Adaptive Digital Watermarking Based on Wavelet Transform Using Successive Subband Quantization and Perceptual Model

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Abstract: In this paper, we propose an adaptive digital image watermarking algorithm using successive subband quantization (SSQ) and perceptual model based on wavelet domain. The watermark is embedded into the perceptually significant coefficients (PSCs) of image. The PSCs in the baseband are selected according to the amplitude of the coefficients and the high frequency subbands are selected by SSQ. To embed the watermark, we use perceptual model. The perceptual model is based on the computation of the noise visibility function (NVF) and embed at the texture and edge region stronger embedded watermarks.

1. Introduction

With the rapid growth of Internet and networks technique, Multimedia data transforming and sharing is common to many people. Multimedia data is easily copied and modified, so necessity for copyright protection is increasing. Digital watermarking has been proposed as technique for copyright protection of multimedia data. Digital watermarking invisibly embeds copyright information into multimedia data. Thus, digital watermarking has been used for copyright protection, finger printing, copy protection and broadcast monitoring. Indeed, a watermarking algorithm requires both invisibility and robustness, which exist in a trade-off relation. Thus good watermarking algorithm must be satisfied the requirements.

In general, we classify the digital watermarking into two classes by depending on the domain of watermarking embedding: the spatial domain watermarking [1], [2] and the frequency domain watermarking [3]-[6]. The spatial domain watermarking algorithms usually embed the watermark to the least significant bits (LSBs) of the image pixels. But, these algorithms have relatively low-bit capacity and are not resistant enough against the lossy image compression and other image processing. For example, JPEG operation may eliminate the watermark. But, the frequency domain watermarking algorithms can embed more bits of watermark and are more robust against attack. Thus, all the watermark embedding and extracting process is performed in frequency domain. In general, we use discrete cosine transform (DCT) and discrete wavelet transform (DWT).

Cox *et al.* proposed a secure spread spectrum [3] in which a watermark can be embedded using the largest amplitude DCT coefficients. This algorithm can be result in a poor image quality due to the manipulation of the most perceptually significant portion of the image. And it is sensitive to noise, image processing even though it is robust to LPF and lossy compression.

Recently, watermarking algorithms is using to a DWT. Podilchuk *et al.* [4] proposed image adaptive watermarking using visual models. This algorithm calculated a JND threshold of wavelet coefficients and selected perceptually significant coefficients. But it is less robust because it is not consider the wavelet coefficients characteristics. Voloshynovskiy *et al.* [5] proposed an stochastic model for content adaptive digital image watermarking. Using stochastic models of the watermark and the host image, one can formulate the problem of watermark estimation and detection according to the classical MAP and estimate the capacity of the image watermarking method.

The conventional watermarking algorithms using global information of the image characteristic embed the watermark in the whole host image with the same watermark strength regardless of the local property of image. Therefore, this watermarking method leads in practice to visible artifacts in the flat regions that are characterized by small variability. In order to decrease visual artifacts, the watermark strength has to be decreased. This reduces the robustness of the watermark, since the image region selects to determine the maximum strength of the watermark to be embedded.

In this paper, we propose an adaptive digital image watermarking algorithm using successive subband quantization and perceptual model based on wavelet domain. This model use local image properties to determine the optimal watermark location for stronger embedded watermarking. The original image decomposed into 4 levels using a DWT, then the watermark is embedded into the perceptually significant coefficients (PSCs) of image. The PSCs in the baseband are selected according to the amplitude of the coefficients and the high frequency subbands are selected by successive subband quantization (SSQ), that is, by setting the thresholds as the one half of the largest coefficient in each subband and comparing the maximum threshold with coefficients in that subband in which the maximum threshold is located. And the used threshold is updated as one half of it. For the PSCs, the watermark is embedded based on perceptual model. The perceptual model is based on computation of the noise visibility function (NVF) and embed at the texture and edge region stronger embedded watermarks. In computer experiments, the proposed algorithm was tested with the conventional algorithms in the same watermarks length. The proposed algorithm was found to be more invisible and robust than the conventional algorithm of Podilchuk *et al.*.

Following sections explain the proposed watermarking algorithm. Section 2 explains the watermark embedding process. Section 3 shows the experimental results. And the conclusion of the paper is in section 4.

2. Proposed Watermarking Algorithm

In this paper, we propose an adaptive digital watermarking algorithm using SSQ and perceptual model based on wavelet domain. DWT is widely used in the image processing, because it can reveal multi-resolution characteristics, which are similar to human visual structure, plus effectively localize an image into the spatial and frequency domain.

In proposed algorithm, an image decomposed into 4 levels, then select the PSCs in the baseband and the subband except the highest frequency components. For the PSCs, the watermark is embedded based on perceptual model. The perceptual model is based on computation of the noise visibility function (NVF) and embed at the texture and edge region stronger embedded watermarks.

2.1 Choice of PSCs

The PSCs in the baseband are selected according to the amplitude of the coefficients in the baseband. And SSQ [6] is performed to select the PSCs in the high frequency subbands. The SSQ procedure is as follow.

Step 1. Set the initial threshold of each subband to one half of the maximum amplitude value of the coefficients inside the same subband. Set all coefficients as unselected.

Step 2. Select the subband with the maximum value of threshold, the within the selected subband examine all unselected coefficients with the current threshold and select those coefficients which are greater than threshold as the PSCs.

Step 3. Change the new threshold of the selected subband to one half.

Step 4. Repeat Step 2 and 3 until all require PSCs are selected.

As illustrated above, the PSCs is selected by SSQ, then the watermark is embedded into these selected PSCs. The selected PSCs for the BABOON image are represented in Figure 1.

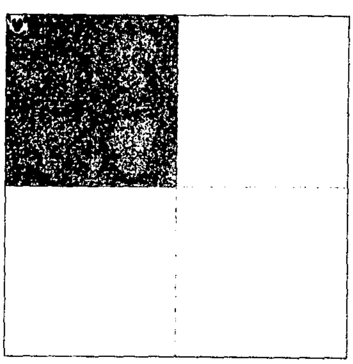

Figure 1. The PSCs for the BABOON image.

2.2 Watermark Embedding using Perceptual Model

In this paper, perceptual model for embedding watermark use stochastic approach of original image in wavelet domain. And this method is base on the computation of a noise visibility function (NVF) that has local image properties. In order to determine the optimal NVF, we consider the watermark as noise. And the NVF use the mean and variance of original image and hence, produces content adaptive criteria according to edge and texture region, flat region. The proposed watermark model is shown by block diagram of Fig 2.

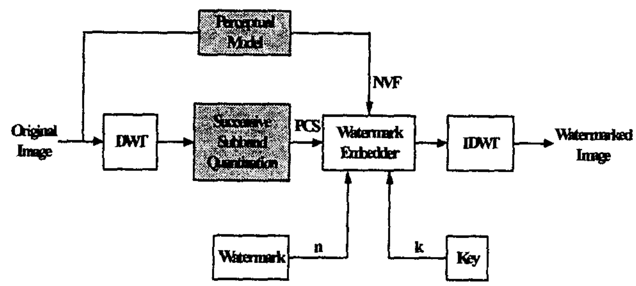

Figure 2. The block diagram of the proposed watermark embedding model.

In the case of non-stationary Gaussian model, NVF can be written in the eq.(1):

$$NVF = \frac{1}{1+\sigma_x^2(i,j)} \tag{1}$$

where $\sigma_x^2(i,j)$ denote the local variance of the image in a window centered on the pixel with coordinates (i,j), $1 \le i, j \le M$. Following equations use to compute $\sigma_x^2(i,j)$.

$$\sigma_x^2(i,j) = \frac{1}{(2L+1)^2} \sum_{m=-L}^{L} \sum_{n=-L}^{L} (x(i+m, j+n) - \bar{x}(i,j))^2 \tag{2}$$

$$\bar{x}(i,j) = \frac{1}{(2L+1)^2} \sum_{m=-L}^{L} \sum_{n=-L}^{L} x(i+m, j+n) \tag{3}$$

where $\bar{x}(i,j)$ is the mean of local region, $(2L+1)^2$ is a size of window. And watermark is an i.i.d. (independent identically distributed) Gaussian process with zero mean and unit variance, N(0,1).

In this paper, equation with adaptive watermarking embedding is:

$$y = x + (1 - NVF) \times w \times S \tag{4}$$

where S denotes the watermark strength, w denotes the watermark. The above equation embeds the watermark in highly the texture and the edge regions stronger than in the flat regions.

In any region, if NVF is 1, the strength of the embedded watermark is zero. As a consequence of the embedding rule, the watermark is lost in these regions. Therefore, to avoid this problem, eq. (4) is modified to eq.(5).

$$y = x + (1 - NVF) \times w \times S_T + NVF \times w \times S_F \qquad (5)$$

where S_T is a watermark strength for the edges and textures, and S_F is a strength for the flat regions. We use that Watson *et al.* [7] and Safranek *et al.* [8] proposed visual quantization matrices. And Appendix shows the visual quantization matrices of S_T and S_F.

3. Experimental Results

To evaluate the proposed watermarking algorithm, we simulated by computer. In experiment, we simulated our algorithm on several images of 512 × 512 size. A biorthogonal DWT was used to decompose the original images into 4 levels. And the proposed algorithm was tested with the conventional algorithms in the same watermarks length. The performance measure was invisibility and robustness. The PSNR and similarity were used as the metric of the invisibility and robustness. The authenticity of the original watermark in the recovered image can be determined by calculating the similarity as follows:

$$Z(X, X^*) = \frac{X \cdot X^*}{\sqrt{(X^* \cdot X^*)}} \qquad (6)$$

where X and X^* represent the original and extracted watermark, respectively, and $<\cdot>$ is the inner product of the vector. An original image for BABOON image is shown in Figure 3(a). The corresponding watermarked image for embedded the NVFs based on perceptual model is Figure 3(b). The difference image of the original image and watermarked image is shown Figure 3(c). The binary image of difference image is shown Figure 3(d). In four cases, the watermarked image appears visually identical to the original. The watermark values corresponding to flat regions are smaller than watermark values of edge regions.

The PSNR value of the several watermarked images with respect to the original images is shown the Table 1. The proposed algorithm was found to be superior to Podilchuk's algorithm in PSNR of 0.27-0.92 [dB].

To verify the robustness of the proposed algorithm, the watermarked image was subjected to JPEG compression and image processing, then the similarity was calculated. Figure 4 shows the robustness value of the watermarked image for JPEG attack. We did compression by JPEG with a quality factor varying 10% to 90%. Figure 4 confirms that the proposed algorithm is more robust than Podilchuk's algorithm because the proposed algorithm uses the coefficients of the baseband in the embedding step.

The similarity after image processing and geometric transformation is shown in Table 2. Table 2 indicates that proposed algorithm was far more robust, except for the cropping attack. Because the proposed algorithm embeds the watermark at maximum amplitude into PSCs based on perceptual model.

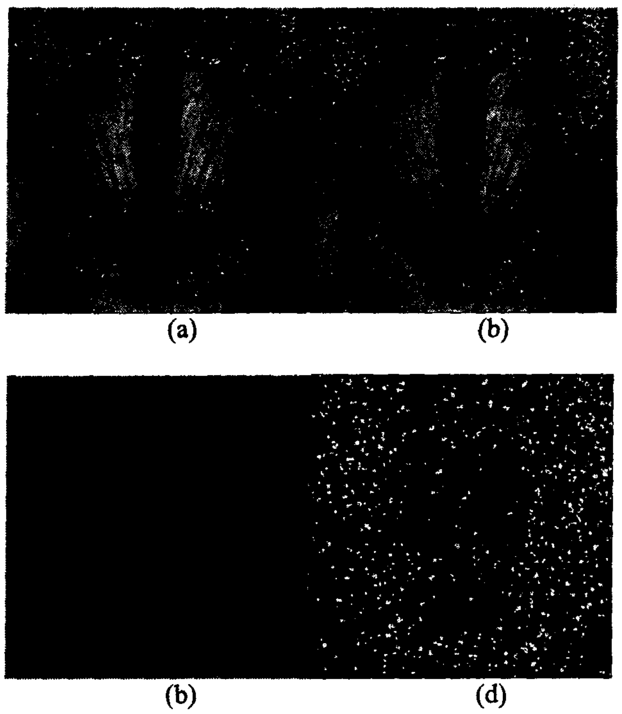

Figure 3. (a) The original BABOON image, (b) watermarked image, (c) their difference image, and (d) the binary image of the difference image.

Table 1. The PSNR of the proposed method and Podilchuk's method. [dB]

method / image	Proposed method	Podilchuk's method
BABOON	33.05	32.13
GOLDHILL	38.29	37.51
LENA	39.81	39.54
MAN	37.43	36.96

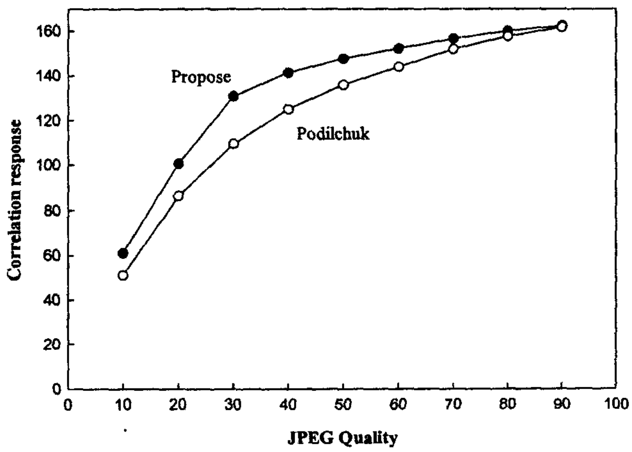

Figure 4. The robustness value of JPEG attack for BABOON image

Table 2. The similarity according to a series of attack for BABOON image.

Attack \ method	Proposed method	Podilchuk's method
3×3 LPF	66.01	27.53
5×5 LPF	12.09	6.34
7×7 LPF	1.92	1.03
3×3 Median filter	70.79	33.28
5×5 Median filter	13.84	7.29
7×7 Median filter	2.80	1.46
cropping	76.97	56.37

4. Conclusions

In this paper, we propose an adaptive digital image watermarking algorithm using SSQ and perceptual model based on wavelet domain. The original image decomposed into 4 levels using a DWT, then the watermark is embedded into the PSCs of image. The PSCs are selected in the baseband and the high frequency subbands. The PSCs of the high frequency subbands are selected by SSQ. For the PSCs, the watermark is embedded based on perceptual model. The perceptual model is based on computation of the noise visibility function (NVF) and embed at the texture and edge region stronger embedded watermarks. In computer experiments, the proposed algorithm was tested with the Podilchuk's algorithm in the same watermarks length. The proposed algorithm was found to be more invisible and robust than the Podilchuk's algorithm.

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Appendix

Visual quantization values

In this paper, we use visual quantization values that proposed by Watson's model [7] and Safranek's model [8]. S_T show the visual quantization values of Watson's model and S_F show those of Safranek's model.

Table 3. The visual quantization values of Watson's model (S_T).

orientation \ level	1	2	3	4
HL	23.028	14.485	12.707	14.156
LH	23.028	14.485	12.707	14.156
HH	58.756	28.408	19.54	17.864

Table 4. The visual quantization values of Safranek's model (S_F).

orientation \ level	1	2	3	4
HL	2.0	0.5	0.2	0.1
LH	2.0	0.5	0.2	0.1
HH	4.0	1.0	0.5	0.2