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Watermarking Marbled Image Based on Linear Enhancement Hologram

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Abstract. *A marbled image is generated by performing marbling operations on an image. When the marbled image is recovered to the original image, the parameters of the marbling operations should be known in the decoding process. By embedding these into the marbled image, we can eliminate an additional internet transmission. This paper proposes a watermark algorithm for marbled images based on a linear enhancement hologram. First, the parameters of the marbling operations are converted into a QR code image. Second, the QR code image is used to create a hologram. Then, the hologram is linearly enhanced to form a watermark. Finally, the watermark can be embedded into the subband of the discrete wavelet transform of the marbled image using different quantization embedding strengths. Experimental results showed that the algorithm has good invisibility and is robust to various attacks, including cropping, cutting, adding noise, JPEG compression, and filtering.*
Keywords: Marbled image; QR code; Linear enhancement; Hologram

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1. **Introduction.** Marbling is a traditional art form that started in either Turkey or Persia in the 12th century for decorative purposes [1, 2]. A marbled image is generated by performing marbling operations on an image [3]. When the marbled image is recovered to the original image, the parameters should be known. When a user receives a marbled image on the web, he recovers the original image using an additional parameters transmission. Embedding the parameters in the marbled image can eliminate the need for this additional transmission. Therefore, to ensure that the extracted watermark is correct, the watermark algorithm must be robust to many attacks, including cropping, cutting, adding noise, JPEG compression, filtering, and so on.

Recently, digital watermarking techniques have become available to resist various attacks, but geometric attacks are still a major problem[4-7]. Because of a hologram′s adjustable spectrum and tearing resistance, holographic technology is used in watermarking algorithms. The hologram was overwritten on the original image using Fourier transformation [8-11]. Chang used an optical hologram technology to embed watermarks in the DCT domain. The watermarked image shows advantages in invisibility. However, since the realization of blind extraction, the anti-attack ability of the algorithm is weak

[12]. Hologram-based watermarking capable of surviving the print-scan process has been reported by Wang. A hologram is produced using a conjugate symmetric extension technique, and is inserted into the DCT domain. A trade-off between transparency and robustness is achieved, but the correlation coefficients of the attacked watermark are not sufficiently high [13]. In order to improve the capacity and accuracy of the watermark, we propose a watermarking algorithm using QR code. Moreover, because QR code has a large capacity, it can encode the parameters and realize the function of automatic identification and correction [14]. A blind watermarking algorithm based on the lifting wavelet transform and QR code was introduced by Li. The lifting wavelet transform is applied to the original image, and the watermark image is dealt with using the QR code and chaotic systems. The algorithm has a high robustness, but the invisibility is poor [15]. A digital watermarking scheme using hologram quantization was proposed by Jin. The watermark is a hologram generated using a QR code and quantization based on the cover image, and is then embedded into the subband of the DWT. This method gives improvements in invisibility and security, but the watermark has poor robustness [16].

Thus, the present algorithm is designed to enhance the robustness against JPEG compression and noise signal processing methods by using the characteristics of a linear enhancement hologram. Furthermore, the use of QR code improves the detection performance and enables the practical use of hidden information. The method does not require a large number of calculations, and it is relatively simple to implement.

2. Background.

2.1. Linear Enhancement Hologram.

A hologram was first proposed in 1948 by Gabor [17]. Leith and Upatnieks published a study on off-axis holograms that used the interference of two separate coherent lights [18]. The holographic technique allows the light scattered from an object to be recorded and later reconstructed. When an imaging system is placed in the reconstructed beam, an image of the object will be reconstructed. This procedure is described mathematically as follows.

$$g(x,y) = m(x,y)exp[i\varphi(x,y)] \tag{1}$$

where g(x,y) is the object wave with real amplitude m(x,y) and phase φ(x,y).

$$G(\varepsilon,\eta) = \int\int g(x,y)exp[-2\pi i(\varepsilon x + \eta y)]dxdy \tag{2}$$

where $G(\varepsilon,\eta)$ is the complex amplitude of the object wave g(x,y).

$$R(\varepsilon,\eta) = R_0 exp[2\pi i(a\varepsilon + b\eta)] \tag{3}$$

where $R(\varepsilon,\eta)$ is the complex amplitude of a light wave with real amplitude R_0.

The two waves interfere at the surface of the recording medium, and the Fourier transformed hologram can be described as

$$H(\varepsilon,\eta) = G^*(\varepsilon,\eta)R(\varepsilon,\eta) + G(\varepsilon,\eta)R^*(\varepsilon,\eta) \tag{4}$$

Restoring the object representing the complex amplitude of the wave uses Equation (5).

$$S(\varepsilon,\eta) = |S(\varepsilon,\eta)|exp[i\varphi(\varepsilon,\eta)] \tag{5}$$

Here $|S(\varepsilon,\eta)| = 1$,$\varphi(\varepsilon,\eta) = 0$, an image of and an image of the object is reconstructed.

$$\begin{aligned} g_R(x,y) &= \int\int H(\varepsilon,\eta)exp[2\pi i(\varepsilon x+\eta y)]d\varepsilon d\eta \\ &= g(x-a,y-b)+g^*[-(x+a),-(y+b)] \end{aligned} \tag{6}$$

The image changes with the position and orientation of the viewing system in exactly the same way as if the object wave $g(x,y)$ was still present.

To improve the robustness of the watermarking algorithm, a linear enhancement hologram is proposed in this paper. The linear enhancement to hologram $H(\varepsilon,\eta)$ is described by Equation (7).

$$H'(\varepsilon,\eta) = cH(\varepsilon,\eta)+d \tag{7}$$

where c and d are constants.

The linear enhancement of hologram $H(\varepsilon,\eta)$ to form hologram $H'(\varepsilon,\eta)$ will lead to the linear enhancement to $g_R(x,y)$.The reconstruction procedure is described as

$$\begin{aligned} g'_R(x,y) &= \int\int H'(\varepsilon,\eta)exp[2\pi i(\varepsilon x+\eta y)]d\varepsilon d\eta \\ &= cg(x-a,y-b)+cg^*[-(x+a),-(y+b)] \\ &+\int\int dexp[2\pi i(\varepsilon x+\eta y)]d\varepsilon d\eta \end{aligned} \tag{8}$$

Let $A = \int\int dexp[2\pi i(\varepsilon x+\eta y)]d\varepsilon d\eta$ and then

$$\begin{aligned} A &= \int\int dexp[2\pi i(\varepsilon x+\eta y)]d\varepsilon d\eta \\ &= d\delta(x,y) \end{aligned} \tag{9}$$

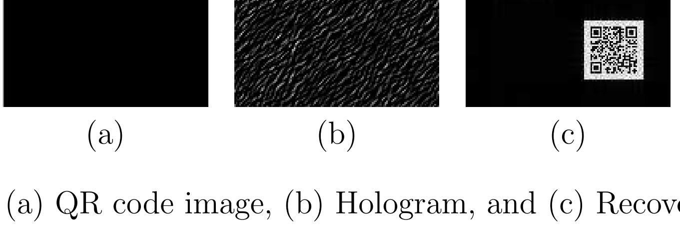
where $\delta(x,y)$ is a unit impulse-response function.

$$\delta(x,y) = \begin{cases} 0 & x\neq 0 \quad or \quad y\neq 0 \\ 1 & x=0 \quad and \quad y=0 \end{cases} \tag{10}$$

which leads to $A = d$. Equation (11) expresses the linear enhancement of $g'_R(x,y)$ to $g_R(x,y)$.

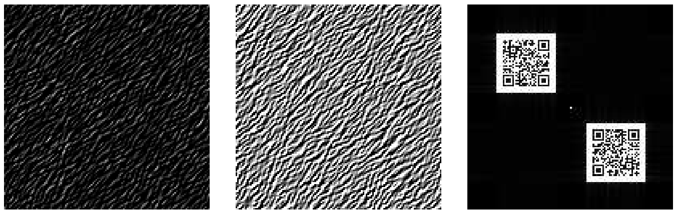
$$\begin{aligned} g'_R(x,y) &= cg(x-a,y-b)+cg^*[-(x+a),-(y+b)] \\ &= cg_R(x,y)+d \end{aligned} \tag{11}$$

In this paper, we use a QR code instead of the parameters because of its fast readability and high data capacity. A QR code image is represented by $g(x,y)$. Figure 1 shows the original QR code image $g(x,y)$, the hologram image $H(\varepsilon,\eta)$, and the binary image $g_R(x,y)$ recovered from the hologram. Figure 2 shows the linear enhancement hologram $H'(\varepsilon,\eta)$, and the linear enhancement $g'_R(x,y)$.



(a) (b) (c)

FIGURE 1. (a) QR code image, (b) Hologram, and (c) Recovered image.

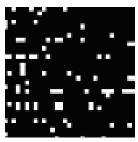


(a) (b) (c)

FIGURE 2. (a) Hologram, (b) Linear enhancement hologram, and (c) Recovered image.

A linearly enhanced hologram is more robust to several attacks. Table 1 shows a comparison of the extracted QR code from the watermarked images after JPEG compression.

TABLE 1. Comparison results after JPEG compression.

JPEG Compression	Qulity factor	
	JPEG-QF10	JPEG-QF10
Original hologram		
Decoded (Yes or No)	No	No
Linearly enhanced hologram		
Decoded (Yes or No)	Yes	Yes

2.2. **QR Correction.** QR codes consist of different parts and are designed to be fault-tolerant to a certain degree. Figure 3 shows the structure diagram of the QR code.

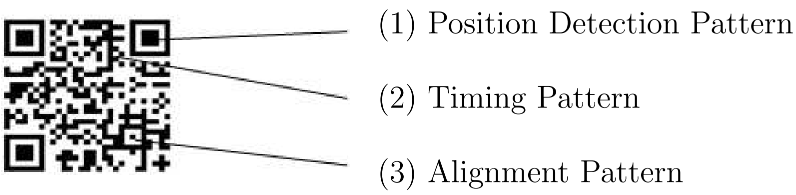


FIGURE 3. Structure of QR code.

Position Detection Pattern (1): The position detection pattern consists of three identical structures that are located in every corner of the QR code except the bottom right one. The patterns enable the decoder software to recognize the QR code and determine the correct orientation.

Timing Pattern (2): The timing pattern contains horizontal and vertical positioning graphics made up of alternating dark and light modules. The timing pattern enables the decoder software to determine the width of a single module.

Alignment Pattern (3): The alignment pattern supports the decoder software in compensating for moderate image distortions. With an increase in the size of the code, more Alignment Patterns are added.

After the watermarked image is attacked, the structure of the extracted QR code is damaged and can not be decoded correctly. To improve the QR code recognition rate, we compensate for the position detection pattern, timing pattern, and alignment pattern of the damaged QR code. Table 2 shows the experimental results.

TABLE 2. QR correction results after being attacked.

Description	Noise Attack	
	Gaussian	Salt&Pepper
Original extraction		
Decoded (Yes or No)	No	No
QR correction		
Decoded (Yes or No)	Yes	Yes

3. Proposed Watermarking Scheme.

3.1. Embedding Scheme.
Figure 4 shows the process of the embedding scheme.

Step 1. The marbled image is transformed using two-depth DWT. The transform is applied to LL1, along with the subband, which is LH1 in the 2nd DWT.

Step 2. Encode the parameters into a QR code (37×37). Transform the QR code using a DFT, and generate the hologram. Linearly enhance the hologram.

Step 3. Calculate the average of the HH2 subbands′ (128×128) energy for each 32×32 block. Form a quantization table based on the average energy matrix, and quantify the embedding strength into four grades corresponding to this average value.

Step 4. Multiply the quantization embedding strength, and generate the linear enhancement hologram quantization block. Replace the matrix of the LL1-HH2 and LH1-LH2 subbands with the quantization block.

Step 5. Transform them using two-depth inverse DWT.

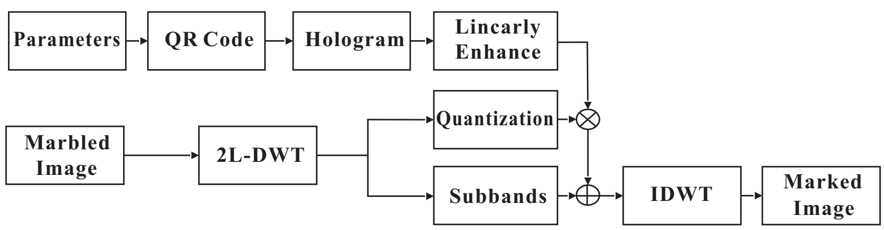


FIGURE 4. Watermark embedding process.

3.2. **Extraction Scheme.** The watermark extraction process is almost the opposite of the embedding procedure. Figure 5 shows the process of the extraction scheme.

Step 1. The marked image is transformed using two-depth DWT, and then the high frequency block at the LL1-HH2 and LH1-LH2 subbands is selected.

Step 2. Add the two subbands to obtain a new matrix.

Step 3. Restore the matrix with rehologram, and generate a symmetrical watermark image. Extract one QR code from the image.

Step 4. Compensate the position detection pattern, timing pattern, and alignment pattern of the extracted QR code.

Step 5. Obtain the parameters by processing the QR correction image using the QR decoder software.

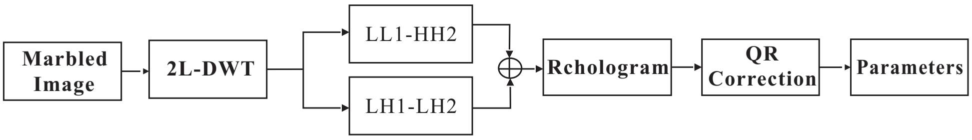


FIGURE 5. Watermark extraction process.

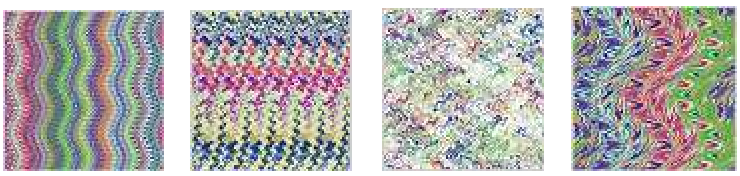
4. **Experimental Evaluation.** The original marbled image has an image size of 1200×1200 (Figure 6). The size of the QR code is 37×37. The QR code is generated from the parameters. QR codes have the capability to recover data after a code degradation of up to 30% to ensure that the watermark is recovered correctly. The size of the linear enhancement hologram is 128×128, and the extracted QR code is a symmetrical watermark image with an image size of 128×128 (Figure 7). The embedding strengths are 80, 75, 70, and 65. The watermark′s invisibility is generally measured using the peak signal-to-noise ratio and the mean squared error.

$$PSNR = 20log_{10}(255/MSE) \tag{12}$$

$$MSE = \sqrt{\frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N}[f^{\omega}(x,y) - f(x,y)]^2} \tag{13}$$

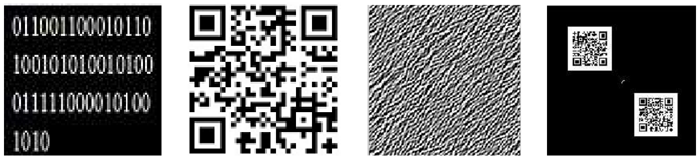
To evaluate the degree of similarity between the original watermark and the extracted watermark, the normalized cross correlation is defined as follows.

$$NC = \frac{\sum_i \sum_j W_{ij}W'_{ij}}{\sum_i \sum_j (W_{ij})^2} \tag{14}$$



(a) (b) (c) (d)

FIGURE 6. Marked images. (a) Move, (b) Sin, (c) Code1, and (d) Code2.



(a) (b) (c) (d)

FIGURE 7. (a) Parameters, (b) QR code, (c) Linear enhancement hologram, and (d) Rehologram.

Table 3 lists the PSNRs and NCs corresponding to the extracted QR images. This proves that the algorithm has good invisibility, and the watermark can be extracted completely.

TABLE 3. PSNR and NC values for various marbled images.

Marbing Images	PSNR(dB)	NC
Move	33.17	1.00
Sin	33.71	1.00
Code1	33.71	1.00
Code2	33.19	1.00

The proposed method is robust to several types of attack, including Gaussian noise (Figure 8) and Salt & Pepper noise (Figure 9) .Gaussian noise is added to the watermarked image with a variance of 0.12, and the salt and pepper noise is added with a variance of 0.25. Table 4 shows that our algorithm is more robust than Jin′s method [16].

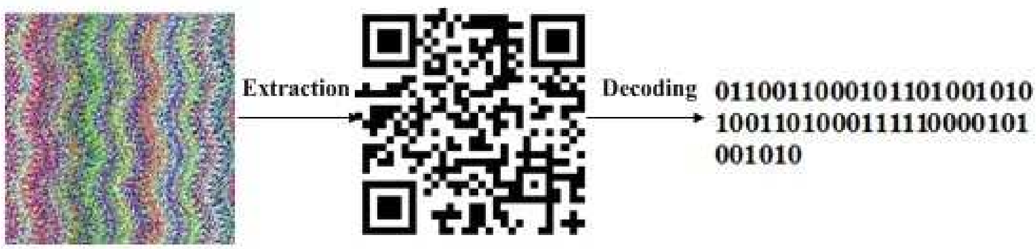


FIGURE 8. Gaussian noise(10%).

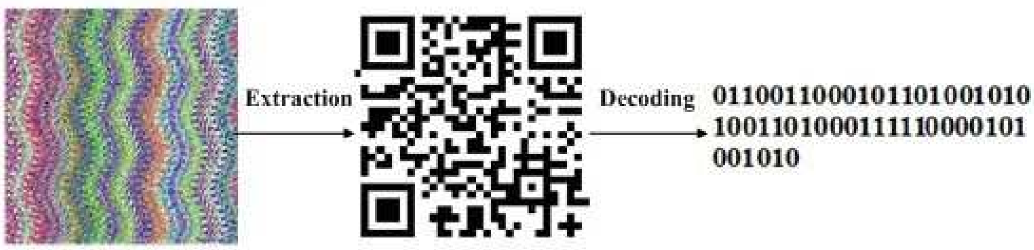


FIGURE 9. Salt and Pepper noise(10%).

TABLE 4. Comparison results between our method and Jin′s method [16].

Image Process	Our method	Jin′s method
	Decoded (Yes or No)	Decoded (Yes or No)
Gaussian (1%)	Yes	Yes
Gaussian (12%)	Yes	No
Salt & Pepper(1%)	Yes	Yes
Salt & Pepper(25%)	Yes	No

Figure 10 shows the correlation against JPEG compression. The attacked image′s PSNR is about 9 dB. The average value of NC is 0.99 in our algorithm, and it is robust to compression above QF10, while Jin′s algorithm is robust to JPEG compression with QF40 to QF90 [16]. It is obvious that the proposed algorithm is more robust than Jin′s method for the JPEG compression.

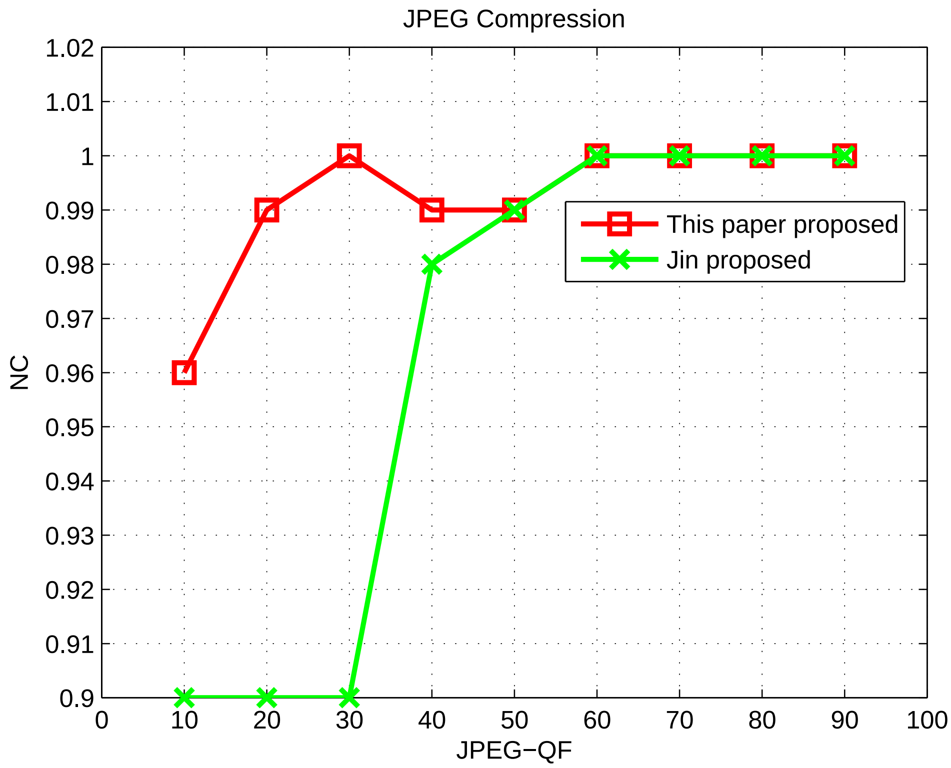


FIGURE 10. Comparison of JPEG compression between our method and Jin′s method [16].

Table 5 presents QR codes extracted from the watermarked image (Sin) after attacks, including contrast adjusting and lightness adjusting. The contrast adjusted images and lightness adjusted images are shown in Figure 11 and Figure 12, respectively.

Table 6 presents QR codes extracted from the watermarked image, including tampered, filtered, and sharpened images. The parameters used in the processing are listed in this table. The attacked watermarked images are shown in Figure 13. All of the extracted QR codes are almost complete and can be decoded correctly.

Table 5. PSNR and NC values after image processing.

Image Processing	Description	PSNR	NC
Contrast adjustment	Histogram equalized	24.46	1.00
Contrast adjustment	Contrast enhanced	16.49	0.99
Contrast adjustment	Contrast reduced	16.72	1.00
Lightness adjustment	Lightness enhanced	16.97	1.00
Lightness adjustment	Lightness reduced	13.07	1.00
Lightness adjustment	Part of lightness	26.64	1.00

(a) (b) (c)

Figure 11. Contrast adjustment. (a) Histogram equalized, (b) Contrast enhanced, and (c) Contrast reduced.

(a) (b) (c)

Figure 12. Lightness adjustment. (a) Lightness enhanced, (b) Lightness reduced, and (c) Part of lightness.

Table 6. PSNR and NC values from different attacks.

Image Processing	Description	PSNR	NC
Tampering	Scribbled	23.00	1.00
Tampering	Painted	18.69	1.00
Gaussian Filtering	3×3 mask,σ =1	34.09	0.99
Gaussian Filtering	4×4 mask,σ =0.6	28.02	0.96
Wiener Filtering	3×3 mask,σ =1	35.46	0.99
Wiener Filtering	4×4 mask,σ =1	30.43	0.99
Laplacian filtering	σ =0.9	8.59	1.00
Sharpening	Ps	20.30	0.99

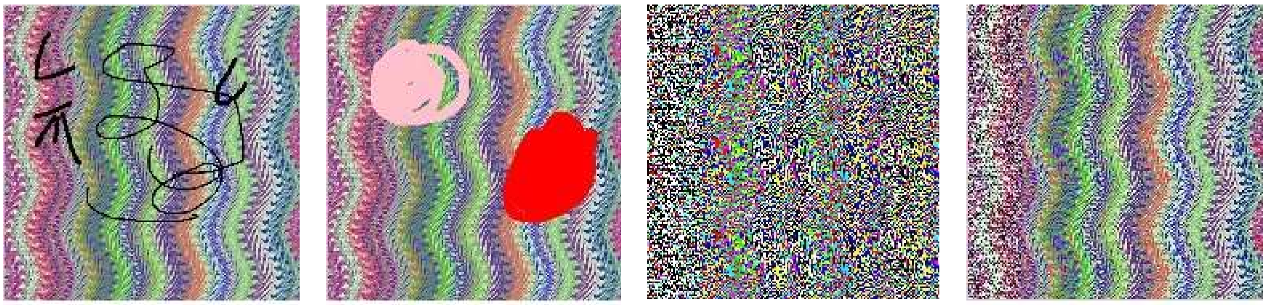


Figure 13. Attacked watermarked images. (a) Scribbled, (b) Painted, (c) Laplacian filtered, and (d) Sharpened.

Figure 14 shows that all of the NCs are about 0.99 with this algorithm, and the watermark can be detected after cropping 60% of the watermarked image. In contrast, Wang′s algorithm is robust to the cropping of 30% of the watermarked image [13].

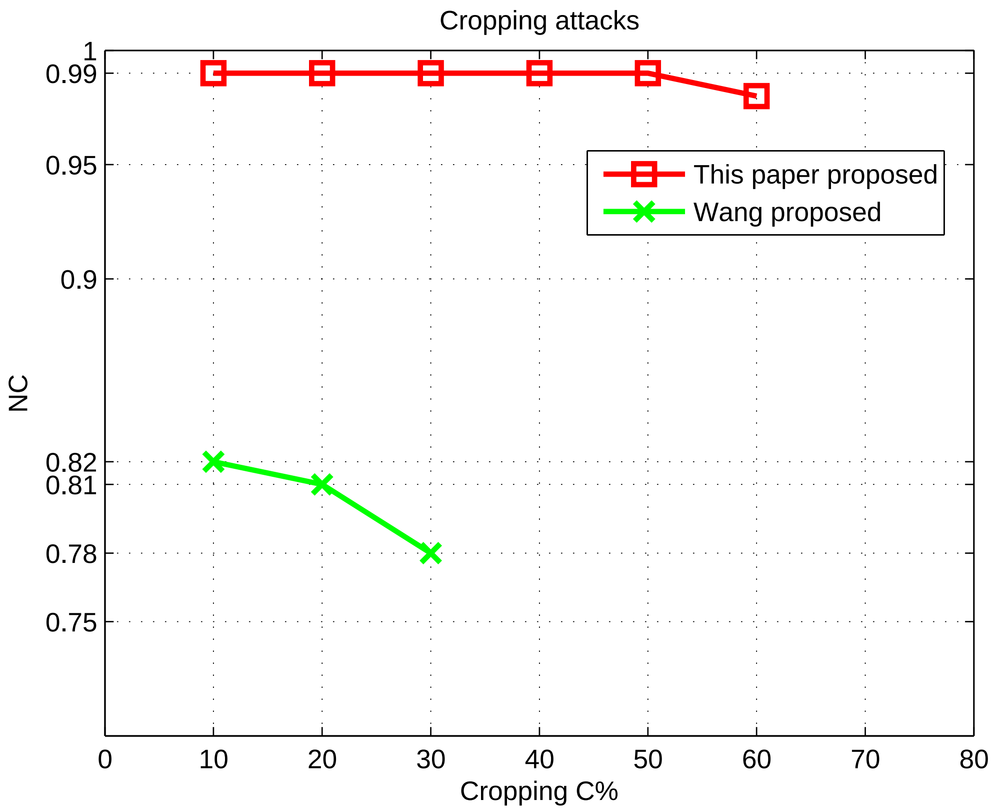


Figure 14. Comparison of cropping between our method and Wang′s method [13].

The results of the comparison with Wang′s method are shown in Table 7. Obviously, our method is better than Wang′s method based on the rate of correct detection.

Table 7. Comparison results between our method and Wang′s method [13].

Image Processing	Our method	Wang′s method
	NC	NC
Histogram equalized	1.00	1.00
Contrast enhanced	0.99	0.88
Contrast reduced	1.00	0.96
Gaussian blur 3×3 mask,σ =0.6	1.00	0.98
Gaussian blur 3×3 mask,σ =0.7	1.00	0.87

5. **Conclusions.** In this paper, we proposed a digital watermarking scheme. The watermark is based on the parameters of a marbled image, which are used to generate a QR code. The QR code is used to produce a linear enhancement hologram. Linear enhancement is an image enhancement approach to improve the robustness of a hologram. The algorithm is robust to various attacks such as JPEG compression, Gaussian noise, filtering, cropping, and so on. The QR code can be extracted without the original image. Compared with previous similar schemes, the proposed approach shows advantages in its invisibility, robustness, and embedding capacity.

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