DIGITAL WATERMARKING USING ZEROTREE OF DCT

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Abstract

Watermarking technique has been proposed as a method to embed an invisible signal into multimedia data so as to attest the owner identification and discourage the unauthorized copying. In this paper, an efficiently DCT-based watermarking technique is proposed. In the proposed method, we take the advantage of zero-tree in the rearranged DCT coefficients to embed watermark into image and extract watermark from watermarked image more efficiently. The proposed method can directly extract the embedded watermark from the watermarked image without using original image so as to implement it to the real time system is feasible. And a scheme of spreading watermarking information is also used to provide the robustness of digital watermark. The experimental results show that the imperceptibility and robustness of the digital watermark can be guaranteed.

I. INTRODUCTION

Digital watermarking technique has been proposed as a method to embed an invisible signal into multimedia data so as to attest the owner identification of the data and discourage the unauthorized copying. The present watermarking techniques are divided into two different classifications. One is applied to the spatial domain [1-3], and the other is applied to the frequency domain [4-8].

The spatial domain watermarking techniques are developed earlier. Simple but not robust is their obvious weakness. They can't against unintentional or intentional attacks or image processing, for example, low-pass filter and compression. The embedding signal is easily distorted, disfigured, or removed. Contrarily, the frequency domain watermarking techniques are more complicated and robust. They can easily against intentional or unintentional image processing. The drawbacks of them are the overhead and complication of computation. A good watermarking technique will include the capability to support the following requirements, [1-8]:

• Imperceptibility

The perceived degradation of the watermarked image should be slight. The watermark should be imperceptible so as not to affect the viewing experience of the image.

• Robustness

The watermark should survive the lossy compression techniques like JPEG and MPEG. The watermark also should be retrievable even if common signal processing operations are applied, such as signal enhancement, noise, filtering, etc. The most importance of the watermark is that it should be difficult to remove from the watermarked image.

• Extraction without original image

The embedded watermark should be extracted without using the original image so as to enhance the efficiency of extraction.

• Real-time processing

The watermarking technique should guarantee the real-time embedding and extraction process.

• Unambiguity

The goal of watermarking technique is expanded from author identification to copyright protection. The watermark should be unambiguously identifying the owner. No matter what kind of attacks it suffer, the accuracy of identification should degrade gracefully.

Most of the proposed watermarking techniques have been focused on imperceptibility and robustness against signal processing and intentional attacks on the embedded watermark. Many of the early techniques embed the watermark in the perceptual insignificant area of image or in the high frequency component. The main issue of early techniques is how to embed a watermark in an image without obvious degradation of image perceptual quality. However, embedded watermark will be easily removed without degrading the perceptual quality of image by using simple signal processing functions, for example, low pass filtering.

The current issue of watermarking techniques becomes how to maintain imperceptibility and robustness at the same time. The imperceptibility and robustness always conflict with each other. The key issue to the watermarking technique is to compromise between the imperceptibility and the robustness. What we should determine is where the watermark can be embedded and how much energy can be added. Thus, watermark should be embedded in the perceptual significant portion of the image to satisfy the robustness issue.

In addition to the imperceptibility and robustness issues, extract the watermark from real-time multimedia application without original multimedia data should be provided. Similarly, real-time embedding and extraction process for watermarking information should be necessary.

In this paper, zerotree of rearranged DCT coefficients is used to determine the embedded location of the multimedia

Contributed Paper

Original manuscript received June 9, 1999
Revised manuscript received November 16, 1999
data. By taking advantage of the characteristic of zero tree, we can easily and efficiently embed the watermarking information in the significant area of multimedia data. Meanwhile, spreading of watermarking information and significant embedding area are used to achieve the robustness and imperceptibility. Thus, the imperceptibility and robustness of the embedded watermark can be guaranteed.

This paper is organized as follows. In section II, the zero tree of rearranged DCT coefficients, spreading of watermarking information, and the proposed watermarking techniques are described in detail. Section III shows the experimental results. Finally, section IV concludes this paper.

II. DIGITAL WATERMARKING USING ZEROTREE OF DCT

A. Zerotree of rearranged DCT Coefficients

First, we describe wavelet structure of DCT and the rearrangement of original DCT coefficients in this section. Next, the scheme to find the zerotree of the rearranged DCT coefficients of image block is described specifically.

Wavelet Structure of DCT [9]

Figure 1 illustrates the relationship between wavelet and DCT.

<table>
<thead>
<tr>
<th></th>
<th>Wavelet</th>
<th>DCT</th>
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<tr>
<td>1</td>
<td>1</td>
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<tr>
<td>2</td>
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Fig. 1: The relationship between wavelet and DCT.

Consider a DCT that is applied to 2x2 non-overlapping blocks of an image. Referring to Figure 1(a), each DCT transformed block contains four DCT coefficients, labeled 1 (the lowest frequency) to 4 (the highest frequency). Also, now consider decomposing the same image by using 2x2 analysis filters and decimating by a factor of two in each direction. It can be shown that the DCT representation is entirely equivalent to a wavelet representation [10-12].

As shown in Figure 1(b), the highest subband image merely corresponds to a grouping of the lowest frequency coefficients in each DCT transform block. The other DCT coefficients are similarly grouped to form the remaining subband image. Generally, a DCT on N x N blocks of an image could be viewed as a wavelet decomposition with an uniform N x N subband decomposition.

Rearranged DCT block

The 8x8 DCT block is not directly regarded as one 3-level wavelet decomposition. We rearrange the DCT blocks into 3-level wavelet pyramid structure before find the zerotree of DCT coefficients. This scheme makes it possible for DCT to be well coupled with the zerotree structure. The rearrangement of DCT coefficients is shown in Figure 2. Figure 2(a) illustrates the original DCT coefficients and Figure 2(b) illustrates the rearranged DCT coefficients. Figure 2(a) illustrates the original DCT coefficients and Figure 2(b) illustrates the rearranged DCT coefficients. Labelled (a) the lowest frequency to 64 (the highest frequency).

(a) Original 8x8 DCT coefficients.
(b) Rearranged 8x8 DCT coefficients.

Fig. 2: The rearrangement of DCT coefficients.

Zerotree in rearranged DCT block

Now, we give a brief description of the zerotree structure of rearranged DCT coefficients. Reference [13] describes the algorithm in further detail. In this section, insignificant mean that the absolute value of DCT coefficient is smaller than the threshold value T but not mean that the coefficient is perceptual insignificant. A DCT coefficient x is said to be insignificant with respect to given threshold T if |x| ≤ T. Conversely, x is said to be significant if |x| > T. The zerotree is based on the hypothesis that if a coefficient at a coarse scale is insignificant with respect to a given threshold T, then all coefficients of the same orientation in the same spatial location at finer scales are likely to be insignificant with respect to T.

More specifically, in a hierarchical subband system, with the exception of the highest frequency subbands, every coefficient at a given scale can be related to a set of coefficients at the next finer scale of similar orientation. The coefficient at the coarse is called the parent, and all coefficients corresponding to the same spatial location at the next finer scale of similar orientation are called children. For a given parent, the set of all coefficients at all finer scales of similar orientation corresponding to the same location are called descendants. For a given child, the set of coefficients at all coarse scales of similar orientation corresponding to the same location are called ancestors.

Coefficient x is said to be an element of a zerotree for threshold T if itself and all of its descendants are insignificant with respect to T. An element of a zerotree for threshold T is a zerotree root if it is not the descendant of a previously found zerotree root for threshold T. And the isolated zero, which means that the coefficient is insignificant but has some significant descendants.

The parent-child dependencies are shown in Figure 3. Note that the arrow points from the subband of parent to the subband of the children. The lowest frequency subband is the top left, and the highest frequency subband is at the
bottom right. Also shown is a tree consisting of all of the descendants of a single coefficient in subband L1H1. The coefficient in H1H1 is a zero tree root if it is insignificant and all of its descendants are insignificant.

Scanning order is scanning of the coefficients, which is performed in such a way that no child node is scanned before its parent. For an $N$-scale transform, the scan begins at the lowest frequency subband, denoted as $L_{0S}$, and scans subbands $L_1S$, $L_2S$, and $L_3S$, at which point it moves on to scale $N-1$, etc. The scanning pattern for a 3-scale pyramid can be seen in figure 4. Note that each coefficient within a given subband is scanned before any coefficient in the next subband.

![Fig. 3: Parent-child dependencies of subbands.](image)

![Fig. 4: Scanning order of the subbands.](image)

**B. Spreading of Watermarking Information [14]**

The watermark should not be placed in perceptually insignificant regions of the image, since many common signals and geometric processes affect these components. The problem then becomes how to insert a watermark into the most perceptually significant regions of the spectrum in a fidelity preserving fashion.

In order to solve this problem, the frequency domain of the image is viewed as a communication channel, and correspondingly, the watermark is viewed as a signal that is transmitted through it. Attacks and unintentional signal distortions are treated as noise that the immersed signal must be immune to.

The watermark is spread over many frequency bins so that the energy in any one bin is very small and certainly undetectable. Nevertheless, because the watermark verification process knows the location and content of the watermark, it is possible to concentrate these weak signals into a single output with high signal-to-noise ratio (SNR). However, to destroy such a watermark would require noise of high amplitude to be added to all frequency bins.

Spreading the watermark throughout the spectrum of an image ensures a large measure of security against unintentional or intentional attack. An attacker may only have knowledge of the possible range of modification. To be confident of eliminating a watermark, an attacker must assume that each modification was at the limit of this range, despite the fact that few such modifications are typically large. As a result, an attack creates visible (or audible) defects in the data. Similarly, unintentional signal distortions due to compression or image manipulation must leave the perceptually significant spectral components intact, otherwise the resulting image will be severely degraded. This is reason why the watermarking technique is robust.

The watermarking information is spread by chiprate [11]. The chiprate is spreading range of a bit. We define the chiprate as one block in this paper. Each block hiding a bit of information. The maximum watermarking information length is according to the size of the watermarked image. When we take cognizance of the security of the watermarking information, each information bit is encoded by a pseudo random noise code PN. The PN is used to provide additional protection of image data for the author or copyright holder.

**C. Watermark Embedding**

![Fig. 5: Robust watermark embedding process block diagram.](image)

The watermark embedding process is shown in figure 5. Each block of the original image is used in the watermarking information via changing the amount of zero-tree of rearranged DC block. By taking advantage of zero-tree, we can easily embed the watermark in the watermarked image with slight perceptual degradation and against the common signal processing attack, for example, the lowpass filtering process. Although the high perceptual quality of watermarked image and the high imperceptibility of watermarking information, regrettably, the watermarked image can not against the compression attacks. So we call it as unrobust watermark embedding process.

In order to improve the robustness, against the compression attack, and consider the reality condition that most images used and transferred on the computer and network environment are compressed formats, for example, JPEG or MPEG, we apply our embedding process to the quantized DCT block of watermarked image. The watermarking information is embedded in the relatively insignificant one of the significant quantized DCT coefficients. The imperceptibility and robustness of the watermarking information can be guaranteed in the modified watermark embedding process, so we call it as robust watermark embedding process. The robust watermark embedding process is shown in figure 6.
A rearrangement is applied to each block and zero trees of each rearranged block are found. The zero trees of each block are stored in an 8x8 block called zero tree block, ZB.

Figure 7 shows the finding of the zero tree block ZB. Let N(ZB) and ZT(ZB) are the amount of zero tree elements and the amount of zero trees in ZB respectively. Because the amount of elements in a zero tree may be 2$^i$ (i=1,2,3,...) or 5(1,4,16), so that we can find that OE(N(ZB)) is equal to OE(ZT(ZB)). The OE(N) is a function used to indicate N is odd or even. When N is odd, the value of [E(N)] is 1. Conversely, the value of [E(N)] is 0 when N is even.

The quantized rearranged DCT coefficient $C_F(X,Y)$ is scanned in the scanning order stated earlier in the part A of section II. No child node is scanned before its parent. In order to reduce the perceptual degradation of watermarked image, the threshold value is defined for each scale of subband respectively.

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**Fig. 6:** Robust watermark embedding process block diagram.

- **Zero tree finding in rearranged block**
  
  Original image is divided into 8x8 blocks and each divided block is transformed in DCT domain. Then each block is quantized with the default quantization table.

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**Fig. 7:** Flow chart for the creation of zero tree block.

The threshold value for subbands HHH, LHH, and HHH is $T_3$. According to the experience of experiments, it is define as:

$$T_3 = \left[ 10 \cdot (QBLK_{x,y}(x,y) / \log_2 (QBLK_{x,y}(x,y)))^{-1} \right]$$

where $\left[ \cdot \right]$ is the quantized DCT function and QBLK is the quantized DCT block. The threshold value for the subbands HHH, LHH, and HHH is $T_3$. $T_2$ is defined as
\( \text{MAX}(T_1/2, 1) \), where \( \text{MAX}(X, Y) \) returns the largest elements taken from \( X \) or \( Y \). And the threshold value for the subbands \( HH_1, LH_1, \) and \( HL_1 \) is \( T_1 \). \( T_1 \) is equal to \( \text{MAX}(T_1/4, 1) \). Notice that \( \text{TMP} \) is an \( 8 \times 8 \) matrix with all ones at initial and \( X \), \( Y \) is the column index and row index of \( \text{TMP} \) and \( \text{CH} \). \( ZB \) denotes the zerotree block. The symbols \( G, U, I, J, U, V, X, \) and \( Y \) are integer. And \( 1 \leq G, H, I, J, U, V, X, \) and \( Y \leq 8 \).

Instead of embedding the watermarking information in all element of zerotree block with high perceptual degradation, we embed the watermarking information simply changing the amount of nonzero elements in the zerotree block, \( ZB \). The amount of nonzero element in the zerotree block is an important rule for embedding process. The rule for embedding process is performed as follows:

\[
\text{If } (\text{EWI}(k) \oplus \text{OH}(N_{ZB}(ZB_{k})) < 0) ,
\]

\[ WQBNI_{k} = \text{QBLK}_{k} \]

Else

\[ A \text{ non-zero element } ZB(X, Y) \text{ is selected from the subbands } HH_2, LH_2, \text{ or } HL_2 \text{ of zerotree block, } ZB. \]

The parent of the \( ZB(X, Y) \) is zero:

\[ QBLK_{k}(X, Y) < Y_2, \]

\[ WQBNI_{k} = \text{QBLK}_{k}. \]

End

where \( \text{EWI}(k) \) is the Encoded Watermarking Information of bit number \( k \) and \( \text{EWI}(k) \) is defined as \( \text{EWI}(k) = \text{W}(k) \oplus \text{PN}(k) \). The \( \text{OH}(N_{ZB}(ZB_{k})) \) indicates the amount of nonzero elements in the zerotree block of block \( \text{ZB}(X, Y) \) is an nonzero element of the zerotree block.

The \( ZB(X, Y) \) is not randomly selected. In order to enhance the robustness against unintentional or intentional attacks and image processing such as a lowpass filter or a smoothing process, this element is selected from the lower frequency subbands \( HH_2, LH_2, \) or \( HL_2 \). Since the watermark information is embedded in the lower frequency coefficient of each block, so that the watermark image can against the unintentional or intentional lowpass filter and smoothing process. In order to minimize the perceptual degradation of watermarked image, we select \( ZB(X, Y) \) which \( \text{QBLK}(X, Y) \) satisfies the requirement that the value of \( |T_2 - QBLK(X, Y)| \) is a minimum, where \( |T_2 - QBLK(X, Y)| \) denotes the absolute value of difference between \( \text{QBLK}(X, Y) \) and threshold value, \( T_2 \). The respected location in an initial zero matrix \( E_{M_{k}} \), called as Embedding Matrix, will be set to one to indicate that the coefficient of corresponding coordinate in \( \text{QBLK} \) will be changed to \( T_2 \) and becomes a non-zero element. Figure 8 illustrates an example of the creation of zerotree block, \( ZB \). We can easily find that there are three zero trees in the \( ZB \), the coordinates of them are \((2,4), (3,7), (4,7), (3,8), (4,8),(3,3), (3,5), (5,5), (5,6), (6,6)\), and \((1,4), (1,7), (8,7), (7,8), (8,8)) respectively. According to the rule for the embedding process described previously, if the watermarking information bit is one, the \( WQBNI_{k} \) is set as \( \text{QBLK}_{k} \). Otherwise, if the watermarking information bit is zero, the amount of zeroes in \( \text{QBLK} \) will be decreased from three to two. One of the nonzero elements in subbands \( HH_2, LH_2, \) or \( HL_2 \) of \( ZB \) will be selected, and it will be set to zero by changing the value of the element that has the same coordinate in \( \text{QBLK}_{k} \) to \( T_2 \). In this example, the selected nonzero element is one out of \( (2,4), (3,3), \) and \( (4,4) \). And the coefficient of corresponding coordinate in \( \text{QBLK} \) will be set to \( T_2 \).

(a) Rearranged DCT block          (b) Quantization table

\[
\begin{array}{cccccccc}
1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\
9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 \\
17 & 18 & 19 & 20 & 21 & 22 & 23 & 24 \\
25 & 26 & 27 & 28 & 29 & 30 & 31 & 32 \\
33 & 34 & 35 & 36 & 37 & 38 & 39 & 40 \\
41 & 42 & 43 & 44 & 45 & 46 & 47 & 48 \\
49 & 50 & 51 & 52 & 53 & 54 & 55 & 56 \\
57 & 58 & 59 & 60 & 61 & 62 & 63 & 64 \\
65 & 66 & 67 & 68 & 69 & 70 & 71 & 72 \\
\end{array}
\]

\[
\begin{array}{cccccccc}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\end{array}
\]

(c) Quantized block          (d) Zerotree block

\[
\begin{array}{cccc}
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
\end{array}
\]

\[
\begin{array}{cccc}
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
\end{array}
\]

\[
\begin{array}{cccc}
0 & 0 & 0 & 0 \\
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\end{array}
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\begin{array}{cccc}
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0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
\end{array}
\]

**Embedding process**

Since we know that the main cause of watermark extraction errors is the relative large DCT coefficient [12], so we use the zero trees of the rearranged DCT coefficients to find the appropriate DCT coefficients to embed watermarking information in. The elements within the zerotree structure of rearranged DCT block are the relatively insignificant one out of the significant coefficients. They are the appropriate locations to embed the watermarking information. Instead of embedding the watermarking information in all elements of the zero trees of the block, we embed the watermarking information in a selected element of zero trees. The selected element needs to satisfy the requirement that the difference value between it and the threshold \( T_2 \) would be a minimum. By slightly changing
the value of selected element within zero trees, the watermarking information is embedded with slight perceptual degradation and high robustness. According to the rule shown in (2), we can embed the watermarking information in proper DCT coefficients without obvious perceptual degradation of watermarked image. With the rule obtained from (2), we embed the watermarking information as follows.

\[ r_{\text{EM}}(i_k) = r_{\text{EM}}(i_k) - \alpha \text{EM}(i_k) \times \text{NZ}(i_k) \]

where:
- \( r_{\text{EM}}(i_k) \): Quantized DCT function
- \( I_k \): Watermarked image block, dimension 8x8
- \( I_k \): Original image block, dimension 8x8
- \( W_k(\cdot) \): Watermark information bit sequence
- \( PN(\cdot) \): Pseudo random noise code
- \( \text{NZ}(\cdot) \): The amount of nonzero element
- \( ZB_{i_k} \): Zero-tree block of \( I_k \)
- \( \text{EM}(\cdot) \): Embedding mask matrix of \( I_k \)
- \( \text{OE}(\cdot) \): 1 and 0 for odd and even value respectively
- \( k \): Watermark information bit number
- \( T_k \): Threshold value
- \( M(i,j) = \alpha \text{EM}(i_k,j) \times \text{NZ}(i_k) 
\]

Finally, the information bits are concentrate to form the original watermarking information. The extraction process can directly extract the embedded watermarking information from the watermarked image without using original image so as to implement it to the real time system is feasible.

### III. EXPERIMENTAL RESULTS

Computer simulations are performed to evaluate the performance of the proposed algorithm. In our experiments, the original image “Lena” with size 256x256x8 bits was shown in figure 10. To embed a watermark into the original image, we employed a watermark image with a size 32x32, which is the maximum capacity of the proposed watermarking technique. The watermark image is shown in figure 11. The watermark contains a Chinese signature, “Sun Yat-Sen University”.

The watermarked images resulting from the unrobust embedding process and robust embedding process were shown in figure 12.1, figure 15.1, respectively. The watermarked image retrieved from figure 12.1 and figure 15.1 were shown in figure 12.2 and figure 15.2, respectively. The values of the peaks of the signal-to-noise ratio (PSNR) of the watermarked images resulting from unrobust embedding process and robust embedding process were shown in the table 1. The experimental results show that the imperceptibility of the watermark images resulting from the two embedding processes can be guaranteed.

The lowpass filtering process and JPEG compression are applied to the watermarked images to evaluate the robustness of the watermarking technique. The result images of applying lowpass filtering process and JPEG compression to figure 12.1 are shown in figure 13.1 and figure 14.1, respectively. The figure 13.2 and figure 14.2 are the watermarked retrieved from figure 13.1 and figure 14.1.
14.1, respectively. The experimental result shows that the robust embedding process can against the lowpass filtering process but can not against the compression attacks.

Next, the result images of applying lowpass filtering process and JPEG compression to figure 15.1 are shown in figure 16.1 and figure 17.1, respectively. The extracted watermark images are shown in figure 16.2 and figure 17.2, respectively. The experimental result shows that the robust embedding process can improve the robustness against the image compression attacks. Meanwhile, it also reduces very slight perceptual degradation of watermarked image. The requirement of robustness and imperceptibility can be guaranteed.

<table>
<thead>
<tr>
<th>Watermark image embedded by Unrobust embedding process</th>
<th>PSNR (dB)</th>
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<tr>
<td>Robust embedding process</td>
<td>34,7335</td>
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</table>

### IV. CONCLUSION

Watermarking technique has been proposed as a method to embed an invisible signal into multimedia data so as to attest the owner identification and discourage the unauthorized copying. In this paper, an efficiently DCT based watermarking technique is proposed. In the proposed method, we take advantage of zero-rate of wavelet structure of DCT coefficients to embed watermark into image and extract watermark from watermarked image more efficiently. The proposed method can directly extract the embedded watermark from the watermarked image without using original image so as to implement it to the real time system is feasible. A scheme of spreading watermarking information is also used to enhance the robustness of digital watermark. The watermarking information is embedded in lower frequency range so that the proposed embedding process can against the signal processing such as low pass filter or smoothing process. Similarly, the requirement of robustness can also be guaranteed because the spread watermarking information is embedded in the significant area of images and the robust embedding process can keep the embedded watermarking information under the lossy compression attack. The experimental results show that the imperceptibility and robustness of the digital watermark can be guaranteed.

### REFERENCES


### BIOGRAPHY

Chuan-Fu Wu received the BS degree in Computer Science and Information Engineering from National Chiao Tung University, in 1986. In 1997, he was a postgraduate for the MS degree in the Department of Computer Science and Engineering from National Sun Yat-Sen University in 1998. Now he is working toward the Ph.D. degree. His research interests include multimedia network, network security and image security.

Wen-Shyong Hsieh is the Secretary General in National Sun Yat-Sen University. He is also a professor of Department of Computer Science and Engineering. He received the BS degree from National Cheng-Kung University, in 1972. He obtained the MS degree and Ph.D. degree in 1974 and 1992 from National Cheng-Kung University. His researches include distributed multimedia, video on demand, network security, and multimedia network.
Fig. 10: Original image of "Lena" (256x256)

Fig. 11: Watermark image of "Sun Yat-Sen University" (32x32)

Fig. 12.1: Watermarked Lena image that watermark is embedded by the robust embedding process

Fig. 12.2: Retrieved Watermark from Fig. 12.1.

Fig. 13.1: Lowpass filtering process applied to figure 12.1.

Fig. 13.2: Retrieved Watermark from Fig. 13.1.

Fig. 14.1: JPEG compression applied to figure 12.1.

Fig. 14.2: Retrieved Watermark from Fig. 14.1.

Fig. 15.1: Watermarked Lena image that watermark is embedded by the robust embedding process

Fig. 15.2: Retrieved Watermark from Fig. 15.1.

Fig. 16.1: Lowpass filtering process applied to figure 15.1.

Fig. 16.2: Retrieved Watermark from Fig. 16.1.

Fig. 17.1: JPEG compression applied to figure 15.1.

Fig. 17.2: Retrieved Watermark from Fig. 17.1.