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A dual color images watermarking scheme based on the optimized compensation of singular value decomposition

Qingtang Su[a,b,*], Yugang Niu[b], Yongsheng Zhao[a], Shan Pang[a], Xianxi Liu[c]

[a] School of Information Science and Engineering, Lu Dong University, Yantai 264025, PR China
[b] Key Laboratory of Advanced Control and Optimization for Chemical Process, Ministry of Education, East China University of Science and Technology, Shanghai 200237, PR China
[c] Mechanical & Electrical Engineering College Shandong Agricultural University, Tai'an 271018, PR China

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ABSTRACT

This paper proposes a novel watermarking algorithm based on the improved compensation of SVD for embedding the color image watermark into the color host image. Firstly, the watermark bit is embedded into 4×4 block by modifying the second row first column and the third row first column elements of U component after SVD. Then, the embedded block is compensated by the improved optimization operation for obtaining higher PSNR and larger threshold T. The embedded watermark is extracted from various attacked images by using the relation between the modified elements of U component without resorting to the original data. Moreover, the proposed algorithm overcomes the problem of false positive detection. The experimental results show that the proposed algorithm not only guarantees the invisibility and robustness of the watermark, but also has better performance than other methods mentioned in this paper.

1. Introduction

With the rapid development of Internet and multimedia technology, storing information and data such as documents, images, video, and audio in digital formats is very common. It is a daily activity for many people to transfer digital files via Internet. As is well known, due to the nature of digital information, it is easy to make unlimited lossless copies from the original digital source, to modify the content, and to transfer the copies rapidly over the Internet. Therefore, the demands of copyright protection, ownership demonstration, and tampering verification for digital data are becoming more and more urgent. Among the solutions for these problems, digital watermarking is the most popular one. Researchers have given consideration to this in the past decade.

Digital watermarking is to embed a signal into digital data (audio, image, video, and text). According to the processing domain of the host image, the existing techniques on image watermarking may be roughly divided into two categories, i.e., frequency-domain and spatial-domain methods [1]. Although more information for embedding and better robustness against the common attacks can be achieved through frequency-domain method, the computational cost is higher than that of spatial domain. Embedding the watermark into the component of the original image in spatial domain is a straightforward method which has the advantages of low computational complexity. However, the watermarking algorithm in spatial domain is generally fragile to common image processing operations or other attacks. In order to overcome these shortcomings, the method based on singular value decomposition (SVD) has been becoming one of the hot research fields [2].

SVD-based watermarking technique and its variations have been mostly considered, e.g., in [3–14]. It was found from the recent research that there are two obvious drawbacks in the SVD-based watermarking algorithms: (1) The watermarked image has lower invisibility [3], which is because all values in a pixel matrix would be changed when one singular value is modified, that is, if one singular value of a $N \times N$ matrix is modified, then N^2 pixels will be modified. (2) The false positive detection problem has existed in most SVD-based watermarking algorithms [11]. The detailed reason for false positive detection problem is that only the singular values of the watermark W are embedded into the host image [7,12–14], that is, if the singular value decomposition of W is $W = U_W S_W V_W^T$, only the diagonal singular values matrix S_W is embedded while the orthogonal matrices U_W and V_W are not. In extraction procedure, only the diagonal matrix S_W is extracted, but the U_W and V_W can be simply provided by the owner without any extraction. However, the orthogonal matrices U_W and V_W contain the major information of an image [15]. Thus any one can provide a fake pair of orthogonal matrices and claim that his

* Corresponding author at: School of Information Science and Engineering, Lu Dong University, Yantai 264025, PR China. Tel.: +86 535 6673554.
E-mail addresses: sdytsqt@163.com, acsqtwhy@163.com (Q. Su).

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watermark is present in the watermarked image. In order to overcome the drawbacks mentioned above, Chang et al. [4] presented a block-based watermarking algorithm, in which the image was divided into several blocks and then the elements in U component of each block were modified to embed watermark. Although this method may reduce the number of modified pixels from N^2 to $2N$, the modified quantity of each pixel is bigger. Thus, Fan et al. [6] further considered to modify the elements in the first column of U component (V component) for watermarking and adopt the V component (U component) to compensate visible distortion when embedding watermark into the component of SVD. Although this method can reduce the modified quantity, the number of modified pixels is again increased to N^2 at some time, which will change the other pixels that do not need to be modified. The detailed reasons can be explained in Section 3. Therefore, how to improve the invisibility of watermark based on SVD is still a difficult problem.

In addition, most of the existing algorithms are performed in the non-blind method. For example, a color image watermarking method is proposed in [7]. The singular values of original watermark were required to extract the embedded singular value, and then the U and V orthogonal matrices of original watermark were utilized to recover the watermark. In [8], three matrices U, V and D of SVD for watermark are viewed as the user's secret keys to extract watermark, and the original host image is also needed to extract watermark. The method in [9] also requires the D component to extract a color watermark from a color host image. Although a blind color image watermarking was proposed in [10], one or more singular values must be modified to keep the order of singular values, which seriously affected the quality of the watermarked image. As a major intermediate step in SVD, QR decomposition is also used to embed watermark. Yashar and Saied [18] proposed to embed a watermark bit in all elements of the first row of R matrix after each 8×8 block was decomposed by QR decomposition, in which the watermark was 88×88 binary image. As is well known, the watermark information of the 24-bit color image is twenty-four times more than that of the binary image with the same size. When the color image watermark was embedded into color host image, the watermark capacity increases by eight times, which will affect the quality of watermark. That is, the non-SVD method [18] could not be effectively used to embed large amounts of color watermark information into host image.

Motivated by the above discussion, we propose an improved scheme to optimize the compensation operation when color image watermark is embedded into color host image based on SVD. In this paper, the watermark bit is embedded into 4×4 block by modifying the second row first column and the third row first column elements of U component after SVD. Then, the proposed optimization operation is used to compensate the V component and optimize the final watermarked block for obtaining higher PSNR and larger threshold T. The relation between the modified elements of U component can be preserved and further used to extract the embedded watermark without resorting to the original data. Moreover, the proposed algorithm overcomes the problem of false positive detection mentioned in [7,12–14]. The experimental results show that the proposed watermarking method based on optimized compensation for SVD is effective and has better performance than some existing methods.

The rest of this paper is organized as follows: Section 2 gives a brief description of the SVD. The proposed optimization compensation method is introduced in Section 3. Section 4 describes the proposed watermarking method that includes watermark embedding and watermark extraction. In Section 5, the experimental results are presented to show the performance of the proposed watermark. Finally, we draw the conclusions of this paper in Section 6.

2. Singular value decomposition

For an $N \times N$ square matrix I with rank r, $r \le N$, its SVD is represented by Eq. (1).

$$I = UDV^T = \begin{bmatrix} u_{1,1} & \cdots & u_{1,N} \\ u_{2,1} & \cdots & u_{2,N} \\ \vdots & \ddots & \vdots \\ u_{N,1} & \cdots & u_{N,N} \end{bmatrix} \begin{bmatrix} \lambda_1 & 0 & \cdots & 0 \\ 0 & \lambda_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & \cdots & \lambda_N \end{bmatrix} \begin{bmatrix} v_{1,1} & \cdots & v_{1,N} \\ v_{2,1} & \cdots & v_{2,N} \\ \vdots & \ddots & \vdots \\ v_{N,1} & \cdots & v_{N,N} \end{bmatrix} \quad (1)$$

where U and V are $N \times N$ orthogonal matrices and D is singular diagonal matrix with diagonal elements satisfying $\lambda_1 \ge \lambda_2 \ge \cdots \ge \lambda_r > \lambda_{r+1} = \cdots = \lambda_N = 0$.

It is assumed that the 4×4 matrix A is one of the blocks of the input image, then its SVD is given by Eq. (2).

$$A = \begin{bmatrix} A_1 & A_2 & A_3 & A_4 \\ A_5 & A_6 & A_7 & A_8 \\ A_9 & A_{10} & A_{11} & A_{12} \\ A_{13} & A_{14} & A_{15} & A_{16} \end{bmatrix} = UDV^T$$
$$= \begin{bmatrix} u_1 & u_2 & u_3 & u_4 \\ u_5 & u_6 & u_7 & u_8 \\ u_9 & u_{10} & u_{11} & u_{12} \\ u_{13} & u_{14} & u_{15} & u_{16} \end{bmatrix} \begin{bmatrix} \lambda_1 & 0 & 0 & 0 \\ 0 & \lambda_2 & 0 & 0 \\ 0 & 0 & \lambda_3 & 0 \\ 0 & 0 & 0 & \lambda_4 \end{bmatrix} \begin{bmatrix} v_1 & v_2 & v_3 & v_4 \\ v_5 & v_6 & v_7 & v_8 \\ v_9 & v_{10} & v_{11} & v_{12} \\ v_{13} & v_{14} & v_{15} & v_{16} \end{bmatrix}^T \quad (2)$$

It is noted that the component U has an interesting property, i.e., all its first column elements are of the same sign and their values are very close. For example, a sample matrix A obtained from a digital image is

$$A = \begin{bmatrix} 201 & 201 & 199 & 198 \\ 202 & 202 & 199 & 199 \\ 203 & 203 & 201 & 201 \\ 203 & 204 & 202 & 202 \end{bmatrix} \quad (3)$$

By performing SVD on A, the orthogonal component U of A is

$$U = \begin{bmatrix} -0.49627 & -0.32583 & 0.80128 & 0.07426 \\ -0.49813 & -0.57109 & -0.57014 & 0.31727 \\ -0.50185 & 0.14742 & -0.17355 & -0.83444 \\ -0.50371 & 0.73890 & -0.05270 & 0.44445 \end{bmatrix} \quad (4)$$

As can be seen from the U matrix, all the elements in the first column, u_1, u_5, u_9, u_{13}, are of the same sign and the differences between them are very small. Suppose that one matrix is composed by element u_m in the first column of each U component block and another one is composed by another element u_n in the first column of each U component block, then normalized cross-correlation (NC) between the u_m and u_n can be computed. Table 1 shows the results with many standard test images. As can be seen from the table, the average value of NC (u_5, u_9) is 0.9886, which shows the u_5 and u_9 are the closest elements in the first column of 4×4 U for many standard images. Therefore, it is noted that there exists a strong correlation between the second row first column element and the third row first column element of U component when SVD is performed. This property can be explored for image watermarking in Section 4.

3. The proposed optimization compensation method of SVD

As well known, modifying the values of u_5 and u_9 will change the values of A_i (i = 5, 6, . . ., 12) in Eq. (2), and maybe decrease the invisibility of the embedded watermark [5]. Therefore, a note, which adopted V component or U component to compensate visible distortion when U component or V component was used to embed