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Content Based Image Public Watermarking

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Abstract

In this paper, a content based image public watermarking technique which operates in DCT domain is proposed. First, the 8×8 DCT sub-blocks of the host image are rearranged into a Hilbert sequence in Hilbert scanning order, then two neighboring sub-blocks in the Hilbert sequence is pseudo-randomly selected by using chaotic sequences. Then a watermark with visually recognizable pattern is embedded into the original image by changing the polarity of the corresponding middle-frequency coefficients in the two chosen neighboring sub-blocks, and the watermark is adapted to the image by exploiting the masking characteristics of the human visual system (HVS), thus ensuring the watermark invisibility, and the watermark don't need the original image. The experimental results show that the proposed algorithm in this paper is robust to common signal processing techniques and some geometric distortions, such as cropping, scaling and rotation. Especially, it achieves high robustness under signal enhancement operations, such as sharpening, contrast enhancement, edge enhancement and histogram equalization.

1. Introduction

Digital watermarking is a novel technique that doesn't boom until 1990's. It deals with a variety of disciplines, such as image processing, digital communication, encryptography, and so on. As a effective solution to the problem for copyright protection of multimedia against unauthorized uses, digital watermarking have received a considerable amount of attention of a great number of researchers in different disciplines during the last few years. The drive forces are the urgent need of intellectual property and copyright protection in the World Wide Web and the immense potential on which digital watermarking exhibits.

Digital watermarking techniques embed unobtrusively information about the copyright owner, the creator or authorized consumer of the digital work into digital media to protect the copyright of the digital media. A effective digital watermarking must satisfy the following features:

(1) **Perceptual transparency:** The embedding watermark shouldn't result in remarkable degradation or distortion in data quality of the host media under typical perceptual conditions. That is, human observers cannot distinguish the original host media from the watermarked media. As a result, human eyes should not perceive the existence of the watermark.

(2) **Robustness:** Watermarking system should resist various malicious or unintentional attacks. Removal of the embedded watermark should be difficult for an attacker or any unauthorized users. Attempts to remove or destroy it should produce a remarkable degradation in data quality before the embedded watermark is lost. The watermark must still be present in the host media if some common signal processing operations are applied to the watermarked media. These operations include

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resampling, requantization, lossy compression, filtering, geometric distortions, as well as digital-to-analog and analog-to-digital conversion.

(3)**Unambiguity:** The retrieval of a watermark should unambiguously identify the data owner.

(4)**Tamper-resistance:** The embedded watermark must be resistant to tampering through collusion by comparing multiple copies of the media embedded with different watermarks.

Since 1993 Tirkel issued a article named by "Electronic Watermark" [TSR*93], papers on digital watermarking have been increasing dramatically in the past few years. Image watermarking techniques proposed so far can be divided into two main groups: spatial-domain techniques [KJB98,Pit96] and frequency-domain techniques [FGD2001,GP96,SZT96,TD97,PZ97,RP98, KKP99,PZ98]. The spatial-domain techniques directly modify the intensities or color values of some selected pixels while the frequency-domain techniques modify values of some transformed coefficients. The transform may be DCT [FGD2001,GP96,SZT96,TD97,PZ97], Fourier transform [RP98] or wavelet transform [KKP99,YC2003] etc. The watermark is then embedded in the transformed coefficients of the image such that the watermark is less invisible and more robust to some image processing operations. Finally, the coefficients are inverse-transformed to form the watermarked image. The masking characteristics of the human visual system can be utilized to ensure that the watermark is invisible and more robust to some attacks [PZ98,DDVM98].

The proposed algorithm in this paper belongs to block-DCT domain techniques. Most previous watermarking algorithms based on block-DCT embed a watermark by modifying the coefficients in each DCT sub-block according to the watermark bit [FGD2001,GP96, SZT96,TD97,PZ97]. In this paper, a content based image public watermarking technique which operates in DCT domain is presented, and we embed a watermark into the original image by modifying the polarity of two corresponding middle-frequency DCT coefficients in two different DCT sub-blocks which neighbor in Hilbert sequence. Firstly, the 8×8 DCT sub-blocks of the host image are rearranged into a Hilbert sequence in Hilbert scanning order, then two neighboring sub-blocks in the Hilbert sequence is pseudo-randomly selected by using chaotic sequences. A watermark with visually recognizable pattern is embedded into the original image by modifying the polarity of two corresponding middle-frequency coefficients in the two chosen neighboring DCT sub-blocks, and the watermark is adapted to the image by employing the HVS masking characteristics, thus ensuring the watermark invisibility. The experimental results show that the proposed algorithm is robust to common signal processing operations and some geometric distortions, such as cropping, scaling and rotation. Especially, it receives high robustness under signal enhancement operations, such as sharpening, contrast enhancement, edge enhancement and histogram equalization..

2. Chaotic sequences and hilbert curve

2.1 Chaotic sequences

Chaotic phenomena are certain, random-like procedures in nonlinear dynamical systems. A very simple but being-researched widely is logistic map [May76,Hui99]. It is defined as follows:

$$\chi_{k+1} = \lambda\chi_k(1-\chi_k), \quad 0 \le \lambda \le 4, \chi_k \in (0,1)\,. \quad (1)$$

Logistic map is chaotic when λ satisfies $3.5699456\cdots < \lambda \le 4$, we can map it into range (-1,1) by using simple variable-substitute, it can be defined as:

$$\chi_{k+1} = 1-\eta\chi_k^2, \quad 0 \le \eta \le 2, \chi_k \in (-1,1)\,. \quad (2)$$

Sequences generated by logistic map are non-periodic, nonconvergent and sensitive to the initial value. At the same time, it is simple in style. Given only an initial value and a chaotic map parameter, a chaotic sequence will be produced..

2.2 Hilbert scanning

In 1890, Italy mathematician G.Peano constructed a sort of space-filling curves which pass each point in a space self-avoidably. Then, German mathematician D.Hilbert constructed a sort of simplest Peano curves called by Hilbert curves (as shown in Fig.1) [Gri85]. Hilbert curves map n-D space into 1-D space, and C.Gostman & M.Lindenbaum proved that Hilbert curve is the curve that can best retain space local adjacency in all of the space-filling curves [GL96].

3. The proposed algorithm

In this section, we will describe the proposed image public watermarking using visual models and Hilbert curves. The watermark used is a visually recognizable binary image. In our approach, firstly, the 8×8 DCT sub-blocks of the host image are rearranged into a 1-D Hilbert sequence by using Hilbert curve, then two neighboring sub-blocks in the Hilbert sequence is pseudo-randomly selected by using chaotic sequences. A visually recognizable binary watermark is embedded into the original image by modifying the polarity of the corresponding middle-frequency coefficients in the two chosen neighboring sub-blocks, and the watermark is adapted to the image by exploiting the HVS characteristics, thus ensuring the watermark invisibility. In addition, to prevent tampering or unauthorized access, the watermark is first permuted into scrambled data. The block diagram of the watermark embedding is depicted in Figure 2. In the following subsections, first, we will give the visual models, then describe the watermark embedding and extraction processes.

3.1 Consideration of the human visual system mask characteristics

From the view of signal processing, watermarking can be view as a processing which superimpose a faint signal (watermark) on the strong background (original image). The human eyes will not perceive the existence of the watermark if faint signal superimposed is smaller than contrast sensitivity threshold. We mainly take advantage of 3 characteristics [KRR98,YC2003] of the human visual system:

(1) Human eyes are more sensitive to the noise in image smooth areas, and less sensitive to the one in image texture areas; Human eyes are very sensitive to image edge signal, so we must ensure that the watermark embedding don't result in large change in image edge areas; Human eyes have different sensitivity to different luminance, most sensitive to middle level luminance usually, Weber ratio keeps const 0.02 within a large range of middle level gray, and declines nonlinearly within the low and high luminance range, as shown in Figure.3. We coarsely suppose the nonlinear as conics on luminance in the experiments, and the maximum of the change of contrast sensitivity doesn't exceed β .

Supposed that the chosen sub-block corresponds to position (u,v) in the original image and label it by $B_{u,v}$. Let $ave(u,v)$ be the average luminance of $B_{u,v}$, then we can define the contrast sensitivity factor ω (u,v) as:

$$\omega(u,v)=\begin{cases}\dfrac{(\beta-0.02)[ave(u,v)-I_1]^2}{I_1^2}+0.02, & if \quad ave(u,v)\le I_1\\ 0.02\ , & if \quad I_1<ave(u,v)\le I_2\\ \dfrac{(\beta-0.02)[ave(u,v)-I_2]^2}{(255-I_2)^2}+0.02, & if \quad ave(u,v)>I_2\end{cases} \quad (3)$$

where I_1 and I_2 are the gray threshold.

(2) Let $H(u,v)$ be the entropy of a 8×8 sub-block. Larger entropy value is corresponding to the image texture or edge area, while smaller entropy value corresponds to image smooth area., so we can use the entropy $H(u,v)$ to depict the texture characteristics of the sub-block $B_{u,v}$.

(3) Let $D(u,v)$ be the variances (mean square error). $D(u,v)$ would be large in a block with prominent edges, so we describe the edge of block $B_{u,v}$. by the use of the variances $D(u,v)$, and then normalize $D(u,v)$ as follows:

$$D'(u,v)=\frac{\frac{\max[H(u,v)]}{2}-1}{\max(D)-\min(D)}\big[D(u,v)-\min(D)\big]+1\cdot \quad (4)$$

Because larger entropy value is corresponding to the image texture or edge area, while smaller entropy value corresponds to image smooth area. Image texture area has smaller variances value, while image edge area has larger variances value. The effect of human visual system mask characteristics is incorporated into the JND (Just Noticed Difference) value of the block $B_{u,v}$.

$$J'(u,v)=\omega(u,v)\bullet\big[H(u,v)-D'(u,v)\big]. \quad (5)$$

At last, we normalize $J'(u,v)$ to range [a, b] as follows:

$$J(u,v)=\frac{b-a}{\max(J')-\min(J')}[J'(u,v)-\min(J')]+a\cdot \quad (6)$$

3.2 Watermark embedding

In the approach, the watermark is embedded into the middle-frequency range of each image sub-block using block-transform instead of full-frame transform. Let X be the original gray-scale image of size $M\times N$, and the digital watermark W be a binary image of size $m\times n$. In the watermark, the marked pixels are valued as 1's, and the others are 0's.

(a) Bit extension of the watermark

First, map W into a 1-D matrix W_1 in raster scanning order, in order to enhance the robustness of the proposed algorithm, then we spread this signal by large factor cr, called chip-rate, and obtain the spread sequence

$$b(i)=\begin{cases}1, & if \quad W_1(j)==1\\ -1, & if \quad W_1(j)==0\end{cases} \qquad j\times cr\le i\le(j+1)\times cr \quad (7)$$

(b) Binary chaotic modulation of the watermark

To survive image-cropping operation, a binary chaotic sequence is used to modulate the spread sequence b. First, generate a binary chaotic sequence P with secret key key as the initial value by using formula (2), $P=\{P(i) \mid P(i)\in\{-1, 1\}, 0\le i<m\times n\times cr\}$. Then, multiply b by P to get a modulated watermark signal W_t that will be embedded into the host image. That is, $W_t=b\cdot P=\{W_t(i) \mid W_t(i)\in\{-1, 1\}, 0\le i<m\times n\times cr\}$, where "·" denotes multiply element-wise.

(c) Block transformation of the image

Because Hilbert scanning can preserve the space local correlation of a image very well, firstly, we divide the host image into 8×8 sub-blocks, and number each sub-block from zero to ($M\times N/64$), then rearrange those sub-blocks in Hilbert scanning order to obtain Hilbert sequence Hb of the host image sub-blocks, $Hb=\{Hb(i) \mid Hb(i)\in \{0,\cdots, M\times N/64-1\}, 0\le i< M\times N/64\}$. the Second, use formula (1) to generate a index vector Ind_1 with secret key *key* as the initial value, $Ind_1=\{Ind_1(i) \mid Ind_1(i)\in\{0,\cdots, M\times N/128-1\}, 0\le i< M\times N/128\}$. So, we can choose two neighboring sub-blocks ($H(2\xi -1)$ and $H(2\xi)$) in Hilbert sequence H according to the index value ξ of Ind_1, then go further to find out the position in the original image where they are, and label them by B_1 and B_2. Finally, DCT are applied on B_1 and B_2 independently. That is,

$$D_i=FDCT(B_i),\ i=1, 2.$$

Where *FDCT* denotes the operation of forward DCT.

(d) Modification of the DCT coefficient

In our approach, to embed each watermark pixel by modifying the polarity of the corresponding middle-frequency DCT coefficients in two neighboring sub-blocks in Hilbert sequence H. Firstly, use formula (1) to generate another pseudo-random index matrix Ind_2 with secret key *key* as the initial value, $Ind_2=\{Ind_2(i) \mid Ind_2(i)\in\{0,\cdots,L-1\}, 0\le i<L\}$. Secondly, select L middle-frequency DCT coefficients out of D_1 and D_2 independently, then those chosen coefficients are mapped into 1-D matrix A_1 and A_2, respectively. That is, $A_i(\theta)=\{A_i(\theta), 0\le\theta<L\}$, where i=1,2. Figure 4 exemplifies our definition of the middle-frequency coefficients which are mapped into a reduced matrix of size 1×L. Thirdly, select two corresponding middle-frequency DCT coefficients in A_1 and A_2 independently ($A_1(\theta)$ and $A_2(\theta)$) according to the index value θ of Ind_2. Supposed that sub-block D_i corresponds to the position (u_i,v_i) in the original image, i=1,2. Finally, we can embed a watermark pixel into the host image by modifying the relationship between $A_1(\theta)$ and $A_2(\theta)$ combined with block visual factor $\mu=\frac{J(u_1,v_1)+J(u_2,v_2)}{2}$, the more detailed steps are presented as follows:

$$\begin{array}{ll}
\text{if } W_t(t)==1 & \text{if } W_t(t)==-1 \\
\quad dif=A_1(\theta)-A_2(\theta) & \quad dif=A_2(\theta)-A_1(\theta) \\
\quad \text{if } dif<\mu & \quad \text{if } dif<\mu \\
\quad\quad A_1(\theta)=A_1(\theta)+(\mu-dif)/2 & \quad\quad A_1(\theta)=A_1(\theta)-(\mu-dif)/2 \\
\quad\quad A_2(\theta)=A_2(\theta)-(\mu-dif)/2 & \quad\quad A_2(\theta)=A_2(\theta)+(\mu-dif)/2
\end{array}$$

where t=0, 1,⋯, $m\times n$-1. λ is the weighed coefficient of block visual factor. This modification causes $A_1(\theta)>A_2(\theta)$ when "1" is embedded into the host image, otherwise, $A_1(\theta)<A_2(\theta)$.

(e) Inverse block transform

Finally, map the modified middle-frequency coefficients A_i into D_i to get $\hat{D}_i$, and inverse DCT (IDCT) of the associated results is performed as follows:

$$\hat{B}_i=\text{IDCT}(\hat{D}_i),\ i=1, 2.$$

Then, lay back $\hat{B}_i$ into the original position in the host image to obtain the watermarked image.

3.3 Watermark extraction

The extraction of the watermark doesn't need the original image. The detailed extraction steps are described as follows:

(a) First, locate two DCT blocks $D_1^{'}$ and $D_2^{'}$ by using the same methods in substeps (b) and (c) of the watermark embedding step, and go further to find out the watermark embedding position $D_1^{'}(\theta)$ and $D_2^{'}(\theta)$. The watermark extraction is depicted as:

$$W_t^{'}(i)=\begin{cases}1, & \text{if } A_1^{'}(\theta)\ge A_2^{'}(\theta)\\ -1, & \text{if } A_1^{'}(\theta)<A_2^{'}(\theta)\end{cases} \qquad i=0,1,2,\ldots,m\times n\times cr-1. \tag{8}$$

(b) Second, generate a binary chaotic sequence P with the same way in substep (b) of watermark embedding step to demodulate $W_t^{'}$ That is,

$b^{'}=W_t^{'}\bullet P$, where "·" denotes multiply element-wise.

(c) Thirdly, the hidden information can be retrieved from the extracted demodulated spread sequence $b^{'}$ as fol-

lows:

$$W_1^{'}(t)=\begin{cases}1, & if \sum_{i=t\times cr}^{(t+1)cr-1} b^{'}(i)\geq 0\\ 0, & else\end{cases} \qquad t=0,1,\ldots,m\times n-1. \tag{9}$$

(d) Finally, map $W_1^{'}$ into 2-D matrix in raster scanning order, and get the extracted watermark $W^{'}$, $W^{'}=\{W^{'}(i)\mid W^{'}(i)\in\{0,1\},0\leq i<m\times n\}$.

(e) Similarity measurement: the extracted watermark is a visually recognizable pattern. The viewer can compare the results with the referenced watermark subjectively, In addition, a quantitative measurement is needed to provide objective judgement of the extracting fidelity because that the subjective measurement is dependent on factors such as the expertise of the viewers, the experimental conditions, and etc.. So, we define a similarity measurement between the referenced binary watermark W and extracted binary watermark $W^{'}$ as:

$$Normalized\ Correlation\ Value(NC)=\frac{\sum_{i=1}^{m}\sum_{j=1}^{n} W(i,j)\oplus W^{'}(i,j)}{m\times n} \tag{10}$$

where m×n is the size of the binary watermark, "$\oplus$"denotes inclusive-or.

4. Experimental results

This proposed algorithm is implemented on Matlab6.1, and the simulated experiments are carried out on Photoshop7.0. β, I_1, I_2 in the formula (3) are valued as 0.20, 80, 170, respectively; a, b in formula (6) are valued as 10, 35, respectively. chip-rate cr in formula (7) is 3. We select 6 (i.e. L=6) DCT middle-frequency coefficients out of each 8×8 DCT block to embed the watermark.

The results of the content based image segmentation are shown in figure 5. Highly textured regions are shown in brighter shades of gray, the lesser textured areas and the prominent edge areas are depicted in darker shades of gray. The brightness of the region is inversely proportional to the noise sensitivity of the region. Figure 6 shows an example of embedding and extracting results, where gray-scale image "man" is used as the host image of size 512×512, and a binary image is used as a binary watermark of size 64×64.

In the following subsections, we will carry out some experiments to show the robustness of the proposed algorithm under some image processing operations.

4.1 JPEG lossy compression

Figure 7 shows the extracted results from JPEG compressed version of the watermarked images with quality percent 90, 60, 50, 45, 40, and the NC value is 0.9985, 0.9502, 0.8464, 0.7874, 0.7390, respectively. As the quality percent decreases, the NC value decreases accordingly. The watermark will be destroyed and become indiscernible when the quality percent is much too low. However, when quality percent is smaller than 40, the quality of the JPEG compressed image (watermarked image) has been degraded severely so that the processes of digital watermarking become less meaningful.

4.2 Noise addition

In Figure 8, we add various types of noise to Figure 6(b). The extracted results show that the proposed algorithm can resist common noise addition attacks.

4.3 Signal enhancement and twice watermarking

In Figure 9, we applied twice watermarking and some signal enhancement operations to the watermarked image such as thrice sharpening, thrice edge sharpening, histogram equalization, contrast enhancement, brightness enhancement and twice watermarking, the corresponding NC value of the extracted watermark varies from 0.9810, 0.9495, 0.9956, 0.9978, 0.9976 to 0.9971. The visual quality of the extracted watermarks is very good. The proposed technique in this paper achieves high robustness under signal enhancement and two watermarking.

4.4 Image filtering and image blur

Figure 10 shows the results of applying some filtering and blur operations to Figure 6(b). The extracted watermarks have high NC values, and we can completely verify the existence of the watermark.

4.5 Geometric distortions & mosaic attack

Figure 11 illustrates some results from Figure 6(b) on which some geometric transformations and mosaic attack are applied. We can see that the extracted watermarks can be used to identify the owner of the host image although there is some distortions in the extracted watermark.

5. Conclusion

This paper proposed a content based image public watermarking technique which operates in DCT domain. A watermark with visually recognizable pattern is embedded into the original image by changing the polarity of two corresponding middle-frequency DCT coefficients in two different DCT sub-blocks which neighbor in Hilbert sequence. The watermark is adapted to the host image by exploiting the HVS characteristics, thus ensuring the watermark invisibility, and the watermark extraction don't need the original image. The experimental results show that the proposed algorithm in this paper is robust to common signal processing operations and some geometric distortions, such as cropping, scaling and rotation. Especially, it receives high robustness under signal enhancement operations, such as sharpening, contrast enhancement, edge enhancement and histogram equalization.

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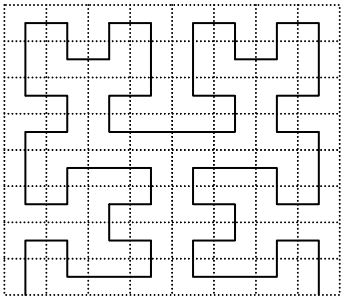


Figure 1: *The third order Hilbert curve*

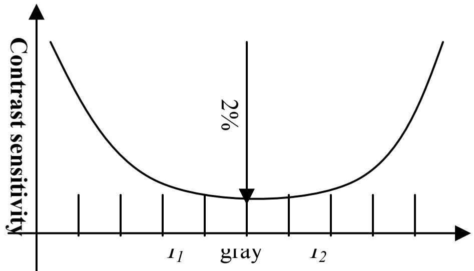


Figure 3: *Contrast sensitivity*

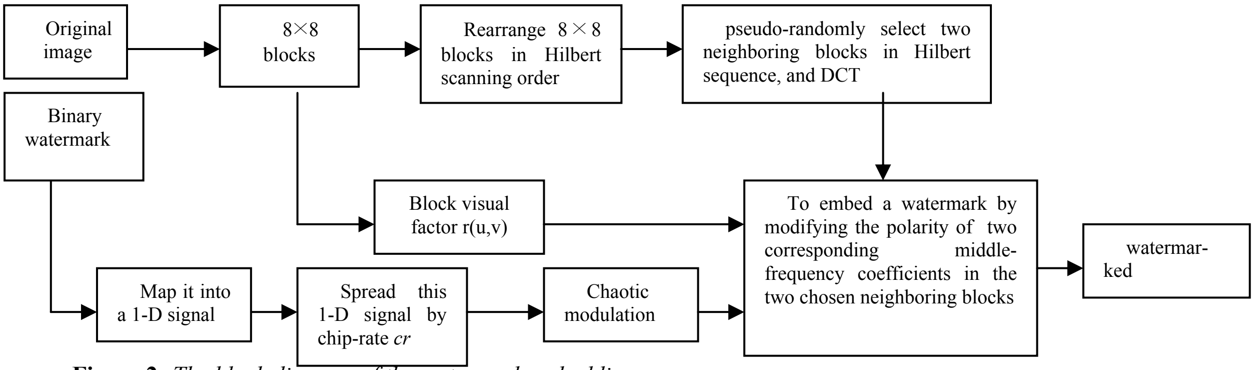


Figure 2: *The block diagram of the watermark embedding*

0	1	5	6	14	15	27	28
2	4	7	13	16	26	29	42
3	8	12	17	25	30	41	43
9	11	18	24	31	40	44	53
10	19	23	32	39	45	52	54
20	22	33	38	46	51	55	60
21	34	37	47	50	56	59	61
35	36	48	49	57	58	62	63

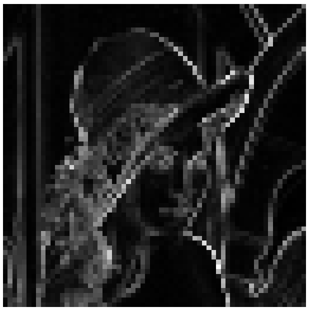
→

15	16	17	18	19	20

Figure 4: *an example of middle-frequency coefficients, which are pick up in zigzag-scan order and then reordered into block of 1×L (L=6).*

*(a) Classification based on gray level of the pix*el

(b) Classification based on the texture



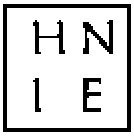
(c) Classification based on the variances

(d) Content based classification the Lena image

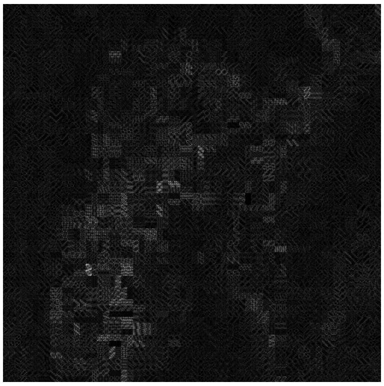
Figure 5: *Perceptual region classification of Lena image.*

(a) Original image

(b) Watermarked image



(c) Watermark



(d) Absolute difference between the original image and the watermarked one, magnified by a factor 10.

Figure 6: *An example to illustrate the proposed method. (a) The host image "man", (b) the watermarked image (with PSNR=39.2565dB), (c) the binary watermark, (d) Absolute difference between the original image and the watermarked one, magnified by a factor 10.*

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

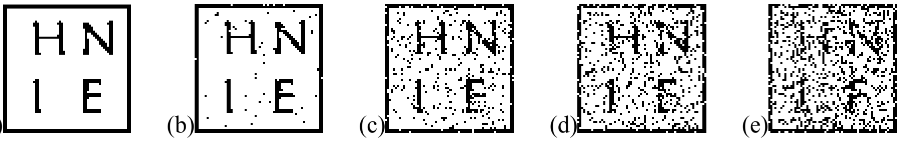


Figure 7: *The extracted watermarks of JPEG compressed version of Figure 6(b), where (a), (b), (c), (d), (e) with quality percent from 90, 60, 50, 45 to 40, respectively, and the NC value varies from 1, 0.9875, 0.9158, 0.8540 to 0.7856 accordingly.*

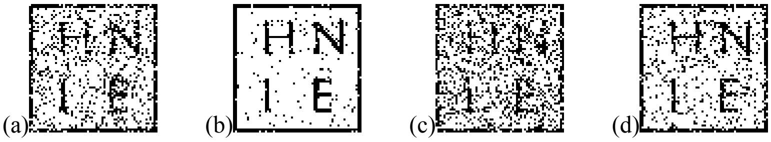


Figure 8: *The extracted watermarks of noise added versions of Fig. 6(b). (a), (b) are the extracted results from the watermarked image to which 10% and 5% density uniform noise are added respectively, and the NC value is 0.8306 and 0.9641 accordingly; (c) add 3% density "salt & pepper" noise to Figure 6(b) (NC=0.7524); (d) add 5% density Gaussian noise to Fig.6 (b) (NC=0.8755).*

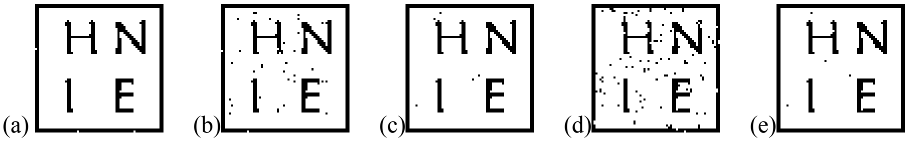


Figure 9: The extracted results of the signal enhanced versions and twice watermarked version of the Fig. 6(b). (a) Apply thrice sharpening to the watermarked image (NC=0.9993); (b) apply 3 times edge sharpening to Figure 6(b) (NC=0.9915); (c) the extracted watermark from the histogram equalized version of Fig. 6(b) (NC=0.9988); (d) enhance the contrast of Fig. 6(b) by 50% (NC=0.9739); (e) apply brightness enhancement by 50% to Figure 6(b) (NC=0.9983).

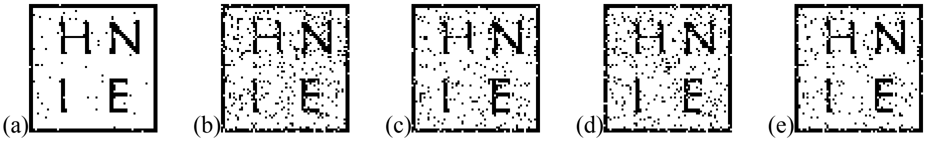


Figure 10: *The extracted watermarks from the filtered and blurred version of the watermarked image. (a) The extracted watermark from the Gaussian-filtered version of Figure 6(b) with NC=0.9866; (b), (c) the extracted results from the mean-filtered and median-filtered version of the watermarked image with NC=0.9026, 0.9319 respectively; (d), (e) apply 3 pixels motion blur and Gaussian blur to Figure 6(b) respectively, and the NC value is 0.9128, 0.9421 accordingly.*

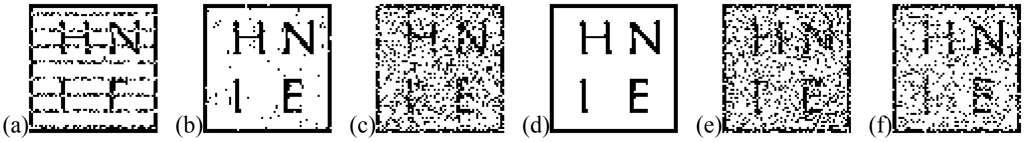


Figure 11: *The extracted watermarks from the watermarked image figure 6(b) on which some geometric transformations and mosaic operation are applied. (a) A quarter of the left-upper corner of the watermarked image is discarded, and the missing portions is filled with white pixels (NC=0.8804); (b) rotate the image clockwise by 3°(but extract the watermark from the rectified image) with NC=0.9802; (c) zoom out the watermarked image by minification 0.25, and extract the watermark after zooming in it to the size of the host image (NC=0.7900); (d) resize Figure 6(b) to 4 times size of the original image, and extract the watermark after resizing it to the original size (NC=0.9988); (e) the extracted watermark from Fig. 6(b) on which vertical shift by 1 pixel is carried out (NC=0.7898); (f) apply 2×2 mosaic to Figure 6(b), and the extracted watermark has the NC value with 0.8550.*