Slant Transform Watermarking for Digital Images

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ABSTRACT

In this paper, we propose a digital watermarking algorithm based on the Slant transform for the copyright protection of images. Our earlier research work associated with the fast Hadamard transform for robust watermark embedding and retrieval of images and characters suggests that this transform could also provide a good "hidden" space for digital watermarking. The Slant transform has many similar properties to the Walsh-Hadamard transform. In terms of transform coding, the Slant transform is considered to be a sub-optimum orthogonal transform for energy compaction. For digital watermarking, the energy spread becomes a significant advantage, as there is now a good spread of middle to higher frequencies with significant energies for robust information hiding. In this paper, an analytical comparative study on the performance of the Slant transform adapting our earlier watermarking schemes for fast Hadamrd transform will be performed based on its robustness against various Stirmark attacks. The performance results of the Slant transform for image watermarking against other transforms such as Cosine transform will also be presented.

Keywords: Slant transform, digital watermarking, copyright protection

I. INTRODUCTION

Copyright protection and authentication of digital multimedia contents is increasingly becoming more and more important in parallel with the tremendous development of the Internet. To counter this growing information security problem of illegal distribution and counterfeiting, much research effort has been invested in digital watermarking in the past few years.

According to the embedding domain of the original image, the watermarking techniques proposed can be divided into two main groups [1]. One is the spatial domain approach. The earliest watermarking techniques are mainly of this kind and the simplest example is to embed the watermark into least significant bits (LSBs) of the image pixels [2]. However, this technique has relatively low information hiding capacity and can be easily erased by lossy image compression. The other is the frequency domain approach, which are receiving a great deal of attention and various methods operating in different transform domains have been presented. The most widely used are DCT-based methods. Cox *et. al.* [3] embedded a Gaussian distributed sequence into the perceptually most significant frequency components of the Cosine transform domain of original images. In recent years, digital wavelet transform (DWT) watermarking techniques are becoming more and more popular and a variety of approaches have been proposed. Hsieh *et. al.* [4] proposed a multi-energy watermarking scheme based on the qualified significant wavelet tree (QSWT). Wang *et al.* [5] selected a middle-frequency band of wavelet domain to insert a binary image watermark. Barni [6] *et. al.* and Kutter *et. al.* [7] developed two novel visual models, which can be used to improve the perceptual quality of images watermarked in the wavelet domain. To resist geometrical attacks, Lin *et. al.* [8] suggested a digital image watermarking using the Fourier-Mellin transform that is invariant to rotation, scaling and translation attacks. The major problem with many of these watermarking schemes is that they are not very robust against different types of image manipulations or attacks. Moreover, some of these techniques are quite complicated to implement in real-time.

In this paper, we propose a digital watermarking algorithm based on the Slant transform for the copyright protection of images. The Slant transform has been applied to many image processing applications, such as transform coding and image restoration [9,10]. However, through our initial survey, this transform has not been reported or investigated by

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other researchers for digital watermarking. Our earlier research work associated with the fast Hadamard transform for robust watermark embedding and retrieval of images and characters [11,12] suggests that this transform could also provide a good “hidden” space for digital watermarking. Experimental results showed that the Hadamard transform based scheme was superior to those based on DCT when the processing noise was high. Moreover, it was also faster and simpler to implement in hardware than the commonly used DCT and DWT techniques [12].

The Slant transform was designed to match basis vectors to areas of constant luminance slope [13]. It has many similar properties to the Walsh-Hadamard transform [14]. In terms of transform coding, the Slant transform is considered to be a sub-optimum orthogonal transform for energy compaction. For digital watermarking, the energy spread becomes a significant advantage, as there is now a good spread of middle to higher frequencies with significant energies for robust information hiding.

In this paper, an analytical comparative study on the performance of the Slant transform adapting the schemes used in [11,12] for digital watermarking will be performed based on its robustness against various Stirmark attacks. Its data integrity will also be evaluated through subjective and objective fidelity criteria. The performance results of the Slant transform for image watermarking against other transforms such as Hadamard and Cosine will also be presented.

The rest of this paper is organized as follows. In Section II, the Slant transform and its relation to Hadamard transform is briefly reviewed. Then, our proposed watermarking method is elaborated in Section III. Simulation results are presented in Section IV, these include comparison of the Slant transform to the Hadamard transform in [11,12] and the DCT method in [3]. Finally, the conclusions are given in Section V.

II. THE SLANT TRANSFORM

The Slant transform was introduced to image coding by Enomoto and Shibata [15] in 1971 and developed by Pratt *et al.* [9,10]. In this section, we give a brief review of the Slant transform representation of image data, which is used in the watermarking embedding and extraction process. The relationship between the Slant transform and the Walsh – Hadamard transform is also revealed.

Let $[U]$ be the original image of size $N \times N$, its 2D-Slant transform is given by

$$[V] = [S_n][U][S_n]^T \tag{1}$$

where $[S_n]$ is the $N \times N$ unitary Slant matrix. The inverse transformation to recover $[U]$ from the transform components $[V]$ is given by

$$[U] = [S_n]^T [V][S_n] \tag{2}$$

The Slant transform is a member of the orthogonal transforms. It has a constant function for the first row, and has a second row which is a linear (slant) function of the column index. The matrices are formed by an iterative construction that exhibits the matrices as products of sparse matrices, which in turn leads to a fast transform algorithm.

The Slant transform matrix of order two is given by

$$S_2 = \frac{1}{2^{1/2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \tag{3}$$

The Slant matrix of order four is obtained by the operation

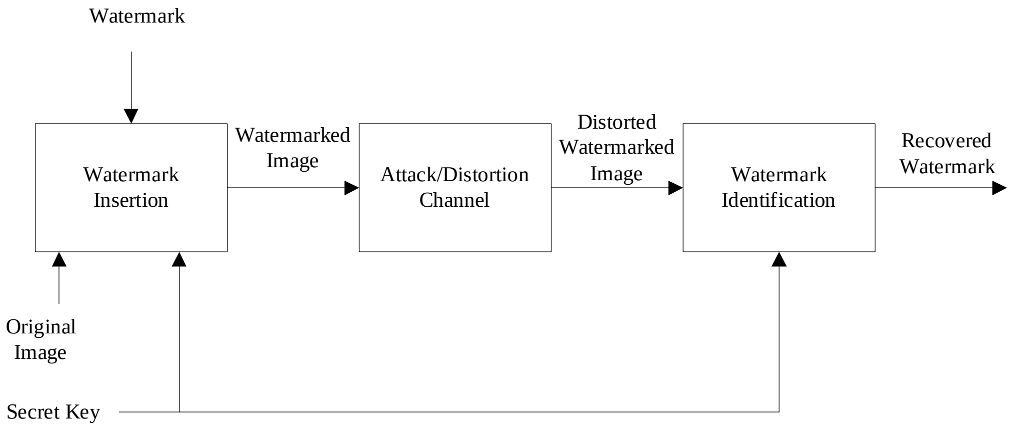


Figure 1 Generic block diagram of a blind watermarking system

$$S_4 = \frac{1}{2^{1/2}} \begin{bmatrix} 1 & 0 & \vdots & 1 & 0 \\ a_4 & b_4 & \vdots & -a_4 & b_4 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 1 & \vdots & 0 & -1 \\ -b_4 & a_4 & \vdots & b_4 & a_4 \end{bmatrix} \begin{bmatrix} S_2 & \vdots & 0 \\ & \vdots & \\ \cdots & \cdots & \cdots \\ & \vdots & \\ 0 & \vdots & S_2 \end{bmatrix} \tag{4}$$

where a_4 and b_4 are scaling constants. The orthonormality conditions lead to

$$a_4 = 2b_4 \quad \text{and} \quad b_4 = \frac{1}{5^{1/2}}$$

Equation (4) can be generalized to give the Slant matrix of order N in terms of the Slant matrix of order $N/2$ by the following recursive relation:

$$S_N = \frac{1}{2^{1/2}} \begin{bmatrix} 1 & 0 & \vdots & & \vdots & 1 & 0 & \vdots & \\ a_N & b_N & \vdots & 0 & \vdots & -a_N & b_N & \vdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ & 0 & \vdots & I_{(n/2)-2} & \vdots & & 0 & \vdots & I_{(n/2)-2} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 1 & \vdots & & \vdots & 0 & -1 & \vdots & \\ -b_N & a_N & \vdots & 0 & \vdots & b_N & a_N & \vdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ & 0 & \vdots & I_{(n/2)-2} & \vdots & & 0 & \vdots & -I_{(n/2)-2} \end{bmatrix} \begin{bmatrix} & \vdots & \\ S_{N/2} & \vdots & 0 \\ & \vdots & \\ & \vdots & \\ \cdots & \vdots & \cdots \\ & \vdots & \\ & \vdots & \\ 0 & \vdots & S_{N/2} \\ & \vdots & \end{bmatrix} \tag{5}$$

The matrix $I_{(n/2)-2}$ is the identity matrix of dimension $(N/2)-2$. The constants a_N, b_N may be computed by the formulas

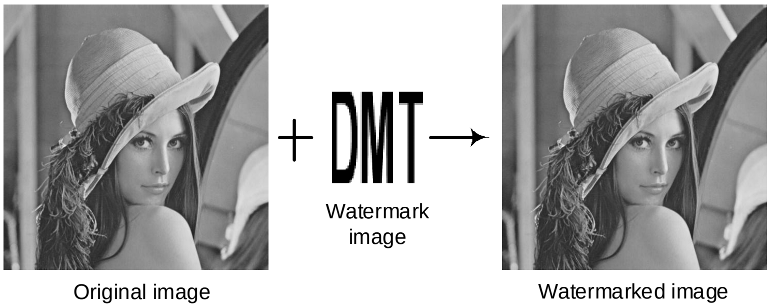


Figure 2 Image-embedded watermarking insertion process

	O	O					
	O	O	O				
		O	O	O			
			O	O	O		
				O	O	O	
					O	O	

Figure 3 Embedding locations

$$a_{2N} = \left(\frac{3N^2}{4N^2 - 1} \right)^{1/2}, \quad b_{2N} = \left(\frac{N^2 - 1}{4N^2 - 1} \right)^{1/2} \tag{6}$$

Many fast algorithms for Slant transform have been proposed [14,16,17]. In [14], Wang proved that the Slant transform may be approached by a series of steps that gradually change the transform from a Hadamard transform, which demonstrates the close relationship between the Slant transform and the Walsh-Hadamard transform. From our study in later sections, we can see that the Slant transform and the Hadamard transform display similar properties when applied to digital watermarking.

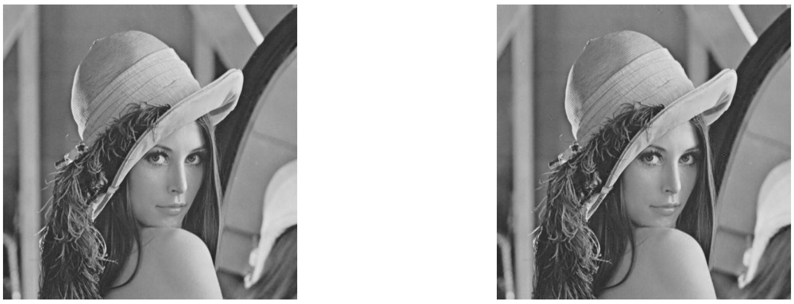
III. WATERMARKING IN SLANT TRANSFORM DOMAIN

A generic block diagram of the blind watermarking system [18] is shown in Figure 1. The original image is not necessary at the watermark recovery stage. This refers to a “blind” watermarking process. A visually recognizable pattern is embedded by modifying the Slant transform coefficients of relevant sub-blocks of the host image. The detailed Image-embedded watermark insertion and extraction algorithm are discussed in this section.

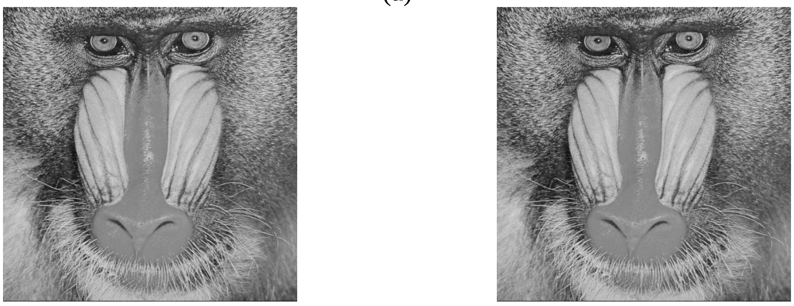
Copyright information in the form of a trademark or logo can be created as a pattern for watermarking. In our experiment, a grayscale image of size 64×64 is used as the watermark. The watermark insertion process is shown in Figure 2. We adapt a similar image-embedded watermark insertion algorithm as in [11], while using the Slant transform domain instead of the Hadamard transform domain. The algorithm can be described as follows.

The watermark image, $W(x,y)$, is first transformed into a set of Slant transform coefficients by equation (1). A Slant transform matrix of order 64 is applied to this image, and then a 64×64 Slant transform coefficients matrix is obtained. The DC component is stored in the secret key file and the AC components are used for watermark embedding.

Let the original image be $I(x,y)$. Similar to the algorithm used in [11,12], it is decomposed into a set of non-overlapped 8×8 sub-blocks. An m-sequence random number generator is used to select a certain number of sub-blocks for watermark embedding, whose initial seed is also kept in the secret key file. In every selected sub-block, sixteen middle and high frequency coefficients are used for later modulation. The way of the coefficients selection affects the performance of the watermarking scheme significantly. The high frequency components are relatively vulnerable to compression operations, while the low frequency components must be retained for visual quality of the watermarked image. Therefore, most existing watermarking schemes choose to embed the watermark into the middle frequency band. In our scheme, embedding locations as shown in Figure 3 are adopted, which are observed, through our experiments, to provide a best tradeoff between robustness and data integrity.



(a)



(b)

Figure 4 Original images (left) and watermarked images (right): (a) “lena”; (b) “baboon”.

Let the watermark Slant transform coefficients denoted by m_i. The AC coefficients of Slant transformed original image sub-blocks, before and after inserting watermark are denoted by x_i and x_i^*, respectively, and $i \in (0, n]$, where n is the number of the watermarked coefficients to be inserted into every sub-block, which is set to 16 in our experiment. The embedding formula is given as follows

$$x_i^* = \alpha m_i \tag{7}$$

where α is the watermark strength factor that controls the tradeoff between visual quality of the watermarked image and robustness of the watermarking scheme.

After embedding, the original coefficient x_i is replaced by x_i^* and a new 8×8 matrix of Slant transform coefficients of image sub-block is obtained. The inverse Slant transform is then applied to the 8×8 matrix using equation (2) to obtain the luminance matrix of the watermarked image sub-block. After performing the watermark insertion for all the selected sub-blocks of the original image, a watermarked image, $I'(x, y)$, is obtained. At the same time, as indicated earlier, the secret key file has been generated for subsequent decoding.

In watermark detection, the positions of the sub-blocks with watermark embedded are computed using the seed of the m-sequence and initial state number that is stored in the key file. All the selected sub-blocks are Slant transformed. Let these coefficients denoted by $x_i^{*'}$ and the retrieved watermark Slant transform coefficients by m_i', and $i \in (0, n]$, where n is the number of the watermarked coefficients to be inserted in every sub-block. The watermark extraction formula is given by

$$m_i' = \frac{x_i^{*'}}{\alpha} \tag{8}$$

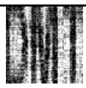
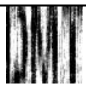
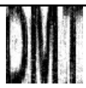
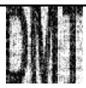
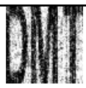
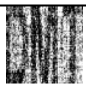
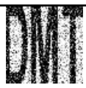
Benchmarking operations	Extracted watermark	Correlation
Frequency mode laplacian removal		0.8143
JPEG compression of factor 50		0.8536
JPEG compression of factor 80		0.94767
Change aspect ratio x_1.00_y_1.20		0.88963
Change aspect ratio x_1.00_y_0.90		0.87625
Scaling 0.90		0.69502
White additive noise of 1.5%		0.82781

Table 1 Results of some Stirmark tests for “Lena”.

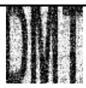
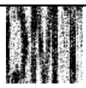
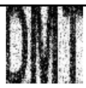
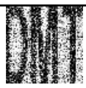
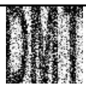
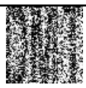
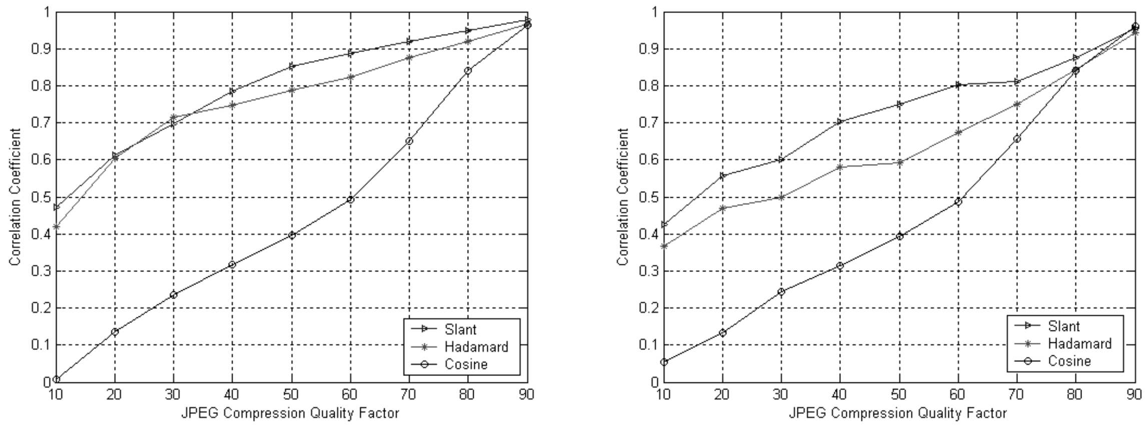
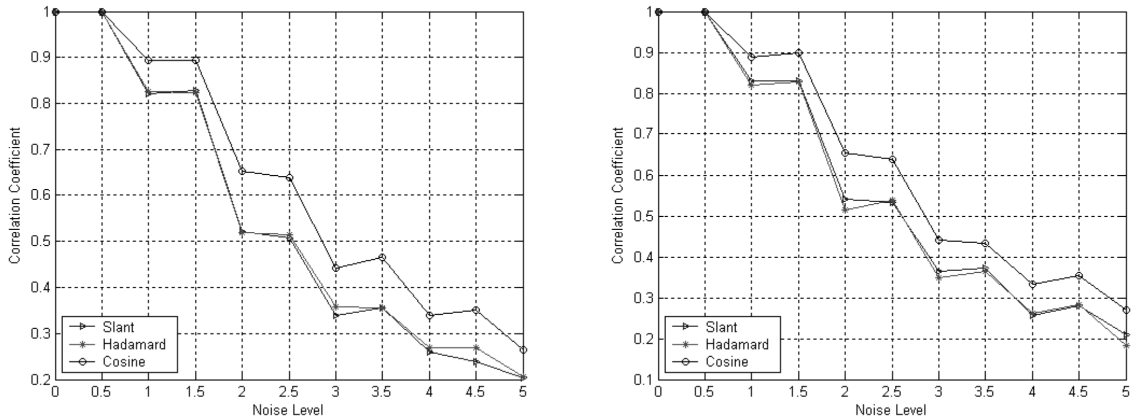
Benchmarking operations	Extracted watermark	Correlation
Frequency mode laplacian removal		0.8814
JPEG compression of factor 50		0.7036
JPEG compression of factor 80		0.87493
Change aspect ratio x_1.00_y_1.20		0.68379
Change aspect ratio x_1.00_y_0.90		0.67416
Scaling 0.90		0.40711
White additive noise of 1.5%		0.83157

Table 2 Results of some Stirmark tests for “Baboon”



(a) “Lena” (b) “Baboon”

Figure 5 Performance comparisons between Slant transform, Hadamard transform and Cosine transform against JPEG compression.



(a) “Lena” (b) “Baboon”

Figure 6 Performance comparisons between Slant transform, Hadamard transform and Cosine transform against white additive noise.

The extracted AC coefficients and the DC component stored in the key file are rearranged into a 64×64 Slant transform coefficients matrix. The extracted watermark image, $W^*(x,y)$, is then obtained by an inverse Slant transform using equation (2).

IV. SIMULATION RESULTS

We use two 512×512 gray-scale images with distinct texture to test our algorithm. The original and watermarked images are shown in Figure 4. Results show that there are no perceptually visible degradations on the watermarked images with a PSNR of 42 dB for “Lena” and 38 dB for “Baboon”.

The Slant transform watermarking scheme is benchmarked using Stirmark 3.1[19]. Some results of the above two images are shown in Table 1 and Table 2, respectively. We can see that the Slant transform watermarking is robust to noise and common image processing techniques. It can also be found that most of the correlations in Table 2 are smaller than those in Table 1. This is due to the fact that there are more AC energies concentrating in the high frequency components in highly textured images such as “Baboon” than smooth images such as “Lena”. Therefore “baboon” suffers more from common image processing operations than “Lena”.

We also compare the robustness of the Slant scheme to the Hadamard scheme in [11,12] and the DCT scheme in [3] against two typical attacks. The results are shown in Figures 5 and 6. We can see that both the Slant transform and the Hadamard transform survive JPEG compression far better than the DCT. The enhanced robustness is due to the fact that there is more useful middle frequency bands in the Slant transform and the Hadamard transform. And furthermore, middle or high frequency coefficients in Slant and Hadamard may have equivalent AC components in many DCT coefficients. For that reason, when the JPEG compression is applied, it is not very likely that any Slant or Hadamard transform band is completely eliminated [20]. It is also interesting to note that while the performance of the Slant transform is only slightly better than that of the Hadamard transform for "Lena", the advantage of the Slant transform is much more significant in the "Baboon" image. Since the Slant transform is designed to match basis vectors to areas of constant luminance slope, it is good for compact energy in "smooth" images. However, in terms of watermarking, it works better for "textured" images, for the energy spread becomes a significant advantage in watermarking and offers a good spread of middle to higher frequencies with significant energies for robust information hiding. For the resistance against additive noise, DCT is slightly more effective than Slant and Hadamard; however, their performances are still comparable.

V. CONCLUTION

This paper has presented a robust watermarking technique for embedding grayscale image watermark into an original image based on the Slant transform. The embedding and extracting processes have been described in details. The Slant transform has more useful middle and high frequency bands than several high gain transforms. Therefore, it is more robust than DCT domain algorithm under various attacks. It also offers a significant advantage in shorter processing time and ease of hardware implementation than commonly used DCT and DWT techniques. This research is based on our previous work on the Hadamard transform [11,12]. Comparison results between the Slant transform, the Hadamard transform and the Cosine transform are also presented.

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