Digital Watermarking for Gray-Level Images Using Wavelet Transform

應用小波轉換於數位灰階影像浮水印技術設計

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摘要
In this paper, we propose a new digital watermarking technique based on wavelet transform for gray-level images. Because the signals on wavelet domain are with more efficient characteristics than those on DCT domain, our technique employs the characteristics of wavelet transform to hide an invisible watermark into gray-level images. In addition, even through the high frequency components of signals are slightly modified, these modified signals are still imperceptible, and we also use this characteristic in our technique. Finally, experimental results are included in this paper to illustrate the watermarking performance and robustness capability of our technique is satisfying in most of cases under consideration.

Keywords: Wavelet Transform; Digital Watermarking; Information Security; Image authentication; copyright protection; Image Processing; JPEG2000 Compression.

Abstract
In this paper, we propose a new digital watermarking technique based on wavelet transform for gray-level images. Because the signals on wavelet domain are with more efficient characteristics than those on DCT domain, our technique employs the characteristics of wavelet transform to hide an invisible watermark into gray-level images. In addition, even through the high frequency components of signals are slightly modified, these modified signals are still imperceptible, and we also use this characteristic in our technique. Finally, experimental results are included in this paper to illustrate the watermarking performance and robustness capability of our technique is satisfying in most of cases under consideration.

Keywords: Wavelet Transform; Digital Watermarking; Information Security; Image authentication; copyright protection; Image Processing; JPEG2000 Compression.

1. Introduction

Because of the rapid growth of the Internet, lots of multimedia can easily obtain from the Internet. Therefore, the copyright protection problem becomes very crucial important. In the past, digital data are encrypted, and transmitted on Internet. By this way, data cannot be directly used before those data are not decrypted. Recently, digital watermarking is effectively employed to protect intelligent property of digital products [5, 7, 8]. An invisible watermark can be embedded into the digital products. Those watermarked products can be directly used, and the embedded watermark can anytime be retrieved from the watermarked products to prove the ownership of the digital products [1, 3, 4, 6]. To achieve the goal of copyright protection, our watermarking techniques have to satisfy several requirements:

- The watermark should be imperceptible to human eye.
- While retrieving the watermark, any information from the original image is not required.
- Except the copyright owner, it should be very difficult or even impossible to delete or remove the watermark from a watermarked image, unless the watermarked image is degraded seriously.
- The watermark should still be...
retrievable even the watermarked image attacked by some common manipulations in image processing, such as sharpening, filtering, and lossy compression.

In Section 2, the wavelet representation for image signals is introduced briefly. In Section 3, Inue’s technique is briefly reviewed [2]. In Section 4, the embedding and the recovery algorithm of our method is described. In Section 5, experimental results are exhibited.

2. Multiresolution Wavelet Representation

2.1 Wavelet Analysis

Let every 1-D image with $2^j$ pixels be a vector in $V^j$. Every vector in $V^j$ is also contained in $V^{j+1}$. \{\phi_i^j | i = 1, 2, \ldots, 2^j\} is defined as a basis for $V^j$. A new vector space $W^j$ is defined as the orthogonal complement of $V^j$ in $V^{j+1}$, and the basis of $W^j$ is \{\psi_i^j | i = 1, 2, \ldots, 2^j\}. These basis functions have two important properties:

- The basis function $\psi_i^j$ of $W^j$, together with the basis function $\phi_i^j$ of $V^j$, form a basis for $V^{j+1}$, that is

$$V^{j+1} = V^j \oplus W^j = V^{j-1} \oplus W^{j-1} \oplus W^j = \cdots = V^0 \oplus V^1 \oplus \cdots \oplus W^j$$ (1)

- Every basis function $\psi_i^j$ of $W^j$ is orthogonal to every basis function $\phi_i^j$ of $V^j$ under the chosen inner product.

$$\langle \phi | \psi \rangle = 0$$ (2)

A collection of linearly independent function $\phi^j$ spanning $V^j$ is called scaling functions, and $\psi^j$ spanning $W^j$ is called wavelets.

2.2 2-D Product Wavelets

Let $\phi(x)$ and $\psi(x)$ be 1-D scaling function and 1-D wavelet, respectively, the 2-D product wavelets can be defined by

$$\psi^1(x, y) = \phi(x)\psi(y)$$
$$\psi^2(x, y) = \psi(x)\phi(y)$$
$$\psi^3(x, y) = \psi(x)\psi(y)$$ (3)

Fig. 1 shows 2-D with 2-order discrete wavelet transform of Lenna image, and Fig. 2 shows the four blocks. LH is the coefficients of $\psi^1$, HL is the coefficients of $\psi^2$, HH is the coefficients of $\psi^3$.

Fig. 1: 2-order 2-D wavelet transform for Lenna image.

Fig. 2: The subband labeled HL, LH and HH present the finest scale wavelet coefficients, the subband LL is further decomposed and critically subsampled.

3. A Review of Inue’s Watermarking Technique
The zerotree is defined as follows. Given an amplitude threshold $T$, if a wavelet coefficient $x$ satisfies $|x| < T$, then the $x$ is said to be insignificant with respect to a given threshold $T$. If a coefficient and all of its descendants are insignificant with respect to $T$, then we call the set of these wavelet coefficients as a zerotree for the threshold $T$.

The algorithm is described as follows:

Step 1. Set the threshold value $T$ as $T = \alpha C_{\text{max}}$, $C_{\text{max}}$ represents the maximum amplitude of wavelet, and $0.01 < \alpha < 0.1$.

Step 2. Find insignificant coefficients for the threshold $T$. Let $Z_1, Z_2, \ldots, Z_N$ denote the zero-tree, where $N$ is the number of the zerotree.

Step 3. Encode watermark to binary digits $W(k), k = 1, 2, \ldots, N$. For $k = 1, 2, \ldots, N$,

If $W(k) = 0$, then the watermark is embedded by writing $-m$ in the location of all elements of zerotree $Z_k$. If $W(k) = 1$, then the watermark are embedded by writing $m$ in the same location.

Step 4. Save the zerotree roots of $Z_1, Z_2, \ldots, Z_N$.

The watermark is detected by using the position of zerotree’s root after the wavelet decomposition of the watermarked image. Inue’s watermark-recovery algorithm is stated as follows:

Step 1. Referring to the zerotree root of $Z_k$, for $k = 1, 2, \ldots, N$, and compute their average value $M_k$.

Step 2. If $M_k < 0$, then the embedded bit is decided to be ‘0’. If $M_k \geq 0$, then the embedded bit is decided to be ‘1’.

The disadvantages of Inue’s technique include a large number of computations to find the zerotree, and the need of a large amount of extra memory to record zerotree locations. In contrast to Inue’s method, our technique needs less computation time than Inue’s technique, and only records two seeds $k_1, k_2$ used in the PRNG (pseudo random number generator) scheme.

4. Our Watermarking Technique

4.1 Watermark Embedding

A watermark is encoded by a binary string $W$, $W = (W(1), W(2), \ldots, W(n))$ where $W(i) \in \{0, 1\}$. $q_1 = 0$ and $q_2 = 0$ are concatenated in front of $W$ to be $W'$, $W' = (q_1, q_2, W(1), W(2), \ldots, W(n))$.

The structure of our algorithm is shown in Fig. 3.

![Fig. 3: The structure of our watermarking based on wavelet transform.](image)
Step 4: Use inverse DWT to obtain the watermarked image.

4.2 Watermark Extraction

The algorithm of our watermark extraction is shown in Fig. 4.

Step 1: Use PRNG with key $k_1, k_2$ to find the location that watermark is embedded.

Step 2: Find $N_1, N_2$, and through DWT processing, and then we count the absolute sum of HH1 and HH2 coefficients, we can obtain $s_1, s_2$.

Step 3: Set a threshold $T$.

$$T = \frac{q_1 + q_2}{2}$$

(4)

Step 4: For block $N_i, i = 3, \cdots, n + 2$, after DWT processing, we also count the absolute sum of HH1 and HH2 coefficients denoted as $s_i$, if $s_i > T$ then $\hat{W}(i) = 0$, and $s_i \leq T$ then $\hat{W}(i) = 1$

Step 5: Compute $\hat{W}(i)$, for $i = 1, 2, \cdots, n$, to be our extracted watermark.

$$\text{MSE} = \frac{1}{m^2} \sum_{i=1}^{m} \sum_{j=1}^{m} (x_{ij} - \hat{x}_{ij})^2$$

(5)

$$\text{MAE} = \frac{1}{m^2} \sum_{i=1}^{m} \sum_{j=1}^{m} \left| x_{ij} - \hat{x}_{ij} \right|$$

(6)

where $x_{ij}$ denotes the original image and $\hat{x}_{ij}$ denotes the watermarked image. We use MSE and MAE are used to indicate the similarity between original image and watermarked image.

Fig. 4: The structure of our watermarking-extraction procedure.

Fig. 5: Original watermark is used in our experiment.

In this experiment, we use the Inue’s technique with threshold $\alpha = 0.05$, and our original watermark is shown in Fig. 5.

From Fig. 6, 7, 8, Table 1 and Table 2, the performance of our watermarking technique makes the watermark $W$ is visual imperceptible.

Fig. 6: (a) Original Lenna image. (b) Watermarked Lenna image uses our technique. (c) Watermarked Lenna image uses Inue’s technique.
Table 1: The performance of visual imperceptions of our technique in terms of MAE and MSE.

<table>
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<tr>
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<th>Baboon</th>
<th>Barbara</th>
<th>Family</th>
<th>Lenna</th>
<th>Peppers</th>
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<tr>
<td>MAE</td>
<td>1.61</td>
<td>1.32</td>
<td>0.71</td>
<td>0.60</td>
<td>0.37</td>
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<td>MSE</td>
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<td>26.63</td>
<td>7.41</td>
<td>7.21</td>
<td>3.13</td>
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</table>

Table 2: The performance of visual imperceptions of Inue’s technique in terms of MAE and MSE.

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>MAE</td>
<td>6.8</td>
<td>6.29</td>
<td>6.16</td>
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<td>MSE</td>
<td>73.74</td>
<td>59.15</td>
<td>52.76</td>
<td>49.27</td>
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</table>

Fig. 9, Fig. 10 and Fig. 11 show the extracted watermark by using our technique and Inue’s technique.
Fig. 11: (a), (b), (c) are respectively extracted from Fig. 6(b), Fig. 7(b), Fig. 8(b), that are attacked by JPEG2000 compression, by using our technique. (d), (e), (f) are respectively extracted from Fig. 6(c), Fig. 7(c), Fig. 8(c), that are attacked by JPEG2000 compression, by using Inue’s technique.

6. Conclusion

In this paper, the characteristics of wavelet transform are used to develop a watermark technique. Due to the extra information that embedded in the original image, our scheme can extract watermark from watermarked image without original watermark. Experimental results in this paper illustrate the watermarking performance and robustness capability of our technique outperform Inue’s technique in most of cases under consideration.

References