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Logarithmic Quantization Image Watermarking By Using the Contourlet Transform

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Abstract. Conventional quantization-based watermarking uses the uniform quantizer to embed the watermark. This method may be easily estimated by averaging on a set of watermarked signals. Furthermore, by uniform quantizer, the perceptual characteristics of the host signal are not considered and the watermark energy is distributed uniformly within the host signal, which introduces perceptible distortions in some parts of host signal. In this paper, inspired by the entropy masking model and logarithmic quantization index modulation (LQIM) strategy, an improved logarithmic quantization-based watermarking method is studied in the contourlet transform domain. Its improved robustness is due to embedding in the high entropy image region and optimal parameter selection of the LQIM from speech communication point of view. At the receiver, the Euclidean distance decoder is utilized to extract the watermark information. Finally, we have performed a series of experiments on the test images to demonstrate the effectiveness of the proposed watermarking. Experimental results confirm the invisibility of the proposed method and its robustness against attacks covers additive white Gaussian noise (AWGN),JPEG compression, ,Gaussian filtering, scaling and cropping attack ,etc.
Keywords: Image watermarking, Logarithmic quantization, Entropy,contourlet transform

1. **Introduction.** With the growing applications on information technology and other multimedia communication systems, tremendous amounts of multimedia data products are being generated and distributed over the Internet each day. The security of these products has becoming an important technical problem which has been studied over the past twenty decades. A typical solution is digital watermarking, which has been widely researched in many information security applications, such as copyright protection, data

authentication, fingerprinting and broadcast monitoring, etc [1, 2, 3, 4, 5]. At present, the research on image watermarking is focused on designing a robust watermarking.

Roughly speaking, there are three kinds of digital watermarking based on the strategy of watermark, including additive [6], multiplicative [7-8] and quantization-based methods [9, 10, 11, 12, 13], respectively. It is known that each method has its own merits and demerits. As a result, the selection of watermark embedding strategy has becoming more and more important. In most quantization-based watermarking method, the Quantization Index Modulation (QIM) method, first proposed by Chen and Wornell [14], provides a good rate distortion-robustness tradeoff. Due to the use of structured lattice code, the QIM has high data capacity. Furthermore, the advantages of the QIM are simple and ease to implement. Besides, it is also a blind watermarking method. It is to say that the original signal is not needed when detecting the watermark information. However, a fixed quantization step size has been utilized in QIM, which may results in poor fidelity in some areas of the host signal. Moreover, the QIM is very sensitive to the amplitude scaling attack. That is, the BER (bit error ratio) of watermark will increase dramatically when the amplitude of the signal is changed,

To address the problem of QIM, several previously works have proposed in recent years. An adaptive quantization index modulation watermarking has been proposed by Jiao Li and Cox [15], which exploits Watsons perceptual model for the adaptive selection of quantization step size. Experimental results confirm the effectiveness of their proposed watermarking. However, their algorithm is sensitive to nonlinear amplitude changes, such as gamma correction. To solve this problem, literature [16] introduces a gain invariant watermarking based on sample projection strategy. By using this method, the watermark data has been embedded into the host signal by projecting the line segment onto some specific lines in the 2-D space according to message bits.

To further improve the robustness of quantization-based watermarking, N.K.Kalantari et al. [17] has proposed a watermarking based on logarithmic quantization index modulation (LQIM) approach which features perceptual advantages. For the watermark embedding, the original signal has been transformed firstly into the logarithmic domain, and then the watermark information is embedded into the signal via the uniform quantization approach. In terms of watermark detection, they extract the watermark by utilizing the Euclidean distance decoder. The merit of proposed method [17] is desirable from perceptual perspective by the u-law concept of speech communication. In this view, small quantization step sizes are devoted to smaller amplitudes and larger quantization step sizes are associated with larger amplitude. However, the method [17] would also suffer from gain attack. In order to improve the robustness against gain attack, literatures [18, 19] introduces a gain invariant quantization-based watermarking method. In these algorithms, they segment signal into two separate parts, then they embed the watermark data by quantizing the ratio of the -norm of each part. Due to the use of the division function, their proposed watermarking is robust to the amplitude scaling and gain attacks. However, the previous works [18, 19] does not consider the geometrical property of the image itself, which may lead to some perceptible distortions when against geometric attacks. To enhance the robustness of logarithmic quantization-based watermarking, we apply the contourlet transform for developing the watermarking method.

In this work, we develop an improved logarithmic quantization watermarking based on entropy masking model in the logarithmic domain. First, under partitioning the host image into non-overlapping blocks, the higher ranking image blocks are selected in estimated entropy measure for watermark embedding. Second, we use the contourlet transform to decompose each image block, and transform the selected contourlet coefficients by using logarithm function. In the next step, distortion-compensated quantization is performed

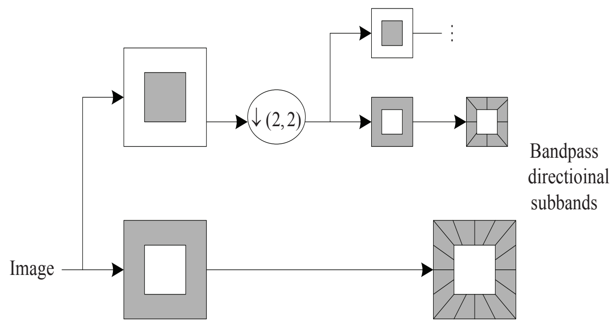

FIGURE 1. The diagram of the contourlet transform, laplacian pyramid as the first stage and directional filter bank as the second stage.

on transformed signal. Finally, the watermarked image is obtained by the reconstruction of contourlet transform.

The contributions of the proposed method are summarized as follows. First, by considering the mechanism of distortion compensation quantization index modulation (DC-QIM), the distortion of the image can be reduced during watermark embedding. Second, the selected image blocks have high entropy and texture complexity. Therefore, we embed strong watermark data into the complex texture region of image for improving the robustness of watermark. Third, although the analysis indicates that the method between [17] and the proposed watermarking seems to be mathematically equivalent, the implements are different. Literature [17] uses the wavelet transform for designing the watermarking. By comparison, this paper utilizes the contourlet transforms technology in our study. Due to the multi-scale geometric characteristics of contourlet transform, the contourlet-based quantization watermarking is robust to some geometric attacks.

2. Contourlet Transform.

Generally, for 1-D signal, wavelets have been established as an efficient image representation tool. However, since real images have many discontinuity points along smooth curves and contours, thus the wavelets cannot efficiently capture more directional information in 2-D signal. In order to overcome these drawbacks, many multi-scale geometric methods have been presented in recent years [20, 21, 22].

As a novel multi-scale geometrical analysis tool, which named contourlet transform, has been exploited by Minh Do et al. in [21]. It provides a sparse representation method at both spatial and directional resolutions. Literature [21] constructs the contourlet transform as the following two steps: the sub-band decomposition and the directional transform. In the first stage, the Laplacian pyramid approach transforms the image into one coarse version plus a set of LP band-pass images. In the second phase, the appropriately 2-D quincunx filtering and critical sub sampling decomposes each LP band-pass image into a number of wedge shaped sub-bands, and thus captures the directional information is captured. Finally, the image is represented as a set of directional sub-bands at multiple scales.

Fig.1 illustrates a diagram of contourlet transform.Fig.2 shows the contourlet transform of the Lena image using 2 LP levels and 8 directions at finest level, and the histograms of the finest sub-band.

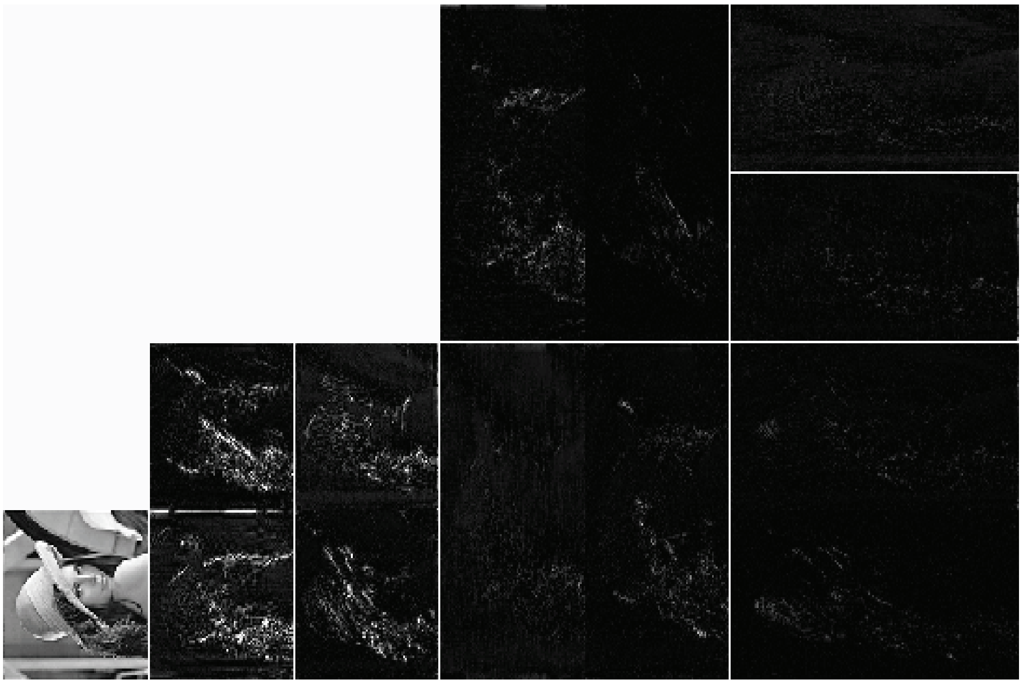

FIGURE 2. Contourlet transform of the Lena using two pyramidal levels, which are then decomposed into four and eight directional sub-bands.

3. **Proposed Watermarking method.** It is well known that the imperceptibility of watermarking depends on the judicious exploitation of the characteristics of the human vision system. According to the entropy masking model [23] and contourlet transform [21], we use the image block with high entropy to embed the watermark data. Fig.3 shows the flow chart of the proposed method, which performs the watermark embedding according to the following steps.

1) We apply Pseudo-random Noise (PN) generator to generate a binary watermark sequence. Let $b_i \in \{-1, 1\}$ be the watermark sequence.

2) Under segmenting the original image into non-overlapping $L \times L$ blocks, the H higher ranking blocks in estimated entropy measure are selected as the watermark embedding space.

3)We use the contourlet transform to decompose each selected image block. Then we obtain one low-frequency sub-band image, denoted I_J, and get the band-pass directional sub-bands, denoted $I_{j,k}^{l_j}$,$k = 1, 2, ..., 2^{l_j - 1}$,$j = 1, 2, ..., J$, where j denotes the j-th level of LP decomposition, k denotes k-th band-pass directional image decomposed by a l_j-th level DFB. Lastly, we compute the average energy of sub-band image by the l_2-norm:

$$E_{j,k} = \frac{1}{MN} \sum_{m=1}^{M} \sum_{n=1}^{N} \left\| I_{j,k}^{l_j} \right\|^2, \tag{1}$$

where$M \times N$denotes the size of the sub-band image $I_{j,k}^{l_j}$ in each block, A larger value of the average energy of sub-band image implies that this sub-band contains more energy and should be treated as a significant sub-band in comparison with other sub-bands. As a result, to improve the robustness of the watermarking system, we embed the watermark into the significant sub-band image with high energy.

4) For each block, let $[x_1, x_2, ..., x_{\bar{N}}]$ be the set of contourlet coefficients of sub-bands with high energy. Then we transform the set of contourlet coefficients by using logarithmic function

$$c = \frac{\ln\left(1 + \rho\frac{|x|}{X_s}\right)}{\ln(1+\rho)}, \rho > 0, X_s > 0, \tag{2}$$

where ρ denotes a parameter measuring the compression level and X_s represents the parameter scaling the host signal. The best value X_s is the value which spreads most of the host signal samples into the range [0, 1].The optimum value of ρ can be computed by [17] in detail.

In the next step, let $\mathbf{c} = [c_1, c_2, ..., c_{\bar{N}}]$ be the set of transformed coefficients in the logarithmic domain. After compressing the host signal via formula (2), the transformed signal c_i is quantized by the DC-QIM for watermark embedding:

$$z_i = Q_{b_i}(c_i) + (1-\lambda)(c_i - Q_{b_i}(c_i)), i = 1, 2, \cdots \bar{N}, \tag{3}$$

where $Q_{b_i}(c_i) = \mathrm{round}(\frac{\mathrm{c_i + b_i\Delta}}{\Delta})\Delta - \mathrm{b_i}\Delta$ is the adaptive quantizer,which applied to the transformed signer c_i. $b_i \in \{-1, 1\}$ is the i-th watermark bit,and Δ denotes the quantization step size, λ represents the quantization scalar factor, which discussed in the following section 4. When λ=1, the DC-QIM corresponds to the quantization index modulation.

5) The watermark data is embedded into the selected contourlet coefficients. Thus, the watermarked signal y_i can be obtained as follows:

$$y_i = \mathrm{sgn}(z_i)\frac{X_s}{\rho}\left[(1+\rho)^{|z_i|} - 1\right], \tag{4}$$

where $\mathrm{sgn}(\cdot)$ represents the sign function, z is the quantized signal in the transformed domain, and y_i represents the watermarked signal.

6) Repeat step 3) - step 5). Finally, we apply the inverse contourlet transform to reconstruct the watermarked image, and then combine with the non-watermarked blocks to obtain the watermarked image. In order to extract the watermark signal, the Euclidean distance decoder is applied. In the decoding process, zero and one are embedded in the received signal using the proposed method resulting in r_0 and r_1 , respectively. Thus the watermark signal can be extracted as

$$\hat{m} = \arg\min \|r - r_i\|^2, i \in \{0, 1\}, \tag{5}$$

where $\hat{m}$ represents the extracted watermark signal.

4. **OPTIMAL PARAMETER ρ FINDING.** In this section, the optimum value for parameter ρ is derived by minimizing the quantization distortion. In order to get the optimum value for ρ , the watermark power should be found and it can be minimized with respect to ρ .Thus, consider the quantization noise in the transform domain to be w. In order to obtain the watermark power, we need to find $E[\|x_w - x\|^2]$. $(x_w - x)$ can be written as following based on vector LQIM [17].

$$x_w - x = \frac{s_q}{s}x - x = \left(\frac{s_q}{s} - 1\right)x, \tag{6}$$

where $s_q = \frac{X_s}{\rho}\left[(1+\rho)^{c+w} - 1\right]$ and. w denotes the quantization noise in the logarithmic transform domain. c denotes the quantized signal. $s = \sqrt{\frac{1}{N}\sum_{i=1}^{N} x_i^2}$ represents the normalized magnitude by embedding one bit of message into the host vector $X = \{x_1, x_2, ..., x_N\}$

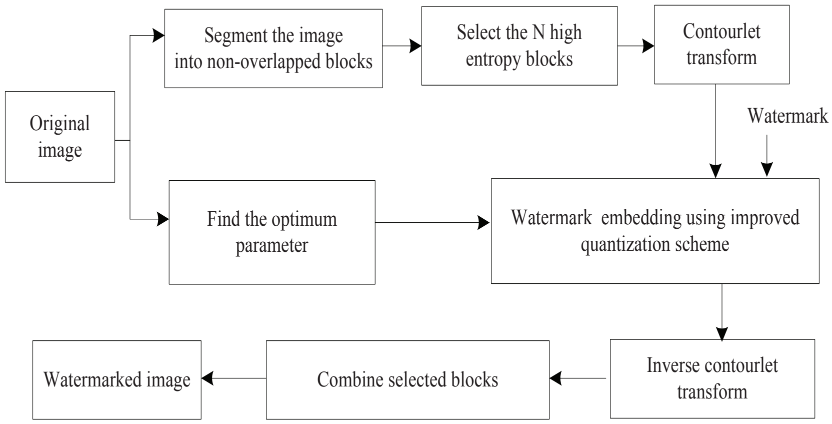

FIGURE 3. The block diagram of watermark embedding.

.Therefore $sgn(s)$ is not considered since s is always positive. By adding and subtracting $(1+\rho)^w$ inside the bracket and using (4), we have

$$s_q{=}\frac{X_s}{\rho}\left[(1+\rho)^w-1\right]+\frac{X_s}{\rho}\left[(1+\rho)^c-1\right](1+\rho)^w{=}\frac{X_s}{\rho}\left[(1+\rho)^w-1\right]+s(1+\rho)^w \tag{7}$$

Thus (x_w-x) can be obtained as

$$x_w-x=\left\{\frac{X_s}{\rho s}\left[(1+\rho)^w-1\right]+(1+\rho)^w-1\right\}x. \tag{8}$$

Simplifying the above equation leads to

$$x_w-x=\left\{\left(1+\frac{X_s}{\rho s}\right)\left[(1+\rho)^w-1\right]\right\}x \tag{9}$$

According to Eq.(9), replacing s with $|x|$ when s is scalar, then we have

$$x_w-x=\left(x+\mathrm{sgn}(x)\frac{X_s}{\rho}\right)\left[(1+\rho)^w-1\right], \tag{10}$$

where $\mathrm{sgn}(x)=x/\left|x\right|$, thus, $E[\|x_w-x\|^2]$ can be expressed as

$$E[\|x_w-x\|^2]=E\left[\left(x+\mathrm{sgn}(x)\frac{X_s}{\rho}\right)^2\right]E\left[\left((1+\rho)^w-1\right)^2\right]. \tag{11}$$

As well, two terms are assumed to be independent each other in equation (11), thus the first term can be written as

$$E\left[\left(x+\mathrm{sgn}(x)\frac{X_s}{\rho}\right)^2\right]=E[x^2]+2E[|x|]\frac{X_s}{\rho}+\frac{X_s^2}{\rho^2}. \tag{12}$$

The watermark power can be calculated using (12) and it can be minimized with respect to ρ by using the same method used in vector LQIM [17]. According to the obtained watermark power, Document to Watermark Ratio (DWR) can be calculated as

$$DWR=\frac{E\left[\|x\|^2\right]}{E\left[\|x_w-x\|^2\right]}=\left\{\left(1+2E[|x|]\frac{X_s}{E[x^2]\rho}+\frac{X_s^2}{E[x^2]\rho^2}\right)\times\left(\frac{1}{\Delta}\int_{-\Delta/2}^{\Delta/2}\left((1+\rho)^w-1\right)^2dw\right)\right\}^{-1}. \tag{13}$$

By applying the Taylor series expansion for $(1+\rho)^w$ in (13), the following equation can be obtained as

$$(1+\rho)^w = 1 + \ln(1+\rho)w + O(2), \tag{14}$$

where the higher order terms are neglected by assuming to be sufficiently small. Using the above approximation, the expectation $E\left[((1+\mu)^w - 1)^2\right]$ in (11) can be rewritten as

$$E\left[((1+\rho)^w - 1)^2\right] = \ln^2(1+\rho)\frac{\Delta^2}{12}. \tag{15}$$

Using the above simplification, the optimum $\rho_o pt$ of LQIM [17] can be obtained as

$$\mu_{opt} = \arg \min_{\rho\in(0,\infty)} \left\{ \left(1 + 2E[|x|]\frac{X_s}{E[x^2]\rho} + \frac{X_s^2}{E[x^2]\rho^2} \right) \ln^2(1+\rho) \right\}. \tag{16}$$

5. **EXPERIMENTAL RESULTS.** In order to evaluate the performance of the proposed watermarking, we implement the algorithm in the contoulet domain. In this study, four natural images (Lena, Barbara, Boat and Mandrill) of size 512 512 are used for testing the performance of watermarking. Firstly, the original images are segmented into non-overlapping 32 32 block size. Then the high entropy image blocks are chosen as the embedding space. Secondly, for each image block, the 9-7 biorthogonal filters with two levels of pyramidal decomposition is adopted in the multi-scale decomposition stage and the PKVA filters is utilized for the multidirectional decomposition stage, then the highest energy contoutlet coefficients are quantized by using logarithmic quantization method.

Fig.4 shows the experimental results of the imperceptibility test for the above well-known images. For each image, the left one is the original image, the middle-one is the watermarked image and the right one is difference image between the original image and the watermarked image. As can be seen in Fig.4, the watermark invisibility is satisfied.

More importantly, the proposed method embeds the watermark data into the high entropy region of image, which has strong components in the complex part of the image. Therefore, the watermark information is hard to see. As a result, the perceptual quality of the watermarked image can be kept at acceptable level. Furthermore, to investigate the performance of proposed method in a objective way, the peak signal-to-noise-ratio (PSNR) and the similarity index measure [24] (SSIM) for the watermarked images are computed, which the PSNR values of the watermarked images are 48.9459, 48.9022, 49.0843 and 50.1278 dB, and the SSIM values of the watermarked images are 0.9864, 0.9890, 0.9983 and 0.9991, respectively. Therefore, this again proves the validity of the proposed watermarking method.

For testing robustness, several common attacks are applied to the watermarked images with the proposed watermarking method. These attacks include common image processing attacks and geometric distortion attacks. The watermark robustness under several intentional or unintentional attacks is evaluated by Bit error-ratio(BER). To save space, the robustness of the proposed method under Gaussian noise attack, median filtering, JPEG compression, scaling attack, cropping and rotation attack on four well-known images including Lena, Barbara, Boat and Mandrill is investigated. Table 1 shows the results of the proposed method in comparison with [15] and [17], which are adaptive quantization index modulation watermarking based on Watson visual perception model, and logarithmic quantization index modulation image watermarking, respectively. 1024 bits have been embedded in each image in all methods. The variance of additive white Gaussian noise is 10 and 20,respectively; the size of median filter are 3×3 and 5×5, respectively; the quality factor in the JPEG compression are is 30%. As can be seen in Table 1, the

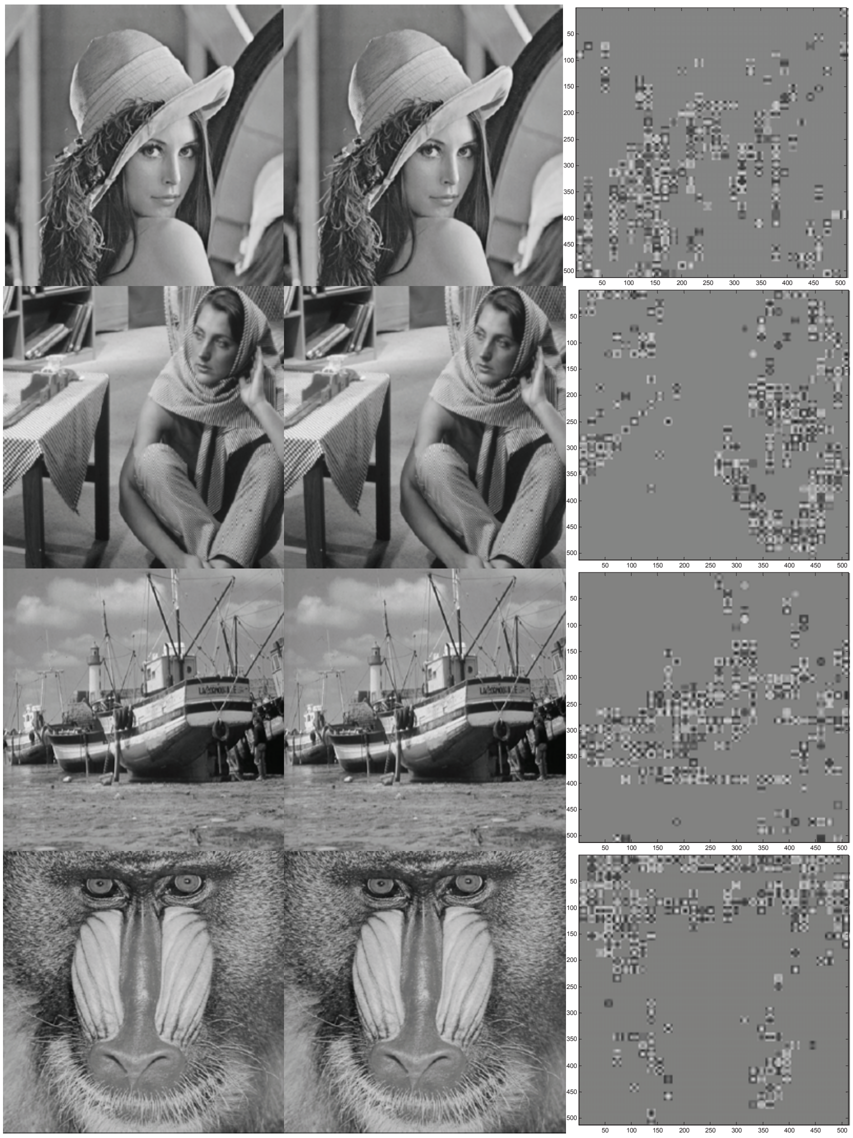

FIGURE 4. Original, watermarked and difference images by using the proposed method.

proposed watermarking method has slightly better performance than those watermarking methods mentioned above.

Table 2 demonstrates the BER results under some geometric distortions with different attack parameters. The scaling factors are 0.70 and 1.20, respectively; the strength factor of cropping are 20% and 40%, respectively, and the rotation degree is 10°. As can be seen in Table 2, the proposed algorithm can successfully resist attacks like scaling, cropping and rotation attacks. This is because the high energy contourlet coefficients of an image are utilized for watermarking, which are degraded less by the above geometric attacks in Table 2.

From Table 1 and table 2, we can see that the proposed watermarking algorithm has strong robustness when against common image processing attacks and some geometric attacks. The main factors are summarized as follows: First of all, contourlet transform not only possess the main features of wavelets (namely, multi-scale and time-frequency

TABLE 1. BER (%) results under common attacks.

Image	Method	Gau.10	Gau.20	Med.3×3	Med.5×5	JPEG 30%
Lena	Ref[15]	15.71	26.63	10.25	16.84	50.40
	Ref[17]	8.44	13.56	5.29	6.74	30.53
	Proposed	6.96	11.62	4.91	5.86	25.28
Barbara	Ref[15]	16.33	28.42	9.56	15.57	49.22
	Ref[17]	38.71	14.24	5.84	7.46	29.65
	Proposed	5.36	10.77	5.17	6.39	24.48
Boat	Ref[15]	15.23	25.38	11.46	16.45	51.78
	Ref[17]	9.18	12.35	7.64	9.58	32.89
	Proposed	6.20	9.90	5.32	6.66	25.55
Mandrill	Ref[15]	14.81	23.92	9.46	14.57	49.10
	Ref[17]	7.65	10.65	5.18	6.24	30.63
	Proposed	5.84	8.73	4.44	5.36	24.79

TABLE 2. BER (%) results under geometric attacks.

Image	Method	Scal.0.70	Scal.1.20	Crop.20%	Crop.40%	Rot. 10°
Lena	Ref[15]	14.37	12.25	20.89	52.36	30.85
	Ref[17]	12.96	11.08	16.54	43.97	24.90
	Proposed	11.22	10.46	13.26	40.15	19.82
Barbara	Ref[15]	16.23	15.84	19.94	48.60	29.77
	Ref[17]	13.45	10.97	14.06	42.13	25.34
	Proposed	12.10	10.68	12.55	39.83	20.11
Boat	Ref[15]	15.36	13.27	19.98	49.09	29.52
	Ref[17]	12.61	10.86	16.73	38.17	24.25
	Proposed	11.67	9.88	11.42	36.75	19.38
Mandrill	Ref[15]	15.58	14.05	20.50	48.51	29.66
	Ref[17]	13.24	13.42	15.45	42.82	24.18
	Proposed	11.65	10.30	11.91	35.92	19.57

localization), but also offer a high degree of directionality and anisotropy, which can be used to develop a robust watermarking method. Second, a modified logarithmic quantization approach is developed, which embeds each watermark bit by modulating a set of contourlet transform coefficients. Using this strategy, the effect of geometric distortion on the watermarked image can be reduced. Lastly, the information entropy of image is exploited to design the watermarking, which achieves a good tradeoff between the invisibility and the robustness of watermarking. Therefore, the robustness of watermarking system can be guaranteed in our method.

6. **Conclusions.** In this paper, a modified logarithmic quantization-based image watermarking has been proposed by using the contourlet transform. Its improved robustness is due to embedding in the high entropy blocks of host image in the logarithmic domain. Watermark information extraction is performed blindly using minimum distance decoder. Finally, the performance of the proposed scheme is evaluated in terms of image quality and robustness. Experimental results demonstrated the effectiveness of the proposed watermarking method. Future work will include investigating a novel watermarking by using other technologies such as visual attention model, machine learning and game theory etc.

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