Int. J. Electron. Commun. (AEÜ) 70 (2016) 172–178

Contents lists available at ScienceDirect

International Journal of Electronics and Communications (AEÜ)

journal homepage: www.elsevier.com/locate/aeue

A mixed modulation scheme for blind image watermarking

Hwai-Tsu Hu[a,*], Ling-Yuan Hsu[b]

[a] Department of Electronic Engineering, National I-Lan University, I-Lan, Taiwan, ROC
[b] Department of Information Management, St. Mary's Junior College of Medicine, Nursing and Management, I-Lan, Taiwan, ROC

ARTICLE INFO

Article history:
Received 31 July 2015
Accepted 13 November 2015

Keywords:
Blind image watermarking
Mixed modulation
Relative modulation
Quantization index modulation

ABSTRACT

Relative modulation (RM) is a scheme developed for effective blind image watermarking. The embedding of a binary bit can be implemented by first selecting a target coefficient along with its prediction and later manipulating this coefficient pair to maintain a desired inequality relationship. The RM has been confirmed to possess superior robustness against malign attacks but suffer undue image distortion. In this paper, a scheme is introduced to ameliorate the quality degradation problem due to excessive coefficient modulation in DCT-based image watermarking. By grafting quantization index modulation (QIM) onto RM, we enable the proposed mixed scheme to achieve a comparable peak signal-to-noise ratio and mean structural similarity and yet remain adequate robustness against commonly encountered attacks. Under the presupposition that the embedding strength is controlled at a similar level, the mixed modulation scheme can compete with the better one between the RM and QIM.

1. Introduction

Due to the advancement of information and Internet technology, the reproduction, distribution and tampering of digital data (such as audio, image and video) have become very easy nowadays. People around the world continuously create digital data every day, and many people incline to prevent their digital works from unauthorized use and/or illegal duplication. Placing a clear proprietary notice is an essential step to protect against copyright infringement. Digital watermarking technology is considered a promising means to resolve this issue. It is a technique of hiding information into multimedia data and later extracting such information for copyright protection, content authentication, ownership verification, etc.

Digital watermarking has been widely studied in recent years [1]. The watermarking schemes are often evaluated from four aspects, namely, security, robustness, imperceptibility and payload capacity. The embedded data (called watermarks) shall remain secure during data transmission and endure various intentional attacks or unintentional modifications. The quality of the watermarked signal has to be as close to the original as possible. Moreover, the watermark capacity needs to be sufficient to contain all necessary information. Apart from the abovementioned properties, blind watermarking imposes an extra challenge that watermark retrieval is performed without the presence of original data.

Image watermark technology can be mainly classified into spatial and transform domains. Spatial domain watermarking is usually done by directly adjusting image pixels in accordance with the intended watermark. This kind of methods has the advantages of low complexity and easy implementation but suffers the disadvantage of weak resistance against malicious attacks. In contrast, transform domain methods require extra computation for cross-domain transformation before carrying out watermark embedding and extraction. For image watermarking, transform-domain approaches are most popular due to their capability of exploiting signal characteristics and human visual perception. Commonly used transforms include discrete wavelet transform (DWT) [2–7], discrete cosine transform (DCT) [8–14], discrete Fourier transform (DFT) [6,15,16], and singular value decomposition (SVD) [17–22], etc. Among these transforms, the DCT holds the advantage of excellent energy compaction for highly correlated image data. Imposing invisibility constraints is also comparatively easy when working in the DCT domain [23]. Owing to its important properties, the DCT is of particular value to image processing applications.

There are generally two ways to embed binary watermarks into images manifested in transformed representations. One modifies a transformed coefficient to a designated range for each bit. The quantization index modulation (QIM) proposed by Chen and Wornell [24] is the most common technique. As well known in the literature, the QIM can achieve a good balance among

* Corresponding author. Tel.: +886 3 9317343; fax: +886 3 9369507.
E-mail address: hthu@mail.niu.edu.tw (H.-T. Hu).

http://dx.doi.org/10.1016/j.aeue.2015.11.003
1434-8411/

payload capacity, robustness and imperceptibility. The other one manipulates a pair of coefficients via relative modulation (RM) [12,19,25–28]. It has also been demonstrated in [12] that the RM possesses excellent robustness against common digital signal attacks but suffers noticeable quality distortion. Our aim in this study is therefore to transplant some favorable properties of QIM into RM for image watermarking so that the issues of robustness and imperceptibility can be well resolved.

This paper is organized as follows. Subsequent to the introduction, Section 2 presents two common schemes, namely RM and QIM, previously used to implement blind image watermarking. Section 3 elucidates the design concept of the proposed mixed modulation (MM) scheme. Experiment results with respect to the imperceptibility evaluation and robustness against common digital signal processing attacks are presented in Section 4. Finally, Section 5 draws concluding remarks.

2. Schemes for binary embedding

In [12], Wang and Pearmain proposed hiding binary information into specific coefficients in DCT domain via self-reference. They divided a host image into blocks of size 8 × 8 pixels, each of which was converted to a two-dimensional DCT representation. Within each block a selected DCT coefficient in the (i,j)th position was modulated according to its estimated counterpart, which was derived from the DC components at the neighboring blocks. The whole process can be expressed as

$$\hat{c}^{i,j}_{x,y} = f\left(c^{i,j}_{x,y}, w_b, \left\{ c^{0,0}_{x',y'} \middle| x' \in \{x-1, x, x+1\}; \right.\right.$$
$$\left.\left. y' \in \{y-1, y, y+1\} \right\}\right) \quad (1)$$

where $c^{i,j}_{x,y}$ and $\hat{c}^{i,j}_{x,y}$, respectively, denote the original and watermarked (i,j)th DCT coefficients in the (x,y)th block. w_b is a binary bit. $\{c^{0,0}_{x',y'}\}$ represents the DC components drawn from nearby blocks. In [12], the formula for estimating $c^{1,1}_{x,y}$ was given as

$$\bar{c}^{1,1}_{X,Y} = 0.16213\left(c^{0,0}_{X-1,Y-1} + c^{0,0}_{X+1,Y+1} - c^{0,0}_{X+1,Y-1} - c^{0,0}_{X-1,Y+1}\right)/8 \quad (2)$$

To embed a binary bit w_b into the (x,y)th block, $c^{1,1}_{x,y}$ is modified as

$$\hat{c}^{1,1}_{x,y} = \begin{cases} \max\left\{c^{1,1}_{x,y}, \bar{c}^{1,1}_{x,y} + g\right\}, & \text{if } w_b = 1; \\ \min\left\{c^{1,1}_{x,y}, \bar{c}^{1,1}_{x,y} - g\right\}, & \text{if } w_b = 0 \end{cases} \quad (3)$$

with

$$g = \max\left\{\xi, 0.05\left|c^{1,1}_{x,y}\right|\right\}, \quad (4)$$

where g denotes the embedding strength. ξ represents a minimum clearance distance between $\bar{c}^{1,1}_{x,y}$ and $\hat{c}^{1,1}_{x,y}$. Eq. (3) intends to move $c^{1,1}_{x,y}$ to a level higher than $\bar{c}^{1,1}_{x,y}$ whenever $w_b = 1$. The movement may not be necessary if $c^{1,1}_{x,y}$ already satisfies the inequality $c^{1,1}_{x,y} \geq \bar{c}^{1,1}_{x,y} + g$. This is why we choose the maximum between $c^{1,1}_{x,y}$ and $\bar{c}^{1,1}_{x,y} + g$ in the first branch of Eq. (3). Analogously, $c^{1,1}_{x,y}$ is shifted to a level lower than $\bar{c}^{1,1}_{x,y}$ whenever $w_b = 0$ but will remain intact if $c^{1,1}_{x,y} \leq \bar{c}^{1,1}_{x,y} - g$.

One major deficiency of the above RM is that the involved DCT coefficient may be excessively altered if $\bar{c}^{1,1}_{x,y}$ is located far away from $c^{1,1}_{x,y}$, thus leading to serious quality distortion. To remedy this deficiency, we develop a mixed approach that grafts QIM onto RM. In principle, the QIM quantizes the gap between $c^{1,1}_{x,y}$ and $\bar{c}^{1,1}_{x,y}$ into an odd integer multiple of quantization step Δ if $w_b = 1$ and into an even integer if $w_b = 0$. More specifically, the formula for QIM is given as

$$\hat{c}^{1,1}_{x,y} = \begin{cases} \bar{c}^{1,1}_{x,y} + \left\lfloor \dfrac{c^{1,1}_{x,y} - \bar{c}^{1,1}_{x,y}}{2\Delta} \right\rfloor \times 2\Delta + \Delta, & \text{if } w_b = 1; \\ \bar{c}^{1,1}_{x,y} + \left\lfloor \dfrac{c^{1,1}_{x,y} - \bar{c}^{1,1}_{x,y}}{2\Delta} + 0.5 \right\rfloor \times 2\Delta, & \text{if } w_b = 0, \end{cases} \quad (5)$$

where $\lfloor\bullet\rfloor$ denotes the floor function.

To extract the embedded bit, we only need to determine whether the quantized integer is odd or not:

$$w_b = \left\lfloor \frac{\hat{c}^{1,1}_{x,y} - \bar{c}^{1,1}_{x,y}}{\Delta} + 0.5 \right\rfloor \ \%\ 2, \quad (6)$$

where % denotes the modulus operator. With the employment of the QIM, the alteration for each $c^{1,1}_{x,y}$ is guaranteed to be within the range of $[-\Delta/2, \Delta/2]$ regardless of the estimation accuracy. Hence we consider borrowing such a good property to alleviate the drawback of RM.

3. Mixed modulation (MM)

Following the steps adopted in [12], we partition a host image into non-overlapped blocks of size 8 × 8 and then apply DCT to each block separately. A prediction of the coefficient $c^{1,1}_{x,y}$, namely $\bar{c}^{1,1}_{x,y}$, can be obtained via Eq. (2) based on the DC terms of surrounding blocks. Depending on the relative positions between $c^{1,1}_{x,y}$ and $\bar{c}^{1,1}_{x,y}$, we adopt two tentative strategies to perform binary watermarking. In general, when $c^{1,1}_{x,y}$ is near to $\bar{c}^{1,1}_{x,y}$, the use of RM to modify $c^{1,1}_{x,y}$ will normally render tolerable distortion. Once $c^{1,1}_{x,y}$ is far away from $\bar{c}^{1,1}_{x,y}$, the RM may alter $c^{1,1}_{x,y}$ significantly in order to implant a desired bit. In that situation, we tactically switch the embedding scheme from RM to QIM.

Let $d = c^{1,1}_{x,y} - \bar{c}^{1,1}_{x,y}$ denote the gap between $c^{1,1}_{x,y}$ and $\bar{c}^{1,1}_{x,y}$. As illustrated in Fig. 1, by referring to d, we presume $\pm\rho$ to be the demarcations for the two available strategies. Suppose the RM is taken for binary embedding and the binary bit to be embedded is $w_b = 1$. The value of the targeted coefficient $c^{1,1}_{x,y}$ will be lifted above $\bar{c}^{1,1}_{x,y}$ by an amount of at least g but confined to a level of $\bar{c}^{1,1}_{x,y} + \lambda$. Likewise, whenever $w_b = 0$, $c^{1,1}_{x,y}$ will be shifted below $\bar{c}^{1,1}_{x,y} - g$ and limited by $\bar{c}^{1,1}_{x,y} - \lambda$. The RM can be expressed in mathematic form as

$$\phi_1 = \begin{cases} \min\left\{\bar{c}^{1,1}_{x,y} + \lambda, \quad \max\left\{c^{1,1}_{x,y}, \bar{c}^{1,1}_{x,y} + g\right\}\right\}, & \text{if } w_b = 1; \\ \max\left\{\bar{c}^{1,1}_{x,y} - \lambda, \quad \min\left\{c^{1,1}_{x,y}, \bar{c}^{1,1}_{x,y} - g\right\}\right\}, & \text{if } w_b = 0. \end{cases} \quad (7)$$

In the above equation, the variable λ ought to be less than ρ. It is assumed that we actuate the RM if $|d| < \rho$ and switch to the QIM otherwise. The relation $\rho > \lambda$ allows us to ensure a suitable RM scheme for watermark extraction. Through Eq. (7), we obtain a candidate ϕ_1 for the intended coefficient. This value will be further compared with the outcome resulting from the QIM.

Suppose the QIM is brought in to modulate the selected DCT coefficient. The entire embedding process consists of three branches, which are expressed in program equations as in the following frame.

Within Eq. (9), $\lceil\bullet\rceil$ denotes the ceiling function. Eqs. (8) and (9) correspond to two standard QIM implementations for $|d| > \rho$. η stands for the ground level in the upward direction and $-\eta$ serves as its alternate in the opposite direction. Our intent here is to regulate the selected coefficient to a multiple of Δ away from the ground level. In the design of MM, we have deliberately inserted a transitive zone between the RM and QIM by arranging $\lambda < \rho < \eta$. The section