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Adaptive spread transform QIM watermarking algorithm based on improved perceptual models☆

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ABSTRACT

The quantization step is one of the most important factors which affect the performance of quantization watermarking used for image copyright protection. According to the characteristic of perceptual model and the specific attacks, improved perceptual model and different implementations of perceptual model are proposed. They are incorporated into the spread transform quantization index modulation (ST-QIM) framework. The experimental results show that the four algorithms we proposed in this paper can reduce the noise attacks and facilitate common digital image processing operations. Among these, adaptive ST-QIM based on further modified Watson model (ST-QIM-fMW-SS) and adaptive ST-QIM based on modified sensitivity model (ST-QIM-MS-SS) have better performance.

1. Introduction

The digital watermarking technique has received widespread attention due to its significant value in the protection of copyright of images. Researchers have proposed various types of watermarking algorithms [1–5]. Among these, the watermarking system which contains side information proves to be most popular currently because of its favorable performance.

Quantization index modulation (QIM) [6] is a typical watermarking scheme containing side information. It has advantages in computational flexibility and implementation, but it is not robust enough against some common signal processing such as additive white Gaussian noise, amplitude scaling and re-quantization. In fact, Chen and Wornell presented a series of extended schemes based on QIM, including dither modulation (DM) [6], distortion compensated quantization index modulation (DC-QIM), and spread transform dither modulation (STDM) [6]. These algorithms, especially STDM, achieve great improvement in robustness against random noise and re-quantization compared with the original QIM algorithm.

QIM and its extended schemes are all based on quantizers. Therefore, the quantization step is one of the most critical factors affecting the invisibility of watermarks and the robustness of watermarking system. Researchers have proposed schemes that optimize quantization step, including using perceptual models to determine quantization steps adaptively [7–9] and determining quantization step size according to the characteristics of carrier or wavelet coefficients [10].

Li and Cox have applied modified Watson model with STDM and proposed STDM-MW [8]. It significantly decreases the perceptual distortion, but is still sensitive to amplitude scaling. Thus, adaptive STDM method (STDM-MW-SS [8]) was proposed. It is robust in performance against amplitude scaling while is poor in robustness against JPEG compression. Therefore, another adaptive STDM method (STDM-OptiMW-SS [8]) was proposed later which are robust against both amplitude scaling and JPEG compression. Nevertheless, the algorithm must use a lot of DCT coefficients for embedding watermark bits to obtain good performance, resulting in low watermark embedding rate such as 1/320 [8]. Moreover, robustness of algorithms against re-quantization is very important, because re-quantization is very common. For example, re-quantization will occur whenever a multimedia signal undergoes lossy compression. Therefore, the robustness against JPEG compression of STDM-OptiMW-SS still needs to be further improved.

Integrating further modified perceptual model [7] with spread transform quantization index modulation dynamically can optimize the quantization step further thus making the watermarking system more robust. In light of this, this paper applies further modified perceptual model with quantization watermarking scheme and proposes four adaptive spread transform quantization index modulation algorithms. Compared with former proposed modified STDM schemes, algorithms proposed in this paper have

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evidently better performance, especially against JPEG compression and Gaussian noise. In addition, high watermark embedding rate is obtained.

The rest of the paper is organized as following. In Section 2, the fundamental of STDM is introduced. In Section 3, STDM-OptiMW-SS, ST-QIM etc. are first described, and then adaptive quantization watermarking algorithms based on further modified perceptual model and different specific implementation of perceptual models are presented. In Section 4, the experimental results of pre-existing algorithm and the schemes proposed in this paper are shown with some comparison and analysis provided. Finally Section 5 summarizes the paper.

2. Spread transform dither modulation

2.1. Quantization index modulation and Dither modulation

The standard quantization operation with step Δ is defined as

$$Q(x, \Delta) = round\left(\frac{x}{\Delta}\right)\Delta \tag{1}$$

where x represents the original signal, $round(\cdot)$ denotes rounding a value to the nearest integer, Δ stands for quantization step, and $Q(x, \Delta)$ represents the quantization operation on x. Corresponding quantization operation is selected according to the watermark bit. For example, x is quantized to even integers when the watermark bit is “0”, and x is quantized to odd integers when the watermark bit is “1”.

Dither modulation is another type of implementation of QIM, which is an extension of QIM algorithm, proposed by Chen and Wornell [6]. Dither modulation is proposed to reduce the quantization error and produce a perceptually superior quantized signal. The embedding process can be described as

$$\begin{aligned} y &= Q_{DM}(x, \Delta, d(m)) \\ &= round\left[\frac{x + d(m)}{\Delta}\right] \times \Delta - d(m) \end{aligned} \tag{2}$$

where y is the watermarked signal, m stands for watermark bit, $d(m)$ is the dither value corresponding to m, and $Q_{DM}(x, \Delta, d(m))$ represents the quantization operation on x.

The decoding process can be illustrated as

$$\hat{m} = arg \min_{m \in \{0,1\}} (r - s[m])^2 \tag{3}$$

where r stands for received signal, $\hat{m}$ represents the extracted watermark bit, and $s[0]$ and $s[1]$ are calculated as follows:

$$\begin{aligned} s[0] &= round\left[\frac{r + d(0)}{\Delta}\right] \times \Delta - d(0) \\ s[1] &= round\left[\frac{r + d(1)}{\Delta}\right] \times \Delta - d(1) \end{aligned} \tag{4}$$

2.2. Spread transform dither modulation

STDM differs from regular QIM in that STDM does not directly quantize the coefficients of the original image. Instead, the vector of the original signal $\mathbf{x}$ is first projected onto a randomly generated vector $\mathbf{u}$, and the resulting scalar value is then quantized to y_w. If dither modulation is selected as the specific quantization method on the scalar value after projection, the algorithm is STDM. The vector after watermark embedding could be achieved as $\mathbf{y} = y_w\mathrm{u} + \mathbf{x} - (\mathbf{x}^T\mathbf{u})\mathbf{u}$. The watermark embedding procedures can be described as follows:

$$\begin{aligned} \mathbf{y} &= \mathbf{x} + (Q_{DM}(\mathbf{x}^T\mathbf{u}, \Delta, d(m)) - \mathbf{x}^T\mathbf{u})\mathbf{u} \\ &= \mathbf{x} + \left(\left(round\left(\frac{\mathbf{x}^T\mathbf{u} + d(m)}{\Delta}\right) \times \Delta - d(m)\right) - \mathbf{x}^T\mathbf{u}\right)\mathbf{u} \end{aligned} \tag{5}$$

Minimum distance decoding is used for detection, and the corresponding detecting procedures are as follows:

$$\hat{m} = arg \min_{m \in \{0,1\}} |\mathbf{r}^T\mathbf{u} - Q_{DM}(\mathbf{r}^T\mathbf{u}, \Delta, d(m))| \tag{6}$$

where $\mathbf{r}$ represents the vector obtained from the received image. The scheme diagram of STDM algorithm is shown in Ref. [3].

3. The adaptive quantization based on visual perceptual models

Watson perceptual model (W) is a model measuring perceptual invisibility proposed by Watson in 1993 [11]; Li and Cox proposed modified Watson perceptual model (MW) later. In this section, STDM-OptiMW-SS algorithm [8] and spread transform quantization index modulation framework are introduced first concisely. Then, further modified Watson perceptual model, different specific implementations of perceptual models and four corresponding adaptive watermarking schemes are proposed. The schemes are adaptive ST-QIM based on better modified Watson model (we refer it as ST-QIM-B1MW-SS in this paper), a special case of ST-QIM-B1MW-SS (we refer it as ST-QIM-B2MW-SS in this paper), ST-QIM-fMW-SS and ST-QIM-MS-SS.

3.1. Adaptive quantizing watermarking algorithms

3.1.1. Watson perceptual model

Watson perceptual model is made up of sensitivity part and two masking parts based on luminance and contrast. Sensitivity table t [11] is defined in Watson model whose elements are constant values. It reflects different sensitivity level for different frequency by human eyes. The fact that a DCT coefficient can be changed by a larger amount before becoming perceptible, if the average intensity of the 8×8 block is brighter has been taken into consideration in luminance-masked threshold $t_L[i, j, k]$. Contrast masking shows the accretion in invisibility of the change in one frequency due to the energy present in that frequency. The sensitivity, luminance masking and contrast masking part in Watson model are all illustrated in Ref. [7] in detail.

3.1.2. MW perceptual model

The adaptive watermarking scheme based on Watson model is sensitive to amplitude scaling. Li and Cox [7] modified the luminance masking threshold in order to make the quantization step vary proportionally along with the alteration of the amplitude. Therefore, the obtained adaptive algorithm would be robust to amplitude scaling. The modified luminance masking is $t_L^M[i, j, k]$ which is given by

$$\begin{aligned} t_L^M[i, j, k] &= t_L[i, j, k]\left(\frac{C_{0,0}}{128}\right) \\ &= t[i, j]\left(\frac{C_0[0, 0, k]}{C_{0,0}}\right)^{\alpha_T}\left(\frac{C_{0,0}}{128}\right) \end{aligned} \tag{7}$$

where $C_0[0, 0, k]$ is the DC coefficient of the kth block in the original image. $C_{0,0}$ is the average value of DC coefficients of the original image, representing the average brightness of the image. Compared