

# A Method for Deciding Quantization Steps in QIM Watermarking Schemes\*

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**Abstract.** In this paper, we propose a method for enlarging quantization steps of a QIM watermarking scheme which determines the perceptual quality and robustness of the watermarked images. In general, increasing the quantization steps leads to good robustness but poor perceptual quality of watermarked images and vice versa. However, if we choose the quantization steps considering the expected quantization results as well as the original images, we can increase both robustness and perceptual quality of the watermarked images.

## 1 Introduction

The advent of the Internet and the wide availability of digital consumer devices such as digital cameras, scanners, and printers make production and distribution of digital contents proliferated. In contrast with analog contents, one can make copy of digital contents without degradation and can tamper without being detected easily. Thus, demanding means for copyright protection is increased rapidly and the digital watermarking is considered as an efficient solution.

Watermarks and watermarking schemes can be divided into various categories in various ways. According to working domain, there are two types of watermarking scheme, spatial domain and frequency domain. The frequency domain schemes are generally considered more robust than the spatial domain schemes and are based on DCT(discrete cosine transform)[3, 4, 13] and DWT(discrete wavelet transform)[12, 14] in general. Various techniques are introduced and applied to watermarking schemes such as spread spectrum[3], SVD(Singular Value Decomposition)[9, 10, 11, 12, 13, 14] and QIM(Quantization Index Modulation)[5, 6, 7, 8, 14].

The QIM watermarking scheme proposed by Chen *et al.* at first, is a blind watermarking model and more robust than spread spectrum or LBM(low-bit

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modulation) one[5]. Though its usefulness and robustness, an attacker can make the watermark undetectable by knowing the quantization steps which are publicly known after proving the existence of watermark.

In this paper, we propose a method for enlarging quantization steps for QIM watermarking scheme which determines the perceptual quality and robustness of the watermarked images. The rest of this paper organized as follows. Section 2 outlines general watermarking model, QIM watermarking scheme, distortion-compensated QIM scheme and Bao’s image-adaptive QIM scheme. Section 3 describes the proposed method for deciding quantization steps. Section 4 presents experimental results. This paper is concluded in Section 5.

## 2 Related Works

### 2.1 Watermarking Model

Watermarking is the process that embeds data called a watermark, tag or another image into a multimedia object such that watermark can be detected or extracted later to make an assertion about the object. Let us denote the multimedia object(host signal) by  $x$ , the watermark by  $m$ , the watermarked object by  $y$ , and the extracted(or detected) watermark by  $m'$ , then the general model of watermarking can be depicted as Fig. 1[5].

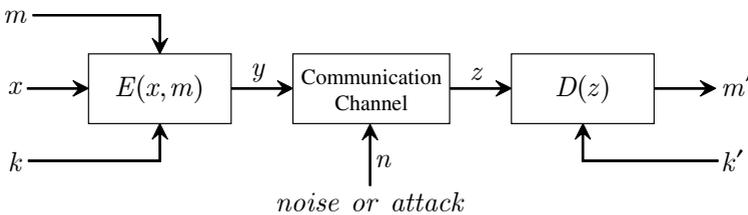


Fig. 1. General Watermarking Model

In Fig. 1, the  $n$  can be considered as noise or attack performed by general signal processing such as compression, rotation, resize, crop, and blurring. The  $E(\cdot, \cdot)$  and  $D(\cdot)$  are embedding function and detecting(extracting) function respectively. If the embedding key  $k$  and the detecting key  $k'$  are the same then the scheme is called *symmetric watermarking scheme*. In detecting, if the host signal is required then the scheme is called *non-blind watermarking scheme*.

### 2.2 Quantization Index Modulation

Chen *et al.* developed in 1998 a framework for characterizing the inherent trade-offs between the robustness of the embedding, the distortion to the host signal, and the amount of data embedded and designed a framework of information embedding systems, namely quantization index modulation(QIM), aiming at optimizing the rate-distortion-robustness trade-offs[5]. They developed a method,

the dither modulation, to realize and demonstrate the QIM framework where the embedded information would modulate the dither signal of a dithered quantizer.

QIM embedding methods embed information in the host signal components by quantizing them with a quantizer chosen from an ensemble of quantizers. The watermark  $m$  determines the choice of quantizer. For example if one wishes embed one bit ( $m = 0$  or  $m = 1$ ) in one host signal component of  $x$ , then  $y = q(x, m)$ , where  $q(\cdot, 1)$  and  $q(\cdot, 0)$  are two different quantizers. In Fig. 2  $q(\cdot, 1)$  and  $q(\cdot, 0)$ , depicted as  $\ominus$  and  $\times$  respectively, are uniform, scalar quantizers with step size  $\Delta$ . In this case both the reconstruction points, which are shown as  $\diamond$  and  $\square$  points, and the quantization cells of the two quantizers are shifted versions of each other so the quantizers are dithered quantizers, and this type of QIM is known as dither modulation.

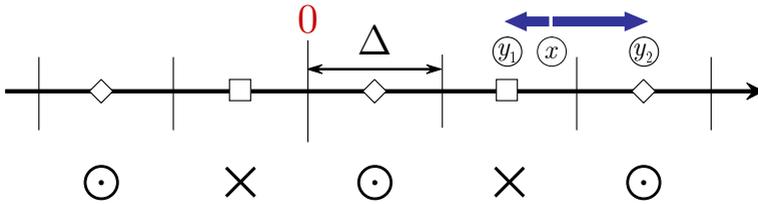


Fig. 2. Quantization Index Modulation

If the watermark  $m$  to be embedded is 1 then the  $\ominus$ -quantizer should be used and thus the quantized value(reconstruction point) will be  $y_2$ . In the same way, the quantized value will be  $y_1$  if  $m = 0$ .

Intuitively, properties of the quantizer ensemble can be related directly to the performance parameters of rate, distortion and robustness. For example, the number of quantizers in the ensemble determines the information embedding rate  $r$ . The distance( $\Delta$ ) of reconstruction points determines the embedding induced distortion and robustness.

The general dither modulation scheme is described bellows.

1. Prepare host signal vector  $x = (x_1, \dots, x_n)$ , quantization step vector  $\Delta = (\Delta_1, \dots, \Delta_n)$  and watermark vector  $m = (m_1, \dots, m_n)$ .
2. For  $i = 1, \dots, n$ , repeat the followings.
  - (a) Set  $d = \lfloor \frac{x_i}{\Delta_i} \rfloor$
  - (b) If  $m_i = 1$ , then
    - If  $d \pmod 2 \equiv 0$ , then  $y_i = d\Delta_i + \frac{\Delta_i}{2}$
    - Else if  $(d \leq x_i)$ , then  $y_i = (d + 1)\Delta_i + \frac{\Delta_i}{2}$  else  $y_i = (d - 1)\Delta_i + \frac{\Delta_i}{2}$
  - (c) If  $m_i = 0$ , then
    - If  $d \pmod 2 \equiv 1$ , then  $y_i = d\Delta_i + \frac{\Delta_i}{2}$
    - Else If  $(d \leq x_i)$ , then  $y_i = (d + 1)\Delta_i + \frac{\Delta_i}{2}$  else  $y_i = (d - 1)\Delta_i + \frac{\Delta_i}{2}$ .
3. Publish  $(y_1, \dots, y_n)$  and  $(\Delta_1, \dots, \Delta_n)$ .

### 2.3 Distortion-Compensated Quantization Index Modulation

Although quantization-based methods have been presented since the beginnings of watermarking, it was not until very recently that the idea was revisited from a sound theoretical perspective in the form of a data hiding scheme known as QIM, which hides information by constructing a data-driven set of quantizers. This was later connected to an old paper by Costa to realize that by adding back a fraction of the quantization error, performance could be significantly improved. This scheme was thus termed *distortion compensated QIM*(DC-QIM)[7].

If we denote the information embedding induced distortion(i.e. quantization error) as

$$e = q(x, m) - x, \tag{1}$$

then a fraction of error can be compensated by

$$y = q(x, m) - (1 - \alpha)e, (0 < \alpha \leq 1). \tag{2}$$

Obviously, the DC-QIM can not improve both robustness and perceptual quality, but adjust the robustness-distortion trade-off.

### 2.4 Bao’s Image-Adaptive Watermarking Scheme

Bao *et al.* proposed an image-adaptive watermarking scheme for image authentication by applying a quantization index modulation process on the SVs of the images in wavelet-domain[14]. SVD(Singular Value Decomposition) is a numerical analysis. The most interesting property of SVD for digital watermarking schemes is that the SVs of an image are very stable, that is, when a small perturbation is added to an image, its SVs do not change significantly. For more details on SVD, refer [1, 2]. The scheme is described as follows.

#### Computing Quantization Steps Phase

1. An image  $I = x_0x_1 \cdots x_l$  is transformed into wavelet subbands. In each of the subbands, the coefficients are segmented into blocks  $B_i(i = 1, \dots, n)$ of size  $k \times k$  and SVDs for each of the blocks are computed.
2. Calculate the standard deviation  $\sigma_{B_i}$  and average value  $m_{B_i}$  for DWT coefficients of each block  $B_i$ .
3. Calculate the value  $w_i$  for each block  $B_i$

$$w_i = c_m m_{B_i} + c_\sigma \sigma_{B_i}$$

where  $c_m$  and  $c_\sigma$  are the weight parameters for  $m_{B_i}$  and  $\sigma_{B_i}$ .

4. Calculate  $w_M = \max(w_i)$  and  $w_m = \min(w_i)$  for all  $w_i$ .
5. Compute the quantization step  $\Delta_i$  for block  $B_i$  as

$$\Delta_i = \text{qs}^{\min} + (\text{qs}^{\max} - \text{qs}^{\min}) \frac{w_i - w_m}{w_M - w_m}, \quad i = 1, \dots, n$$

where  $\text{qs}^{\min}$  and  $\text{qs}^{\max}$  are the minimum and maximum quantization step values, respectively, specified by user.

In their experiment, they set  $\text{qs}^{\min} = 9$  and  $\text{qs}^{\max} = 36$  or  $45$ , and let  $c_m = 1.0$ ,  $c_\sigma = 3.0$ .

**Embedding and Extracting Watermark Phase**

1. Compute  $n_v = \|v\| + 1, v = (\lambda_1^i, \dots, \lambda_k^i)$ , where  $v$  is a vector formed by the SVs of each block  $B_i$ .
2. Compute  $S = \lfloor \frac{n_v}{\Delta_i} \rfloor$ , where  $\Delta_i$  is the quantization step for  $n_v$  corresponding to the block  $B_i$  that is computed in the computing quantization steps phase.
3. IF  $(m_i = 1 \wedge S(\bmod 2) \equiv 1)$ , then  $S = S + 1$   
 IF  $(m_i = 0 \wedge S(\bmod 2) \equiv 0)$ , then  $S = S + 1$
4. Compute the value  $n'_v = \Delta_i S + \frac{\Delta_i}{2}$  and the modified SV

$$(\gamma_1^i, \dots, \gamma_k^i) = (\lambda_1^i, \dots, \lambda_k^i) \times \frac{n'_v}{n_v}.$$

5. Reconstruct the blocks and watermarked image using the modified SVs.

Let  $\tilde{B}_i$  be a block with an embedded watermark bit, the extraction of the watermark can be described as follows.

1. Segment the watermarked image into blocks  $\tilde{B}_i (i = 1, \dots, n)$  of size  $k \times k$  after wavelet transform.
2. Compute the value  $\tilde{n}_v = \|u\| + 1, u = (\gamma_1^i, \dots, \gamma_k^i)$ , where  $u$  is a vector formed by the SVs of each block  $\tilde{B}_i$ .
3. Compute  $S = \lfloor \frac{\tilde{n}_v}{\Delta_i} \rfloor$ .
4. IF  $S(\bmod 2) \equiv 0$ , then the embedded bit is 1. Otherwise, it is 0.

**3 Proposed Method**

**3.1 Basic Ideas**

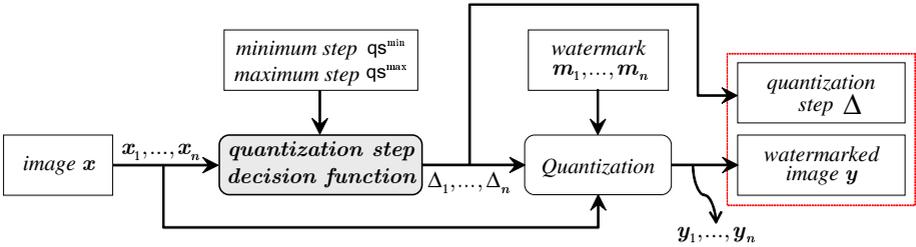
One desires a watermarking scheme to have high rate, low distortion, and high robustness, but in general these three goals tend to conflict. Thus, the performance of an information embedding system is characterized in terms of its achievable rate-distortion-robustness trade-offs.

Let's consider distortion and robustness among those three aspects. Higher robustness means larger quantization steps used and induces higher distortion, i.e. quantization error. To tackle this robustness-distortion tradeoff, Bao *et al.* proposed image-adaptive decision method for quantization steps which is better than using constant steps. We propose a different decision method for quantization steps considering the expected quantization results as well as the host signal in order to increase robustness and decrease distortion. Fig. 3 shows (a) the Bao's method and (b) the proposed method respectively. Moreover, Bao's quantization method is not efficient because the  $x_i$ 's distortion range is  $0 - \frac{3\Delta_i}{2}$  while in case of general dither modulation it ranges from  $0 - \Delta_i$  [5, 6, 7]. The comparison of Bao's quantization method and the binary dither modulation is depicted in Fig. 4.

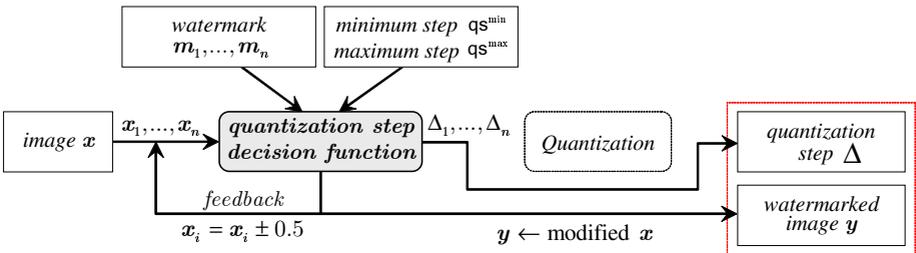
Let  $x_i$  be the  $i$ -th positive integer source signal,  $q_i$  be the  $i^{th}$  quantizer with quantization step  $\Delta_i$ , and  $y_i$  be the watermarked signal. If we use binary dithered modulation, the  $\Delta_i$  can be chosen from one of the two sets  $\Delta_{m=1}$  and  $\Delta_{m=0}$ .

$$\Delta_{m=0} = \left\{ \frac{2y_i}{2c + 1} \right\}, \text{ where } c = 1, 3, \dots \tag{3}$$

$$\Delta_{m=1} = \left\{ \frac{2y_i}{2c + 1} \right\}, \text{ where } c = 0, 2, \dots \tag{4}$$

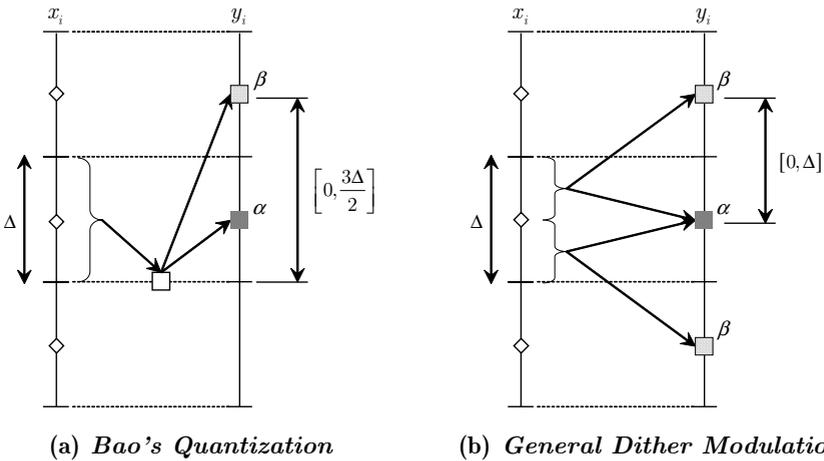


(a) Bao's quantization steps decision and watermarking method



(b) Proposed quantization steps decision and watermarking method

Fig. 3. The two methods for deciding quantization steps. (a) Bao's method. (b) Proposed method.



(a) Bao's Quantization

(b) General Dither Modulation

Fig. 4. The comparison of Bao's quantization method and the general dither modulation

**Table 1.** The possible quantization steps for  $x_i = 351$

$m = 1$						$m = 0$							
$c = 0$	$c = 2$	$c = 4$	$c = 6$	$c = 8$	$c = 10$	...	$c = 1$	$c = 3$	$c = 5$	$c = 7$	$c = 9$	$c = 11$	...
702	140.4	78	54	41.29	33.43	...	234	100.29	63.82	46.8	36.95	30.52	...

Thus, if we set  $y_i = x_i$  and can find appropriate integer  $\Delta_i$ , the embedding induced distortion will be zero. For example, given  $x_i = 351$  the possible quantization steps are shown in the following Table 1.

Intuitively,  $\max_{c=0,2,\dots} \left(\frac{2y_i}{2c+1}\right)$  is  $2y_i$  and  $\max_{c=1,3,\dots} \left(\frac{2y_i}{2c+1}\right)$  is  $\frac{2}{3}y_i$ . If we assume that only integer values can be quantization steps,  $\Delta_{m=1}$  has at least one integer value whereas  $\Delta_{m=0}$  does not. The algorithm for finding integer quantization steps is described as follows.

1. select maximum and minimum quantization step  $qs^{\max}$  and  $qs^{\min}$  respectively and distortion threshold  $t$ .
2. set  $x' \leftarrow x$ .
3. if  $m = 0$ , for  $c = 0, 2, 4, \dots$ , compute integer quantization step  $qs$  as

$$qs^{\min} \leq qs_i = \max_{\forall c} \left(\frac{2x'_i}{2c+1}\right) \leq qs^{\max}. \tag{5}$$

4. if  $m_i = 1$ , for  $c = 1, 3, 5, \dots$ , compute integer quantization step  $qs_i$  as (5).
5. if no quantization step is found, increase or decrease  $x'_i$  by 0.5.
6. go to step 3, until  $|x'_i| > |x_i| + t$ .
7. if  $|x'_i| > |x_i| + t$  then set  $x' \leftarrow x$ .
8. set  $x \leftarrow x'$ .

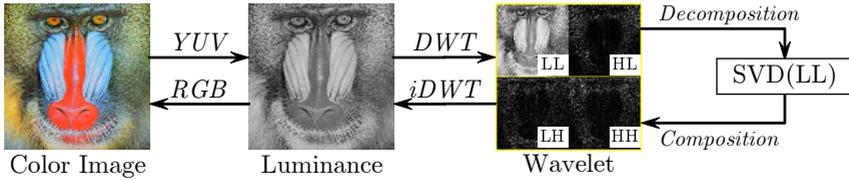
### 3.2 Deciding the Quantization Step Range

Intuitively, proper selection of the range of the quantization step values  $[qs^{\min}, qs^{\max}]$  is important to achieve high robustness and low distortion. Besides robustness and distortion, transmission overhead should be considered for selecting the range of quantization step values.

If we set the range as broad as possible, i.e.  $[1, 2 \max(x_i)]$ , then we can achieve maximum robustness and minimum distortion. However, broader range requires more data size of quantization parameters. Thus, it is necessary to choose a proper range of quantization step values considering the data size of quantization parameters. In this paper, we will use  $[1, 255]$  as the practical range of quantization step values.

## 4 Experimental Results and Performance Comparison

For our experiments, we use a general watermarking scheme based on DWT (discrete wavelet transform) and SVD(singular value decomposition). The scheme is described briefly as follows(see Fig. 5).



**Fig. 5.** Watermarking Procedure for Experiments

1. Perform DWT transform on grayscale image. If a color image is presented in RGB then it can be converted to the corresponding luminance matrix as

$$\begin{pmatrix} Y \\ U \\ V \end{pmatrix} = \begin{pmatrix} +0.299 & +0.587 & +0.144 \\ -0.148 & -0.289 & +0.437 \\ +0.615 & -0.515 & -0.1 \end{pmatrix} \times \begin{pmatrix} R \\ G \\ B \end{pmatrix}. \tag{6}$$

2. Segment the image of LL band into blocks  $B_i$  of size  $4 \times 4$ ,  $i = 1, \dots, (\frac{N}{8})^2$ , where  $N$  is the width and height of the source image.
3. Compute host signal  $x_i = |v_i|$ , where  $v_i = (\lambda_1^i, \lambda_2^i, \lambda_3^i, \lambda_4^i)$ ,  $v_i$  is a vector formed by SVs  $\Lambda$  of each block  $I_i$ .

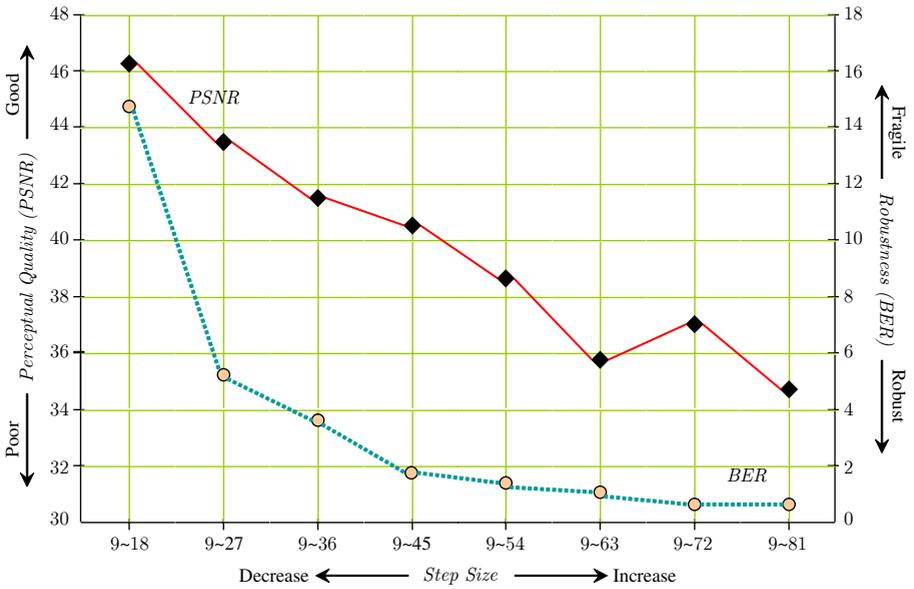
$$B_i = U\Lambda V^T.$$

4. Compute watermarked signal  $y_i = E(x_i, \cdot)$  and modify  $v_i$  as  $v'_i = v_i \times (y_i/x_i)$ .
5. Perform iDWT transform on the watermarked signal and convert it to RGB color space if necessary.

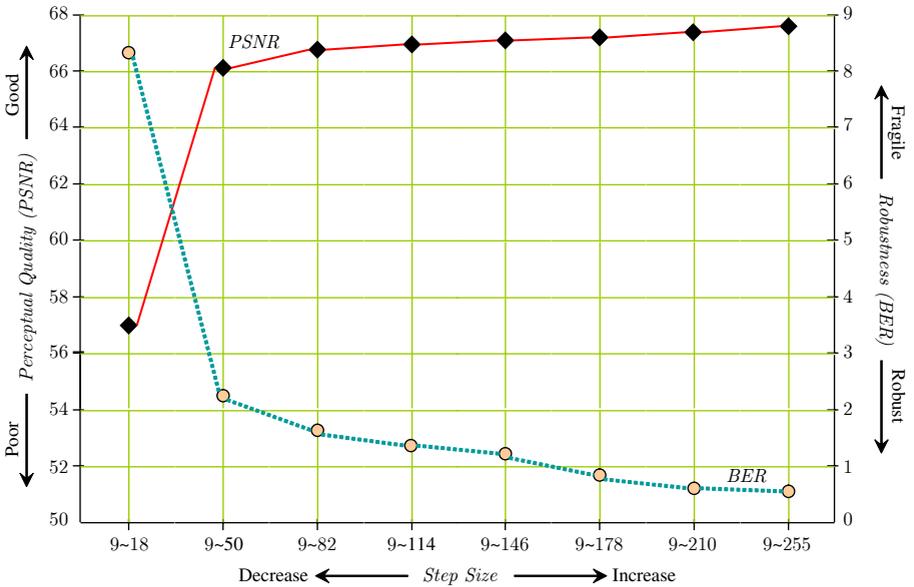
The PSNR of the watermarked image is about 67~68 which is extremely high in compared with the Bao’s QIM watermarking scheme(see Table 2). Moreover, the robustness of the proposed scheme is better than the Bao’s scheme which can be measured by BER(Bit-Error Ratio). It is generally accepted that higher perceptual quality means lower robustness and vice versa. However, using our scheme both good perceptual quality and robustness can be achieved at the same time.

**Table 2.** Performance comparison of Bao’s and the proposed scheme in perceptual quality and robustness

Image	Scheme	Perceptual Quality (PSNR)	Robustness(BER)			Step Size
			JPEG(50%)	JPEG(10%)	Median(4x4)	
Lena	Bao	41.63	3.857	24.457	31.152	9~36
	<b>Proposed</b>	<b>67.95</b>	<b>1.758</b>	<b>7.373</b>	<b>13.379</b>	<b>1~255</b>
Baboon	Bao	40.73	0.415	16.016	42.944	9~36
	<b>Proposed</b>	<b>68.08</b>	<b>0.903</b>	<b>7.251</b>	<b>19.873</b>	<b>1~255</b>
Peppers	Bao	41.28	3.223	20.288	28.633	9~36
	<b>Proposed</b>	<b>68.33</b>	<b>2.222</b>	<b>7.813</b>	<b>13.623</b>	<b>1~255</b>



(a) Bao's Watermarking Scheme



(b) Proposed Watermarking Scheme

Fig. 6. The relations between the step sizes and the PSNR/BER. The dotted line indicates the BER and the solid line indicates the PSNR.

Intuitively the robustness of a QIM watermarking scheme is determined by the quantization steps  $\Delta_i$  as shown in Fig. 6. For Bao's scheme, increasing the step size causes the watermarked images to have poor perceptual quality while good robustness. However, for our scheme, increasing the step size causes the watermarked images to have both good perceptual quality and robustness.

## 5 Conclusion

In this paper, a method for deciding quantization steps for QIM watermarking schemes is presented. It is shown that if we choose quantization steps considering the expected quantization results as well as host signal, we can increase the quantization steps and achieve both good robustness and perceptual quality. Also we presented experimental results of robustness(BER) and perceptual quality(PSNR) in case of two different ranges  $[1, 255]$  and  $[1, 2 \max(x_i)]$ . While choosing the range is depends on the various applications and requirements such as minimum robustness, maximum distortion, and data size of quantization parameters, the range  $[1, 255]$  is a good choice because we can achieve good PSNR, BER, and data size in compared with the range  $[1, 2 \max(x_i)]$ .

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