A Watermarking Algorithm for Color Halftone Image Based on MBVQ

Wang Quan, Pan Rong, Li Jianying, Zhang Jianmei, Chen Ruilin, Tong Tong

Institute of Computer Peripherals, Xidian University, Xi'an, 710071, China,
qwang@xidian.edu.cn

Abstract

This paper presents a new digital watermarking algorithm for color halftone images. According to the Minimal Brightness Variation Quadruples (MBVQ), this paper gets the conclusion that each pixel of color halftone image belongs to one of the five MBVQs. Based on the edge and MBVQ, this algorithm implements the watermark embedding in the halftone process. Experimental results show that the algorithm has a good transparent watermark, furthermore, it is robust against various signal processing such as random alternation, text addition and geometric shear.

Keywords: Color Halftone, Digital Watermark, MBVQ, Error Diffusion

1. Introduction

Digital watermarking technology [1][2] for images embeds or hides data in an image, and then can extract the watermark information through some process. Digital watermarking technology provides a new idea for effective copyright protection of digital information, and it has become a hot topic in the research field of digital information security. The technology has gotten great attention and formed its sound theory and technology gradually, in practice it has also been widely used.

However, the traditional digital watermarking technology is not suitable for halftone images, it cannot be applied simply and directly to halftone images. In addition, according to the research situation of the digital watermark for color halftone images at home and abroad, the relevant literature is less. Muneyasu et al [3] proposed two methods which were Color DHSPT and Extension of the DHSPT. Color DHSPT method simply extends DHSPT algorithm to color halftone images. The embedding positions of the watermark are determined by random number sequence and each color component value in the positions is flipped, then the DHSPT is used for each color component. Extension of the DHSPT method takes into account the image brightness, and the compensation position is determined jointly by the brightness and DHSPT algorithm. Because the watermark embedding locations depend on the random number sequence, each run will get different halftone images, so the visual effect depends on the random number sequence. Fu et al [4] embed the watermark into different color components. When the watermarked image and the original halftone image make boolean or overlap operation, the watermark can be reappeared. This method requires two images to extract the watermark. The above two literatures do not study the anti-attack capability of the watermark.

This paper studies the error diffusion method based on the minimum brightness distribution [5], and takes minimal brightness variation quadruples (MBVQ) into the field of digital watermarking for color halftone images to realize the digital watermark embedding.

2. Related work

2.1. Minimal brightness variation quadruples [5][6]

Minimal brightness variation quadruples are gained through the relocation theory of ink points which are shown in Figure 1. According to the relocation theory for ink points, two points of the halftone image whose positions are adjacent and color brightnesses have larger difference are recombined for color, making them have the smallest difference in the final color brightness, while maintaining their average color unchanged.
In the RGB color space, any color in the RGB color cube can be represented using the eight vertices of the cube (i.e. eight basic colors, R, G, B, C, M, Y, W, K). To compare the difference in brightness among the basic colors, eight basic colors are arranged in accordance with the brightness level, as shown in Figure 2.

If the two adjacent points are a combination of black and main color (C, M, Y), one of the C, M, Y components of the black can be assigned to the corresponding component of the main color, so the following combinations of minor color (R, G, B) are gained.

\[
\begin{align*}
K & \text{111} \Rightarrow R & \text{011} \\
Y & \text{001} \Rightarrow G & \text{101} \\
K & \text{111} \Rightarrow G & \text{101} \\
C & \text{100} \Rightarrow B & \text{110} \\
K & \text{111} \Rightarrow B & \text{110} \\
M & \text{010} \Rightarrow R & \text{011}
\end{align*}
\]

(1)

If the black is still in the transformed image, the corresponding MBVQ is RGBK.

Similarly, the other five quadruples with the smallest difference in brightness can be gotten. They are WCMY, MYGC, RGMY, RGBM and CMGB, as shown in Figure 3.

Figure 3. The partition of the RGB cube to six tetrahedral volumes, each of which the convex hull of the MBVQ is used to render colors in it
2.2. The MBVQ of the color halftone image

For a color halftone image, all the colors are shown in Figure 4.

\[
\begin{array}{cccccccc}
\text{Color} & \text{K} & \text{B} & \text{G} & \text{C} & \text{R} & \text{M} & \text{Y} & \text{W} \\
\text{R} & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\
\text{G} & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\
\text{B} & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\
\end{array}
\]

Figure 4. All colors of color halftone image

According to the MBVQ algorithm [5], all the MBVQ contained in a color halftone image can be calculated. The calculation shows that for a color halftone image, an arbitrary color can be represented as one of the five quadruples such as KRGB, CMGB, RGBW, RGMY and CMYW.

\[
\begin{align*}
K & \leftrightarrow \text{KRGB} & B & \leftrightarrow \text{KRGB} & G & \leftrightarrow \text{KRGB} & C & \leftrightarrow \text{CMGB} \\
R & \leftrightarrow \text{KRGB} & M & \leftrightarrow \text{RGBW} & Y & \leftrightarrow \text{RGMY} & W & \leftrightarrow \text{CMYW} \\
\end{align*}
\]

(2)

2.3. Error diffusion method [7]

Error diffusion method is a treatment approach for the neighborhood. It produces halftone points by comparing the gray value of the current pixel with the threshold, at the same time the error between the gray value of the current pixel and the threshold is diffused to the surrounding neighborhood pixels, so that the halftone quantization error of the point is not obvious in the final result, and the purpose of weakening artificial texture is achieved. A typical error diffusion system is represented in Figure 5, and the description of the error diffusion method is as follows.

\[
x(i,j) + h(k,l) = u(i,j) + q(\cdot)
y(i,j) = u(i,j)
\]

Figure 5. Block diagram of the error diffusion system

1) Calculate the feedback error \(a(i,j)\). \(e(i,j)\) is the quantization error, \(h(k,l)\) is the weight factor of error diffusion kernel.

\[
a(i,j) = \sum_{k,l=1}^{1} e(i-k, j-l) h(k,l)
\]

(3)

2) Update pixel value \(u(i,j)\). \(x(i,j) \in [0,1]\) represents the original continuous tone value.

\[
u(i,j) = x(i,j) + a(i,j)
\]

(4)

3) Compare the updated pixel value \(u(i,j)\) with the threshold \(T\). The output \(y(i,j) \in \{0,1\}\) is the halftone output, and \(T\) is generally 0.5.

\[
y(i,j) = \begin{cases} 
0 & u(i,j) < T \\
1 & u(i,j) \geq T 
\end{cases}
\]

(5)

4) Calculate the quantization error.

\[
e(i,j) = u(i,j) - y(i,j)
\]

(6)

3. A digital watermark embedding algorithm based on MBVQ

In this section the watermark embedding process for the color halftone image based on MBVQ is introduced. This process includes the following aspects: 1) the selection, encryption and dimension
reduction of the binary watermark, 2) the selection of the embedding locations for the watermark, 3) the digital watermark embedding.

3.1. The selection, encryption and dimension reduction of the binary watermark

In this paper, Arnold transform method [8] is used to scramble the binary watermark image of size \( P \times Q \) which is denoted by \( S={S(m,n), 1\leq m\leq P, 1\leq n\leq Q} \), and the iteration time \( t \) is recorded in order to use when extracting the watermark. Then scrambled watermark image of size \( P \times Q \) changes from two-dimensional image to one-dimensional watermark sequence denoted by \( M={M(k), 1\leq k\leq P \times Q} \).

3.2. The selection of the embedding locations for the watermark

Embedding the watermark in different locations of the image will get different results. It is well known that the halftone image is composed only of black or white (0 or 1) pixel. If the pixel values are randomly changed when embedding the watermark, the image will produce a clear pepper-like noise, which can cause image distortion. Figure 7(a) is an edge region of a halftone image. Figure 7(b) is the result after modifying one pixel in all black region and all white region respectively and Figure 7(c) is the result after modifying one white pixel in the edge region. Comparison of the three figures can find that when embedding the watermark in the edge region, the human eyes are not easy to detect, and the image has no significant distortion [9]. Therefore, the edge regions are selected to embed the watermark.

![Figure 7. The edge region of a halftone image](image)

A halftone image can be seen as a rough edge image, apparently Sobel, Prewitt, Canny and other common edge detection operators cannot be used to extract the edge. So in this paper, the edge of the given continuous tone image is extracted to approximate the edge of the corresponding halftone image using a Canny edge detection operator. The noise visible function [10] of the edge can reflect local texture masking effect of the image. The smaller NVF value indicates the more complex texture in that position, which means it allows the more noise, so it is more suitable for embedding the watermark. The NVF value at position \((i, j)\) is calculated as (7):

\[
NVF = 1/(1 + \delta_x^2(i, j))
\]

\[
\delta_x^2(i, j) = (1/(2L+1)^2) \sum_{m=-L}^{L} \sum_{n=-L}^{L} (x(i+m, j+n) - x(i, j))^2
\]

\[
x(i, j) = (1/(2L+1)^2) \sum_{m=-L}^{L} \sum_{n=-L}^{L} x(i+m, j+n)
\]

Selecting the embedding locations of the digital watermark is summarized in Figure 8.

![Figure 8. Embedding positions of the digital watermark](image)

3.3. The embedding process of the digital watermark
After the watermark embedding positions are determined, the selected $P \times Q \times 2$ positions are sorted by row and column. They are divided into two parts, the former $P \times Q$ positions are $Part1$, and the latter $P \times Q$ positions are $Part2$. In the process of the color sub-channel error diffusion which is Floyd-Steinberg error diffusion method [7], if the current processing pixel is located in $Part2$, the current pixel location need to be embedded the watermark. By calculating the MBVQ values of the current pixel and its corresponding pixel in the $Part1$ (if the current pixel is at $i$-th position in $Part2$, the corresponding pixel in $Part1$ is also at $i$-th position), we can embed the watermark. If the current watermark bit is “0”, the value of the corresponding pixel in $Part2$ should be modified to make the two pixels belong to the same quadruple. If the current watermark bit is “1”, the pixel value should be modified to make the two pixels belong to different quadruples.

The steps of the watermark embedding algorithm are as follows, specifically shown in Figure 10.

1) Enter the original image $X$, initially $i=1$, $j=1$ (the original image is a color image of size $M \times N$ with 256 level denoted as $X = \{X(i, j), 1 \leq i \leq M, 1 \leq j \leq N\}$);
2) Traverse every position at Position $(i, j)$ to use sub-channel Floyd-Steinberg error diffusion, then get the output $Y(i, j)$ ($Y = \{Y(i, j), 1 \leq i \leq M, 1 \leq j \leq N\}$ is the watermarked halftone image);
3) Current processed pixel is $Y(i, j)$, and its position is at Position $(i, j)$. If Position $(i, j)$ is in $Part2$, the pixel at current position is taken and denoted by $P2$ (that is, $Y(i, j)$), while the corresponding pixel in $Part1$ is also taken and denoted by $P1$. Otherwise, go to 2).
4) Calculate the MBVQ of $P1$ and $P1$, and denote them by $S1$ and $S2$ respectively;
5) Get the current value of the watermark sequence $M(k)$;
6) Rule 1: $M(k)$ is 0, if $S1$ and $S2$ are the same, do nothing; otherwise let the value of $P2$ be equal to the value of $P1$, namely $P2_x = P1_x$, $P2_y = P1_y$, and $P2_z = P1_z$. If $P1_x$, $P1_y$, and $P1_z$ are the RGB values of $P1$, $P2_x$, $P2_y$, and $P2_z$ are the RGB values of $P2$. Go to 2).
7) Rule 2: $M(k)$ is 1, if $S1$ and $S2$ are the same, change the value of $P2$, and the revised rules are shown detailedly in Figure 9. Otherwise, do nothing. Go to 2).

8) Repeat 2)-7) until the entire image $X$ has been processed (i.e. $i=M$, $j=N$).

Figure 9. The revised rules when watermark bit is “1” and $S1$ equals to $S2$

4. The extraction process of the digital watermark

Let the color halftone image to be detected be $Y$, the digital watermark extraction process is as follows.

According to the recorded information about the locations in $Part1$ and $Part2$, the corresponding pairs of the pixels can be found, which are denoted by $P3$ and $P4$. Then according to the MBVQ algorithm, the quadruples which $P3$ and $P4$ belong to can be calculated and denoted by $S3$ and $S4$. If $S3$ and $S4$ are the same (they belong to the same quadruple), the corresponding binary watermark bit is 0. If $S3$ and $S4$ do not belong to the same quadruple, the corresponding binary watermark bit is 1. Finally, the extracted one dimensional binary sequence is changed to two dimensional matrix, and then it is processed by the inverse Arnold transformation (based on the record of the iteration time $t$). So the extracted binary watermark image $S’ = \{S(m, n), 1 \leq m \leq P, 1 \leq n \leq Q\}$ can be gained. The block diagram of the watermark extraction is shown detailedly in Figure 11.
5. Experimental results and analysis

In the experiments, four color images of size 512×512 are selected as the original images which are shown in Figure 12(a)-(d). The digital watermark is a binary image of size 32×32 which is shown in Figure 12(e). The quality of the watermarked image can be measured with PSNR, and the similarity between the extracted watermark and the original watermark can be measured with NC. Their definition can be seen in reference [11].

![Figure 12. The related images](image)

Table 1 is the comparison between our algorithm and Guo’s algorithm [12] which compares PSNR of the watermarked halftone images using the two algorithms. Guo’s algorithm is a low complexity parity-matched error diffusion watermarking method for gray images. Because the original images are color images, Guo’s algorithm is modified to embed the watermark into the B channel of the color image.
<table>
<thead>
<tr>
<th>Test image</th>
<th>PSNR of our algorithm</th>
<th>PSNR of Guo’s algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lena</td>
<td>6.1147</td>
<td>5.4740</td>
</tr>
<tr>
<td>Baboon</td>
<td>5.7985</td>
<td>5.0760</td>
</tr>
<tr>
<td>Peppers</td>
<td>6.3134</td>
<td>5.5713</td>
</tr>
<tr>
<td>Sailboat</td>
<td>5.6373</td>
<td>5.2228</td>
</tr>
</tbody>
</table>

It can be seen that our algorithm has the better invisibility of the watermark, that is to say, the visual effect of the images is better.

Some attacks are added on the halftone watermarked Peppers image respectively to verify our algorithm. Figure 13(a)-(d) is the images attacked by the random alteration, text adding, and geometric cutting filled with black or white respectively. The extracted watermarks are placed in the right of the attacked images. Experimental results show that the quality of the attacked images is significantly decreased, but through the algorithm the identifiable watermark can still be extracted.

![Attacked Images](image1)

Figure 13. The attacked images and the extracted watermark images

Then our algorithm and Guo’s algorithm are compared again after attacking the halftone watermarked Peppers image, and the result is shown in Table 2.

<table>
<thead>
<tr>
<th>Attack</th>
<th>NC of our algorithm</th>
<th>NC of Guo’s algorithm</th>
<th>Correct decoding rate of our algorithm</th>
<th>Correct decoding rate of Guo’s algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random alteration</td>
<td>0.9638</td>
<td>0.9869</td>
<td>0.9492</td>
<td>0.9814</td>
</tr>
<tr>
<td>Text addition</td>
<td>0.9931</td>
<td>0.9841</td>
<td>0.9902</td>
<td>0.9775</td>
</tr>
<tr>
<td>Geometric shear, filled with black</td>
<td>0.9072</td>
<td>0.9259</td>
<td>0.8730</td>
<td>0.8984</td>
</tr>
<tr>
<td>Geometric shear, filled with white</td>
<td>0.9660</td>
<td>0.9682</td>
<td>0.9492</td>
<td>0.9531</td>
</tr>
</tbody>
</table>

As can be seen from Table 2, Guo’s algorithm is better than our algorithm. The main reason is that our algorithm is based on the edge of the image, if the edge is seriously attacked, the extracted watermark is blurred, and Guo’s algorithm is based on the local statistical properties of the block, so it has better robustness to various attacks.

In this paper, the watermark is indirectly embedded in the process of color halftone based on the minimal brightness variation quadruples. Experimental results show that the algorithm has a good invisible watermark and robustness to random alteration, text addition and geometric shear etc.

6. Acknowledgements

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7. References


