AN IMAGE-QUALITY GUARANTEED METHOD FOR QUANTIZATION-BASED WATERMARKING USING A DWT

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ABSTRACT

This paper proposes a quantization-based watermarking method that generates watermarked images of a desired image-quality independently of the characteristics of the original images. To guarantee the image-quality, this method utilizes the relationship between a transformed domain and the spatial domain for the signal energy. The proposed method extracts an embedded watermark sequence from a watermarked image without referring to any original images.

1. INTRODUCTION

Many digital watermarking methods have been proposed for various applications such as broadcast monitoring, labeling, and so on [1–7]. A watermarking method embeds data referred to as watermark into a target image directly and imperceptibly, then generates a slightly degraded image that is referred to as a watermarked image. In general, this deterioration of image-quality depends on the embedding algorithm used, the statistical properties of the watermark sequence to be embedded, and the target image itself into which data is embedded.

Watermarking methods in which image degradation is independent of the characteristics of target images have been proposed [5–7], and are referred to as image-quality guaranteed watermarking (IQGW) methods in this paper. An IQGW method automatically generates watermarked images of a desired image-quality from any images, whereas most of the conventional methods generate an image of indefinite quality. IQGW methods suit the inside material management at digital museums and digital broadcasting stations, e.g, broadcast monitoring and labeling. Since the number of images is quite large in these applications, the important issue of such applications is guaranteeing a subjective image-quality rather than improving objective quality and guaranteeing resilience against attacks.

Conventional IQGW methods embed watermark into a target image using a quantization-based embedding algorithm in a discrete cosine transformed (DCT) domain, and the image-quality of watermarked images given by the peak signal-to-noise ratio (PSNR) is guaranteed in the DCT domain as well. The principle of conventional IQGW methods holds in orthogonal transformed domains like a DCT domain, but does not hold in unorthogonal transformed domains like a discrete wavelet transformed (DWT) domain. For applying a IQGW method to applications using and/or having affinity for an unorthogonal transformation, a IQGW method is desired to be extended to unorthogonal transformations.

In this paper, a quantization-based IQGW method that embeds watermark into a target image in a DWT domain is proposed. Though this method embeds watermark in an unorthogonal transformed domain, it automatically generates watermarked images of a desired image-quality like conventional IQGW methods. The proposed method also extracts embedded data from a watermarked image without referring to any original images, i.e., obliviously, as conventional IQGW methods do.

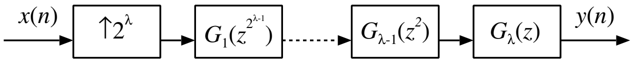

Fig. 1. A one-dimensional DWT synthesis filter bank. Signal $x(n)$ in subband λ is transformed inversely to signal $y(n)$ in the temporal domain.

2. SIGNAL ENERGY IN A TRANSFORMED DOMAIN

2.1. Guaranteeing Image-Quality in a Transformation Domain

Guaranteeing image-quality means serving watermarked images of a desired image-quality independently of the characteristics of target images. To guarantee the image-quality in a transformed domain, a IQGW method utilized the relationship between the signal energy in the transformed domain and that in the spatial domain.

Whereas conventional IQGW methods use an orthogonal transformation where the signal energy in both domains are identical to each other [5–7], the proposed IQGW method uses an unorthogonal transformation where the signal energy in the transformed domain differs from that in the spatial domain. In the next section, the relationship is thus derived to guarantee image-quality in the proposed method.

2.2. Signal Energy in an Unorthogonal Transformed Domain

The relationship between the energy of signal in an unorthogonal transformed domain and that in the spatial domain is derived from the coefficients of synthesis filters that are used in a multirate filter bank representation of the transformation [8].

For its simplicity, one-dimensional DWT is considered here. Let $e^2_{t,\lambda}$ and $e^2_{s,\lambda}$ represent the energy of a signal in subband λ of a DWT domain and that in the temporal domain, respectively. Under the condition that a synthesis filter bank is as shown in Fig. 1, the relationship between $e^2_{t,\lambda}$ and $e^2_{s,\lambda}$ is given by

$$e^2_{s,\lambda} = f_{\lambda} e^2_{t,\lambda}, \tag{1}$$

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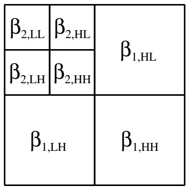

Fig. 2. Subband $\beta_{\lambda,\theta}$ in a two-dimensional DWT. (Decomposition level $\Lambda = 2$. Parameters λ and θ represent the resolution level and the direction, where $\theta \in \{\mathrm{LL}, \mathrm{LH}, \mathrm{HL}, \mathrm{HH}\}$).

Table 1. Scaling factor $f_{\lambda,\theta}$ for two-dimensional DWT with the 5/3 filter used in JPEG 2000 [9].

λ	θ		
	LL	LH (HL)	HH
5	455.5557	128.5211	36.2583
4	114.2227	32.5217	9.2597
3	28.8906	8.5244	2.5152
2	7.5625	2.5352	0.8499
1	2.2500	1.0781	0.5166

where f_λ is referred to as a scaling factor for subband λ in this paper and is defined by the following equations [8].

$$f_\lambda = \frac{1}{2^\lambda} \sum_{n=-\infty}^{\infty} \left| \xi_1(n) * \xi_2(n) * \cdots * \xi_{\lambda-1}(n) * g_\lambda(n) \right|^2 \tag{2}$$

$$\xi_p = \begin{cases} g_q\left(\frac{n}{2^{\lambda-q}}\right), & n = 2^{\lambda-2}p \\ 0, & \text{otherwise} \end{cases}, p = 0, \pm 1, \pm 2, \ldots, \tag{3}$$

where $g_q(n)$ and $A * B$ are the inverse z transformation of $G_q(z)$ and the convolution of A and B, respectively. This result holds not only in two-dimensional DWT but also in other unorthogonal transformations.

Then, an example of two-dimensional DWT is shown in Fig. 2 in which decomposition level $\Lambda = 2$. Subband $\beta_{\lambda,\theta}$ is defined by resolution level λ and direction θ, where $\theta \in \{\mathrm{LL}, \mathrm{LH}, \mathrm{HL}, \mathrm{HH}\}$. Two-dimensional scaling factor $f_{\lambda,\theta}$ that satisfies

$$e_s^2 = f_{\lambda,\theta} e_t^2 \quad \text{for} \quad \beta_{\lambda,\theta} \tag{4}$$

is introduced as one-dimensional DWT described above. As a definite example, scaling factors for subbands in a DWT domain that is two-dimensionally transformed by the 5/3 filter used in JPEG 2000 [9] is shown in Table 1.

In the next section, a DWT-based IQGW method utilizing scaling factors described in this section is proposed. The proposed method uses an unorthogonal transformation to embed a watermark sequence into a target image and guarantees the image-quality in the transformed domain.

3. PROPOSED IQGW METHOD

In this paper, it is assumed that the proposed IQGW method embeds L-length watermark sequence $\mathbf{w}_g$ into a target grayscale image by a quantization-based embedding algorithm in a DWT domain. An image consists of $X \times Y$ pixels and each pixel has A levels from zero to $A-1$. An element of $\mathbf{w}_g$, represented by $w_{g,l}$, is an independently identically distributed sample drawn from a zero-mean distribution whose variance is σ_w, where $l = 1, 2, \ldots, L$. Using a bi-level distribution whose elements are in $\{-\sigma_w, \sigma_w\}$ or a normal distribution $N\left(0, \sigma_w^2\right)$ for watermark sequences is assumed. The proposed IQGW method is capable to embed each of them.

3.1. Embedding Algorithm

Figure 3 shows the embedding diagram of the proposed IQGW method.

1. Set r [dB] to the desired image-quality in the PSNR.
2. Choose one watermark sequence $\mathbf{w}_g$ from available watermark sequences.
3. Apply a two-dimensional DWT whose decomposition level is Λ to a target image to obtain $(3\Lambda+1)$ subbands represented by $\mathbf{s} = \left\{s_i | i = 1, \ldots, 3\Lambda+1\right\}$, and then choose S subbands for embedding from $\mathbf{s}$. Chosen subbands are represented by $\mathbf{o} = \{o_m | m = 1, \ldots, S\}$. Set $m := 1$.
4. Using desired image-quality r and scaling factor φ_m that corresponds to subband o_m, rounding step Q_m for is derived to round off coefficients in o_m. Details are mentioned in Section 3.3 (B). Then, using Q_m, energy adapting factor h_m, corresponding to subband o_m, is given by
$$h_m = \frac{M_\sigma Q_m}{2 N_\sigma \sigma_w}, \tag{5}$$
where parameters M_σ and N_σ are chosen according to the distribution of watermark sequence $\mathbf{w}_g$. Note that $0 < M_\sigma < 1$ and $N_\sigma > 0$. For instance, $M_\sigma = 0.5$ and $N_\sigma = 1$ for a bi-level distribution whose elements are in $\{-\sigma_w, \sigma_w\}$.
5. Divide subband o_m into B_m blocks, where each block consists of $X_m \times Y_m$ DWT coefficients. Blocks are represented by $\mathbf{b}_m = \left\{b_{m,j} | j = 1, \ldots, B_m\right\}$, and then a_m blocks for embedding, $\mathbf{p}_m = \left\{p_{m,n} | n = 1, \ldots, a_m\right\}$, are chosen from $\mathbf{b}_m$. Set $n := 1$.
6. Choose $C_{m,n}$ coefficients from block $p_{m,n}$, where chosen coefficients are defined by $\mathbf{q}_{m,n} = \left\{q_{m,n,d} | d = 1, \ldots, C_{m,n}\right\}$. Set $d := 1$.
7. Round $q_{m,n,d}$ by
$$\bar{q}_{m,n,d} = \mathrm{round}\left(\frac{q_{m,n,d}}{Q_m}\right) Q_m, \tag{6}$$
and obtain rounded coefficient $\bar{q}_{m,n,d}$. Function round(u) returns an integer rounded off by u. Now, choose unembedded element $w_{g,l}$ from watermark sequence $\mathbf{w}_g$, and add $w_{g,l}$ to $\bar{q}_{m,n,d}$ as
$$\hat{q}_{m,n,d} = \bar{q}_{m,n,d} + h_m w_{g,l}. \tag{7}$$
8. Set $d := d+1$ and repeat step 7 until $d = C_{m,n}$.
9. Set $n := n+1$ and repeat steps 6 to 8 until $n = a_m$.
10. Set $m := m+1$ and repeat steps 4 to 9 until $m = S$.
11. Apply the two-dimensional inverse DWT whose composition level is Λ to $(3\Lambda+1)$ subbands including S watermarked subbands to obtain a watermarked image.

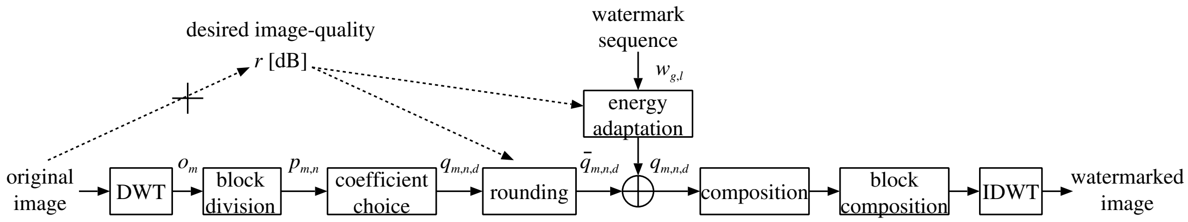

Fig. 3. Embedding diagram of the proposed IGQW method.

Note that parameters Λ, $\mathbf{o}$, X_m, Y_m, $\mathbf{p}_m$, and $\mathbf{q}_{m,n}$ are versatilely chosen according to applications. The proposed method guarantees a desired image-quality for any combinations of these parameters.

3.2. Extracting Algorithm

To extract an embedded watermark from a watermarked image, the following parameters, that are pre-negotiated by an embedder and an extractor, are required; desired image-quality r [dB], decomposition level Λ, subbands for embedding $\mathbf{o}$, block size $X_m \times Y_m$ for subband o_m, blocks for embedding $\mathbf{p}_m$ in subband o_m, coefficients for embedding $\mathbf{q}_{m,n}$ in block $p_{m,n}$. Note, for practical use, that parameters $\mathbf{o}$, $\mathbf{p}_m$, and $\mathbf{q}_{m,n}$ will be not required by using a pseudo-random number generator and its corresponding seed to choose subbands, blocks, and coefficients, instead of utilizing versatility for choosing them.

1. Set r [dB] to the desired image-quality in the PSNR.
2. Apply a two-dimensional DWT to a watermarked image to obtain subbands, and choose S subbands corresponding to step 3 in the embedding algorithm. Set $m := 1$.
3. Using desired image-quality r and scaling factor φ_m corresponding to target subband o_m, obtain rounding step Q_m for o_m. Then, determine energy adapting factor h_m for o_m by Eq. (5).
4. Divide subband o_m into B_m blocks, where each block consists of $X_m \times Y_m$ DWT coefficients. Then, choose a_m blocks corresponding to step 5 in the embedding algorithm. Set $n := 1$.
5. Choose $C_{m,n}$ coefficients corresponding to step 6 in the embedding algorithm. Set $d := 1$.
6. Round target DWT coefficient $\hat{q}_{m,n,d}$, from which watermark element $w_{g,l}$ has not been extracted yet, by

   $$\bar{q}_{m,n,d} = \text{round}\left(\frac{\hat{q}_{m,n,d}}{Q_m}\right) Q_m, \qquad (8)$$

   to obtain rounded coefficient $\bar{q}_{m,n,d}$. Now, subtract $\bar{q}_{m,n,d}$ from $\hat{q}_{m,n,d}$ to extract embedded watermark element $w_{g,l}$ by

   $$w_{g,l} = \frac{\left(\hat{q}_{m,n,d} - \bar{q}_{m,n,d}\right)}{h_m}. \qquad (9)$$

7. Set $d := d+1$ and repeat step 6 until $d = C_{m,n}$.
8. Set $n := n+1$ and repeat steps 5 to 7 until $n = a_m$.
9. Set $m := m+1$ and repeat steps 3 to 8 until $m = S$.

3.3. Features of the Proposed IQGW Method

The proposed method guarantees the image-quality in an unorthogonal transformed domain. It embeds a watermark sequence by a quantization-based algorithm, so that it extracts an embedded watermark from a watermarked image without referring to any original images. In addition, it is versatile at determination of rounding step Q_m.

Image-quality guarantee feature of the proposed IQGW method is focused in the next section, and then an example of determination of Q_m is given in the consecutive section,

(A) Image-Quality Guaranteeing

In this section, it is described that the proposed IQGW method guarantees a desired image-quality of watermarked images.

It is assumed that the rounding error arising in Eq. (6), represented by $\left(q_{m,n,d} - \bar{q}_{m,n,d}\right)$, and watermark elements $w_{g,l}$'s are probability independent of each other. Since the mean value of $\mathbf{w}_g$ and the expected value of rounding error $E\left[\left(q_{m,n,d} - \bar{q}_{m,n,d}\right)\right]$ are equal to zero, omitting details to save space, it is concluded that the expected value of the signal energy in the spatial domain caused by embedding $\mathbf{w}_g$ into a target image is defined as

$$E\left[e_s^2\right] = \sum_{m=1}^{S} \frac{\varphi_m Q_m^2}{D} \sum_{n=1}^{a_m} C_{m,n} = \frac{1}{D} \sum_{m=1}^{S} \varphi_m Q_m^2 \sum_{n=1}^{a_m} C_{m,n}, \qquad (10)$$

where

$$D = \frac{12 N_\sigma^2}{N_\sigma^2 + 3 M_\sigma^2}. \qquad (11)$$

The PSNR between the original image and a watermarked image is thus given by

$$\text{PSNR} = 10 \log_{10} \frac{XYA^2}{E\left[e_s^2\right]} = 10 \log_{10} \frac{XYA^2 D}{\sum_{m=1}^{s} \varphi_m Q_m^2 \sum_{n=1}^{a_m} C_{m,n}} \text{ [dB]}. \qquad (12)$$

In Eq. (12), X, Y, A, D, S, φ_m, a_m, $C_{m,n}$ are constant and independent of the target images in this proposed method. Thus, Eq. (12) is a function of Q_m's. If Q_m's are independent of target images, Eq. (12) is independent of target images. Note that any Q_m's are allowed so long as Eq. (12) is equal to a desired image-quality. With a simple example for determination of Q_m's, it is shown that Q_m's are independent of target images in the next section.

(B) Determination of Rounding Step Q_m

According to parameters S, $\mathbf{o}$, a_m, and $C_{m,n}$, rounding step Q_m's are determined under the condition that Eq. (12) is equal to a desired

Table 2. Simulation conditions.

Grayscale sequences	"flower garden," "football," and "mobile & calendar"
No. of field	64 fields/sequence
Field size	$X = 704$, $Y = 240$ [pixels]
Dynamic range	$A = 255$
Watermark sequence $\mathbf{w}_g$	consists of $\{-1, 1\}$
Sequence length	$L = 1980$
Desired quality	$r = 56$ [dB]
Decomposition level	$\Lambda = 3$
No. of subbands	$S = 3$
Chosen subbands $\mathbf{o}$	$o_m = \beta_{m,\mathrm{HL}}$
Block size	$X_m = Y_m = 16/2^m$
No. of chosen blocks	$a_m = 660\,(= B_m)$
No. of chosen coefficients	$C_{m,n} = 1$
Rounding step	Q_m is given as Eq. (13)
DWT filters	5/3 filter

image-quality. Whereas several strategies exist according to versatility for choosing coefficients for embedding, one simple strategy to determine rounding step Q_m is briefly described in this section,

The strategy described here is that the energy of error signal on DWT coefficient $q_{m,n,d}$ are identical to each other observed in the spatial domain. Details are omitted to save space, but with this strategy, Q_m is defined by

$$Q_m = \frac{A}{10^{0.05r}} \sqrt{\frac{XYD}{\varphi_m L}} \qquad (13)$$

to guarantee the PSNR of r [dB] by embedding an L-length watermark sequence into a target image in the proposed IQGW method. In Eq. (13), parameters A, r, X, Y, D, φ_m, and L are independent of the characteristics of the target image, so Q_m is also independent of the image. Consequently, the proposed method is an IQGW method.

4. EXPERIMENTAL RESULTS

Under the conditions shown in Table 2, the actual PSNR's of 192 watermarked images generated by the proposed IQGW method are investigated. Desired image-quality $r = 56$ [dB] in the PSNR, and $L = 1980$ watermark elements are embedded over three subbands. Results are shown in Fig. 4. Fig. 4 shows that the proposed IQGW method guarantees a desired image-quality like conventional IQGW methods.

In addition, resilience to representing with a finite word-length in the spatial domain, i.e., rounding off the luminance of all pixels and cropping luminance exceeding dynamic range A into dynamic range in the spatial domain, is investigated under identical conditions. Though details are omitted to save space, the proposed IQGW method has resilience to this process.

5. CONCLUSIONS

This paper has proposed an image-quality guaranteed watermarking method using a DWT. It generates a watermarked image of a desired PSNR independently of the characteristics of target images and extracts the embedded watermark sequence from a watermarked image obliviously.

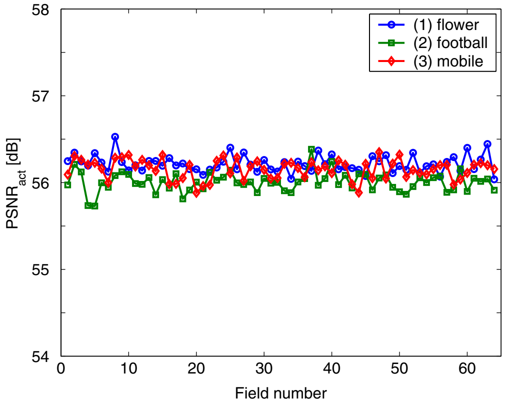

Fig. 4. Actual PSNR's, $\mathrm{PSNR}_{\mathrm{act}}$, for 192 images (desired image-quality $r = 56$ [dB], chosen subbands: $\beta_{1,\mathrm{HL}}$, $\beta_{2,\mathrm{HL}}$, and $\beta_{3,\mathrm{HL}}$, watermark sequence length $L = 1980$).

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