An Imperceptible Watermarking Scheme Using Variation and Modular Operations

Ching-Sheng Hsu
Department of Information Management,
Ming Chuan University
cshsu@mail.mcu.edu.tw

Shu-Fen Tu
Department of Information Management,
Chinese Culture University
dsf3@faculty.pccu.edu.tw

Abstract

The aim of this paper is to propose an imperceptible wavelet-based watermarking scheme. In our scheme, we use variation to define the degree of transparence of coefficients of LL band and further determine transparent coefficients of HL3 and LH3 bands. Then, the watermark is embedded into those coefficients. In addition, the modular operation is utilized during watermark embedding. In the experimental results, we simulate some common attacks on the watermarked image. It is shown that our scheme is robust against most attacks; moreover, the watermarked image is highly imperceptible.

1. Introduction

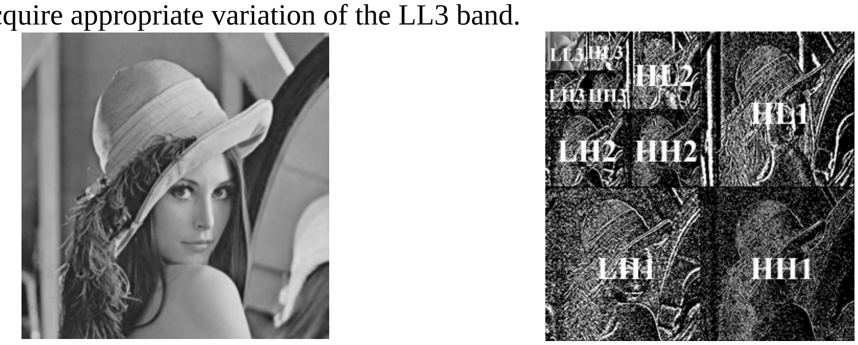
Digital watermarking is a technique to protect intellectual property of digital information. A signature, called a watermark, is embedded into a host image. When piracy happens, the author can extract the watermark to prove his ownership. Generally speaking, a good watermarking scheme should be robust enough to resist attacks; meanwhile, it should be imperceptibility so that human eyes cannot distinguish the difference between the watermarked image and the host image. In other words, the watermark embedded in the host image cannot be removed easily and destroy the host image quality too much.

To enhance the robustness, most researches embed the watermark in the frequency domain. Discrete wavelet transform is a common technique to transform an image from spatial domain to frequency domain due to its computation efficiency. Some wavelet-based watermarking schemes utilize human visual system (HVS) to determine which wavelet coefficients can be modified to embed the watermark so that the change is imperceptible, or transparent, to human eyes [1-3, 5]. However, the formulas and computation for finding transparent coefficients are usually complex. Generally speaking, human eyes are less sensitive to the modification of rough area then that of smooth area. It is simple to gain the information about the variation of an image in the spatial domain. However, such information is lost when the image is in the frequency domain. Observing the transformation of discrete wavelet transform, we can see that the LL band contains useful information about the variation of an image in the spatial domain. In this paper, we propose a method to find transparent coefficients of other bands based on the LL band. Then, the variation is used to determine transparent coefficients. In addition, we employ the modular operation so that coefficients may not be modified too much to degrade the image quality.

The rest of this paper is organized as follows. In section 2, the method is explained in every detail and particular. Then, experimental results are given in section 3 to show the robustness and imperceptibility of our scheme. Finally, some discussions and conclusions are given in section 4.

2. The proposed scheme

In our scheme, the host image is a gray-level image and a 3-level Haar wavelet transform is used to transform it into the frequency domain. Figure 1 is an example of 3-level wavelet transform, and each label on figure 1(b) denotes the name of the band. Generally speaking, wavelet coefficients of higher level are more robust than those of lower level. Therefore, HL3 and LH3 are chose to embed the watermark. Observing figure 1(b), we can see that the LL3 band preserves the information about the original image. Therefore, we can know which wavelet coefficients of HL3 and LH3 are more imperceptible based on LL3. Then, the watermark is embedded into the transparent coefficients of the HL3 and LH3 bands. For each time of embedding, we take two coefficients to adjust their distance. For not modify the coefficients too much to degrade the image quality, we adjust remainders of coefficients according to a predefined modulus. When extracting the watermark, we need the original host image to acquire appropriate variation of the LL3 band.



(a) The original image (512 × 512) (b) The transformed result

Figure 1. An example of 3-level wavelet transform

2.1. Watermark embedding

At first, the LL3, HL3, and LH3 bands are divided into non-overlapping blocks of 2 × 2 size, respectively. Then, we compute the variation v for each block of LL3 by Eq. (1).

$$v = \sum_{c} \left(c - \bar{c}\right)^2 , \qquad (1)$$

where c is the coefficient within a block. Next, each block of LL3 is sorted according to its variation by ascending order. Obviously, the higher the variation is, the more the transparence is. That is to say, the modification of blocks with higher variation is more imperceptible for human eyes. Since coefficients of the same position within respective bands are transformed from the same pixels, we can infer the imperceptibility of coefficients of LH3 and LH3 from those of LL3. Therefore, we sort the blocks of HL3 and LH3 according to the order of blocks of LL3 so that we can see which blocks are more imperceptible. Suppose that B^{θ} = { b_i^{θ} | i = 0..(l – 1)} and denotes the set of sorted blocks, where θ = {HL3, LH3} and l is the number of blocks of a band. Considering imperceptibility, we embed the watermark into $b_{2/l}^{\theta}$ to $b_{(l-1)}^{\theta}$ only.

As we have mentioned in the beginning of the section, we adjust the distance between remainders of two coefficients to embed the watermark. Let's explain how to embed a watermark bit in detail. For each bit w of the watermark, we take a pair of wavelet coefficients $(c_j^i, c_j^{i+1})^\theta$ of successive blocks b_i^θ and b_{i+1}^θ, where $j \in \{0, 1, 2, 3\}$ and denotes the position of the coefficient in a block. Based on a predefined modulus R, we compute the following remainders f and r:

$$f = c_j^i \bmod R$$
$$r = c_j^{i+1} \bmod R \quad (2)$$

Borrowed from the concept of a circular array, we can see f and r as the front and rear pointer of a ring with length R. And the distance d between the front and rear pointer is computed as follows [4].

$$d = (R - f + r) \bmod R \quad (3)$$

If $w = 1$, $(c_j^i, c_j^{i+1})^\theta$ is adjusted so that the distance is a three-fourths R; otherwise, it is adjusted so that the distance is a quarter R. After all watermark bits are embedded, we can get a watermarked image.

The complete algorithm of embedding watermark is as follows.

Algorithm Embedding(c_1, c_2, w, R)
$f = |c_1| \bmod R$
$r = |c_2| \bmod R$
$\Delta(c_1) = c_1 - \frac{c_1}{|c_1|} \cdot f$
$\Delta(c_2) = c_2 - \frac{c_2}{|c_2|} \cdot r$
$d = (R - f + r) \bmod R$
if $w = 1$ **then**
$d' = (R - 1)*(3/4) - d$
else
$d' = (R - 1)/4 - d$
$f = (f - \left\lceil \frac{d'}{2} \right\rceil + R) \bmod R$
$r = (r + \left\lfloor \frac{d'}{2} \right\rfloor + R) \bmod R$
$c_1' = \Delta(c_1) + \frac{c_1}{|c_1|} \cdot f$
$c_2' = \Delta(c_2) + \frac{c_2}{|c_2|} \cdot r$

2.2. Watermark extraction

At first, the watermarked image is 3-level wavelet transformed, and the LL3, HL3, and LH3 bands are divided into blocks of 2×2 size. However, the watermarked image may be attacked, and the order of blocks of LL3 band may be changed. Therefore, it would be best to get the correct order of blocks of LL3 band from the original image. Then, the blocks of HL3 and LH3 of the watermarked image are ordered accordingly. Suppose that the set of sorted blocks is $B'^{\theta} = \{ b_i'^{\theta} \mid i = 0..(l-1)\}$, where $\theta = \{HL3, LH3\}$ and l is the number of blocks of a band. Note that the extraction of watermark begins from $b_{2/l}'^{\theta}$ to $b_{(l-1)}'^{\theta}$.

For each time of extraction, we take a pair of coefficients $(c_j'^{i}, c_j'^{i+1})^{\theta}$ of successive blocks $b_i'^{\theta}$ and $b_{i+1}'^{\theta}$, where $j \in \{0, 1, 2, 3\}$ and denotes the position of the coefficient in a block. Similar to watermark embedding, we compute the following remainders:

$$f' = c_j'^{i} \bmod R$$
$$r' = c_j'^{i+1} \bmod R \qquad (4)$$

Then, the distance d' is computed as follows.

$$d' = (R - f' + r') \bmod R \qquad (5)$$

If d' is greater than a half R, then the recovered bit w' is 1; otherwise, w' is 0. After all bits are extracted from $b_{2/l}'^{\theta}$ to $b_{(l-1)}'^{\theta}$, we can get the recovered watermark.

The complete algorithm of embedding watermark is as follows.

Algorithm Extracting(c_1', c_2', R)
$f' = |c_1'| \bmod R$
$r' = |c_2'| \bmod R$
$d' = (R - f' + r') \bmod R$
if $d' \geq (R-1)/2$ **then**
$w' = 1$
else
$w' = 0$

3. Experimental results

In the experiment, we use PSNR (Peak Signal to Noise Ratios) and NC (normalized correlation) to measure the quality of the watermarked image and the extracted watermark, respectively. The PSNR is computed as follows.

$$PSNR = 20 \log_{10} (255 / MSE^2), \qquad (6)$$

where

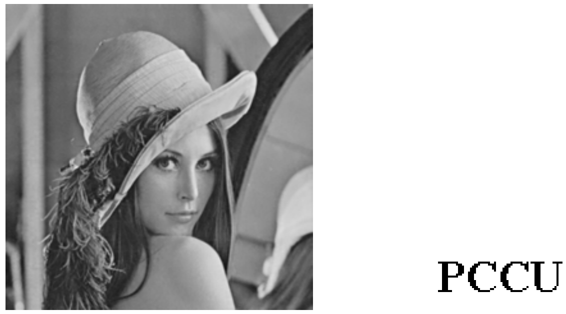
$$MSE = \frac{1}{M \times N} \sum_{i=1}^{M} \sum_{j=1}^{N} (p_{i,j} - p'_{i,j}). \qquad (7)$$

In Eq.(7), $p_{i,j}$ is the pixel of the host image, and $p'_{i,j}$ is that of the watermarked image. The larger the PSNR is, the more similar the watermarked image is to the host image. Generally speaking, human eyes cannot perceive the difference if PSNR is greater than 30. The other measurement NC is computed as follows.

$$NC = \frac{\sum_i \sum_j w_{i,j} w'_{i,j}}{\sum_i \sum_j w_{i,j}^2} \times \frac{\sum_i \sum_j (1 - w_{i,j})(1 - w'_{i,j})}{\sum_i \sum_j (1 - w_{i,j})^2}, \qquad (8)$$

where $w_{i,j}$ is the pixel of the original watermark, and $w'_{i,j}$ is that of the extracted watermark. If NC is close to 1, the extracted watermark is similar to the original watermark.

Figure 1(a) is the host image, figure 2(a) is the watermarked image, and figure 2(b) is the watermark. The PSNR of figure 2(a) is 48.13, which tells us that the watermarked image generated by our scheme is imperceptible to human eyes.



(a) 512 × 512 (PSNR = 48.13) (b) 64 × 32

Figure 2. The watermarked image and the watermark

In addition, we simulate some common attacks on the watermarked image, and the attacked name and result are shown in figure 3(a) – 3(g). The extracted watermarks from these attacked images are shown in figure 3(h) – 3(n), and the NC values are listed as well. Observing those extracted watermarks, we can see that our scheme can resist most attacks, especially the lightening and darkening attacks. However, the watermark extracted from the sharpening image seems not good enough. The main reason is that sharpening may have a great impact on HL3 and LH3 bands, hence further damage the watermark inside.

(a) Lightening (PSNR = 30.13)

(b) Darkening (PSNR = 29.32)

(c) Blurring (PSNR = 29.33)

(d) Sharpening (PSNR = 29.13)

(e) Cropping (PSNR = 27.32)

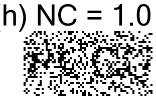
(f) Drawing (PSNR = 29.23)

(g) JPEG (PSNR = 38.72)

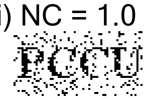
(h) NC = 1.0

(i) NC = 1.0

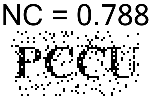
(j) NC = 0.788



(k) NC = 0.533



(l) NC = 0.762



(m) NC = 0.807

(n) NC = 0.947

Figure 3 The experimental results

Table 1 lists the NC values of the extracted watermark of ours and Reddy and Chatterji's method [1]. Note that the watermark used in this comparison experiment is of size 32×32 due to the inherence of Reddy and Chatterji's method. But all the attacks are the same as figure 3(a) to 3(f). Observing table 1, we can see that our method performs better than Reddy and Chatterji's except for the cropping attack.

Table 1. The comparison of Reddy and Chatterji's and ours method under various attacks

	Reddy and Chatterji's	Ours
Lightening	0.993	1.0
Darkening	0.947	1.0
Blurring	0.005	0.851
Sharpening	0.013	0.577
Cropping	0.868	0.738
Drawing	0.785	0.863

In addition, we compare the NC values of the extracted watermark under JPEG attack with various compression ratios, and the result is shown in figure 4. Naturally, the NC value decreases with the increment of the compression ratio. However, the NC values of ours decline more slightly than those of Reddy and Chatterji's.

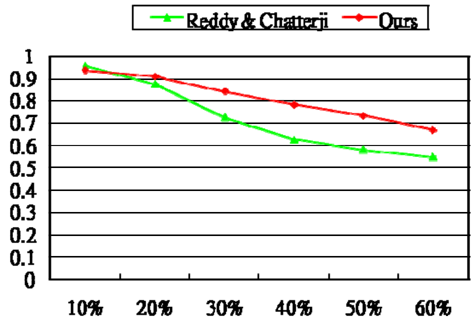


Figure 4. The comparison of Reddy and Chatterji's and ours method under JPEG attack with various compression ratios

4. Discussions and conclusions

It is reasonable that embedding a watermark into rough area is better than embedding it into smooth area of an image. However, when images are transformed from spatial-domain to frequency-domain, the information about variations is usually lost. In this paper, the host image is 3-level wavelet transformed, and the watermark is embedding in HL3 and LH3 bands. Observing the process of wavelet transform, we can see that the information about imperceptibility of coefficients of HL3 and LH3 can be acquired from the LL3 band. Therefore, we embed the watermark into transparent coefficients of HL3 and LH3 to improve the imperceptibility of the watermarked image. In addition, the transparent is defined by variation. When embedding the watermark, we modify a pair of transparent coefficients. For not changing coefficients too much, we apply modular operations rather than directly altering the coefficients.

In our scheme, we do not rely on complex formula to determine transparent coefficients, but the watermarked image is imperceptible as well. The experimental results show that our scheme can resist most common attacks. Besides, our scheme outperforms other researchers' method under most attacks.

5. Acknowledgements

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6. References

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Authors

Ching-Sheng Hsu was born in Taiwan, R.O.C. in 1971. He got his B.A. degree from the Department of Information Management, National Cheng-Chi University, Taiwan, R.O.C. in 1994, M.A. degree from the Institute of Information Management, National Chi-Nan University, Taiwan, R.O.C. in 1998, and Ph.D. degree from the Institute of Information Management, National Central University, Taiwan, R.O.C. in 2005. From 1998 to 1999, he was a software engineer at the Syscom Group Co., Taiwan, R.O.C. where his work focused on the Web-based stock trading systems. From 2000 to 2004, he was a part-time lecturer of the National Open University, Taiwan, R.O.C. Currently, he is an assistant professor of Department of Information Management, Ming Chuan University. His current research interests include digital watermarking and information hiding, visual cryptography, optimization algorithms, and intelligent computer-assisted learning and testing systems.

Shu-Fen Tu was born in Taiwan, R.O.C. in 1974. She received the BS degree in Management Information System from National Cheng-Chi University, Taiwan, R.O.C. in 1996, the MS degree in Information Management from National Chi-Nan University, Taiwan, R.O.C. in 1998, and the Ph.D. degree from the Institute of Information Management, National Central University, Taiwan, R.O.C. in 2005. From 1998 to 1999, she is a software engineer of the Syscom Group Co., Taiwan, R.O.C. From February 2005 to July 2005, she is an assistant professor of Department of Information Management, Chaoyang University of Technology. Currently, she is an assistant professor of Department of Information Management, Chinese Culture University, Taiwan, R.O.C. Her current research interests include steganography and secret sharing.