Watermarking for Digital Images Using Differences and Means of the Neighboring Wavelet Coefficients

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Abstract: In this paper, a watermarking technique for digital images is proposed. In our method, an image is 1-level wavelet transformed, and then the watermark of a binary stamp is embedded into the baseband. The watermark is embedded by inverting the polarities of the selected coefficient pairs. In the inverting process, we can increase perceptual image quality by finding means and differences of the selected neighboring coefficient pairs, and then adding values, which are inversely proportional to the differences, to the means. The experimental results show that the proposed method has good quality and is robust to JPEG lossy compression and various image processing operations.

1. Introduction

Due to the increase of digital media, data distribution becomes easier and faster. Especially, the growth of internet makes it so easy to copy images without authentication. Digital watermarking has been proposed as a way to identify the owner and to secure images from pirating.

Various watermarking techniques have been proposed in spatial domain or in transform domain[1]-[4]. In this paper, a watermarking algorithm in wavelet transform domain is proposed. The energy differences and the polarities between neighboring wavelet coefficient pairs are found. By using these two factors, we insert watermark into images.

In [4], reversing the original polarities has been used to embed watermark. That is, instead of inserting watermark as an additive noise, they used polarities. The major disadvantage of this method is bad quality in edge region. If polarities in edge region are reversed, the edges are also reversed. So the image quality is seriously reduced.

To avoid this disadvantage, coefficient pairs are selected. These coefficient pairs consist of neighboring coefficients with low differences. The watermark is embedded by changing the polarities of these low difference pairs. This prevents polarity changes in edge region, so makes image quality good.

2. Watermarking Using Differences and Menas of Wavelet Coefficient Pairs

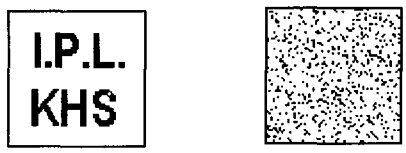
2.1 Making the watermark

In this paper, the visual stamp in daily life is used as the watermark. As like [3], most previous works used the random noise as the watermark. But man has used signatures, stamps, or logos to claim his ownership. For example one claims that he is the owner of his paintings by signing his name. So a visual seal is more intuitive than random numbers.

In the proposed method, the digital watermark $w(m,n)$ is a binary stamp image with size $R_W \times C_W$.

$$\{w(m,n), 0 \le m < R_W, 0 \le n < C_W\}, w(m,n) \in \{0,1\} \quad (1)$$

In the binary stamp, the region of 1s, i.e. the part of one's name, is concentrated on some part. So direct embedding of the watermark reduces image quality in the inserted region seriously. To avoid this disadvantage the watermark is reordered randomly as shown in Fig. 1.



(a) (b)

Fig. 1. (a) Binary watermark (b) randomized watermark.

In the reordered watermark, 1s are distributed randomly. This makes watermarked images more robust to image processing operations like clipping. The reordered watermark $w_r(m,n)$ with size $R_W \times C_W$ is made by 'linear feedback shift register' in [5] as like [4]. $w_r(m,n)$ is embedded into the wavelet coefficients in baseband by reversing polarities.

2.2 Choosing the pairs with low difference values

The original image with size $R_I \times C_I$ is 1-level transformed as shown in Fig. 2. The 1-level transformed image has baseband I_{LL} with size $(R_I/2) \times (C_I/2)$.

$$I_{LL} = \{i_{LL}(m,n), 0 \le m < (R_I/2), 0 \le n < (C_I/2)\} \quad (2)$$

For each pair of neighboring coefficients, the difference $d(m,n)$ is computed.

$$d(m,n) = \{| i_{LL}(m,2n) - i_{LL}(m,2n+1)|, \\ 0 \le m < (R_I/2), 0 \le n < (C_I/4)\} \quad (3)$$

Among these pairs in Eq. (3), we exclude the pairs having high d values, i.e., we use only the pairs having lower d values than predefined threshold TH.

These selected pairs are denoted by $\{i'_{LL}(m,2n), i'_{LL}(m,2n+1)\}$, which are used to embed the watermark.

$$\{i'_{LL}(m,2n), i'_{LL}(m,2n+1)\},\ 0 \le m < R_W,\ 0 \le n < C_W \tag{4}$$

Fig. 2 shows the selection of the coefficients. The coefficient pairs of white color are the pairs excluded from watermark embedding. As shown Fig. 2, the most excluded pairs are edge coefficients. By excluding these pairs we can remove polarity inversion of edge coefficient pairs, thus improve the perceptual image quality.

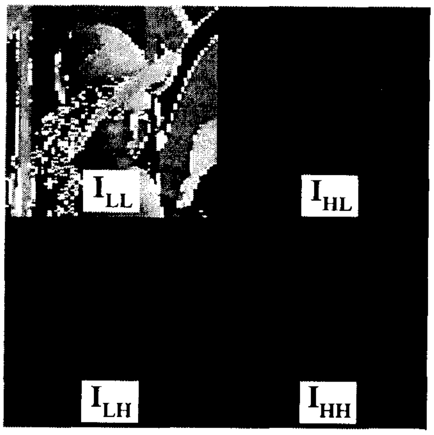


Fig. 2. Selection of the coefficients used to embed the watermark.

2.3 Inserting and extracting of the watermark

In the proposed algorithm, the watermark is embedded by inverting the polarities instead of direct embedding. As in [4], if the watermark value is 1, the corresponding polarities are changed. In the inverting process, we find the mean of the pair and reverse polarity by adding or subtracting the value $0.2(\max - d(m,n) + 2.5)$.

$$
\begin{aligned}
& If(w_r(m,n) == 1)\{ \\
& \quad d(m,n) = |i'_{LL}(m,2n) - i'_{LL}(m,2n+1)| \\
& \quad M(m,n) = [i'_{LL}(m,2n) + i'_{LL}(m,2n+1)]/2 \\
& \quad if(i'_{LL}(m,2n) < i'_{LL}(2n+1))\ \{ \\
& \qquad \hat{i}_{LL}(m,2n) = M(m,n) + 0.2(\max - d(m,n) + 2.5), \\
& \qquad \hat{i}_{LL}(m,2n+1) = M(m,n) - 0.2(\max - d(m,n) + 2.5) \\
& \quad \} \\
& \quad else\{ \\
& \qquad \hat{i}_{LL}(m,2n) = M(m,n) - 0.2(\max - d(m,n) + 2.5), \\
& \qquad \hat{i}_{LL}(m,2n+1) = M(m,n) + 0.2(\max - d(m,n) + 2.5) \\
& \quad \} \\
& \}
\end{aligned} \tag{5}
$$

In Eq. (5), 'max' is the maximum $d(m,n)$ value. By using mean to reverse the polarities, we can reduce sharp changes and then increase visual quality. In this paper, the scaling factor and the additional factor in Eq. (5) are 0.2 and 0.25, respectively. Increase of these makes the watermarked image to more robust to attacks of outside, such as JPEG compression, clipping, noise addition, blurring, etc.

As in Eq. (5), by adding the value, which is inversely proportional to the difference, we can decrease the change of the coefficient pair having high difference value compared to that having low difference. And by using mean $M(m,n)$, we make the two mean values, the mean before embedding and the mean after emgedding, be the same. This also improves perceptual image quality. Fig. 3 shows the embedding steps.

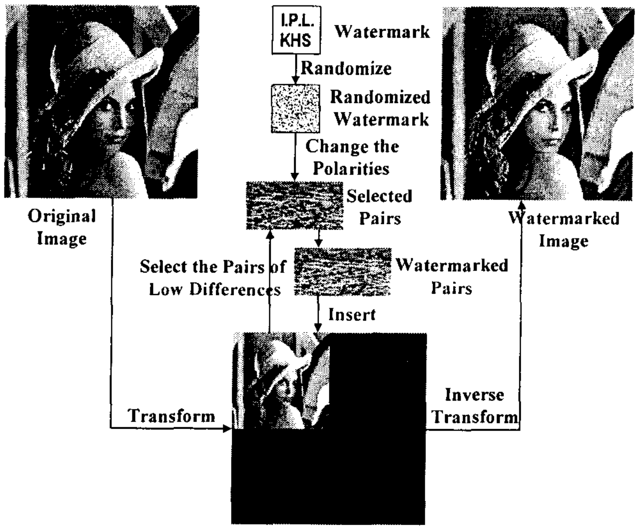


Fig. 3. The watermark embedding steps.

Extracting of the watermark is the reverse process of the embedding process. The extraction of the watermark requires the original image, the watermarked image, randomization information of the watermark, and the position information of the coefficients which have been used to embed the watermark. The extraction process is described as follows.

Both the original image I and the image in question $\tilde{I}$ are wavelet transformed. By using the the position of the coefficients which have been used to embed the watermark, we select the pairs $\{i'_{LL}(m,2n), i'_{LL}(m,2n+1)\}$ from the original image and the pairs $\{\tilde{i}_{LL}(m,2n), \tilde{i}_{LL}(m,2n+1)\}$ from the image in question. The image in question is the watermarked image suffered from various intentional or unintentional outer attacks.

The extracted randomized watermark $\tilde{w}_r(m,n)$ can be obtained as shown in Eq. (6). Finally extracted watermark $w_e(m,n)$ can be obtained by reordering the $\tilde{w}_r(m,n)$ according to the randomization information.

$$
\begin{aligned}
& if(\ [\{i'_{LL}(m,2n) < i'_{LL}(m,2n+1)\}\ AND\{\tilde{i}_{LL}(m,2n) \geq \tilde{i}_{LL}(m,2n+1)\}] \\
& OR[\{i'_{LL}(m,2n) \geq i'_{LL}(m,2n+1)\}\ AND\{\tilde{i}_{LL}(m,2n) < \tilde{i}_{LL}(m,2n+1)\}]\ ) \\
& \qquad \tilde{w}_r(m,n) = 1 \\
& else \\
& \qquad \tilde{w}_r(m,n) = 0
\end{aligned} \tag{6}
$$

3. Experimental Results

For our experiments, we have used Lena of size 256×256 as the test image, and a binary image of size 64×64 as the watermark. As a wavelet filter, we used common Haar filter.

In our method, the extracted watermark is a visually recognizable seal image. Thus we can compare the results with the original watermark subjectively. In addition to the subjective comparision, it is needed to provide objective judgment of the extracting fidelity.

We use the similarity measurement NC (Normalized Correlation) between the referenced watermark $w(m,n)$ and the extracted watermark $w_e(m,n)$.

$$
NC = \frac{\sum_m \sum_n w(m,n) w_e(m,n)}{\sum_m \sum_n [w(m,n)]^2} \tag{7}
$$

To define threshold value TH, we ordered all the difference values in descending order. Then found the difference value at the high 20% position. This value is used as TH. I.e., the high 20% edge coefficients are excluded from embedding process.

Fig. 4 shows the watermarked Lena image and the extracted watermark.

(a) (b)

Fig. 4. (a) Watermarked image(43.99 dB) (b) extracted watermark($NC = 1$).

Fig. 5 shows the extracted watermarks from the JPEG compressed image, from the noise added image, and from the clipped image. We used Gaussian noise with mean 0 and variance 100.

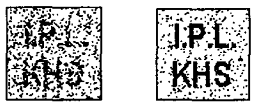
(a) (b)

(c) (d)

(e) (f)

Fig. 5. (a) JPEG compressed image of Fig. 4(a)(compression ratio=5.97) (b) extracted watermark from (a)($NC = 0.88$) (c) noise added image of Fig. 4(a) (d) extracted watermark from (c)($NC = 0.82$) (e) quarter of Fig. 4(a) is discarded (f) extracted watermark from (e)($NC = 0.78$).

Fig. 6 shows the extracted watermarks from the blurred image and from the sharpened image.



(a) (b)

Fig. 6. (a) The extracted watermark from the blurred image of Fig. 4(a)($NC = 0.68$) (b) the extracted watermark from the sharpened image of Fig. 4(a)($NC = 0.98$).

The experimental results shows that the proposed method is robust to JPEG lossy compression and various image processing operations such as noise addition, clipping, and sharpening. But the result for blurring is not good and must be improved.

4. Conclusion

We have proposed a watermarking technique in wavelet transform domain. In the proposed method, the image is 1-level wavelet transformed and the coefficient pairs of low differences are selected. By inverting the polarities of these selected pairs, the binary watermark is embedded. To invert the polarities, we compute the means and differences, and then add the values, which are inversely proportional to the differences, to the means. This inverting method reduces the abrupt changes of the coefficients in edge region and then improves perceptual image quality.

References

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