# Improved Quantization Watermarking with an Adaptive Quantization Step Size and HVS

Zhao Yuanyuan and Zhao Yao

The Institute of Information Science, Beijing Jiaotong University, Beijing, China
zyykxp@hotmail.com, yzhao@center.njtu.edu.cn

**Abstract.** This paper proposes a new image-adaptive watermarking technique which utilizes a new combination of an adaptive quantization step size and a HVS(human visual system) model in the wavelet domain. Here we use Quantization Index Modulation(QIM) method with an adaptive quantization step size to realize the embedding scheme. The HVS masking is accomplished pixel by pixel by take into account the luminance and the frequency content of all the image subbands. The watermarking consists of a pseudorandom sequence which is adaptively embedded into the subbands. As usual, the watermark bits are detected by a minimum distance detector. Experimental results prove the effectiveness of the new algorithm.

## 1 Introduction

As a result of the rapid development of digital technology, image watermarking is finding more and more support as a possible solution for the protection of intellectual property rights. Many techniques have been proposed in the literature over the last few years. One of the most important approaches proposed so far is Quantization Index Modulation (QIM) [1]. QIM methods are multi-bits watermark scheme. It can achieve very efficient trade-offs among the amounts of embedded information (rate), the amounts of embedding-induced distortion to the host signal, and the robustness to intentional and unintentional attacks.

To the aim of effectively image compression without degrading subjective image quality, theoretical models of the human visual system (HVS) have been deeply studied. Similarly, it is today widely accepted that robust image watermarking techniques should largely exploit the characteristics of the HVS, for more effectively hiding a robust watermark.

In this paper, a novel blind watermarking algorithm, which embeds the watermark in the DWT domain by exploiting the adaptive QIM method, is presented. The main novelty of the algorithm resides in the adaptive quantization. Here, the adaptive quantization is accomplished through the values of the pixels in adjacent domain and a mask giving a pixel by pixel measure of the sensibility of the human eye to local image perturbations. As said above, to effectively hide the watermark, each bit is quantized by one of the two non-intersect quantizations with an adaptive step size. Mask construction relies on a work by Lewis and Knowles [2], in which the authors propose a method to evaluate the optimum quantization step for each DWT coefficient according to psychovisual considerations. Some modifications used here are in order to make it suitable to the computation of the maximum visibly tolerable water-

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mark energy that can be used for each DWT coefficient [3][4]. For watermark detection, we use the minimum distance decoder. Extensive experiments aimed at assessing the performance of the new system both from the point of view of watermark invisibility and from the point of view of robustness; the system has demonstrated to be resistant to JPEG compression and Gaussian noise.

This paper has five parts. The first part is the introduction. The second part is the watermarking embedding scheme, the adaptive quantization step size will be introduced particularly. The third part is watermarking extraction scheme. In the fourth part we will show the experimental results. The last part is the conclusion.

## 2 Perceptual Watermark Embedding Scheme

Since its excellent spatio-frequency localization properties, the DWT is very suitable to exploit the adaptive watermark embedding scheme: if a DWT coefficient is modified, only the region of the image where the particular frequency corresponding to that coefficient is present will be modified.

### 2.1 Watermark Embedding

The watermark embedding scheme is shown as Fig.1:

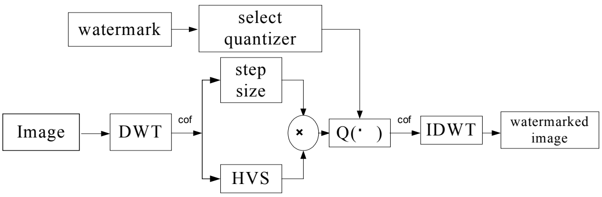
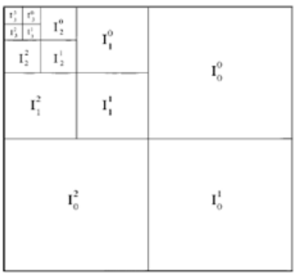



**Fig. 1.** Watermark embedding scheme

The image to be watermarked is first decomposed through DWT in four levels.



$$\begin{bmatrix} x(i-2,j-2) & x(i-2,j-1) & x(i-2,j) \\ x(i-1,j-2) & x(i-1,j-1) & x(i-1,j) \\ x(i,j-2) & x(i,j-1) & x(i,j) \end{bmatrix}$$

**Fig. 2.** Sketch of the decomposition of an image

**Fig. 3.** The adaptive quantization step size's in calculation

We call $I_l^\theta$ the subbands at resolution level $l = 0,1,2,3$ and with orientation $\theta = \{0,1,2,3\}$ (see Fig.2). The watermark, consisting of a pseudorandom binary (0,1) sequence, is inserted by modifying the wavelet coefficients belonging to the detail bands at level 1 and level 2, i.e., $I_1^\theta, I_2^\theta$.

The choice of embedding the watermark into this middle detail subbands was motivated by experimental tests, as the one offering the best trade-offs between robustness and invisibility. Inserting the watermark into these middle frequency subbands could give a higher robustness (e.g., compression or noise), and give the low visibility of disturbs at the same time. In more detail, subbands coefficients are quantized with two non-intersect quantizers indexed the pseudorandom binary sequence (0 or 1) as follows:

$$X_l^\theta = \begin{cases} round\left(\dfrac{x_l^\theta - \Delta_l^\theta/4}{\Delta_l^\theta}\right)\cdot \Delta_l^\theta + \Delta_l^\theta/4, w=0 \\ round\left(\dfrac{x_l^\theta + \Delta_l^\theta/4}{\Delta_l^\theta}\right)\cdot \Delta_l^\theta - \Delta_l^\theta/4, w=1 \end{cases} \tag{1}$$

The adaptive quantization step size are modified according to the rule

$$\Delta_l^\theta(i,j) = \Delta_l^{\theta'}(i,j)\cdot P_l^\theta(i,j) \tag{2}$$

where $\Delta_l^{\theta'}$ is the adaptive quantization step size lying on the adjacent pixels for watermark embedding, and $P_l^\theta$ is a weighing function considering the local sensitivity of the image to noise. It is this weighing function that allows to exploit the masking characteristics of the HVS.

## 2.2 The Adaptive Quantization Step Size

The mainly advantage when using the adaptive quantization step size is that the embedding strength is more or less proportional to the perceptual sensitivity to distortions. Because for bright image areas a larger quantization step size is chosen, a larger robustness is achieved in those areas; information embedded in bright areas can be retrieved at the detector with larger reliability. The overall robustness will gain from this adaptive quantization, while the watermark is as perceptible as in the case of a fixed quantization step size.

Here we use a model for determining the adaptive quantization step size: there is a linear relation between $\Delta$ and the group of pixel values $x(i,j)$. Such a linear relationship can be defended by referring to Weber's law which gives a linear relationship between the sensitivity of the human eye and the luminance value. So the quantization step size is determined by

$$\Delta'(x) = \frac{\alpha}{(2M+1)\cdot(2N+1)}\sum_{i=i-M}^{i+M}\sum_{j=j-N}^{j+N} x(i,j) \tag{3}$$

where $(2M+1)\cdot(2N+1)$ is the number of pixels in the aforementioned group and $\alpha$ is embedding strength parameter. It can easily be seen that this model is brightness scale invariant.

For a fixed quantization step size, both at the embedder and the detector, $\Delta$ is known. But for an adaptive quantization step size $\Delta$ is a function of $x(i,j)$. At the embedder the quantization step size is calculated by $\Delta'(x)$, but at the detector $\Delta$ has to be calculated from the received signal $(y+n)$, so the quantization step size is $\Delta(y+n)$. This $\Delta$ is only an estimation of the quantization step size used at the embedder and therefore may not be completely accurate. Because the detection depends on the adaptive quantization step size, the estimation error causes bit errors in estimating the received message. Based on this errors, we have modified this step size as follows:

$$\Delta_l^{\theta'}(i,j)=\frac{\alpha}{(M+1)\cdot(N+1)-1}\left(\sum_{i=i-M}^{i}\sum_{j=j-N}^{j}x_l^{\theta}(i,j)-x_l^{\theta}(i,j)\right) \tag{4}$$

This equation means that we only calculate the pixels on the top left corner of $x_l^{\theta}(i,j)$. In order to reduce the estimation error, $x_l^{\theta}(i,j)$ is not included in the calculation as Fig.3.

## 2.3 Perceptual Weighing

In order to embed into the images the maximum, but still unperceptible, level of watermark, the weighing function has to consider how the eye perceives disturbs. In particular, the eye is less sensitive to noise in high resolution bands, and in those bands having orientation of 45; the eye is less sensitive to noise in those areas where brightness is high or low; the eye is less sensitive to noise in highly textured areas.

Based on these considerations, we computed the quantization step of each coefficient as the weighted product of two terms where the meaning of each term in this equation is explained below.

Let us start the analysis of by the first of the expression in (2):

$$P_l^{\theta}(i,j)=F(l,\theta)\cdot L_l(i,j) \tag{5}$$

To take into account how sensitivity to noise changes depending on the band (in particular depending on the orientation and on the level of detail), we let

$$F(l,\theta)=\begin{Bmatrix}\sqrt{2}, & if \quad \theta=1\\ 1, & otherwise\end{Bmatrix}\cdot\begin{Bmatrix}1.00, & if \quad l=0\\ 0.32, & if \quad l=1\\ 0.16, & if \quad l=2\\ 0.10, & if \quad l=3\end{Bmatrix} \tag{6}$$

The second term takes into account the local brightness based on the graylevel values of the low pass version of the image. Since the eye is less sensitive in the regions with high brightness, we can compute this factor in the following way:

$$L_l(i,j)=\frac{1}{256}I_3^3\left(1+round\left(\frac{i}{2^{3-l}}\right),\ 1+round\left(\frac{j}{2^{3-l}}\right)\right) \tag{7}$$

Based on the consideration that the human eye is less sensitive to changes in very dark regions as well, the modified factor can be as follows:

$$L_l'(i,j)=\begin{cases}1-L_l(i,j), & if \quad L_l(i,j)<0.5\\ L_l(i,j), & otherwise\end{cases} \tag{8}$$

In our scheme, we use the normalization of this factors.

## 3 Watermark Detection

Watermark detection is accomplished without referring to the original image. In general, we use minimum distance decoder in QIM watermark detection.

With the received sequence, we can easily find the nearest reconstruction sequence of each quantizer (the 0-quantizer and the 1-quantizer) with the adaptive quantization step.

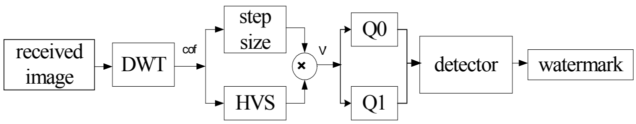



**Fig. 4.** Watermark detection scheme

At first, we should calculate the received image's adaptive quantization step according to the formula (2); then with using this step, we can decide the corresponding quantizer by the minimum distance decoder; from the quantizer, we can estimate the embedded watermark bits. Watermark detection process is shown in figure 4.

## 4 Experimental Results

The algorithm has been extensively tested on various standard images and attempting different kinds of attacks, in this section some of the most significant results will be shown. For the experiments presented in the following, the Daubechies-1 filtering kernel has been used for computing the DWT.

In our experiments we embed $32 \times 32$ bits binary sequence into $256 \times 256$ test image namely Lena and Boat as Fig.5 and Fig.6. PSNR value is 42.7262dB and 41.0642dB. Here $\alpha = 5$.

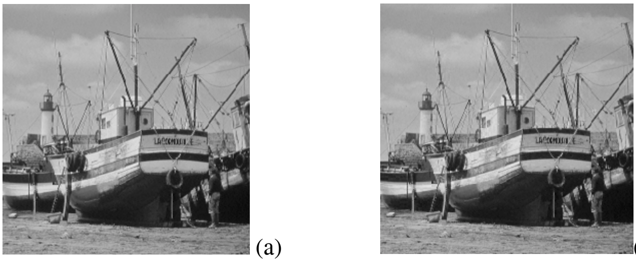
First, watermark invisibility is evaluated: in Fig. 5(a) and Fig. 6(a), the original "Lena" and "Boat" image is presented, while in Fig. 5(b) and Fig. 6(b), the watermarked copy is shown: the images are evidently undistinguishable, thus proving the effectiveness of DWT watermarking and the masking procedure. In particular, it is evident that the watermark is mainly hidden into high activity regions and around edges from Fig. 7 which $\alpha = 7$ (see, such as Lena, the high level of watermark at the borders of the hat and the shoulders of the girl, and over the feathers). Fig.8 shows the Lena image with the mixed quantization step size which use the same quantizers. The mixed step size is 16 and it's robustness is close to Fig. 5(b). But the PSNR is 39.7538dB, less than our scheme with the adaptive quantization in Fig. 5(b). And we can easily found that Fig.5(b) is better than Fig.8.

A set of distortions is applied to the watermarked image and the watermark is extracted from the distorted image. The corresponding bit error rate (BER) is calculated to measure the robustness of the algorithm to that particular distortion. Here the attacks are JPEG compression and additive noise.

As a first experiment, JPEG coding with decreasing quality was applied to the watermarked image, and 1024 different watermarks were tested for presence. In fact, we have embedded 1024 watermark bits repeatedly into 6 detail subbands. So we have quantized almost 15360 pixels. Fig. 9 illustrates the bit error rate when the applied distortion is JPEG compression with quality factors on the image Lena and Boat. In Fig. 9, the quality factor is in the range of 50-100.

(a) (b)

**Fig. 5.** (a) Lena original image, (b) Lena watermarked image ( $\alpha = 5$ )



(a) (b)

**Fig. 6.** (a) Boat original image, (b) Boat watermarked image ( $\alpha = 5$ )

**Fig. 7.** Lena watermarked image ( $\alpha = 7$ )

**Fig. 8.** Lena watermarked image with fixed step size

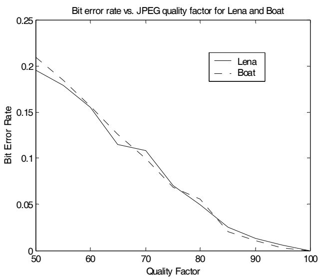



**Fig. 9.** Effect of JPEG compression

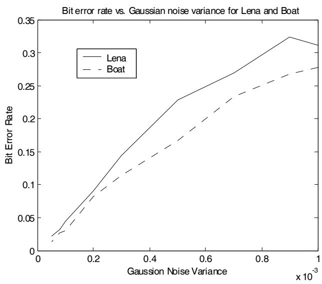



**Fig. 10.** Effect of additive noise

Additive Gaussian noise of zero mean and variance in the range 0.0001-0.0015 is added to the watermarked image. Fig.10 show the plot of BER versus noise variance.

From the above results, we can conclude that our scheme can get good performance with different attacks. With HVS and the adaptive quantization step size, we can get the watermarked image which has invisible distortion and good robustness.

## 5 Conclusion

In this paper, a novel algorithm for image watermarking has been presented. The algorithm embeds the watermark code by quantized the DWT coefficients of the image. With exploiting an adaptive quantization step size and a model of the HVS, the performances of the novel algorithm are good. Experimental results, in fact, supported the suitability of DWT watermarking schemes for hiding watermarks into images.

## References

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