DIGITAL WATERMARKING BY USING A FEATURE-BASED MUTLIWAVELET FUSION APPROACH

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Abstract

In this paper, a feature-based image fusion approach in the multiwavelet domain for embedding watermark in a host image is presented. The multiwavelet simultaneously offers orthogonality, symmetry, and short support, which is not possible with a scalar two-channel wavelet system. The proposed embedding procedure consists of three steps: 1) decomposition of both the host and watermark images with GHM multiwavelet; 2) fusion in the transform domain; and 3) reconstruction of the fused image with the inverse transform. The fusion process is implemented based on an absolute measure of image feature namely phase congruency. The sub-blocks of the watermark image are embedded into the most salient features like step edges and lines that are extracted by the phase congruency measure in the host image. The fusion is adaptive to the variance of the phase congruency map of each sub-block. Therefore, the scheme is optimized for the robustness and fidelity.

Keywords: *Digital watermarking; multiwavelet; image fusion.*

1. INTRODUCTION

Digital watermarking has been applied to kinds of applications like copyright protection and authentication. The embedding of digital watermark to host image can be implemented in either spatial domain or transform domain. Requirements for the implementation of the embedding and detecting algorithms largely depend on the application. One typical application is the intellectual property management, where secret information for labeling digital picture is hidden in the host image. This paper will report the preliminary results of the study on the invisible robust grayscale logo watermarking by using a multiresolution approach.

The advantage of implementing watermarking in the transform domain is that the perceptual significance feature may be easier to access. The watermark can be embedded in the feature that is robust to distortions and attacks. The general procedure for transform domain watermarking consists of three steps: host image decomposition, watermark embedding, and reconstruction of watermarked image.

Ohnishi et al. embedded a binary seal image into a picture by using the Haar wavelet transform [1]. The maximum and minimum values of the detailed image components were used to guide the embedding process. Kundur improved the approach by quantizing the detail coefficients between the corresponding maximum and minimum values [2]. Another scheme proposed by Kundur was adding watermark in the transform domain [3]. The weighting coefficients were determined by the contrast sensitivity. This method was first proposed by Wilson et al. in the fusion of hyperspectral images. Hsu et al. proposed a method to embed binary watermark image in the transform domain [4,5]. Instead of adding the watermark to the selective coefficients of the transformed host image, the watermark is embedded to the neighboring relationship within the transformed image. Therefore, the watermark can be extracted by certain logical operation rather than detecting by computing the correlation coefficients with a reference watermark. The watermark image needs to be binary. Zhang et al. embedded a binary logo watermark in the multiwavelet domain [6]. In the multiwavelet representation, there are four sub-blocks at the coarsest level. By adjusting the polarity between the coefficient in one sub-block and the mean value of the corresponding coefficients in other three sub-blocks, the watermark was embedded [6]. The watermark detection was conducted by a back-propagation neural network (BPNN). The BPNN implemented an operation similar to inverting or restoration process. However, the neural network needs a lot of data for training. In most situations, the attacks or the distortion may not be known in advance.

In this study, we use the multiwavelet constructed by Geronimo, Hardin, and Massopust (GHM) to represent both the host and watermark image [7]. The watermark image is embedded into the corresponding frequency bands of host image. The significance of the coefficients or the features of the sub-images are detected by the phase congruency algorithm proposed by Peter Kovesi. The phase congruency algorithm provides an absolute measure of image feature like step edge, line, and Mach band with a value between 0 and 1 [8]. Larger value

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indicates salient feature. The watermark image is weighed more at the points of host image with a higher phase congruency value. In this report, the preliminary experimental results are given. Further improvement is under implementation.

2. THE ALGORITHM

2.1 Multiwavelet

Different from scalar wavelet, multiwavelet has multiple scaling and wavelet functions. The set of scaling function can be written as [7]:

$$\Phi(\mathbf{t}) = [f_1(t), f_2(t), \cdots f_r(t)]^T \quad (1)$$

The translations $\Phi(t-k)$ are linearly independent and produce a basis of the subspace V_0; the dilates $\Phi(2^j t - k)$ generate the subspace V_j, $j \in Z$, such that

$$\cdots \subset V_{-1} \subset V_0 \subset V_1 \subset \cdots \subset V_j \subset \cdots$$

$$\bigcup_{j=-\infty}^{+\infty} V_j = L^2(R), \quad \bigcap_{j=-\infty}^{+\infty} V_j = \{0\}$$

Similarly, the multiwavelet function is defined as [7]:

$$\Psi(t) = [y_1(t), y_2(t), \cdots, y_r(t)]^T \quad (2)$$

Its translations produce a basis of the detail subspace W_0. The following equation holds:

$$V_1 = V_0 \oplus W_0 \quad (3)$$

The multiwavelet equations resemble those for scalar wavelet:

$$\Phi(t) = \sum_{k=0}^{m-1} \mathbf{C}_k \Phi(2t-k) \quad (4)$$

$$\Psi(t) = \sum_{k=0}^{m-1} \mathbf{D}_k \Psi(2t-k) \quad (5)$$

where $\mathbf{C}_k$ and $\mathbf{D}_k$ are $r \times r$ matrix low-pass filters and matrix high pass filters respectively. m denotes the number of scaling coefficients.

In GHM wavelet representation, there are two scaling functions and two wavelet functions. An example of the decomposition is given in Figure 1. The application of multiwavelet requires that the input image first be vectorised. In this report, the preprocessing is based on Strela' algorithms [7]. The theory of multiwavelet is also based on the idea of multiresolution analysis. However, the multiwavelet used herein has two channels and there are two sets of scaling coefficients and two sets of wavelet coefficients. At one level of 2D decomposition, sixteen sub-band images will be generated. The multiwavelet has several advantages over scalar wavelet: short support, orthogonality, symmetry, and with a high number of vanishing moments. Thus, the multiwavelet provides the possibility of superior performance for image processing applications compared with scalar wavelet.

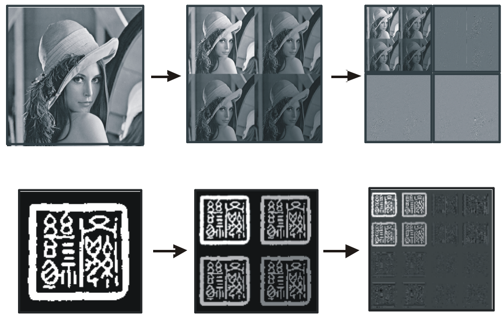


Figure 1. Representation of the host and logo image by GHM multiwavelet.

2.2 Feature Detection: Phase Congruency

A major problem with gradient-based operators is that they use a single model of an edge, that is, they assume edges are step discontinuities [8]. Many image features are represented by some combination of step, delta, roof and ramp profiles. Kovesi provided an invariant measure of significant feature points in images, which is known as phase congruency. Phase congruency allows constant threshold values, which do not have to be determined empirically for individual images.

Kovesi used logarithmic Gabor wavelet to calculate the phase congruency. The concept of his approach is briefly described below. The definition function of phase congruency is [8]:

$$PC(x) = \frac{E(x)}{\sum_n A_n(x) + e} \quad (6)$$

$$E(x) = \sqrt{F^2(x) + H^2(x)} \quad (7)$$

where $PC(x)$ is the phase congruency at some location x and $E(x)$ is the local energy function. A_n represents the amplitude of the nth component in the Fourier series expansion. A very small positive constant e is added to the denominator in case of small Fourier amplitudes. In the expression of local energy (7), $F(x)$ is the signal with its DC component removed and $H(x)$ is the Hilbert transform of $F(x)$. To calculate these parameters in equation (7), wavelet transform is employed. Let M_n^e and M_n^o denote the even-symmetric and odd-symmetric wavelet at scale n. We use $I(x)$ to denote the signal. The outputs of each quadrature pair of filters are $e_n(x) = I(x) * M_n^e$ and $o_n(x) = I(x) * M_n^o$ respectively. The outputs can be used to estimate the parameters in (7). These are [12]:

$$F(x) \approx \sum_n e_n(x) \quad (8)$$

$$H(x) \approx \sum_n o_n(x) \quad (9)$$

$$\sum_n A_n(x) \approx \sum_n \sqrt{e_n(x)^2 + o_n(x)^2} \quad (10)$$

To deal with the noise, the above equation (6) changes to

$$PC(x) = \frac{\lfloor E(x) - T \rfloor}{\sum_n A_n(x) + e} \quad (11)$$

where $\lfloor \ \rfloor$ denotes that the enclosed quantity is not permitted to be negative. T is the compensation for the influence of noise. To extend the algorithm to images, the one-dimensional analysis is applied to several orientations and the results are combined in different ways.

2.3 Watermark Embedding

As stated previously, both the watermark image and the host image are decomposed by the GHM multiwavelet to one level. The decomposed watermark image will be embedded to the decomposed host image. The equation used for embedding is as:

$$\hat{F}_k = F_k + \exp\left(b \cdot \frac{\sum_i \sum_j PC_k(i,j)}{MN} \cdot \sqrt{\sum_u \sum_v Q(u,v)}\right) \cdot W_k \cdot (3 + 5PC_k) \quad (12)$$

where:

$\hat{F}_k$: The k-th watermarked sub-image;

F_k: The k-th sub-band components of host image;

W_k: The watermark image;

$Q(u,v)$: The JPEG quantization table;

PC_k: The phase congruency map of F_k.

The strategy for the embedding can be seen from above equation. First, the redundant embedding is considered. For example, the host image is of size 512 by 512. The watermark image is 128 by 128. In the transform domain, for each component of host image, we can embed four watermark sub-images in it, i.e. the watermark components will be tiled on the component of host image. Second, the significant coefficients of watermark image should be embedded into the significant coefficients of the host image. The significance is measured by the phase congruency algorithm proposed by Kovesi [8]. From equation (12), we can see that the mean value of phase congruency measurement for each block is employed as the weighting coefficient for this block. Meanwhile, it is also used as a weighting map for the watermark image component W_k. Thirdly, the JPEG quantization table is introduced to the weighting coefficients in order to weight more for the detailed parts of the decomposition and less for the approximation parts. To keep an acceptable fidelity, the low-pass components of the host image should not be changed a lot. The JPEG quantization table is divided into 4 by 4 block and the average values of each block are used as one of the weighting coefficients in Equation (12).

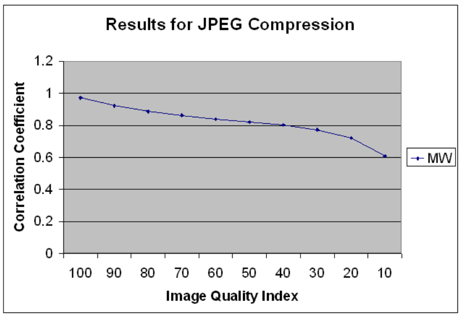
The components of watermark image are not added to the components of host image directly. The components are vectorised and sorted in a descent order. Therefore, the lager value of watermark corresponds to the larger value of host image. After the embedding operation, the modified coefficients will be reconstructed to generate the watermarked image.

2.4 Watermark Extraction

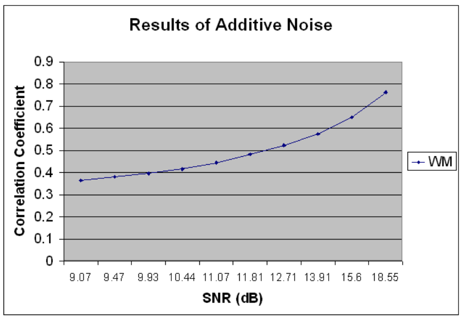
The detection of the watermark is an inverse process of the embedding. The detecting process is not blind and the host image is needed. As stated previously, from each sub-block of watermarked image, we will get 16 sub-images for the watermark image at this frequency band. In this report, the average value of these sub-images is calculated and used for reconstructing the watermark image.

3. EXPERIMENTAL RESULTS

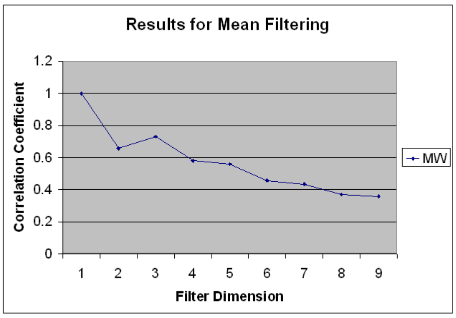
In the experiments, the watermarked image will be distorted by several operations. The robustness of the algorithm is investigated in this part. The processing operations include: JPEG compression, Gaussian additive noise, mean filtering, and median filtering. The normalized correlation coefficient is employed to evaluate the quality of the detected watermark. The experimental results are given in Figure 2 below.



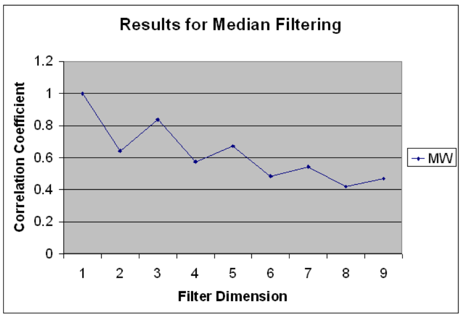
(a)



(b)



(c)



(d)

Figure 2. Test results of watermarked image.

4. DISCUSSION

From the preliminary experimental results, we can see that proposed scheme is robust to most of the distortions. However, the performance on the Gaussian additive noise is not ideal as expected. This implies that certain optimal or restoration operation should be considered to post-process the detected watermark sub-images before the reconstruction operation like the procedure as suggest by Kundur [5].

This embedding scheme considers the effects of JPEG compression and the image feature measurement. Nevertheless, Equation (12) is empirical. Extensive experiments including the cropping and scaling attacks should be carried out so that the embedding scheme is improved and the formula may be further modified to increase the robustness.

In this study, the detection of the watermark image needs the presence of the host image at the detection side, i.e. the detection process is not blind. Further more, the invariant for rotation and translation is not investigated, although this is an important aspect of the watermarking technique. However, this topic remains a challenge for the study on multiresolution based digital watermarking.

5. CONCLUSIONS

In this paper, a scheme based on multiwavelet transform for digital image watermarking is presented. The algorithm tries to integrate the effect of compression and image feature measurement. The information of the watermark is embedded into the salient feature of the host image that will survive kinds of distortions or attacks. The preliminary results indicate the feasibility of the promising approach. Extensive experiments will be carried on to improve the robustness of the algorithm.

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