IEICE Electronics Express, Vol.2, No.20, 523–529

An accurate method for image quality evaluation using digital watermarking

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Abstract: This paper presents a watermarking-based image quality evaluation method that estimates image quality in terms of classical objective metrics, such as PSNR, wPSNR, and Watson JND, without the need for original image. Considering the different frequency distribution of image, the watermark is embedded into the original image and its vulnerability is adjusted using automatic control. After processing, the degradation of the extracted watermark is used to estimate image quality in terms of the classical metrics. By comparing the image quality obtained by the proposed method with the calculated PSNR, wPSNR, and JND, it is clear that the proposed method can be used to evaluate image quality against JPEG compression with high accuracy.

Keywords: digital watermarking, image quality evaluation, automatic control

Classification: Science and engineering for electronics

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DOI: 10.1587/elex.2.523
Received September 06, 2005
Accepted October 06, 2005
Published October 25, 2005

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1 Introduction

To evaluate image quality, PSNR, weighted PSNR (wPSNR) and Watson model are commonly used. These classical metrics require knowledge of the original image because they are based on point-to-point calculation between the original image and the degraded image in the spatial domain or in the frequency domain [1]. This requirement makes these metrics less than optimal for those applications that require video information to be delivered through a network (e.g., mobile video). For these applications, it might be impossible or too expensive to allocate the extra bandwidth required to send information about the original image. We here propose a watermarking-based method that does not require access to the original image at the receiver side. The watermark is invisibly embedded into the cover image and is inseparable from the image, which means it will undergo the same transformations and distortions as the image. Therefore, it is possible to evaluate the image quality by only evaluating the watermark degradation [2].

The proposed image quality evaluation method can be used to estimate the image quality in terms of PSNR, wPSNR, or Watson JND (Just Noticeable Difference). In the rest of the paper, we will use "PSNR quality", "wPSNR quality", "JND quality" to mean the image quality either evaluated by the proposed method or calculated by equations or models, in terms of PSNR, wPSNR, and Watson JND, respectively. In order to make the evaluated quality (PSNR, wPSNR, and JND) comparable with the image quality calculated using the original image (PSNR, wPSNR, and JND), the watermark is embedded with different vulnerabilities according to the different frequency distribution of the cover image. Automatic control is used to adjust the watermark vulnerability. From experimental results, it is shown that the proposed method can be used to evaluate image quality (PSNR, wPSNR, and JND) against JPEG compression with high accuracy.

2 Proposed image quality evaluation method

Fig. 1 shows the proposed watermarking based image quality evaluation method. The 3-level discrete wavelet transform (DWT) is applied first to the original image. The watermark is embedded into the DWT coefficients based on quantization. In order to have accurate measures of image quality, feedforward and feedback automatic controls are employed to optimize the quantization parameters. The quantization-based watermark extraction process is similar to the embedding process. By comparing the original watermark and the extracted watermark, the True Detection Rates (TDR) of the watermark can be calculated and the image quality can be estimated by mapping the TDR to the respective quality (PSNR, wPSNR, and JND) according to the respective ideal mapping curves. There are three ideal curves for mapping from the TDR to PSNR, wPSNR and JND, respectively.

DOI: 10.1587/elex.2.523
Received September 06, 2005
Accepted October 06, 2005
Published October 25, 2005

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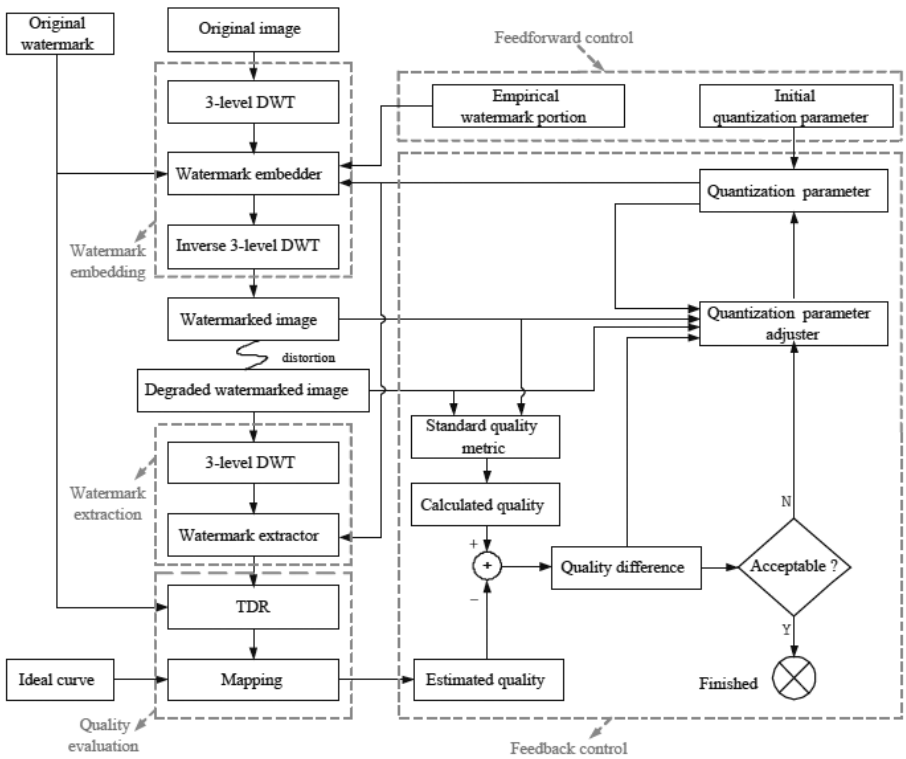

Fig. 1. Proposed watermarking based quality evaluation method.

2.1 Watermark embedding and extraction

The watermark embedding and extraction are implemented in the 3-level DWT domain of the cover image using a quantization method [3, 4]. We choose to embed watermark in the DWT domain because the DWT can decompose an image into different frequency components, which makes it easier to adjust the watermark vulnerability. Eq. (1) shows how the quantization method works and how the quantization parameter controls the watermark vulnerability.

$$Q(e) = \begin{cases} 1 & \left\lfloor \frac{DWT\ coefficient}{Quantization\ parameter} \right\rfloor \ is\ even \\ 0 & \left\lfloor \frac{DWT\ coefficient}{Quantization\ parameter} \right\rfloor \ is\ odd \end{cases} \tag{1}$$

Using Eq. (1), each DWT coefficient is assigned a binary 0 or 1. The binary bits associated with the DWT coefficients are denoted as $Q(e)$. A watermark bit is embedded into a DWT coefficient by checking the watermark bit, $W(e)$, and the $Q(e)$ associated with the target DWT coefficient. If $W(e) \neq Q(e)$, the DWT coefficient is changed by adding the quantization parameter to make the $Q(e)$ of the modified DWT coefficient equal to $W(e)$. If $W(e) = Q(e)$, we do not change the DWT coefficient. Each watermark bit is embedded into 50 selected DWT coefficients to add some redundancy.

After the 3-level DWT decomposition, the image is decomposed into 10 blocks. Each block contains different frequency components of the image. To achieve a balance between robustness and fidelity, we embed more watermark bits into the blocks containing more middle frequency components

DOI: 10.1587/elex.2.523
Received September 06, 2005
Accepted October 06, 2005
Published October 25, 2005

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and fewer watermark bits into the blocks containing more low/high frequency components.

The watermark extraction is conducted in a way similar to the embedding.

2.2 Automatic adjustment of the watermark vulnerability

The watermarking-based quality evaluation method is designed to accurately evaluate image quality in terms of PSNR, wPSNR, and JND without the need for the original image. To ensure the evaluated quality is as close as possible to the calculated quality, we embed the watermark with different vulnerabilities according to the characteristics of different images. An automatic control system consisting of both feedforward control and feedback control is designed to automatically adjust the watermark vulnerability, as shown in Fig. 1, according to the frequency distribution of the image.

2.2.1 Feedforward control

The feedforward control coarsely adjusts the watermark vulnerability using the empirical watermark portions and the initial quantization parameters which were obtained based on initial estimation. The empirical watermark portion indicates how many watermark bits are embedded into each DWT decomposed block and is tested in [3]. Meanwhile, for each DWT decomposed block, a pre-set quantization parameter is assigned. With the watermark portions and the pre-set quantization parameters, the watermark is initially embedded with a reasonable vulnerability and the PSNR of the watermarked image is ensured to be better than 40 dB. The feedforward control makes it much easier and faster for the feedback control to make the evaluated quality converge to the quality calculated by PSNR, wPSNR or Watson model. Then, the feedback control is used to finely tune the quantization parameters.

2.2.2 Feedback control

The feedback control is to finely tune the watermark vulnerability using the feedback information, by adjusting the quantization parameters as shown in Fig. 1. The feedback control consists of two parts: the quality difference calculation and quantization parameter adjustment.

The quality difference calculation is to calculate the difference between the quality evaluated by the proposed method and the quality calculated by the standard quality metrics (PSNR, wPSNR, or Watson JND). If the quality difference is larger than some threshold, the quantization parameter adjuster will continue to adjust the quantization parameters until the quality difference is smaller than the threshold.

The quantization parameter adjuster works by checking the DWT decomposed blocks' contributions to the current quality loss. The quantization parameter of the block that has contributed most to the current quality loss will be adjusted according to the quality difference.

Through automatic adjustment, the evaluated quality will approach the calculated quality. Then the image quality can be accurately estimated without the need for the original image at the receiver side.

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2.3 The watermarking based quality evaluation

To evaluate the quality of the degraded image, we first calculate the True Detection Rates (TDR) of the extracted watermark using Eq. (2).

$$TDR = \frac{Number\ of\ correctly\ detected\ watermark\ bits}{Total\ number\ of\ watermark\ bits} \tag{2}$$

Through experiments, we found that with increasing compression ratios, the TDRs decrease monotonously [3]. Therefore, the quality of the degraded image can be estimated by mapping the calculated TDR to PSNR, wPSNR, or JND using a respective empirical ideal curve. The ideal curves are the pre-defined relationship between the calculated TDR values after the watermark extraction and the quality values calculated with the standard quality metrics such as PSNR, wPSNR, and JND. These three curves are generated by testing 20 different textured images compressed by JPEG with quality factors varying from 100 to 20 with a step of 10 and are the basis for quality evaluation using the calculated TDR values.

"Mapping" in Fig. 1 is to map the calculated TDR to PSNR, wPSNR, or JND quality. After watermark extraction, the calculated TDR value could possibly lie between two neighboring TDR values on the ideal curve. In this case, bilinear interpolation is used to estimate the PSNR, wPSNR, and JND based on the calculated TDR value, which is expressed using Eq. (3):

$$Q_E = Q_C(j) + \frac{T - T(j)}{|T(j+1) - T(j)|} \times |Q_C(j+1) - Q_C(j)| \tag{3}$$

where, Q_E is the evaluated quality, Q_C is the calculated quality, T is the calculated TDR after the watermark extraction, and j is the indexes of the points on the curve.

3 Evaluation

In this paper, three sets of experimental results are presented. The proposed method was used to respectively evaluate image quality in terms of PSNR, wPSNR, and Watson JND. In the experiments, 25 different textured images were tested with each image compressed using JPEG with quality factors from 100 to 20 in a step of 10. Therefore, a total of 225 different combinations are tested in each set of experiments.

Fig. 2 (a), (b), and (c) respectively show the correlations between the evaluated PSNR values and the calculated PSNR values, the evaluated wPSNR values and the calculated wPSNR values, and the evaluated Watson JND values and the calculated Watson JND values. In Fig. 2, the solid line is the match line indicating that the evaluated quality equals to the calculated quality. The scattered points in the figures indicate the accuracy of the evaluated quality compared with the calculated quality. The closer the scattered point is to the solid line, the more accurate the evaluated quality compared with the calculated quality.

Normally the larger the JPEG quality factor, the better the image quality after compression. Consequently, the calculated PSNR and wPSNR will be

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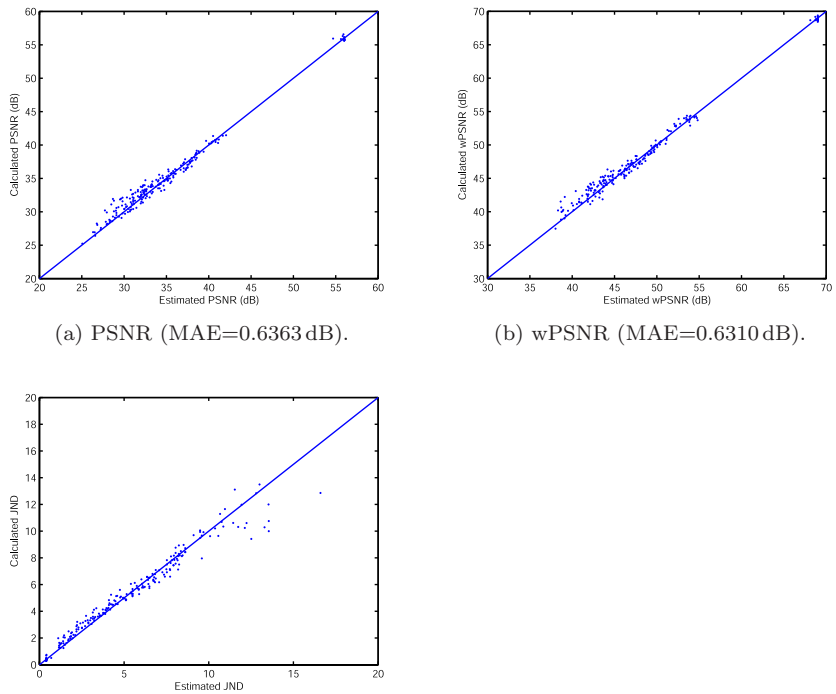

(a) PSNR (MAE=0.6363 dB).

(b) wPSNR (MAE=0.6310 dB).

(c) Watson JND (MAE=0.4054 JND).

Fig. 2. Correlations between the evaluated quality and the calculated quality

larger and the Watson JND will be smaller. So it can be seen in Fig. 2 that with the decreasing of JPEG quality factors, these points are more scattered. This is because the evaluation accuracy decreases as the image quality deteriorates severely when compressed using a very small JPEG quality factor.

We use the maximum absolute error (MAE) to measure how close the scattered points are to the solid line. In Fig. 2, the MAE between the evaluated PSNR and the calculated PSNR is 0.6363 dB; the MAE between the evaluated wPSNR and the calculated wPSNR is 0.6310 dB; and the MAE between the evaluated JND and the calculated JND is 0.4054 JND. We can see in Fig. 2 (c) that the points become more scattered when the JND value is greater than 8. This is due to the fact that the JPEG compression factor is smaller than about 30% and the resulting image and the watermark are severely damaged. However, when the JND is bigger than 8 (or when the JPEG compression ratio is smaller than 30%), the image begins to lose its value. For the points whose JNDs are less than or equal to 8 in Fig. 2 (c), the MAE is 0.2975.

From the experimental results, we can see that the proposed method can be used to evaluate image quality in terms of PSNR, wPSNR, and JND with quite high accuracy.

4 Conclusions

In this paper, we presented a new image quality evaluation method based on digital watermarking. The method can be used to evaluate image qualities

DOI: 10.1587/elex.2.523
Received September 06, 2005
Accepted October 06, 2005
Published October 25, 2005

in terms of PSNR, wPSNR, or Watson JND without using the original image at the receiver side. From the experimental results, it is clearly shown that the proposed method can evaluate the image qualities with a high accuracy. By employing a different ideal mapping curve, the method can be used to evaluate image quality in terms of other metrics.

DOI: 10.1587/elex.2.523
Received September 06, 2005
Accepted October 06, 2005
Published October 25, 2005