Applied Mathematics and Computation 219 (2013) 8455–8466

Contents lists available at SciVerse ScienceDirect

Applied Mathematics and Computation

journal homepage: www.elsevier.com/locate/amc

A blind dual color images watermarking based on singular value decomposition

Qingtang Su [a,b,*], Yugang Niu [b], Hailin Zou [a], Xianxi Liu [c]

[a] School of Information Science and Engineering, Lu Dong University, Yantai 264025, Shandong, 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, Shandong, PR China

ARTICLE INFO

Keywords:
Color image
Blind watermarking
Singular value decomposition
U matrix

ABSTRACT

In this paper, a blind watermarking scheme based on Singular Value Decomposition (SVD) is proposed. By analyzing the orthogonal matrix *U* via SVD, it is found that there exists a strong similarity correlation between the second row first column element and the third row first column element. Hence, this work will utilize this property for image watermarking. Firstly, the 4×4 non-overlapping pixels block of each component in color host image is processed by SVD. And then, the color watermark is embedded by slightly modifying the value of the second row first column element and the third row first column one of *U* matrix, and the modified relation can be utilized to extract watermark. Hence, without resorting to the original watermark image and original host image, the embedded watermark can be easily extracted. The experiment results show that the proposed watermarking algorithm can ensure the invisibility and stronger robustness for the common image processing operations and geometric attacks, and the performance of this proposed method outperforms that of other proposed methods considered in this work.

1. Introduction

With the wide and easy transmission of digital multimedia contents, e.g., text, audio, image and video, over the Internet, the copyright protection has been receiving an increasing attention. Among these existing strategies, digital watermarking provides a promising way of protecting multimedia data from illegal manipulation and duplication.

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 the ones based on 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 and easy implementation. 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 research hot fields. The main advantages of watermarking method based on SVD include: (1) the size

* Corresponding author at: School of Information Science and Engineering, Lu Dong University, Yantai 264025, Shandong, PR China.
E-mail address: sdytsqt@163.com (Q. Su).

0096-3003/$ - see front matter
http://dx.doi.org/10.1016/j.amc.2013.03.013

of the matrix from SVD is not fixed; (2) when a small perturbation is added to an image, larger variation of its singular values does not occur; (3) singular values represent intrinsic algebraic image properties [2].

In the last few years, SVD-based watermarking technique and its variations have been mostly considered, e.g., in [3–6]. Among them, an vector quantization-and SVD-based image hiding algorithm was introduced for embedding the secret data into the D matrix of the SVD in [3]. Chang et al. [4] discussed a block-based watermarking algorithm, in which the image was divided into several blocks and then the elements in U matrix in each block were modified to achieve the watermarking effect. In [5], two notes were proposed to increase invisibility and capacity of SVD-based watermarking scheme, in which the elements in column/row vector were modified to attain less visible distortion than modifying the elements in row/column vector of U matrix after SVD transformation. On the basis of the method in [5], Fan et al. [6] further considered modifying the elements in the first column of U matrix and V matrix for watermarking. Moreover, the V matrix or U matrix to compensate visible distortion was adopted in [6] when embedding watermark into the matrix of SVD. However, it is noted that the above SVD-based methods only consider the case that the binary image as the watermark is embed into the gray-scale image. More recently, the SVD technique has been utilized to deal with the problem of dual color image watermarking in [7–9]. However, the aforementioned watermarking methods were usually performed in a non-blind manner. For example, in [7], the singular values of original watermark are 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 used the user's secret keys to extract watermark, and the original host image is also need to extract watermark. Although the watermarking proposed in [9] can attain a blind color image extraction watermarking, one or more singular values must be modified to keep the order of singular values such that the quality of the watermarked image will be seriously affected. That can be seen from the following simple example. For example, supposed that the singular values $\lambda_1 - \lambda_{16}$ of one pixel block with size 16×16 are 3165.613, 457.5041, 31.54169, 9.85382997, 5.796001, 4.991171, 3.688464, 2.544742, 2.064232, 1.691997, 1.130058, 1.074023, 0.819865, 0.448544, 0.37897, 0.101045, respectively. When a watermark value is 0, according to the method in [9], these singular values will be changed to 3165.613, 457.5041, 31.54169, 9.85382997, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0. That is, 12 singular values will be modified such that all pixel values in this pixel block will be obviously changed. Thus, the visual quality of the watermarked image may be affected. Hence, how to improve the performance of watermarking based on SVD for color image is a noticeable problem.

Motivated by the above discussion, this paper proposes a blind SVD-based dual color watermarking scheme. In this paper, it is firstly found the elements in the second row first column and the third row first column are the closest elements of U matrix after SVD, which means that the relation between the both elements can be preserved and further used to extract the embedded watermark without resorting to the original data. Thus, the blind extraction can be achieved. In order to keep the similarity between the anterior two elements in first column of U matrix, it is only required to slightly change the value of the two elements. The experimental results show that the proposed method 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 principle and points out its key feature that be used in this work. Section 3 describes the proposed watermarking method that includes watermark embedding and watermark extraction. In Section 4, the experimental results are presented to show the performance of the proposed watermark. Finally, we draw out the conclusions of this paper in Section 5.

2. Singular value decomposition

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

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

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

It is assumed that the 4-by-4 matrix A is one of the blocks of the host image, whose SVD is given by Eq. (2).

$$A = \begin{bmatrix} A_1 & A_2 & A_3 & A_4 \\ A_5 & A_6 & A_7 & A_8 \\ A_9 & A_{10} & A_{11} & A_{12} \\ A_{13} & A_{14} & A_{15} & A_{16} \end{bmatrix} = UDV^T = \begin{bmatrix} a_1 & a_2 & a_3 & a_4 \\ a_5 & a_6 & a_7 & a_8 \\ a_9 & a_{10} & a_{11} & a_{12} \\ a_{13} & a_{14} & a_{15} & a_{16} \end{bmatrix} \begin{bmatrix} \lambda_1 & 0 & 0 & 0 \\ 0 & \lambda_2 & 0 & 0 \\ 0 & 0 & \lambda_3 & 0 \\ 0 & 0 & 0 & \lambda_4 \end{bmatrix} \begin{bmatrix} c_1 & c_2 & c_3 & c_4 \\ c_5 & c_6 & c_7 & c_8 \\ c_9 & c_{10} & c_{11} & c_{12} \\ c_{13} & c_{14} & c_{15} & c_{16} \end{bmatrix}^T \tag{2}$$