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Image Watermarking through Joint Spatial Segmentation and Wavelet Packet Frequency Division

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Abstract: *In this paper we consider a method for image watermarking based on wavelet packet frequency division and spatial segmentation. We present a new direct structured decomposition, with both spatial segmentation and orthogonal frequency branching from each node. Whereas traditional wavelet packet decomposition adapts to a global frequency distribution, this technique finds the best joint spatial segmentation and local frequency basis. To achieve better performance in case of robustness and visual quality, we take advantage of singular value decomposition characteristic. Experimental evaluations demonstrate that the proposed scheme is robust against variety of attacks.*

Keywords: Digital image watermarking, Wavelet packet transform, Spatial segmentation and singular value decomposition.

1. Introduction

Digital image watermarking has attracted a lot of interest in recent years, due to the development of internet. The aim is to protect ownership by including copyright information in the image. After embedding the watermark there should be no perceptual degradation. Also, watermark should not be removable by unauthorized user and should be robust against intentional and unintentional attacks.

A number of watermarking techniques have already been proposed in both spatial and transform domains to insert robust and invisible watermarks [1-4]. Spatial domain methods are less complex as no transform is used, but are not robust against attacks. Also, computations in frequency domain techniques involve a lot of matrix multiplications.

We propose here a new method for image watermarking based on joint spatial segmentation and wavelet packet frequency division. Since the spatial partitions do not overlap, this segmentation allows the nodes to be further analyzed independently. Also, we can mostly take advantage of wavelet packet in case of controlling the embedding location both in space and frequency domain [5-7]. All sub bands are thoroughly examined regarding their variance intensity. After finding the best suited locations, watermark, which is a binary logo, is embedded by modifying the singular values of the host image. The watermarking process is a non-blind watermarking, so the host image is needed for extraction.

The paper is organized as follow; In section 2, there is an overview on singular value decomposition. Section 3 presents the embedding and extraction strategies used by the proposed watermarking method. Finally experimental result and conclusion are given in sections 4 and 5.

2. Singular Value Decomposition

Every real matrix A of order $m \times n$ can be decomposed into a product of three matrices,

$$A = U\,S\,V^T \tag{1}$$

where U and V are orthogonal and $S = diag(\lambda_1, \lambda_2, \ldots)$, where $\lambda_i, i = 1, \ldots, r$ are called the singular values of the matrix A with $r = min(m,n)$ and satisfying $\lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_r$. The first r columns of V are the right singular vectors and the first r columns of U are the left singular vectors of A. This decomposition is known as the *singular value decomposition* (SVD) of A, and can be written as

$$A = \lambda_1 \mathbf{U}_1 \mathbf{V}_1^T + \lambda_2 \mathbf{U}_2 \mathbf{V}_2^T + \ldots + \lambda_r \mathbf{U}_r \mathbf{V}_r^T \tag{2}$$

The use of singular value decomposition technique in digital image processing has some advantages [8, 9]. An important property of SVD in watermarking application is that the largest of the modified singular values changes very little in the face of most types of attacks. Thus, in this paper, we take advantage of singular value decomposition to develop a new hybrid image watermarking scheme that resists variety of attacks.

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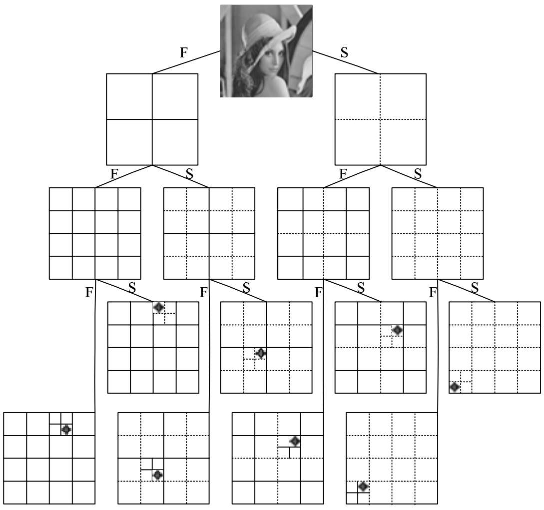


Figure 1 . Decomposing the host image to 3-level using both spatial segmentation and wavelet packet frequency division, "F" denoted for frequency and "S" denoted for spatial.

3. Proposed Watermarking Algorithm

In this section, we discuss our watermarking algorithm. This algorithm uses an approach based on spatial segmentation and frequency division wavelet packet. We assume that the host image I of size $N \times N$ and the watermark W is a binary image of size $M \times M$. The watermark needs to be very small in order to make it spatially localized.

3.1 Embedding Procedure

The proposed watermarking algorithm to embed a watermark in the host image is briefly described in the following steps,

1. We first decompose the host image into three level using joint spatial segmentation and wavelet packet transform. Result is eight possible nodes in which "*F*" and "*S*" stand for *frequency* and *spatial* as can be seen in Fig. 1.
2. To select the best subband, for embedding the watermark bits, both robustness against attacks and quality of the watermarked image should be considered. So, we calculate variance intensity of each subband to find the subband with the midst value for inserting the watermark [10].
3. SVD is applied to both selected subband and watermark image.

$$\begin{cases} A_s = U_s S_s V_s^T \\ W_w = U_w S_w V_w^T \end{cases} \quad (3)$$

4. Modify the singular values of A_s with singular values of W_w using (4),

$$S_s^* = S_s + a\, S_w \quad (4)$$

In which, S_w is singular values of the watermark and S_s is singular values of the selected subband. Also, a gives the watermark strength.

5. Perform inverse SVD to construct the watermarked coefficients.
6. Perform inverse wavelet packet transform and spatial desegmentation to obtain the watermarked image.

3.2 Extraction Procedure

Watermark extraction is the inverse process of embedding the watermark. Our proposed algorithm is a non-blind watermarking, i.e. the host image is required in watermark extraction.

1. Decompose the watermarked image into frequency and spatially subbands in the same way as in embedding.
2. Consider the correspond subband in embedding, the singular values of the selected subband are computed as,

$$A'_s = U'_s S'_s V'^T_s \quad (5)$$

3. Extract the singular values of the watermark as in (6),

$$S_{w-extracted} = \frac{(S'_s - S_s)}{a} \quad (6)$$

4. Perform inverse SVD to construct the extracted watermark.

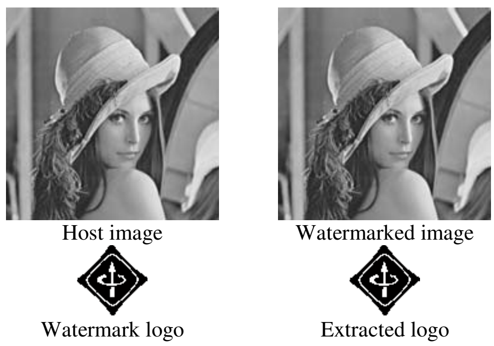
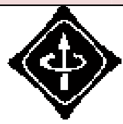
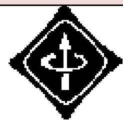
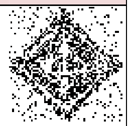
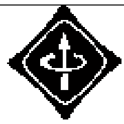
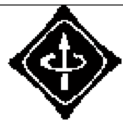
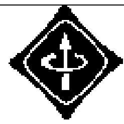
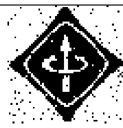
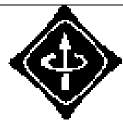
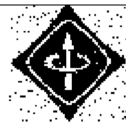
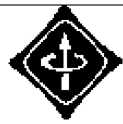
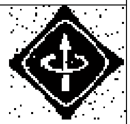
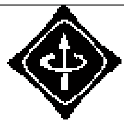
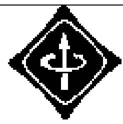
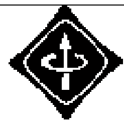
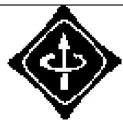
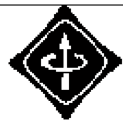
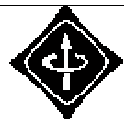
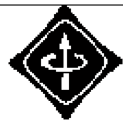
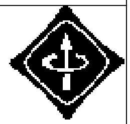
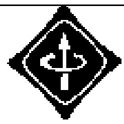
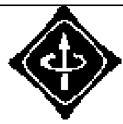
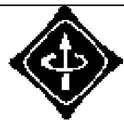
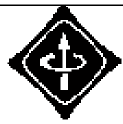
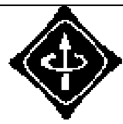
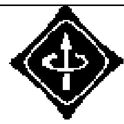
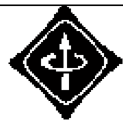
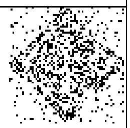


Figure 2 . The host image, its watermarked, watermark and extracted logo; PSNR=74.17 , NC=1 and a=0.5.

4. Experimental Results

In this section, by using Matlab, we present the performance of proposed watermarking algorithm in terms of robustness and objective quality. Experiments are tested on standard 512×512 grayscale Lena image and IEEE binary image with 64×64 pixels, shown in Fig. 2.

TABLE I. Extracted watermark with corresponding NC and PSNR values of watermarked Lena image against variety of attacks; for example: "FFS" shows 2-level decomposition in frequency domain followed by 1-level decomposition in spatial domain.

	FFF	FFS	FSF	FSS	SFF	SFS	SSF	SSS
Histogram Modification								
PSNR	19.41	19.37	19.40	19.37	19.40	19.37	19.36	19.37
NC	1	1	1	1	1	1	1	0.901
Median Filtering, mask 7*7								
PSNR	28.92	28.92	28.92	28.92	28.92	28.92	28.92	28.92
NC	1	1	1	0.958	1	0.948	1	0.963
Gaussian Filtering $\sigma = 0.001$								
PSNR	73.70	73.65	73.79	73.65	73.79	73.65	73.72	73.59
NC	1	1	1	1	1	1	1	1
Gaussian Noise $\sigma = 0.001$								
PSNR	10.68	10.68	10.68	10.68	10.68	10.68	10.68	10.68
NC	1	0.999	1	1	1	0.999	0.999	0.886

The similarity measurement of the original and the extracted watermark is the normalized correlation (NC) coefficient, defined as

$$\textit{Normalized Correlation}=\text{NC}=\frac{\sum_i w_i^* w_i}{\sum_i w_i^2} \qquad (7)$$

In which, w_i is the watermark image and w_i^* is the extracted watermark. From Table I, we can see that in all joint spatial and frequency nodes watermark can be perfectly extracted in the face of common attacks such as histogram modification, Gaussian noise, Gaussian and median filtering.

By comparing the experimental result in Table I, we can select the desired node and its subband in which embedded watermark is more robust against each type of attacks. Also proposed method gives good perceptual quality for the watermark images.

JPEG compression is one of the important attacks which any image watermarking algorithm should be resistant to. It is obvious from results in Table II that the proposed method shows good resistance to JPEG compression for all the nodes.

The robustness of the algorithm in terms of NC is shown in Table III when the watermarked image is attacked by rotation.

TABLE II. Normalized correlation for all nodes under attack of JPEG with different quality factors.

JPEG Compression			
	QF=10	**QF=30**	**QF=80**
FFF	0.860	0.921	0.998
FFS	0.844	0.889	0.998
FSF	**0.950**	0.969	**1**
FSS	0.853	0.886	0.987
SFF	0.948	**0.972**	0.978
SFS	0.848	0.872	0.983
SSF	0.911	0.944	0.995
SSS	0.864	0.916	0.988

TABLE III. Normalized correlation for all nodes under attack of rotation with different rotation angle.

Rotation			
	1	**5**	**10**
FFF	0.993	**0.994**	0.988
FFS	**1**	0.923	**0.990**
FSF	0.998	0.978	0.961
FSS	**1**	0.946	0.902
SFF	0.998	0.977	0.969
SFS	**1**	0.922	0.908
SSF	0.962	0.958	0.887
SSS	0.914	0.878	0.837

5. Conclusion

We presented a new algorithm for image watermarking using joint spatial segmentation and wavelet packets. We started with decomposing the host image to 3-level both spatially and frequency. To find suitable subband to embed watermark bits, we examine each subband in case of its variance intensity. The subband with midst variance value was selected to embed the watermark in each node. Experimental results showed that the proposed algorithm resist most common attacks such as JPEG compression, rotation, histogram modification, Gaussian noise, cropping, Gaussian and median filtering. However, to extent which algorithm can resist each attack, depends on the node and the kind of attack.

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