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Signal Processing 84 (2004) 95–106

SIGNAL PROCESSING

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A color image watermarking scheme based on color quantization

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Received 1 October 2001; received in revised form 12 November 2002

Abstract

Digital watermarking has been widely applied to solve copyright protection problems of digital media relating to illegal use or distribution. In the past few years, several gray-level image watermarking schemes have been proposed, but their application to color image watermarking schemes is scarce and usually works on the luminance or individual color channel. In this paper, a new color image watermarking scheme based on the color quantization technique is proposed. Experimental results are shown to demonstrate the validity of the proposed scheme. Furthermore, the proposed scheme can be applied to other multimedia applications that are based on the color quantization technique.

Keywords: Image watermarking; Color quantization; Pixel mapping; DES

1. Introduction

Due to the nature of digital media and the popularity of the Internet, illegal operations such as duplication, modification, forgery, etc. performed on digital media are easy, fast, and difficult to prevent. These illegal operations hurt the author's motivation for creative endeavor. Therefore, the protection of digital media intellectual property rights has become an urgent matter. Among various digital media, the image-related data is very important because the information carried by image data can be easily observed through human eyes.

Of all methods that have been introduced to protect the intellectual property rights of digital images, the development of digital watermarking schemes is the commonly used approach. In digital watermarking schemes, some types of digital data such as logos, labels or names (called watermarks), representing the author's ownership, are embedded into the desired host image. Generally, a registration to the authentication center is necessary, which helps to solve ownership disputes by identifying the owner of the disputed media. If necessary, the embedded watermark in the host image can be used to verify ownership.

The watermarking schemes can be classified into two categories: spatial domain watermarking schemes and transform domain watermarking schemes. In spatial domain watermarking schemes, the watermark is embedded into the host image by directly modifying the pixel value of the host image without causing

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doi:10.1016/j.sigpro.2003.07.012

obvious change in appearance. The main advantage of the spatial domain watermarking schemes is that less computational cost is required.

On the other hand, transform domain watermarking schemes perform the domain transformation procedure by using transformation functions such as discrete cosine transformation (DCT), discrete fourier transformation (DFT), discrete wavelet transformation (DWT), etc. Then, the transformed frequency coefficients are modified to embed the desired watermark. Finally, the inverse transformation function of the specific one used in the forward transformation procedure is performed. The main advantage of the frequency domain watermarking schemes is that they are more robust than the spatial domain schemes. However, they generally incur more computational cost because additional forward transformation and inverse transformation must be performed.

In related research, several spatial domain watermarking schemes have been proposed. The least significant bit (LSB) [15] scheme proposed by Van Schyndel et al., introduced a new approach for image watermarking by modifying the low-order bits of pixels. Chang et al. [3] considered human visual effects to adaptively adjust the embedding watermark bits. The number of watermark bits for embedding in this scheme is determined by the visual effect of the pixel values in the host image.

Recently, the image watermarking research has moved toward embedding the watermark into transformed coefficients because of the robustness consideration. In [1], DCT transformation is employed in the domain transformation procedure. The watermark is embedded into the predefined medium frequency coefficients in zigzag scanning order after DCT transformation is performed. Furthermore, the watermark strength is adapted according to human visual perception to ensure the invisibility of the watermark.

In [2], DWT transformation is first applied to the domain transformation procedure. Then, the most detailed sub-band coefficients are used to embed the watermark. The watermark strength is modulated with a mask in order to keep the modification imperceptible. The correlation between the original and the extracted watermarks is computed to identify the image copyright.

In the past few years, most of the watermarking schemes employ gray-level images to embed the watermarks, whereas their application to color images is scarce and usually works on the luminous or individual color channel. Kutter et al. [8] proposed a color image watermarking scheme that embeds the watermark into the blue-channel of each pixel by modifying its pixel value. The reason why the pixels in the blue channel are selected to embed the watermark is because the message in the blue channel is less sensitive to the human eyes.

Piva et al. [13] introduced another color image watermarking scheme based on the cross-correlation of RGB-channels. In this scheme, DCT transformation is first performed separately on each color channel. A set of coefficients is then selected from each color channel, which is used to embed the watermark by modifying these coefficients. To fine-tune the different channel sensitivity, the modification is adapted using different watermark strengths. The correlation of RGB channels is computed to verify the existence of the watermark.

In practice, some display devices have limited frame buffers that can only display a small amount of colors simultaneously. For example, a display device with an 8 bits frame buffer can only display 256 colors. However, an RGB-color image with 24 bits/pixel holds 16,777,216 colors. In order to display RGB-color images in such display devices, the color quantization technique have been proposed. In this technique, a set of representative colors, called a palette or a color palette, is selected to represent the original image colors. Each pixel in the RGB-image is mapped to the closest color in the palette. Usually, an amount of distortion exists between the original and the quantized images.

The advantages of limited frame buffer and shorter transmission times make the color quantization technique to be widely applied in computer animation, pseudocoloring, color adjustment, etc. To provide image copyright protection for these applications, a new image watermarking scheme based on the color quantization technique is introduced, which extends some image watermarking researches [11,12] that directly embed the watermark into the compressed host image.

The rest of this paper is organized as follows. In Section 2, a new watermarking scheme based on the color quantization technique will be introduced. The experimental results of the proposed scheme will be shown in Section 3. Finally, the conclusions will be given in Section 4.

2. The proposed watermarking scheme

In this section, a digital watermarking scheme based on the color quantization technique is proposed. The overview of the proposed watermarking scheme is shown in Fig. 1. To clearly introduce the proposed watermarking scheme, the color quantization technique is first described.

2.1. The color quantization technique

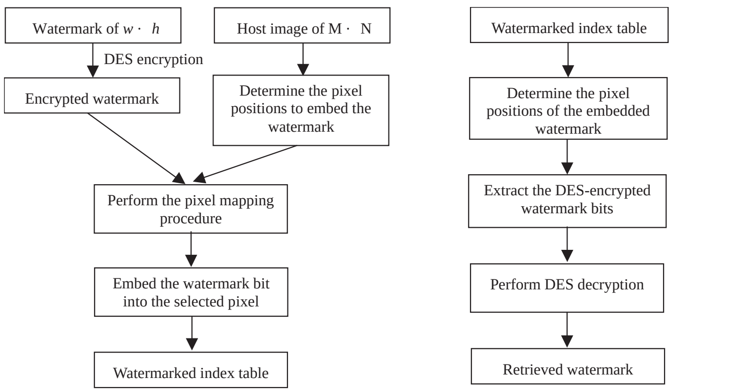
Initially, the purpose of the color quantization technique was to provide different details of images for different display devices that have limited frame buffers. This technique had been applied in interactive graphics and real-time image operations. The main operations of the color quantization technique are the palette design procedure and the pixel mapping procedure.

The task of the palette design procedure is to select some representative colors for a particular image. Generally, a palette consists of some representative colors, each having three dimensions for RGB-color images, which can be considered as a codeword in the codebook where the palette is the codebook.

In the color quantization technique, the color palette strongly affects the image quality of the quantized image. In related research, several schemes have been proposed for the design of the color palette. Both the LBG algorithm [10] and the genetic algorithm [14] employ the iterative refinements of some initial palette to minimize the distortion between the original image and the quantized one. Generally, the performance of these two algorithms strongly depends on the selection of the initial condition. In addition to these two schemes, the median-cut [6], center-cut [7] and mean-split [17] techniques that employ the top-down structure in designing the color palette has also been proposed.

Another approach relating to palette design adopts famous algorithms in the design of the color palette. In Wu's method [16], color palette design is based on the dynamic programming and principal analysis techniques. Also, Lin et al. [9] introduced another scheme by preserving the features of average color, variance of color dimension, and average color radius. In this scheme, the palette is designed based on a bisection technique. Furthermore, Cheng et al. [5] proposed a dimensionality reduction method to extract representative colors. All of these schemes focus on selecting the best possible representative colors with the least computational cost and minimal distortion.

After the color palette is designed, the pixel mapping procedure is performed. The goal of the pixel mapping procedure is to find the closest color from the palette to represent the pixel in a particular image with minimum distortion. Each pixel in the original color



(a) The watermark embedding procedure (b) The watermark extracting procedure

Fig. 1. The overview of the proposed watermarking scheme.

image is mapped to the closest color in the palette to produce the quantized image. Generally, the squared Euclidean distance (SED) is the most commonly used distance measurement in finding the closest color. The SED between the original pixel h_i and the color c_j in the palette can be computed according to the following formula:

$$\mathrm{SED}(h_i, c_j) = \sum_{i=1}^{k} (h_i - c_{ji})^2,$$

where k is the dimensionality of each color in the palette and c_{ji} is the ith dimension of codeword c_j. After finding the index of the closest color in the palette of each pixel in the original image, the indices of the corresponding colors in the palette are stored and used to represent the input image.

2.2. The watermark embedding procedure based on color quantization

In the proposed watermarking scheme, a host image H is an RGB-color image with $M \times N$ pixels, where $H = (h_1, h_2, \ldots, h_{M\times N})$. The watermark W is a binary image consisting of $w \times h$ bits, where $W = (w_1, w_2, \ldots, w_{w\times h})$ and $w_i \in (0, 1)$. The color palette, which was generated previously by the Adobe PhotoShop version 5.0 with optimal palette selection, is used in this color quantization technique.

The principal component analysis (PCA) technique [4] is then performed to reorder the colors in the palette. The colors in the palette are projected onto the first principal component of PCA and sorted with the projected values. The goal of the PCA technique is to rearrange the colors in the palette so that the neighboring colors are very similar.

The characteristic of closest similarity benefits the enhancement of quantized image quality in the proposed watermarking scheme. After the PCA technique is executed to reorder the palette, it can be considered as two sub-palettes. One sub-palette holds the colors with odd indices in the palette. The other keeps the colors with even indices. Two successive colors retain the most similarity among colors and reside in the sub-palette separately.

The proposed watermark embedding procedure is imposed on the structure of the pixel mapping procedure in color quantization. In other words, when the pixel mapping procedure is performed, the watermark is embedded at the same time. For security considerations, the watermark bits to be embedded can be encrypted by the DES encryption procedure before they are actually embedded. In addition, a pseudorandom number generator (PRNG) is employed to determine the positions of the pixels that will be used to embed these watermark bits.

When the positions of the pixels used to embed the watermark are determined, the pixel mapping procedure is then performed. In the pixel mapping procedure, the closest color $c_{\min}$ in the palette with the minimum SED for each pixel h_i is determined. The index I_i recording the index of the searched closest color $c_{\min}$ in the palette for pixel h_i and is stored in the color index table. When the predefined pixel h_i for embedding a watermark bit is encountered, index I_i of the searched color will be further processed to embed the watermark. Otherwise, the pixel mapping procedure is performed to find the closest color in the palette for the next image pixel.

To embed a watermark bit w_i, there are four possible cases that can be used to process the index. Fig. 2 shows the overview of processing these four cases of indexing. First, both the embedding watermark bit w_i and the searched closest color index I_i have the same sign (odd or even). In other words, $(w_i + I_i)$ module 2 equals 0. In this case, I_i is stored directly. Second, there is a different odd or even sign between w_i and I_i. In other words, $(w_i + I_i)$ module 2 equals 1. To embed w_i, another closest color c_{next} in the palette with corresponding index I_{next} that satisfies $(w_i + I_{\text{next}})$ module 2 equals 0 will be found.

If the distance of the SED between h_i and c_{next} and the SED between h_i and $c_{\min}$ is less than or equal to threshold τ, i.e. $\mathrm{SED}(h_i, c_{\text{next}}) - \mathrm{SED}(h_i, c_{\min}) \leqslant \tau$, I_{next} is stored. Otherwise, if $\mathrm{SED}(h_i, c_{\text{next}}) - \mathrm{SED}(h_i, c_{\min}) > \tau$, a predictive technique that attempts to reduce the distortion of the quantized image will be used. The mean value h_{mean} of the encoded immediate left h_{l} pixel and directly above h_{a} pixel of h_i will be computed. In other words, $h_{\text{mean}} = (h_{\text{l}} + h_{\text{a}})/2$. If $\mathrm{SED}(h_i, h_{\text{mean}}) < \mathrm{SED}(h_i, c_{\text{next}})$, two special indices 0 and 255 will be stored for $w_i = 0$ and 1, respectively. Otherwise, the index I_{next} of the searched closest color with the same sign will be stored. After the pixel mapping procedure is completed, the watermark is embedded into the host image.

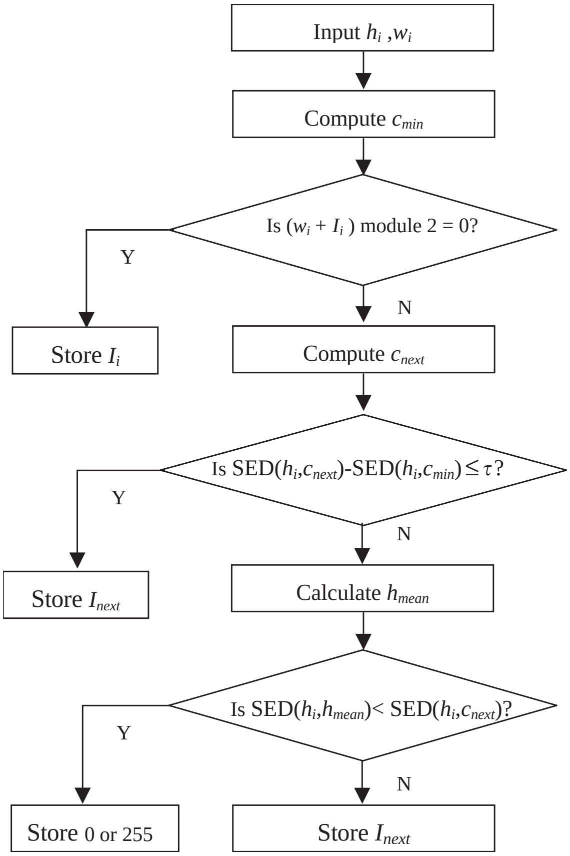


Fig. 2. The flow chart of watermark embedding process.

The watermark embedding algorithm:

Step 1: Perform the DES encryption procedure to watermark W of $w \times h$ bits and choose a PRNG to produce a set of positions of $w \times h$ pixels for embedding the watermark.

Step 2: For each pixel h_i, the closest color $c_{\min}$ with index I_i is chosen using the pixel mapping procedure.

Step 3: When the pixel h_i is one of the selected pixels, if $(w_{i+}I_i)$ module 2 equals 0, I_i will be stored directly. Go to Step 7.

Step 4: Find another closest color c_{next} with index I_{next} in the palette, which satisfies $(w_{i+}I_{\text{next}})$ module 2 equals 0. If $\text{SED}(h_i, c_{\text{next}}) - \text{SED}(h_i, c_{\min}) \leqslant \tau$, I_{next} will be stored. Go to Step 7.

Step 5: Calculate the mean value h_{mean} of the encoded immediate left h_{l} pixel and directly above h_{a} pixel of h_i. If $\text{SED}(h_i, h_{\text{mean}}) < \text{SED}(h_i, c_{\text{next}})$, two special indices 0 and 255 will be stored for $w_i = 0$ and 1, respectively. Go to Step 7.

Step 6: If $\text{SED}(h_i, h_{\text{mean}}) \geqslant \text{SED}(h_i, c_{\text{next}})$, I_{next} will be stored

Step 7: If there is any watermark bit to be embedded, go to Step 2.

The proposed watermark embedding procedure is imposed on the processing of the pixel mapping procedure. The major difference is that when each selected pixel that is encountered, additional computational cost is required to adequately embed the watermark bit. In this scheme, the watermark bits are embedded into the color index table, which the size of index table is not modified. In addition, the use of the DES encryption procedure and the PRNG increases the security of the proposed scheme. It can be easily seen that the proposed scheme provides better security than other schemes that employ either the PRNG technique or the cipher function.

2.3. The proposed watermark extracting process

The proposed watermark extracting procedure is imposed onto the structure of the image decoding procedure in the color quantization process. First, the PRNG determines the positions of image pixels that were used to embed the watermark bits. In the image decoding procedure, each entry in the color index table will be replaced with the corresponding color in the palette. When an entry containing the watermark is encountered, the corresponding watermark bit is extracted before the color replacement is performed. If the entry value is odd, it means that the embedded watermark bit is valued one. Otherwise, the embedded watermark bit is valued zero. The extracted watermark bits are decrypted by the DES decryption procedure.

The watermark extracting algorithm:

Step 1: Use the PRNG to determine the positions of entries in the color index table that contains the watermark bits.

Step 2: If the value of the selected entry is odd, the extracted watermark bit is set to one. Otherwise, the extracted watermark bit is valued zero.

Step 3: Perform the DES decryption procedure to recover the watermark.

3. Experimental results

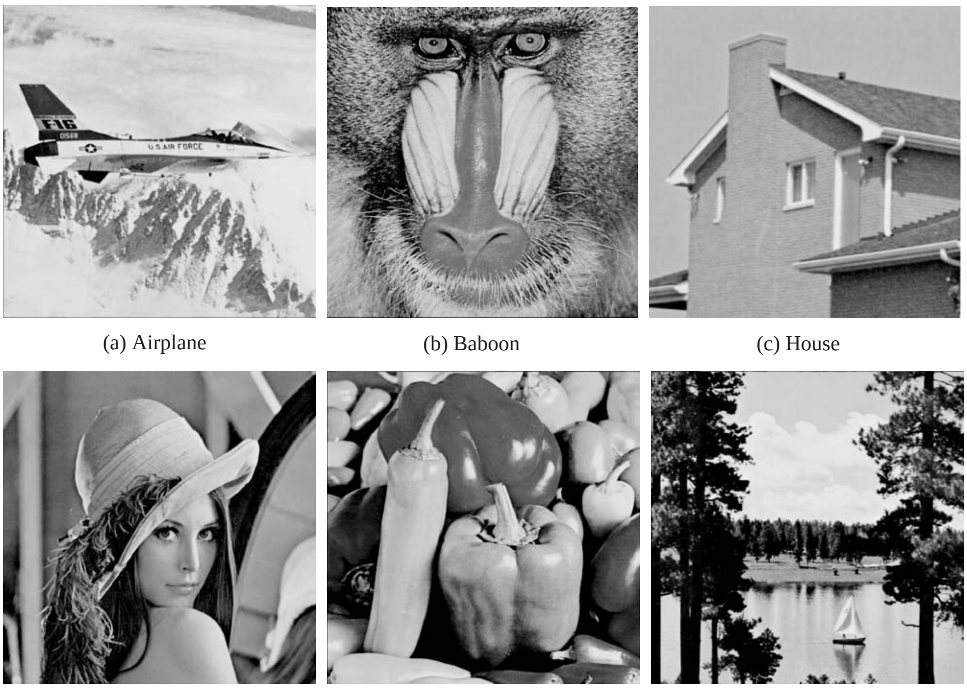
Several simulations were performed on an IBM compatible Notebook with PIII-850 MHz 128 MB main memory. Those simulations were used to verify the validity of the proposed watermarking scheme. A set of RGB-color images of 512×512 pixels, “Airplane”, “Baboon”, “House”, “Lena”, “Peppers”, and “Sailboat”, was used as host images. Two binary images, “CCU” and “IEEE”, each with 64×64 and 128×128 bits, were used as watermarks in the simulations.

Figs. 3 and 4 show the host images and watermarks used in the simulations, respectively. For each host image, a corresponding palette was generated by Adobe PhotoShop version 5.0 with optimal palette selection. Each palette consisted of 256 colors and was indexed from 0 to 255. Each color in the palette contained RGB channels.

The PCA technique was employed to sort the colors in the palette that preserved the color similarity. Furthermore, the DES encryption was performed to permute the watermark and the PRNG was used to determine the positions of pixels for embedding the watermark. Fig. 5 shows the DES-encrypted watermarks of the four watermarks shown in Fig. 4. We find that the pixels within each encrypted image are quite different.

Fig. 6 shows the results of four watermarked images of test image “Lena” of the proposed scheme. Here, four watermarks as shown in Fig. 5 were used to generate the four corresponding watermarked images. According to the results, we find that the visual quality of each watermarked image is good.

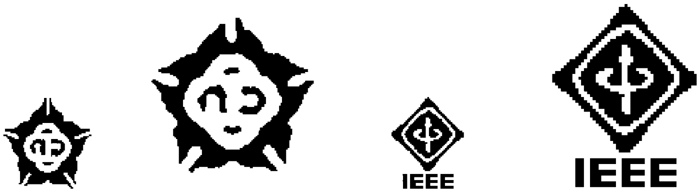
To identify the ownership of the watermarked image, the proposed watermark extracting procedure was performed. Fig. 7 shows the extracted DES-encrypted watermarks. The extracted DES-encrypted watermark was then further processed by the DES decryption procedure. The resultant watermarks after the DES decryption are shown in Fig. 8.



(a) Airplane (b) Baboon (c) House

(d) Lena (e) Peppers (f) Sailboat

Fig. 3. Six host images of 512×512 pixels.

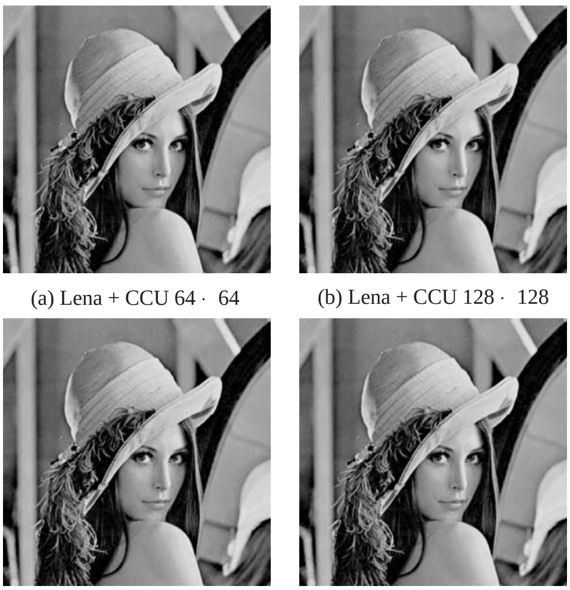


(a) 64×64 image (b) 128×128 image (c) 64×64 image (d) 128×128 image

Fig. 4. Four watermark images.

(a) 64 · 64 image (b) 128 · 128 image (c) 64 · 64 image (d) 128 · 128 image

Fig. 5. The DES-encrypted watermark images.



(a) Lena + CCU 64 · 64 (b) Lena + CCU 128 · 128

(c) Lena + IEEE 64 · 64 (d) Lena + IEEE 128 · 128

Fig. 6. The watermarked images of test image "Lena" of the proposed scheme.

To demonstrate the validity of the proposed watermarking scheme, another example using the test image "Baboon" is shown in Fig. 9. The four watermarks as shown in Fig. 4 were embedded into the test image "Baboon" using the proposed scheme to generate the four corresponding watermarked images. From the results, we find that the image quality of the four watermarked images is quite good. It is hard to distinguish between the original test image and each of these four images.

In order to find out whether the watermarking embedding procedure could cause image degradation, a set of simulations that performs the basic pixel mapping procedure was executed. The quantized images of six host images using the pixel mapping procedure are shown in Fig. 10. According to the results shown in Figs. 6, 9, and 10, it is hard for the human eye to distinguish the difference between them.

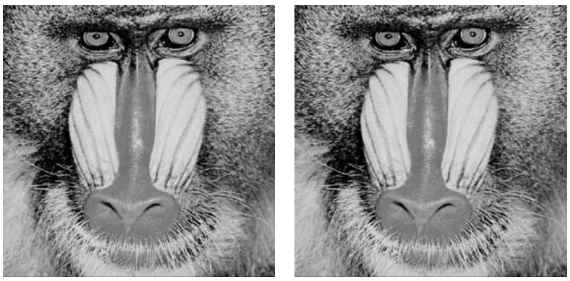
Furthermore, the experimental results of the image quality (PSNR) of the color quantized images and the proposed scheme with different watermarks are shown in Table 1. From the results, it is seen that only a slight PSNR loss is found in the proposed scheme. In addition to the PSNR results shown in Table 1, the results of the execution times of the proposed watermark embedding and extracting procedures and the color quantization technique are shown in Table 2. It is obvious that the proposed watermarking scheme requires only a little more execution time than the color

(a) 64·64 image (b) 128·128 image (c) 64·64 image (d) 128·128 image

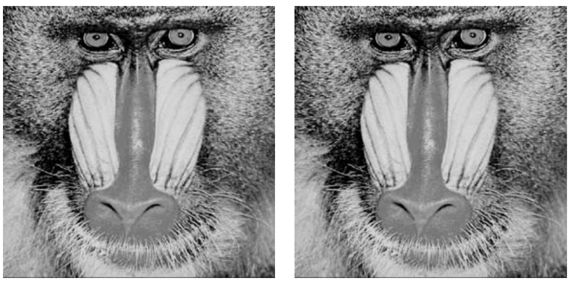
Fig. 7. The extracted DES-encrypted watermarks.

(a) 64 × 64 image (b) 128 × 128 image (c) 64 × 64 image (d) 128 × 128 image

Fig. 8. The resultant watermarks after the DES decryption procedure.



(a) Baboon + CCU 64 · 64 (b) Baboon + IEEE 64 · 64



(c) Baboon + CCU 128 · 128 (d) Baboon + IEEE 128 · 128

Fig. 9. The watermarked Baboon images after image decoding.

quantization technique. In other words, the proposed watermarking scheme is efficient.

To evaluate the robustness of the proposed watermarking scheme, several attacks including the Gaussian noise addition process, the cropping process, the JPEG compression process, and the JPEG 2000 compression process have been performed. In the simulations, the size of the watermark is 64×64 bits. Each color quantized image is first reconstructed to generate the decompressed color image. Then the specific attack is performed on the decompressed color image. Finally, the color quantization process is executed on the attacked image to construct the indices.

In the Gaussian noise addition process, 3% and 5% of Gaussian noises are added, respectively. In the cropping process, one-fourth size of the upper-left decoded watermarked image is cropped. In the JPEG lossy compression process, the decoded watermarked image is compressed by the JPEG scheme with quality factors (QF) of 8 and 9 (1–10 scale), separately. In addition, the quality factor of 9 is set in the JPEG 2000 compression process. In this simulation, the encryption procedure is not performed to the embedding watermark.

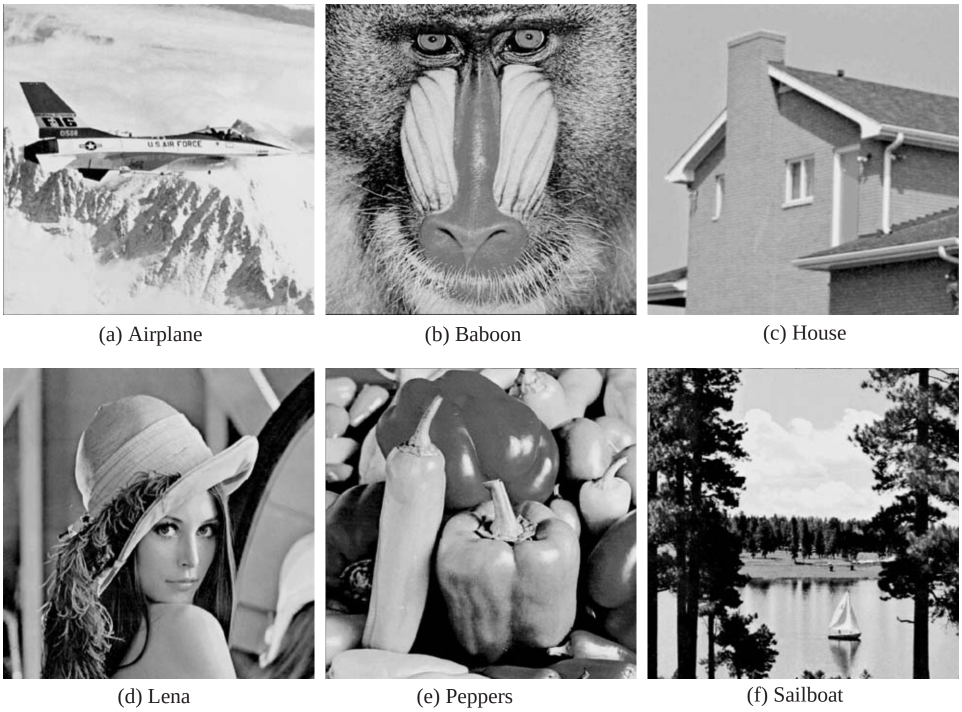


Fig. 10. The quantized image taken directly from the original host image.

Table 1
Results of the image quality (PSNR) of the color quantized images and the proposed scheme with different watermarks

Images	Watermark				
	Without	64 × 64 pixels CCU	128 × 128 pixels CCU	64 × 64 pixels IEEE	128 × 128 pixels IEEE
Airplane	38.6624	38.5525	38.5301	38.5343	38.5364
Baboon	31.8441	31.6974	31.6973	31.6947	31.6963
House	37.4871	37.2685	37.2657	37.2661	37.2651
Lena	36.7206	36.6210	36.6203	36.6227	36.6207
Peppers	33.0681	32.9486	32.9505	32.9497	32.9491
Sailboat	33.0924	33.0501	33.0488	33.0497	33.0482

Experimental results of the error rates of the extracted watermarks of different attacks have been shown in Table 3. According to the results, it is seen that the complex images including test images “Baboon”, “Peppers” and “Sailboat” are much more robust against most attacks than the smooth images. On the other hand, the smooth images including “Airplane”, “House” are much fragile to the attacks.

In the proposed scheme, the color palette plays an important role on the performance of the proposed. The image quality of the each color quantized image is highly dependent on the selected colors in the palette. In addition, the robustness of the proposed scheme also relies on the design of palette. To understand the relationship between the robustness of the proposed scheme and the distribution of the color palette, the

Table 2
Results of the execution times (unit: second) of the proposed watermarking scheme and the color quantization technique

Images	Watermark				
	Color Quantization	64 × 64 pixels CCU	128 × 128 pixels CCU	64 × 64 pixels IEEE	128 × 128 pixels IEEE
Airplane	5.859	6.379	6.379	6.359	6.620
Baboon	6.249	6.459	6.470	6.449	6.459
House	6.169	6.409	6.410	6.409	6.409
Lena	6.019	6.309	6.310	6.309	6.309
Peppers	6.239	6.449	6.499	6.500	6.500
Sailboat	6.119	6.389	6.640	6.369	6.629

Table 3
Results of the error ratio (units: %) of the extracted watermark of different attacks

Images	Attacks					
	Noise 3%	Noise 5%	Crop 25%	JPEG QF = 8	JPEG QF = 9	JPEG 2000 QF = 9
Airplane	11.82	33.28	8.18	31.76	18.21	23.78
Baboon	0.59	6.62	18.31	9.08	1.17	34.40
House	10.64	30.98	8.52	43.02	24.83	29.15
Lena	6.86	24.85	8.44	27.30	9.90	21.34
Peppers	0.22	9.64	7.98	18.29	1.86	26.78
Sailboat	0.34	10.01	8.27	14.18	1.83	27.86

distributions of color in each palette design from these six test images are given in Fig. 11. According to the results shown in Table 3 and Fig. 11, we find that a higher robustness is achieved in the proposed scheme when the distribution of colors in the palette is uniform. In other words, to enhance the robustness of the proposed scheme, this property can be used to design good color palette.

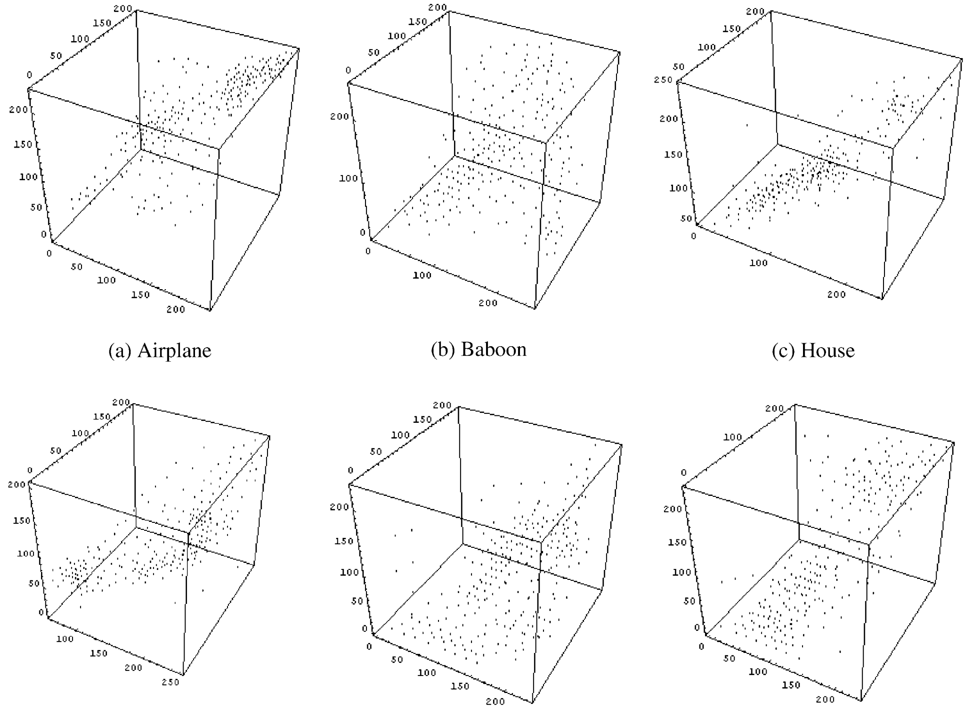
4. Conclusions

In this paper, a new color image watermarking scheme based on color quantization is proposed. The proposed watermark embedding procedure is imposed on the pixel mapping process of the color quantization process. When the pixel mapping procedure is performed, the watermark is embedded at the same time. Indeed, the watermark is embedded into the color index table.

The proposed watermark extracting procedure is also imposed on the image decoding procedure in color quantization. It means that the watermark can be extracted simultaneously while the image decoding procedure is being executed. To increase security, a product cipher is implemented in this scheme. First, the DES encryption procedure is employed to permute the watermark image. Then, the DES-encrypted watermark is embedded into the host image pixels, which were selected by a PRNG. This product cipher manipulation provides better security than using only one or the other.

In the proposed scheme, the palette plays an important role on the quality of the quantized image. In addition, the palette affects the robustness of the proposed scheme. According to the results, we find that the proposed scheme provides a strong robustness for the images with uniform distribution palette.

According to the experimental results, it is shown that the proposed scheme not only provides good image quality but also requires very little computational cost. In addition, the proposed scheme provides a secure image watermarking approach for the color quantization technique. In summary, this scheme



(a) Airplane (b) Baboon (c) House

(d) Lena (e) Peppers (f) Sailboat

Fig. 11. Results of the distributions of color palettes of six different images.

introduces an effective watermarking approach that can be applied to other multimedia applications based on color quantization. To enhance the robustness of this scheme, we will exploit the global property of color composition to enhance the robustness of the proposed scheme.

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