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Article

JPEG-Based Image Enhancement Method with Steganographic Data Embedding and Its Performance Evaluation

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Abstract

We propose a concrete configuration that enables a sender who has high resolution images to embed high frequency components of the images in the JPEG codes for lower resolution images using steganographic data embedding method. In this configuration, public receivers of the JPEG files can decode low resolution images, while specific receivers who know the fact that the high frequency components are embedded in the JPEG files can obtain high resolution images by extracting the embedded enhancement codes. For this purpose, three key methods are developed: a construction method for 16×16 higher frequency quantized DCT coefficients in the encoder, an embedding method to 8 × 8 lower resolution quantized DCT coefficients in the encoder, and an extraction method for the enhancement codes in the decoder. Moreover, it is clarified that the embedding operation for the enhancement codes can be omitted under specific conditions. As a result of simulation experiments that employ the proposed key methods are executed using natural images, the performance of the system is evaluated in terms of a total amount of enhancement codes, a relationship between quantization quality factors for lower and higher frequencies, a payload for embedding enhancement codes, and SNR characteristics.

Key Words: steganography, image enhancement, JPEG compression, DCT, entropy coding

1. INTRODUCTION

Currently, various kinds of images and videos are distributed on the Internet, and high definition television (HDTV) is already implemented in digital broadcasting. The compression methods such as JPEG and MPEG are inevitable for the distribution in the Internet and broadcasting because the images and videos have very large data size in comparison with the transmission speed or bandwidth in the line and wireless communications. The important parameters that decide the size of the transferable image data include image resolution, so that the image resolution suitable for the limit of the transmission capacity available to the communication and broadcasting has to be selected.

In general, higher resolution image is more valuable than lower resolution image. This can be seen in the trend that pursues high resolution images in digital cameras and 4K broadcasting (3840×2160 pixels) as well as 4K specification (4096×2160 pixels) of the digital cinema. The media communication of the present low resolution image in the Internet or HDTV broadcasting system have a possibility that enhance the media quality for specific members who know secret information of high resolution images, if the information of high resolution images can be embedded in the compression codes used in the existing communication systems and the resulting compression codes have a compatibility with the

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original compression code format. In this paper, we call such a mechanism an image enhancement method with steganographic data embedding.

Although a challenge toward the quality enhancement along with the above mentioned method has been studied for speech signals [1], no investigations for images or videos are known so far. The image enhancement method that estimates a high resolution image from several frames of the an identical scene [2], or makes higher frequency components with non-linear filtering [3] are studied recently, and a similar technique is also applied to the up-conversion to 4K video from HDTV content. These techniques are called SR (super resolution), and basically they are ill-posed problems. This means that it is not guaranteed to obtain the true high frequency components.

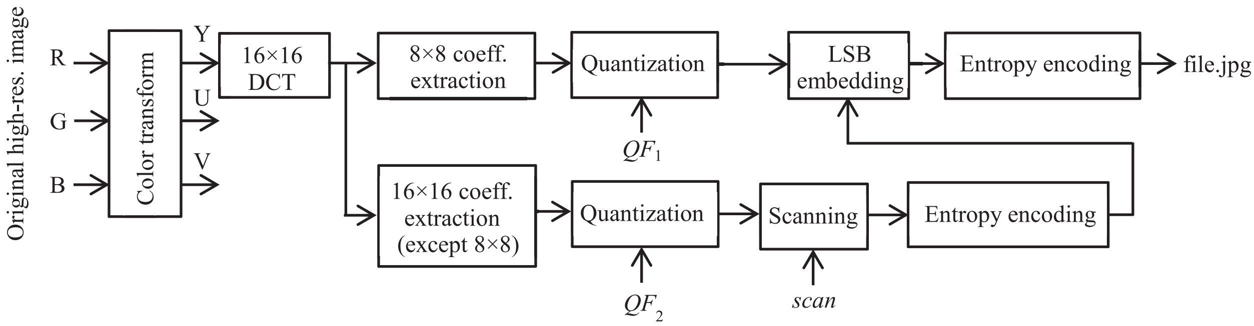
In this paper, we discuss the image enhancement method with steganographic data embedding in which the sender, who has high resolution images, embeds the higher frequency components to the lower frequency components, while the receiver reconstructs high resolution images by extracting the embedded enhancement data. In Section 2, basic system configuration to realize the above scenario is presented. The embedding and extracting methods for the enhancement codes are described in Section 3. In Section 4, special conditions that can avoid embedding the enhancement codes are discussed when the payload for the embedding is critical. The performance evaluation is demonstrated in Section 5, and conclusions are given in Section 6.

2. SYSTEM CONFIGURATION

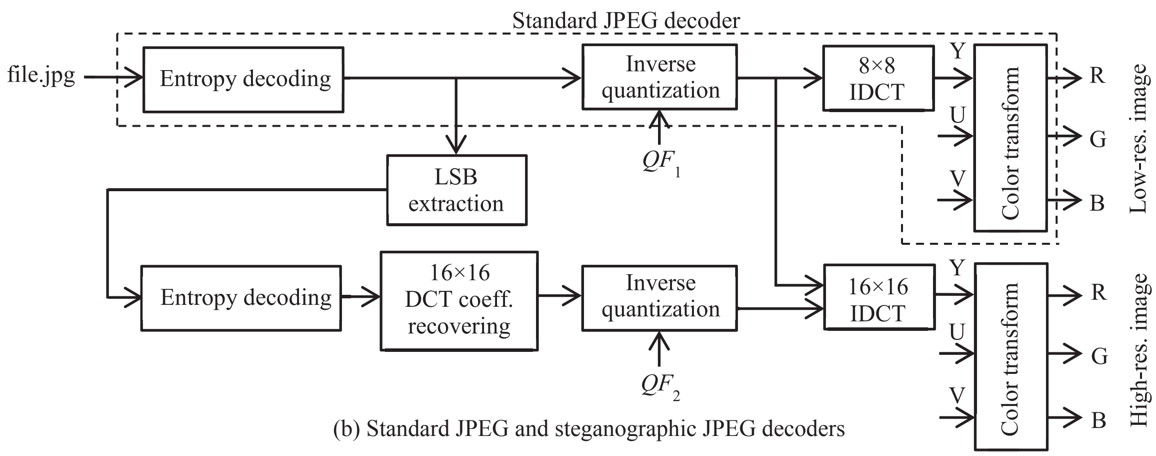
Figure 1 shows the basic configuration for the image enhancement method with steganographic data embedding. The encoder and the decoder have the following functions.

(a) Encoder:

This is a special encoder that makes JPEG compressed file for *N*×*N* resolution image. In this encoder, a *2N*×*2N* resolution image, namely original image, is transformed with 16×16 DCT, and the quantized DCT coefficients except 8×8 DCT coeffi-



(a) Steganographic JPEG encoder



(b) Standard JPEG and steganographic JPEG decoders

Fig. 1 Configuration of steganographic JPEG encoder/decoder and standard JPEG decoder.

cients are entropy coded and then embedded into 8× 8 quantized DCT coefficients.

(b) Decoder:

This decoder includes standard and special decoders.

・The standard decoder receives JPEG compressed file for $N\times N$ resolution image, and reconstructs the image conforming to the JPEG specification.

・The special decoder receives JPEG compressed file for $N\times N$ resolution image, and reconstructs a $2N\times 2N$ resolution image. The 16×16 quantized DCT coefficients are recovered with the extracted enhancement codes from 8 × 8 quantized DCT coefficients.

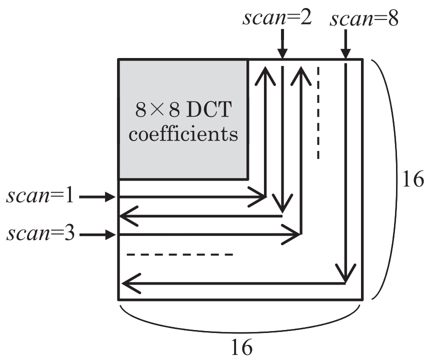


Fig. 2 Scan pattern for high frequency DCT coefficients.

The encoder is divided into two parts: one encodes 8×8 quantized DCT coefficients obtained from 16×16 DCT coefficients, the other encodes 16 ×16 quantized DCT coefficients except 8×8 DCT coefficients. The scanning pattern for the DCT coefficients of higher frequency in the latter encoder is simply along the L-shaped lines as shown in Fig. 2. The numbers of higher frequency quantized DCT coefficients on $scan$ = 1〜8 are 17, 19, 21, 23, ..., 31, respectively, and the total number of the higher frequency DCT coefficients is at most 192.

The enhancement entropy codes using run-length Huffman encoding are constructed with a default JPEG table for zigzag scanned AC coefficients. Note that the enhancement entropy codes include only special EOB (end of block) code, if all the higher frequency quantized DCT coefficients are zeros. Only the enhancement for the luminance component is considered for the proposed system because it is shown that most of the enhancement codes comprise the luminance component [4].

The amount of enhancement codes depends on the quality factor, QF_2, for the quantization of higher frequency DCT coefficients. The payload available for embedding the enhancement codes are also determined by the quality factor, QF_1, for the quantization of lower frequency DCT coefficients. In practice, the balancing among quality factors, QF_1, QF_2, and number of scans, $scan$, is a prominent issue.

3. EMBEDDING ENHANCEMENT CODE

The ranges of DC and AC of the quantized DCT coefficients in JPEG are restricted within [2047, ..., +2047] and [1023, ..., +1023], respectively. The LSB (least significant bit) embedding to DC coefficient degrade the image quality [5], so that the LSB embedding to and extracting from only AC coefficients is considered in the system. First of all, the bit embedding is applied to 1st LSB of all the available quantized DCT coefficients. If there remain more enhancement codes, then 2nd LSB of all the available quantized DCT coefficients are used, and so on. In this case, the following two points must be considered.

(1) Minimizes the distortion by embedding enhancement codes.

(2) The range of AC coefficients after embedding enhancement codes should be within [1023, ..., +1023].

Of these, (1) means the embedding must be done in the order of 1st, 2nd, 3rd, ... LSBs, though what frequency range has high priority is an open problem. On the other hand, (2) determines the maximum allowable number of LSBs for embedding. For example, DCT coefficient of +1023 can be embedded up to 9th LSB because $+1023_D = 03FF_H = 0000\ 0011\ 1111\ 1111_B$ (the subscripts D, H, and B mean decimal, hexadecimal, and binary notations, respectively) for positive DCT coefficients, and this value cannot exceed +1023 if 0s or 1s are embedded up to 9 LSBs. In the case of negative DCT coefficients, if a 0 is embedded in 1st LSB then $1023_D = FC01_H = 1111\ 1100\ 0000\ 0001_B$ obviously becomes out of permissible range because $1024_D = FC00_H = 1111\ 1100\ 0000\ 0000_B$.

The theoretical allowable number of bits for embedding is determined in such a way that the resulting allowable number of bits after embedding random *m* bits is not different from that before embedding. This condition has a role to carry possible number of bits for embedding from the encoder to the decoder. For example, it can be decided in the encoder that *m* is 9 for the quantized DCT coefficients ranging from +1023 to +512. It also can be decided in the decoder that *m* is 9 because the quantized DCT coefficients ranging from +1023 from +512 are still within the same range even if random bits are embedded up to 9 LSBs.

It is necessary to pay an attention that the resulting coefficients after LSB embedding do not transit beyond 1024 for negative DCT coefficients. For example, the number of allowable bits for 1023 is zero because the embedding to 1st LSB results in 1024, and it is out of permissible range as described above. The coefficients of 1022 and 1021 are allowed to embed up to 1st LSB because 2nd LSB is 1, and the embedding 0 to 1st LSB results in the coefficient from 1021 to 1022. This restriction is imposed to the coefficients less than 513, in which 10th LSB becomes 0. In this case, the allowable number of bits should be 8 because 513_D = $FDFF_H$ = 1111 1101 1111 1111_B, and the coefficient transits to 1024 if 0s are embedded in all the 9 LSBs. A part of the allowable number of bits, *m*, for embedding to the LSBs of the negative DCT coefficients is shown in Table 1.

Table 1 Example of allowable number of bits for embedding to negative DCT coefficients (D, H, and B mean decimal, hexadecimal, and binary notations, respectively).

D	H	B	m
⋮	⋮	⋮	⋮
−256	FF00	1111 1111 0000 0000	7
−257	FEFF	1111 1110 1111 1111	8
⋮	⋮	⋮	⋮
−512	FE00	1111 1110 0000 0000	8
−513	FDFF	1111 1101 1111 1111	8
⋮	⋮	⋮	⋮
−768	FD00	1111 1101 0000 0000	8
−769	FCFF	1111 1100 1111 1111	7
⋮	⋮	⋮	⋮

Consequently, we have a formula that describes the relationship between the permissible number of enhancement bits, *m*, and the quantized DCT coefficient value, DCT_q, as (1).

$$
\left.\begin{aligned}
&m = 0, \quad \text{if } DCT_q = +1, 0, \text{ or } -1023,\\
&2^m \le DCT_q \le 2^{m+1} - 1, \quad (1 \le m \le 9)\\
&m = 1, \quad \text{if } DCT_q = -1 \text{ or } -2\\
&-2^{m+1} \le DCT_q \le -2^m - 1, \quad (1 \le m \le 8)\\
&-\sum_{k=m}^{9} 2^k \le DCT_q \le -\sum_{k=m+1}^{9} 2^k - 1, \quad (1 \le m \le 8)
\end{aligned}\right\} \qquad (1)
$$

Although the above formula shows a theoretical permissible number of bits for embedding, the embedding to higher LSBs leads to larger distortion in practice. For positive DCT coefficients (except 0 and 1), maximum distortion for the quantized coefficients, $2^m \le DCT_q \le 2^{m+1} - 1$, that allow embedding up to *m* LSBs is $2^m - 1$. Therefore, there is a possibility that *m* should have an upper limit because the image quality would be largely degraded in this case.

4. AVOIDING EOB CODE EMBEDDING

The visible quality of enhanced image will require high SNR when the bit embedding is performed in LSBs of lower frequency quantized DCT coefficients, and this requirement suggests the quality factor, QF_1, for lower frequency DCT coefficients should be higher than the default value of 50. Therefore, first of all, we examine the total amount of entropy codes produced from lower and higher frequencies for two combinations of (QF_1, QF_2), i.e. (80, 80) and (80, 50). The number of scans for higher frequency quantized DCT coefficients is set to 8 for all combinations.

Figure 3 shows the distribution of entropy codes for the luminance component of lower and higher frequencies per 16 × 16 block for two images (these images, L3 and H3, will be explained in Section 5). The result demonstrates that the amount of enhancement codes for blocks having relatively low JPEG entropy codes is only 4 bits that correspond to the EOB code. Furthermore, it is not recognized that a strong dependency exists between the amount of entropy codes for lower and higher frequencies. Note that the entropy codes for higher frequency, which are embedded in the LSBs of the lower frequency quantized DCT coefficients, increase with the quality factor, QF_2, and the number of scans.

It is impossible to embed the enhancement codes to LSBs of quantized DCT coefficients when the 8×8 lower frequency DCT coefficients consist of only DC component, i.e. 63 AC components are all zeros. We can reasonably assume that all the higher frequency quantized DCT coefficients are zeros when 8×8 lower frequency DCT coefficients consists of only DC component because the minimum length of the enhancement code for luminance component is 4 bits (EOB code).

In general, there is a special case that can avoid EOB code embedding to LSBs of 8×8 quantized DCT coefficients in the encoder and also can reconstruct all-zero higher frequency quantized DCT coefficients in the decoder: all the higher frequency quantized DCT coefficients are zeros (the enhancement code includes only EOB), and the payload, which represents the number of available bits for embedding, is less than 4. The decoder can easily determine whether these conditions follow. Moreover a distortion that could be added to the 8×8 quantized DCT coefficients by embedding EOB code to the LSBs does not occur in this case. Notice that the permissible payload for 8×8 quantized DCT coefficients can be determined using the method described in Section 3.

Table 2 Possible combinations of lower and higher frequency quantized DCT coefficients.

		Higher DCT coefficients	
		All zero	Not all zero
Lower DCT coefficients	DC only	Case 1	Case 2
	DC + ACs	Case 3[1)]	Case 4

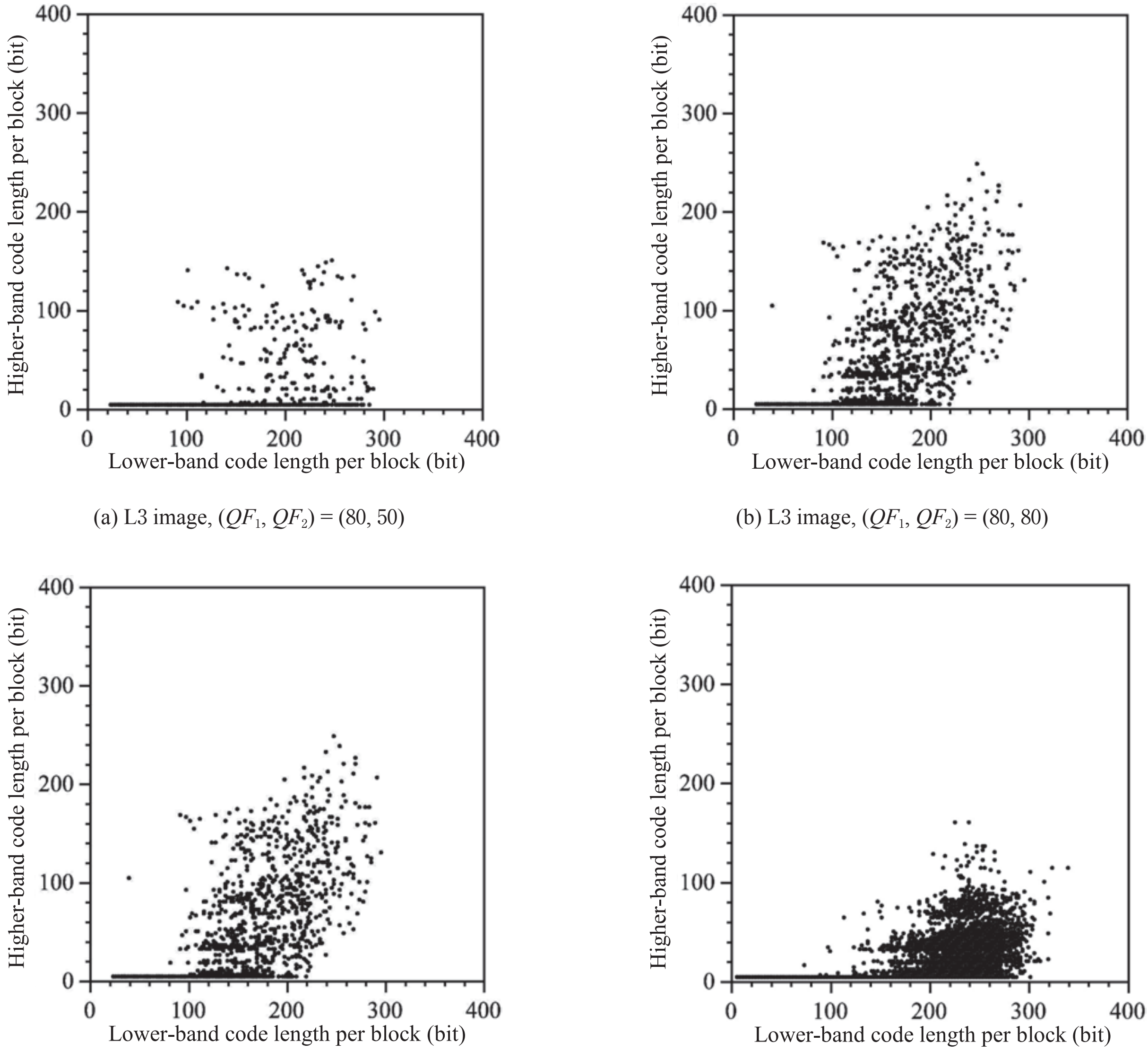
1) Case 3 includes a payload less than 4 even if the higher frequency quantized DCT coefficients are not all zero.

Table 2 shows the possible combinations between 8 × 8 lower frequency quantized DCT coefficients and 16×16 higher frequency quantized DCT coefficients excluding 8×8 coefficients. The state of lower frequency DCT coefficients is divided into two cases: DC only and DC+ACs, and the state of higher frequency DCT coefficients is also divided into two cases: all zero or not all zero.

The four cases in Table 2 are explained as follows:

- Case 1: The lower frequency quantized DCT coefficients include only DC component and all the higher frequency quantized DCT coefficients are zeros, so that it is impossible to embed the enhancement codes.
- Case 2: The lower frequency quantized DCT coefficients include only DC component and higher frequency quantized DCT coefficients include non-zero components, so that it is impossible to embed the enhancement codes. It is in question that the case 2 appears for real images because the case corresponds to an extreme condition in which the enhancement codes excluding EOB exist even if the lower frequency quantized DCT coefficients include only DC component.
- Case 3: The enhancement codes (EOB code only) can be embedded if the payload of the lower frequency quantized DCT coefficients is greater than or equal to 4. When the payload is less than 4, it is impossible to embed the enhancement code, so that the case 3 includes the situation. In this case, all the higher frequency quantized DCT coefficients are forced to all zeros in the decoder even if these coefficients are not all zeros in the encoder. This situation is similar to the case 2, and it is also in question that this situation appears for real images.
- Case 4: This is the most popular case. It is impossible to embed the enhancement codes if the payload is less than enhancement code length.

The basic idea of above mentioned cases is as follows. The enhancement codes are not embedded in the encoder when cases 1, 2, and 3 follow. All the higher frequency quantized DCT coefficients are forced to zeros as if the EOB code is extracted in the decoder when the lower frequency quantized DCT coefficients include only DC component or its payload is less than 4. Therefore, cases 1, 2, and 3 can be distinguished in the encoder, though the case 2 cannot be distinguished in the decoder despite the distinguishability between cases 1 and 3. In the case 3, all the higher frequency quantized DCT coefficients in a block having the payload less than 4 are set to zeros because the decoder cannot decide whether all these coefficients are zeros or not in the encoder.



(a) L3 image, $(QF_1, QF_2) = (80, 50)$

(b) L3 image, $(QF_1, QF_2) = (80, 80)$

(c) H3 image, $(QF_1, QF_2) = (80, 50)$

(d) H3 image, $(QF_1, QF_2) = (80, 80)$

Fig. 3 Distribution of entropy codes for lower- and higher-band frequencies per 16×16 block.

5. PERFORMANCE EVALUATION

It can be impossible to embed the enhancement codes according to the combination of quality factors, QF_1 and QF_2, and the number of scans of higher frequency DCT coefficients, *scan*, when the 8×8 quantized DCT coefficients include only DC component and it is not allowed to embed the enhancement codes to the DC component. The method for avoiding EOB code embedding described in Section 4 alleviates the problem. We incorporate the proposed techniques described in Sections 3 and 4 into the basic system configuration shown in Fig. 1, and evaluate the performance of the image enhancement method with steganographic data embedding for real images.

The performance evaluation is focusing on the following measures using various combinations of $(QF_1, QF_2, scan)$.

- Rate of enhancement codes against JPEG codes
- JPEG compression ratio
- SNRs of JPEG image and enhanced image
- Embedding capability of enhancement codes

Six real images [4] are chosen for the experiment, and here, only the results for L3 image (672×544 pixels) and H3 image (2048×2048 pixels) are demonstrated for explanations. These original images are shown in Figures 4 (a) and 5 (a).

Figures 4 and 5 ((b), (c), and (d)) shows the rate of enhancement codes against JPEG codes, JPEG compression ratio, SNRs of JPEG image (SNR_{low}) and enhanced image (SNR_{high}), respectively, for images L3 and H3 in case of *scan*=1. In all these Figures, the horizontal axis is for the lower frequency quality factor, QF_1. The rate of enhancement codes against JPEG codes is shown for various higher frequency quality factors, QF_2s. In the Figure of JPEG compression ratio, the blue arrows show that it is impossible to embed the enhancement codes if the higher frequency quality factor is greater than the value attached beside the arrow. SNR_{low} and SNR_{high} are SNRs when the higher frequency quality factor is set to 40. The properties for each image can be estimated from the data using *scan*=1 because above measures do not change widely for the number of scans except images having much higher frequency component such as L2 image.

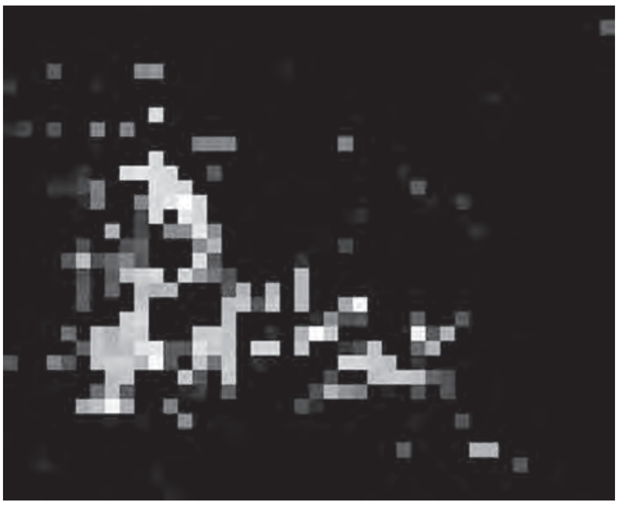
The simulation results are summarized as follows:

1) The selection of QF_1 has a great impact on SNR_{low} and JPEG compression ratio, while the selection of QF_2 has a little contribution to SNR_{high}.
2) The range of parameter selections that enables to embed the enhancement codes is expanded widely. These area include situations that the lower frequency quantized DCT coefficients has only DC component, and all the higher frequency quantized DCT coefficients are zeros or the payload is less than 4 when lower frequency quantized DCT coefficients has non-zero AC components.
3) The upper limits of the amount of enhancement codes that can be embedded in the LSBs of the lower frequency quantized DCT coefficients are 1.5~4.5%, 2.9~4.5%, 2.1~7.0%, 2.2~11.0%, 1.2~4.7%, 1.6~5.4% for L1, L2, L3, H1, H2, H3 images, respectively (including all scanning cases). In particular case of *scan*=8, the upper limits are around 2% against the JPEG code length. The images L2 and L3 need the quality factor, QF_2, less than 40 in order to enable the enhancement code embedding with *scan*=8.
4) If the QF_1 is fixed, then the range of the combination (QF_1, QF_2, *scan*) that enables the enhancement code embedding becomes narrower, though SNRs of JPEG and enhanced images do not virtually change (the former degrades a little, while the latter improves a little, and this matches the intuition).

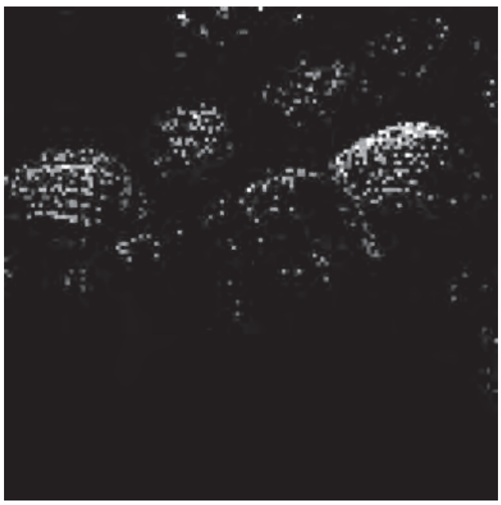
Figures 6 and 7 show enlarged partial scenes of JPEG and enhanced images for images L3 and H3 using two combinations of parameters, (QF_1, QF_2, *scan*), shown in Table 3.

Table 3 Simulation parameters for Figs. 6 and 7.

image	Combinations of (QF_1, QF_2, scan)	
	Combination-1	Combination-2
L3	(95, 55, 4)	(80, 45, 2)
H3	(95, 65, 8)	(80, 55, 3)



(a) L3 image,
(QF_1, QF_2, *scan*) = (95, 55, 4)



(b) H3 image,
(QF_1, QF_2, *scan*) = (95, 65, 8)

Fig. 8 Enhancement code length embedded to LSBs of 8×8 quantized DCT coefficients (The luminance values have a range from 0 to 255 in such a way that the maximum enhancement code length corresponds to 255).

For both images, although JPEG images are coarser than the enhanced images, the combination-2 in Table 3 leads to some degradation such as block noise. Therefore, much attention should be paid for selecting the parameters to prevent perceptual image degradation.

Figure 8 shows the amount of enhancement codes (run-length Huffman codes) embedded to LSBs of 8×8 quantized DCT coefficients with the parameter combination-1 shown in Table 3 for images L3 and H3. In this figure, the luminance values have a range from 0 to 255 in such a way that the maximum enhancement code length corresponds to 255, so note that the amount of enhancement codes differs between these images. It can be seen that the textured scene produces large enhancement codes for both images, and the enhancement code length also depends on the color for H3 image (green generates larger enhancement codes).

6. CONCLUTION

In this paper, we proposed the image enhancement method with steganographic data embedding. The proposed embedding scheme for the enhancement codes enlarged possible parameter combinations to the case that the 8×8 quantized DCT coefficients have only DC component. Under this condition, we measured the rate of enhancement codes against JPEG codes, JPEG compression ratio, and SNRs of JPEG and enhanced images for relatively low and high resolution real images. In addition, examples of JPEG and enhanced images were shown with two parameter combinations of (QF_1, QF_2, $scan$) that enables enhancement code embedding. These parameter combinations cannot be much lower because coarse quantization or lack of many DCT coefficients could cause the aliasing distortion when viewing this system as a DCT-IDCT filter bank. This aliasing distortion is perceives as block noise or pseud-contour.

Our future topics are to study how much aliasing distortion can be permissible and how to embed the enhancement codes efficiently from the view point of perceived quality.

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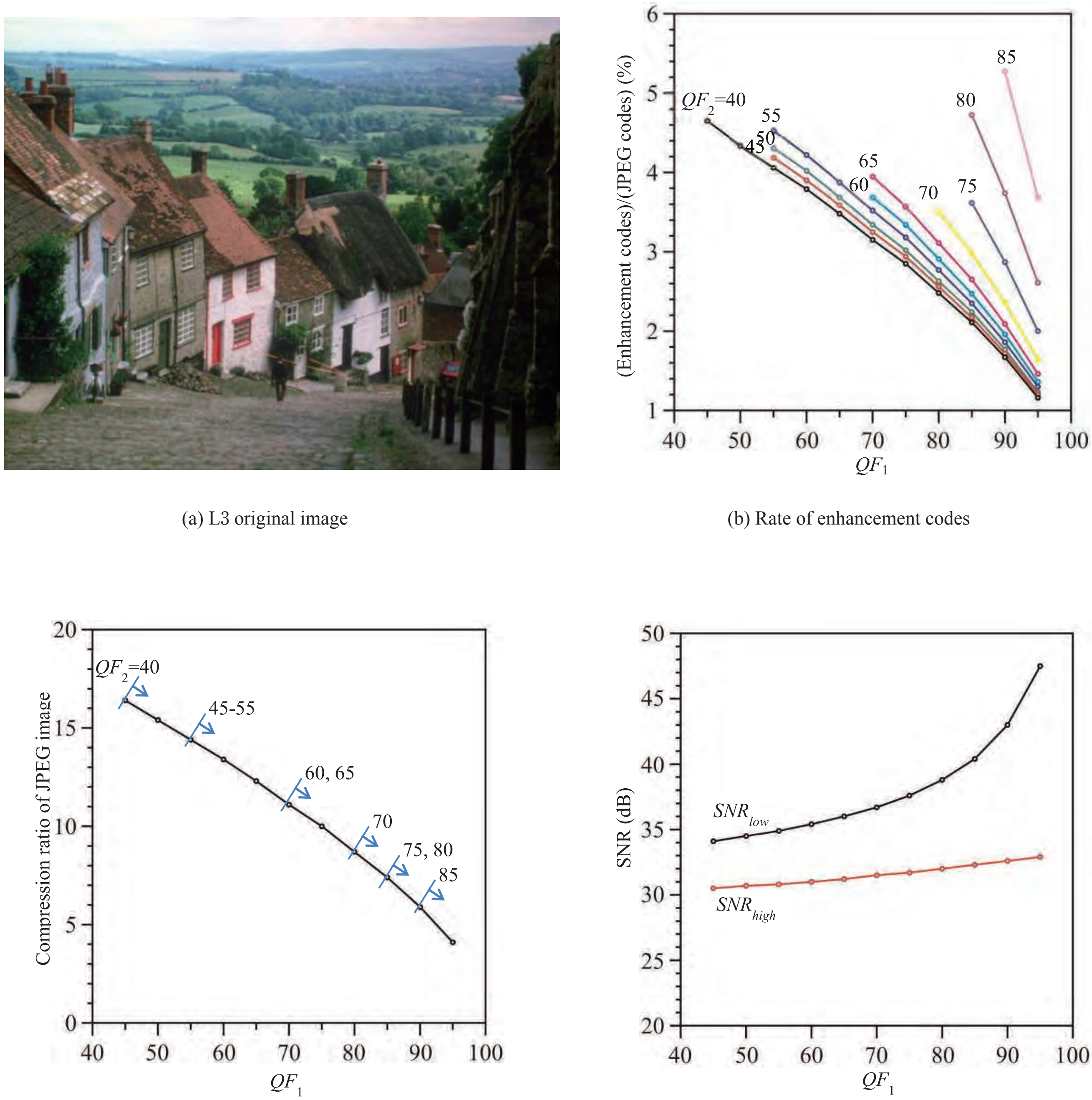


(a) L3 original image

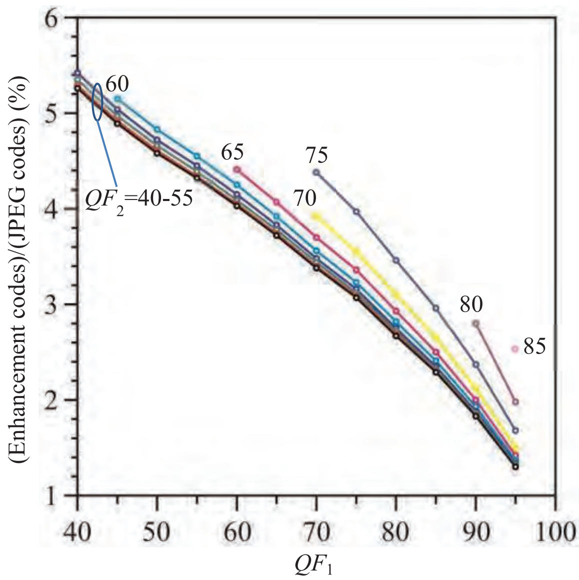
(b) Rate of enhancement codes

(c) Compression ratio for JPEG image

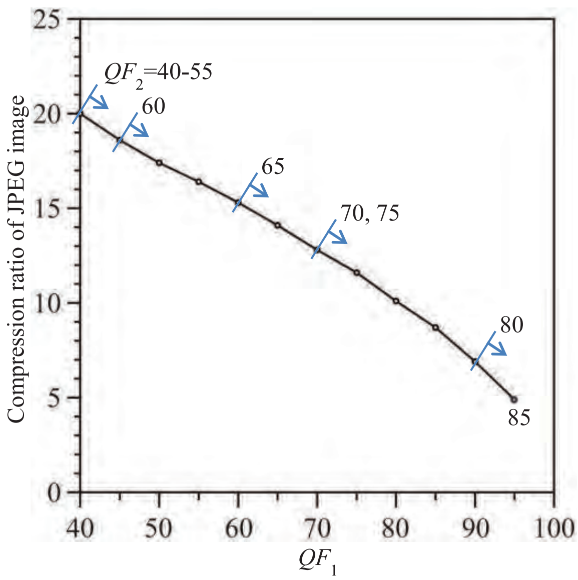
(d) SNR_{low} and SNR_{high}

Fig. 4 L3 original image and experiment results of embedding enhancement codes.

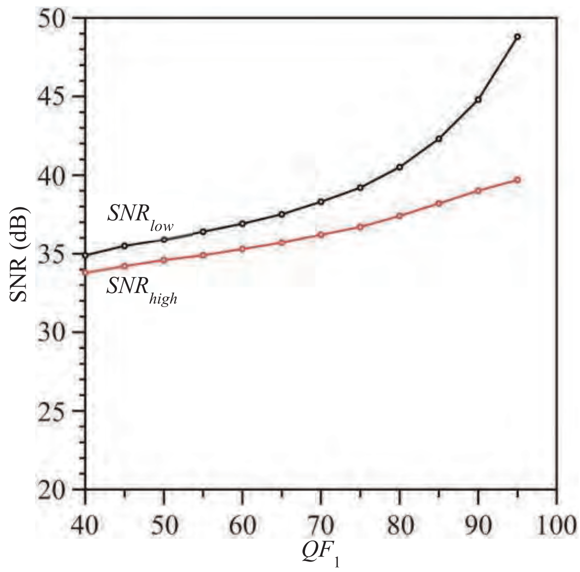
(a) H3 original image



(b) Rate of enhancement codes



(c) Compression ratio for JPEG image



(d) SNR_{low} and SNR_{high}

Fig. 5 H3 original image and experiment results of embedding enhancement codes.

(a) Original image (160 × 160 pixels)

(b) JPEG image,
(QF_1, QF_2, $scan$) = (95, 55, 4)

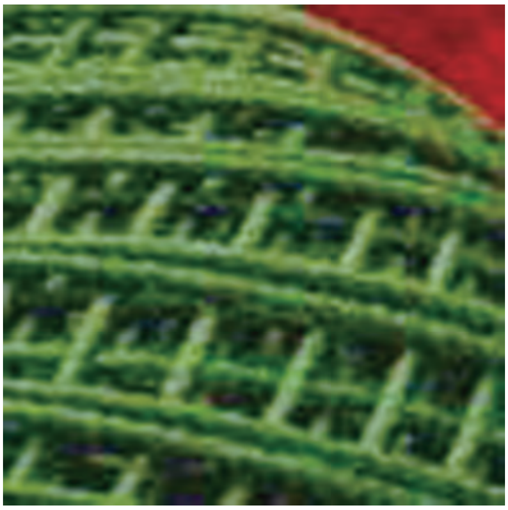
(c) Enhanced image,
(QF_1, QF_2, $scan$) = (95, 55, 4)

(d) JPEG image,
(QF_1, QF_2, $scan$) = (80, 45, 2)

(e) Enhanced image,
(QF_1, QF_2, $scan$) = (80, 45, 2)

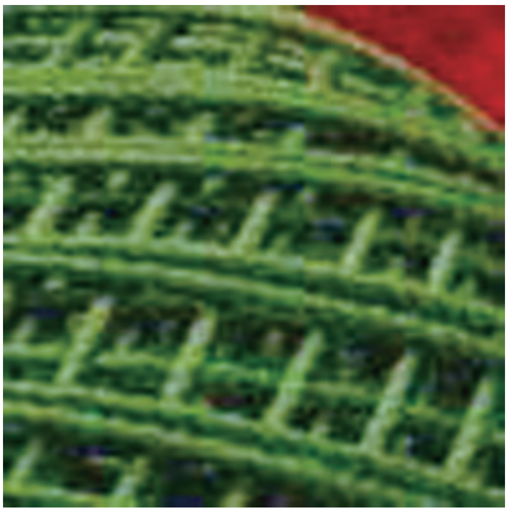
Fig. 6 Enlarged partial scenes of JPEG and enhanced images for L3 image.

(a) Original image (160 × 160 pixels)



(b) JPEG image,
(QF_1, QF_2, *scan*) = (95, 65, 8)

(c) Enhanced image,
(QF_1, QF_2, *scan*) = (95, 65, 8)



(d) JPEG image,
(QF_1, QF_2, *scan*) = (80, 55, 3)

(e) Enhance image,
(QF_1, QF_2, *scan*) = (80, 55, 3)

Fig. 7 Enlarged partial scenes of JPEG and enhanced images for H3 image.