LETTER

Reversible Watermarking Method for JPEG Images

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SUMMARY In this letter, we propose a simple reversible watermarking method for JPEG images using the characteristics of JPEG compression. The method embeds a watermark into a JPEG image, and it extracts the watermark from the watermarked JPEG image and at the same time can recover the watermarked JPEG image to an original unwatermarked JPEG image. Moreover we investigate the number of embeddable blocks, the quality of watermarked images, and the increase of file-size by embedding a watermark.

key words: watermark, reversible watermarking, JPEG image

1. Introduction

Digital watermarking schemes are techniques that embed additional data into digital contents so that the distortion by embedding them is perceptually undetectable [1]. Usually, additional data are embedded within permissible limits of distortion. However, there are such cases where no distortion is allowed. So the techniques called reversible watermarking have been proposed [2]–[5]. Reversible watermarking schemes embed additional data into an image, and can reconstruct the original image from the watermarked image as well as extract the embedded data.

Reversible watermarking methods have been presented now for raw images such as bitmap-formatted (BMP) images. This is because non-reversibly compressed images such as JPEG images have already been degraded by compression and so the reconstruction seems to be meaningless.

However, in some uses, it seems that there are cases where secret information is embedded into a JPEG image and where no distortion of the cover image is desirable. In those cases, reversible watermarking schemes for JPEG images are useful. For example, medical images are often filed in JPEG format and so it is desirable that the original JPEG images are reconstructed from the watermarked JPEG images in which private information is embedded for privacy protection. Sakai, et al. have applied the reversible watermarking method [3] to JPEG images [6], and Xuan, et al. have proposed a reversible data hiding scheme for JPEG images [7].

This letter proposes a new simple reversible watermarking method for JPEG images that not only extracts embedded data from the watermarked JPEG images but also reconstructs the original JPEG images from the watermarked

images. The proposed method uses the characteristics of JPEG compression.

2. Watermark Embedding

A JPEG image is decoded with Huffman coding and run-length coding to get quantized DCT coefficients. A watermark is embedded in the quantized DCT coefficients and the quantized DCT coefficients are encoded with run-length coding and Huffman coding again to get a watermarked JPEG image. A watermark can be embedded into luminance component (Y) and color difference components (Cb, Cr). We describe the method in the case of embedding a watermark in one of the three components.

Let $w_j \in W = \{0, 1, 2, \dots, 2n - 1\}$ ($j = 1, 2, \dots, N$) be the symbols of a watermark to be embedded, where n and N are positive integer. When $n = 2^{k-1}$, k bits can be embedded in an 8×8 -pixel block. The number of embeddable blocks is different in each image.

Figure 1 shows the principle of watermark embedding, and Fig. 2 shows the schematic view of watermark embedding. A watermark is embedded as follows:

Step 1) Let $j = 1$ and select a block in which w_j is going to be embedded.

Step 2) Let C_i ($i = 0, 1, \dots, 63$) be quantized DCT coefficients of the j -th 8×8 -pixel block in zigzag-scanning order. Search m such that $C_m \neq 0$ and $C_i = 0$ ($i = m + 1, \dots, 63$).

Step 3) When $m < 63$,

$$\begin{aligned} C_{m+1} &\leftarrow w_j - n + 1 & \text{for } w_j \geq n \\ C_{m+1} &\leftarrow w_j - n & \text{for } w_j < n. \end{aligned}$$

When $m = 63$, a watermark does not embedded and

$$\begin{aligned} C_{63} &\leftarrow C_{63} + n & \text{for } C_{63} > 0 \\ C_{63} &\leftarrow C_{63} - n & \text{for } C_{63} < 0. \end{aligned}$$

Then $j \leftarrow j + 1$.

Step 4) Select the next block, and repeat from Step 2 to Step 3 until w_N is embedded.

3. Watermark Extraction and Recovery of JPEG Image

The JPEG image in which a watermark has been embedded is decoded with Huffman coding and run-length coding, and an embedded watermark is extracted from the quantized

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(a) Before embedding

$$C_{m+1} = \begin{cases} w_j - n + 1 & (w_j \geq n) \\ w_j - n & (w_j < n) \end{cases}$$

(b) After embedding

Fig. 1 Principle of embedding watermark (modification of DCT coefficients). **Fig. 2** Schematic view of embedding watermark.

DCT coefficients of 8×8 -pixel blocks as described below. Then the quantized DCT coefficients are encoded with run-length coding and Huffman coding again to get the original JPEG image. Figure 3 shows the schematic view of extract-

Fig. 3 Schematic view of extracting watermark and recovering JPEG image.

ing watermark and recovering JPEG image.

Step 1) Let $j = 1$, and select the block in which w_j has been embedded.

Step 2) Let C_i ($i = 0, 1, \dots, 63$) be quantized DCT coefficients of the j -th 8×8 -pixel block in zigzag-scanning order. Search C_m such that $C_m \neq 0$ and $C_i = 0$ ($i = m + 1, \dots, 63$).

Step 3) When $m = 63$ and $|C_{63}| > n$,

$$\begin{aligned} C_{63} &\leftarrow C_{63} - n & \text{for } C_{63} > 0 \\ C_{63} &\leftarrow C_{63} + n & \text{for } C_{63} < 0. \end{aligned}$$

Otherwise,

$$\begin{aligned} w_j &= C_m + n - 1 & \text{for } C_m > 0 \\ w_j &= C_m + n & \text{for } C_m < 0, \end{aligned}$$

and $C_m \leftarrow 0$.

Then $j \leftarrow j + 1$.

Step 4) Select the next block and repeat from Step 2 to Step 3 until w_N is extracted.

4. Performance

We investigated the performance of the proposed method for several JPEG qualities. In the experiment, we used bitmap (BMP) color images with 256×256 pixels and 256 brightness levels for R, G and B components respectively, which are shown in Fig. 4. A watermark was made from a uniform random number sequence consisting of 0 and 1. Each set of k ($1 \leq k \leq 4$) bits of the watermark was embedded in an 8×8 -pixel block of Y component. We used PSNR for the evaluation of image quality. PSNR was calculated for

Fig. 4 Original images.

an original JPEG image and the watermarked JPEG image which were converted to BMP format.

4.1 The Number of Embeddable Blocks

In the proposed method, the symbol of a watermark cannot be embedded in the 8×8 -pixel block where $C_{63} \neq 0$. Then we investigated the relation between the number of embeddable blocks and JPEG quality. Figure 5 shows the relation between the number of embeddable blocks and JPEG quality for each image. Now, the maximum number of blocks is 1024.

As shown in Fig. 5, the higher JPEG quality is, the less the number of embeddable blocks is. It is because the values of quantization table decrease and the number of the blocks where $C_{63} = 0$ decreases as JPEG quality increases. "Mandrill" has the much smaller number of em-

Fig. 5 The number of embeddable blocks.

Fig. 6 Relation between JPEG quality and PSNR ($n = 1$).

beddable blocks than other images. It is because "Mandrill" contains more high-frequency components and so contains more blocks where $C_{63} \neq 0$.

The method in [6] embeds 154 bytes of payload in "Lena" image of 512×512 pixels[†], while the proposed method can embed up to 512 bytes of payload in "Lena" image of 512×512 pixels when $n = 1$. On the other hand, the maximum payload of the method in [7] is greater than that of the proposed method. However, the performance, which is the relation between payload and PSNR, of the proposed method of $k \leq 3$ is almost the same as that of the method in [7] though the images used in the experiment are different.

4.2 Image Quality

Figure 6 shows the relation between PSNR and JPEG quality when $n = 1$. Figure 7 shows the relation between PSNR and k when JPEG quality is 90%. Now, $n = 2^{k-1}$.

As shown in Fig. 6, the higher JPEG quality is, the higher PSNR is. The symbols of a watermark are embedded in high-frequency DCT coefficients when JPEG quality is

[†]It is written in [6] that the payload is 128 bytes, but it was corrected to 154 bytes later.

Table 1 Increase of file-size (bytes) ($n = 1$).

Image	size	70%	75%	80%	85%	90%	95%
Lena	watermarked	11663	12784	14478	16846	21012	30016
	original	11371	12489	14198	16564	20722	29758
	increase	292	295	280	282	290	258
Girl	watermarked	9408	10339	11847	14084	17942	26996
	original	9130	10056	11567	13787	17652	26689
	increase	278	283	280	297	290	307
Aerial	watermarked	16527	18271	20946	24746	31309	45232
	original	16240	17991	20664	24451	31028	45028
	increase	287	280	282	295	281	204
Airplane	watermarked	12389	13480	15189	17776	22125	31450
	original	12085	13210	14900	17488	21835	31166
	increase	304	270	289	288	290	284
Parrots	watermarked	10075	10980	12428	14437	18058	25795
	original	9790	10700	12140	14147	17770	25510
	increase	285	280	288	290	288	285
Pepper	watermarked	13150	14327	16221	18953	23689	33978
	original	12865	14038	15936	18671	23408	33719
	increase	285	289	285	282	281	259
Milkdrop	watermarked	9798	10770	12225	14297	17742	25827
	original	9512	10462	11943	13990	17477	25555
	increase	286	308	282	307	265	272

Fig. 7 Relation between k and PSNR (Quality 90%).

high. So it is because the influence of modification of high-frequency DCT coefficients on PSNR is less that PSNR is higher when JPEG quality is higher.

As shown in Fig. 7, PSNR (dB) almost linearly decreases as k increases. The same tendency was shown for other JPEG qualities.

4.3 Increase of File-Size by Watermark Embedding

Table 1 shows the watermarked file-size (bytes), the original file-size (bytes) and the increase of file-size (bytes) by watermark embedding for each JPEG quality. As shown in Table 1, the increase of file-size by embedding a watermark is almost constant in spite of JPEG quality. In other words, the higher JPEG quality is, the less the rate of increase of file-size is, where the rate of increase of file-size means the ratio of the increase of file-size by embedding a watermark to the size of an original JPEG image. It is because the size

of an original JPEG image is larger for higher JPEG quality that the rate of increase of file-size decreases.

5. Conclusion

We have proposed a reversible watermarking method for JPEG images. The proposed method embeds a watermark into a JPEG image, and it extracts the watermark from the watermarked JPEG image and at the same time can recover the watermarked JPEG image to an unwatermarked JPEG image. Moreover, the proposed method is easy to implement. We have investigated the number of embeddable blocks, the quality of watermarked images, and the increase of file-size by embedding a watermark.

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