{new} = U * S_{new} * V'$. Now using LLnew, we apply inverse DWT to get new R, G and B components. Finally, these components are recombined to get the PCA compressed watermarked image.

C. Step 3: Watermark extraction scheme

Fig. 3 depicts step by step process of watermark extraction scheme using DWT-SVD [2]. Firstly, the watermarked image is taken and divided into R, G, and B components. Then DWT is applied onto these components and we take LL matrix of these components. Next SVD is applied to this matrix to get U_{wm}, S_{wm}, V_{wm} matrices [6]. Finally, we have

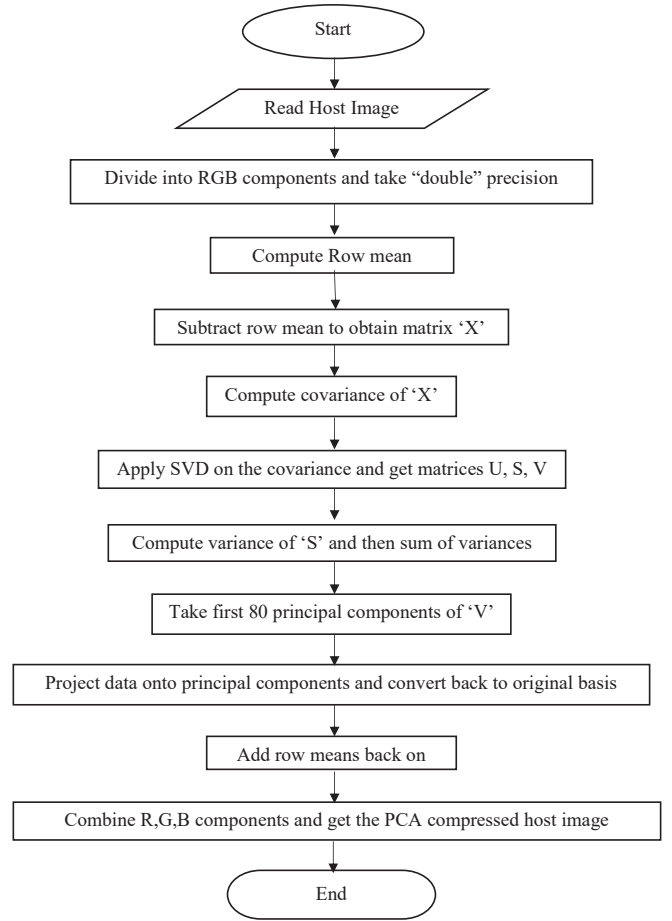


Fig. 1: Flow chart of PCA image compression of the host image.

calculated new sigma matrix by $S_{ext} = (S_{wm} - S)/\alpha$. Then we take average of three sigma matrices to get S_{avg} matrix. This is the extracted sigma matrix. Now we reconstruct the watermark image using this S_{avg} matrix. The performance of the proposed method is described in the following section.

III. SIMULATION RESULTS AND DISCUSSIONS

Based on the aforementioned three steps, the host image is compressed using PCA, and the watermark is embedded using the discrete wavelet transformation-singular value decomposition approach. Simulations have been done using Matlab with $\alpha = 0.01$.

After taking host image, it is compressed using PCA algorithm. In this paper, we have taken 80 principal components to reconstruct the image. Fig. 4 shows the main RGB host image with compressed image. It can be seen that both images are almost same even if we have taken 80 principle components using PCA. In this way, the high dimensional image can be converted to low dimensional. If the number of principal components is low then the compression ratio will be high, and the compressed image will get low quality.

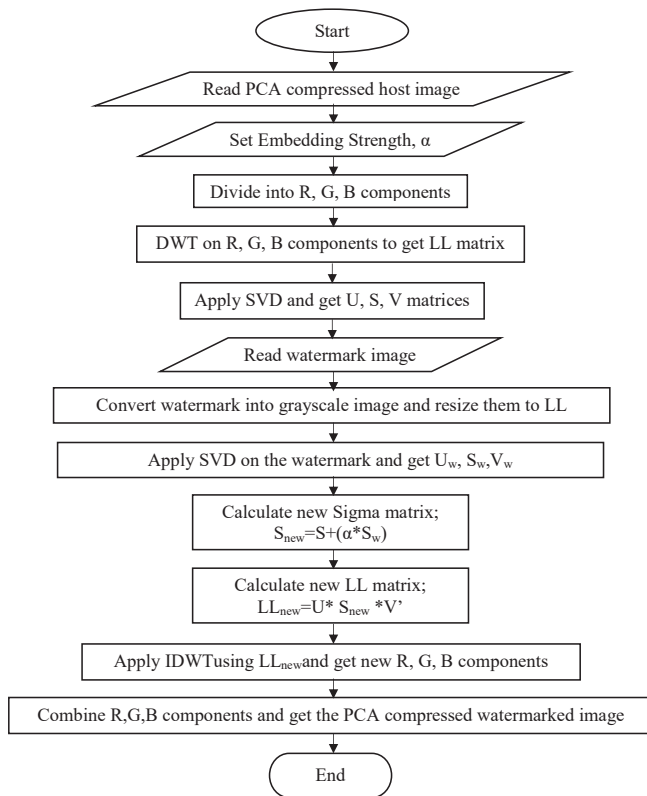


Fig. 2: Flow chart of watermark embedding scheme using DWT-SVD.

Secondly, the watermark embedding scheme is completed using DWT-SVD. To begin with, the watermark is embedded into the PCA compressed image using discrete wavelet transform and singular value decomposition. After taking aforementioned PCA compressed image, the embedding strength is set. Fig. 5 shows the PCA compressed version of host image and watermarked image. At first, the watermarked image is read. Then it is divided into red, green and blue components. The transformation is done using DWT to get the LL matrix. Then SVD is applied on the LL matrix to get the sigma matrix. Now the sigma matrix of the host image is used to extract the watermark image sigma matrix. Using the aforementioned process in step 2, the components are recombined to get the PCA compressed watermarked image. Finally, the DWT-SVD watermark scheme is used to extract image. Fig. 6 shows the watermarked image and extracted ones.

IV. CONCLUSIONS AND FUTURE WORK

After providing a comprehensive literature review, we proposed an optimal image watermarking technique using DWT-SVD. Fundamentally, the PCA compressed image is watermarked using DWT-SVD. The proposed scheme provides better performance compared without any compression method. In this proposed scheme, the watermark invisibility and execution time for embedding and extraction is improved a lot.

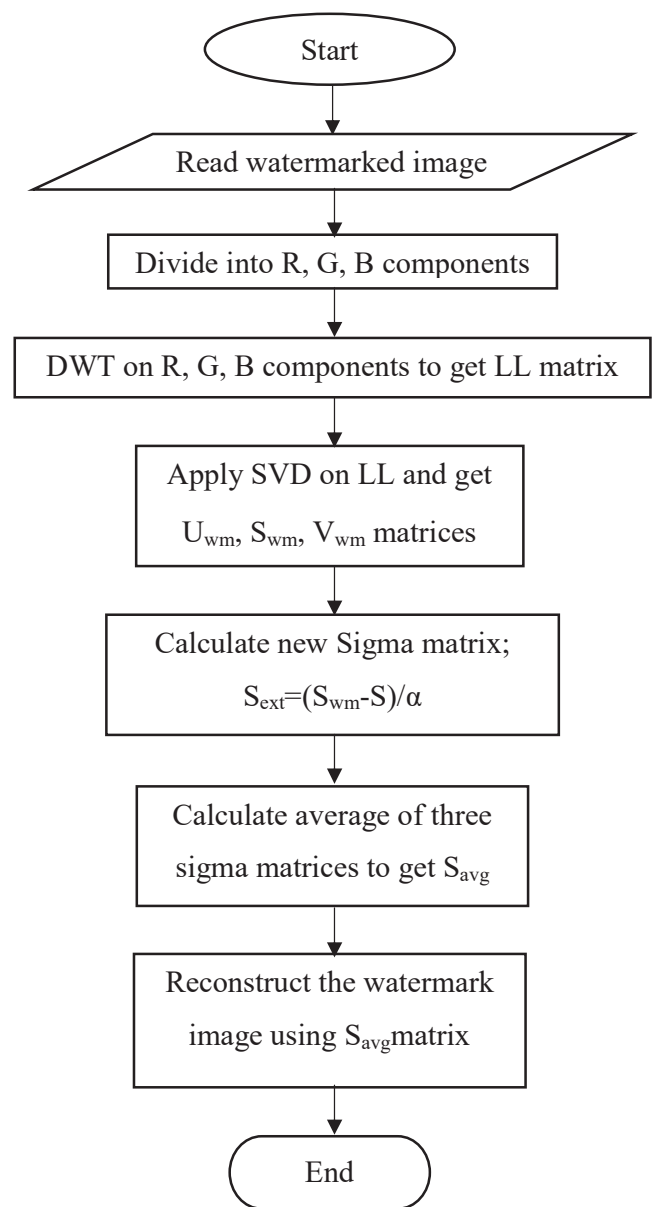


Fig. 3: Flow chart of watermark extraction scheme using DWT-SVD.

These performance criteria demonstrate that our proposed scheme is better compared to normal scheme. Therefore, this framework and analysis is valuable in image watermarking community such as tracing copyright infringements and banknote authentication. In future, a proper value of the embedding strength will be chosen so that the watermark is both invisible and robust enough. The performance parameters greatly depend on the value of embedding strength. So, a criterion will be chosen to select a proper value of embedding strength.



Fig. 4: (a) Main RGB host image, (b) PCA compressed host image with 80 components.



Fig. 5: (a) PCA compressed version of host image, (b) Watermark image, and (c) Watermarked image.

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Fig. 6: (a) Watermarked image, (b) Extracted watermark image.



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