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Robust Digital Image Watermarking Algorithm Using RBF Neural Networks in DWT domain

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Abstract

This paper proposes a new watermarking scheme in which a logo watermark is embedded into the discrete wavelet transform (DWT) domain of the original image using exact radial basis function neural networks (RBF). RBF will learn the characteristics of the image, and then watermark is embedded and extracted by the trained RBF. A watermark is added to the coefficients at the low frequency band of the DWT of an image and a watermark is embedded into the DWT domain using the trained RBF. The trained RBF also used in watermark extracting process. Experimental results show that the proposed method has good imperceptibility and high robustness to common image processing attacks.

Key Words : Watermarking DWT, RBF, QIM

1. Introduction

With the rapid development of computer and communication networks, the digital multimedia reproduction and distribution are becoming extremely easier and faster. However, these advances also afford unprecedented opportunities to pirate copyrighted digital multimedia products. As a result, the watermarking technique, which embeds a watermark into digital multimedia contents for detecting and tracing copyright violations, has recently become a very active area of multimedia security [1]. The watermarking techniques can be classified into two classes depending on the domain of watermark embedding, i.e. a spatial domain and a frequency domain. Among the spatial domain watermark embedding methods, Schyndel et al. proposed a watermark embedding technique by changing the least significant bit of some pixels in an image [2]. Bender et al. described a watermarking approach by modifying a statistical property of an image called 'patchwork' [3]. On the other hand, there are many algorithms for watermark embedding in frequency domain. Cox et al. described a method where the watermark is embedded into the large discrete cosine transform (DCT) coefficients using ideas borrowed from spread spectrum in communications [4]. Xia et al. proposed a frequency domain method of embedding the watermark at all the subbands except LL subband, using discrete wavelet transform (DWT)[5].

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Recently, quantization index modulation (QIM) [6-8] technique is widely used in watermarking area, and this technique is very robust to various attacks such as JPEG compression, noise insertion, image resize and so on.

In this paper, a new watermark embedding/extracting algorithm using RBF is introduced. In this algorithm, an image is 3-level DWT transformed, and starts the RBF learning procedure. After that, embed and extract the watermark by the trained RBF. A watermark is embedded into LL3 low frequency band.

The experimental results show that the watermarked image has at least 43.4 dB in peak signal-to-noise ratio (PSNR). Also, the results are compared between the presented scheme and the method that uses quantization index modulation (QIM) technique on the LL coefficient of DWT domain.

2. Related Theories

2.1 Discrete Wavelet Transform (DWT)

With 2-D signals such as images, the DWT is typically applied in a separable fashion to each dimension. This may also be represented as a four-channel perfect reconstruction four-subband, as shown in Fig. 1. In this paper, the linear-phase 2/2 biorthogonal filters are selected, and the watermark is embedded into LL3 subband for robustness.

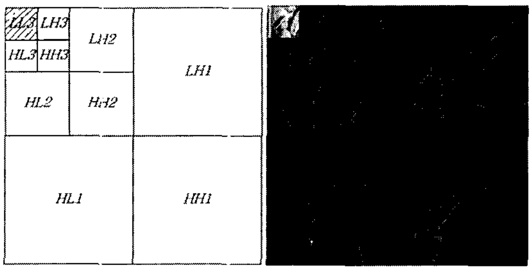

Fig.1. 3-level DWT

$$y_k(x_p) = w_{k0} + \sum_{j=1}^{J} w_{kj}\varphi_j(x_p) \qquad p = 1 \ldots n \qquad (1)$$

where, $\varphi_j(x_p) = \exp\left\{-\sum_{j=1}^{J}\frac{(x_{pi}-\mu_{ij})^2}{2\sigma_j^2}\right\}$, $xp$is the pth input vector, μj and σj are the mean vector and width of the jth basis function respectively, $wk0$ s a bias term and wkj is the output weight connecting the jth basis function with the kth output. Features' information is stored in the centers (μj) and the widths (σj) of the basis functions, and the weights (wkj) represent the relative importance of the basis functions in response to an external input. In this paper, the center is zero while the width is one. RBF will be used to learn the characteristics of image for improving the performance of the proposed watermarking scheme in the section 3.

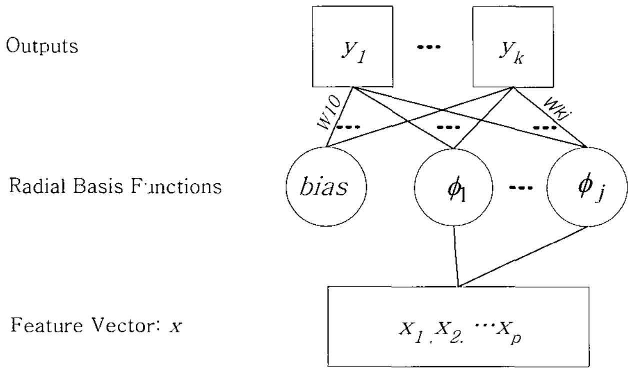

Fig. 2. The structure of a radial basis function (RBF) network with a ***p***-dimensional input vector, ***j*** radial basis function nodes, and ***k*** output nodes.

2.3 The RBF neural network training procedures

The RBF neural network training procedures are shown in Fig. 3. In the Fig. 3, $C(i,j)$ is the LL3 band coefficient when DWT transform is performed on original image. Q is the Quantization value. The output of the calculation of $Round(C(i,j)/Q)$, which is represented as P, is used as an input value for the RBF, and T, which is the original value of $C(i,j)$, is used as a desired output value for the RBF. The RBF trained by this method will be used to embed and extract the watermark.

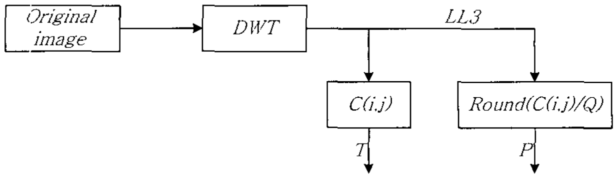

Fig. 3. RBF training procedures

3. Watermark Embedding and Extracting

Generally, a watermark algorithm includes 3 steps: watermark generation, embedding, and extraction. In this paper, a logo image, which can be easily distinguished by human eyes, is embedded as a watermark. The proposed watermark technique is a kind of blind watermarking algorithm, which embed/extract the watermark into/from the DWT domain. Watermarking system block diagram is shown in Fig. 4.

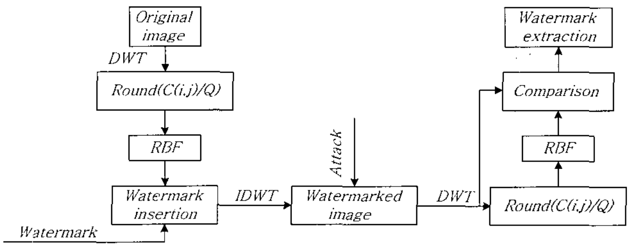

Fig. 4. Block diagram of watermarking system

3.1 Watermark embedding

Fig. 4 is the block diagram of the watermark embedding procedure. The trained RBF in the figure is discussed in section 2.3, and Q is the quantization value.

The embedding procedures are as follows:

Step1: Transform an original image by the 3-level DWT transform. In the Fig. 4, $C(i,j)$ is the LL3 subband coefficient.

Step2: Quantize the DWT coefficient $C(i,j)$ by Q, as the input value of RBF then get the output $RBF(Round(C(i,j)/Q))$.

Step3: Embed the watermark according to the equation 2 below which uses the output value $RBF(Round(C(i,j)/Q))$ and the Q.

$$C'(i,j) = \begin{cases} \frac{1}{4}\times Q + RBF(Round(\frac{C(i,j)}{Q})) & \text{if } w_{ij} = 1 \\ -\frac{1}{4}\times Q + RBF(Round(\frac{C(i,j)}{Q})) & \text{else} \end{cases} \qquad \textbf{(2)}$$

where $w_{i,j}$ is the watermark, and Q is a quantization value, and $C'(i,j)$ is the coefficient value when watermark is embedded. Then do IDWT to have the watermarked image

A change $\frac{1}{4}\times Q$ should be given to each coefficient because $Round(C(i,j)/Q)$ must have no change after embedding a watermark, so that there will be no change in $Round(C(i,j)/Q)$ when extracting the watermark. With many experiments, we concluded that the embedded watermark is most robust to attacks when the change is $\frac{1}{4} \times Q$. While Q increases, robustness is increased, but the quality of the image is decreased.

3.2 Watermark extracting

The watermark extracting procedures are the reverse procedures of watermark embedding, shown in Fig. 4. The watermark extraction procedures are as follows:

Step1: Transform the watermarked image by the 3-level DWT transform. In the figure above, $C'(i,j)$ is the LL3 subband coefficient.

Step2: Quantize the DWT coefficient $C'(i,j)$ by Q, as the input value of RBF then get the output $RBF(Round(C'(i,j)/Q))$.

Step3: Extract the watermark using the equation 3 below, using the output $RBF(Round(C'(i,j)/Q))$ and coefficient $C'(i,j)$.

$$w'_{i,j} = \begin{cases} 1 & \text{if} \quad C'(i,j) > RBF(Round(\frac{C(i,j)}{Q})) \\ 0 & \text{else} \end{cases} \qquad (3)$$

Step 4. The correlation between the original watermark and the extracted watermark is calculated to detect the existence of the watermark. The similarity between the original watermark w and the extracted watermark w' is quantitatively measured by the bit correlation ratio (BCR), defined as follows:

$$BCR = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\overline{(w_{i,j} \otimes w'_{i,j})}}{\sum_{i=1}^{m}\sum_{j=1}^{n}\overline{(w_{i,j} \otimes w_{i,j})}} \times 100\% \qquad (4)$$

Where $w_{i,j}$ is the original watermark bit, $w'_{i,j}$ is the extracted watermark bit, and $\otimes$ is the exclusive OR.

4. Experimental Results

In this paper, 8 bit 256×256 size *lena, baboon, boat, babara* images are used as cover (original) images, and a 32×32 size logo image, which can be easily distinguished by human eyes, is used as watermark. Fig. 5 shows the images used in this experiment and the watermark in use.

Fig. 6 shows the relationship between the embedding quantization step-size Q and the peak signal-to-noise ratio (PSNR). We can see that the PSNR of the watermarked image is decreasing while Q value increasing, but in any case the PSNR is more than 43.4dB. That shows that the watermarked image has a good PSNR.

We tested the robustness of the proposed method with several typical images attacked by JPEG compression. The watermarks extracted from JPEG compressed versions of the watermarked image with various compression quality factors(QF), and their corresponding BCR values are listed in Table 1. According to Table 1, we can see that the extracted watermark is still recognizable when the compression quality factor reaches 40, which means the proposed method has good robustness to JPEG compression.

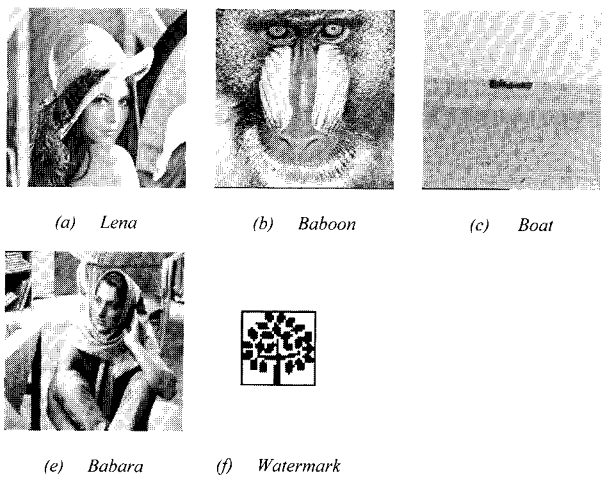

Fig. 5. Experiment images and watermark

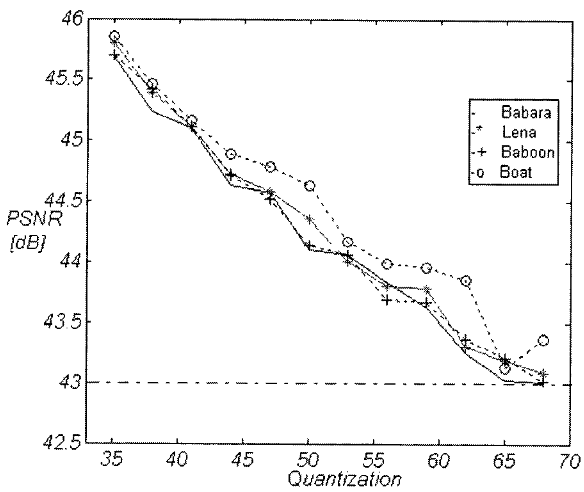

Fig. 6. The relationship between Q and PSNR

Finally, we compared the performance of the proposed method with that of the one proposed in QIM method, and with the performance of the scheme using neural network on DWT domain. All the three methods have the same test conditions including the same test image "Lena" (256×256), the same amount of embedded information (1024 bits i.e. a 32×32 binary pattern watermark). Comparison results are listed in Table 2. In order to test the robustness, attacks are involved: (a) JPEG compression (quality factor=30), (b) Gaussian noise added (SNR=10dB, signal power=28dB), (c) Resize (225×225) (d) Gaussian low-pass filtering (filter size=3×3, standard deviation=10), (e) Media filtering. The results show that the proposed method shows 11.67% BCR improvement against QIM method. This is very important achievement considering that JPEG compression is easily done with images. The new method also shows 3.11% BCR improvement against QIM method in average except JPEG compression attack. These prove that the proposed method has superior performance in robustness.

Table 1. BCR values of the extracted watermarks (%)

Images	Lena	Baboon	Boat	Babara
RSNR	44.51[dB]	44.54[dB]	44.51[dB]	44.45[dB]
QF=100	100	100	99.73	99.98
QF=90	99.81	99.90	99.23	99.32
QF=80	99.71	99.61	99.41	99.41
QF=70	99.32	99.31	97.65	99.22
QF=60	97.46	98.82	94.45	98.93
QF=50	96.48	94.63	95.38	96.97
QF=40	89.28	88.86	87.71	91.41

Table 2. Comparison(BCR) results between QIM method and proposed method

	QIM method (LL3)	Proposed method	% improvement
PSNR [dB]	44.23	44.24	na
Embedded	100	100	na
JPEG	75.39	84.18	11.67
Noise	82.90	86.04	3.79
Resize	79.89	82.74	3.57
Low-pass filtering	83.12	85.55	2.92
Media filtering	86.62	88.48	2.15

5. Conclusions

A new watermarking method for image has been proposed. It has following characteristics: First, a logo watermark is embedded into the DWT domain of the image using RBF. The embedding scheme can result in good quality of the watermarked image. Second, a RBF model is used to learn the characteristics of image. Due to the learning and adaptive capabilities of the RBF, the embedding/extracting strategy can greatly improve the robustness to various attacks. Experimental results illustrate that the performance of the proposed technique is superior to that of the similar one in the literature especially in JPEG compression attack.

References

1. F. Hartung, M. Kutter, M, "Multimedia watermarking techniques," *Proceedings of the IEEE*, Vol. 87, Issue 7, pp. 1079-1094, July 1999
2. R. G. Schyndel, A. Z. Tirkel, C. F. Osborne, "A Digital Watermarking," *Int. Conf. on Image Processing*, pp. 86-90, Feb. 1994
3. W. Bendor, D. Gruhl, N. Morimoto, A. Lu, "Techniques for Data Hiding," *IBM Systems Journal*, pp. 313-336, 3&4 1996
4. I. J. Cox, J. Kilian, T. Leighton, T. Shamoon, "Secure spread spectrum watermarking for multimedia," *IEEE Trans. on Image Processing*, pp. 1673-1687, Dec. 1997
5. X. Xia, C. G. Boncelet, G. R. Arce, "A Multiresolution Watermark for Digital Images," *Proc. IEEE ICIP*, pp. 548-551, Mar. 1997
6. B. Chen, G. W. Wornell, "Quantization index modulation: a class of provably good methods for digital watermarking and information embedding," *IEEE Transactions on Information Theory*, vol. 4, pp. 1423 - 1443, 2001
7. Y. Jang, I. Kim, H. Kang, K. Kim, and S. Han, "Blind watermarking Algorithm Using complex block selection method," *Lecture Notes in computer science*, vol. 2195, pp. 996-1001, 2001
8. H. Inoue, A. Miyazaki, T. Araki, T. Katsura, "A Digital Watermark Method Using the Wavelet Transform for Video Data," *IEICE Trans. fundamentals*, vol. E83-A, pp. 90-95, 2000

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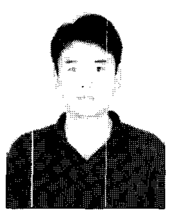

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