Hiding data in ordered dithering halftone images by bit interleaving

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Abstract

In this paper, we present a simple but novel method that does not require the original watermark in decoding to embed watermarks into dithered halftone images by bit-interleaving. In general, the sub-image resulted from bit-interleaving has the property that the sub-image from the consecutive threshold value has increasing number of black pixels. Our method fully utilizes this property such that it not only needs less additive pseudo pixels to eliminate the Non-increased black pixel pairs, but also avoids false positive detection. The experiments show that the technique is sufficiently robust to guard against the cropping and tampering.

1. Introduction

Digital halftoning is a technique to convert multitone images into two-tone format, which is widely used in computer printouts, books, newspapers, and magazines, etc. The two categories of halftoning techniques based on the type of 'dot' are clustered-dot and dispersed-dot dithering. Clustered-dot dithering methods are more suitable for display devices with dot distortion. The dispersed dithering methods offer better visual quality for display devices where dispersed-dot can be accommodated. And it is generally agreed that the blue noise properties are the most pleasant in the category of dispersed dithering [2]. To generate a blue noise halftone image, error diffusion [8][9][10] employs neighborhood operations and direct binarization [11][12] uses multiple iterative optimization algorithms. They are computational expensive compared to ordered dithering. So in this paper we will focus on ordered dithering method. Ordered dithering is still the first choice for the easy and efficient implementation.

To dither an image, each pixel value in the image is compared to the corresponding threshold in the dither matrix. Bayer [3] provided a method to generate the optimum dispersed ordered dithering matrix by putting each consecutive value into a cell furthest away from all previous assigned cell. Ulichney [2] build the matrix by recursive tessellation which recursively filling the center of the largest voids of the matrix. To avoid the fixed pattern artifacts of the above dispersed ordered dithering pattern, methods generate dither matrix with blue noise properties are described in[4][5][6][7].

With the widely used halftone images, it is often desirable to hide data into the halftone images for copyright protection and authentication purposes. To hide watermark into ordered dither halftone image, some methods changed the value of randomly selected pixels [13][14] and the other used different dither matrix that can be statistically discriminated [15][16]. Recently, Pei et al. [1] presented a novel robust method for embedding watermarks into dithered halftone images. The method is named paired sub-image matching ordered dithering (PSMOD). This method provided good embedded quality and good recovery abilities in cropping, tampering, and printed-and-scanned distortions. It groups all of the halftone pixels corresponding to the same threshold value in the halftone screen into sub-images, the process is called bit-interleaving [17], then pairs two consecutive sub-images in the same sequence as the values in the screen matrix. Based on the observation that ideally the sub-image from the consecutive threshold value has increased black pixels, so that one bit can be embedded into a pair by either changing the order of sub-images in each pair or not. To alter the Non-Increased black pixel Pairs (NIPs) into increased black pixel pairs, the solution is to adequately increase the number of the white pixels or black pixels called pseudo-pixels in one of the groups in the pair. The additive black and white pixels affect the tone of the dithered image. Because there are a large portion of NIPs, the decoder is provided with a priori information of the original watermark to reduce the pseudo-pixels required to eliminate the NIPs. Since the watermark is extracted by the "and" operation with the original watermark, the pseudo-pixels only needed in the relative position where the watermark has a black pixel.

After some experiments, we find PSMOD method has a problem of false positive detection because of the "and" operation with the original watermark in the decoder. Though, in general the sub-image resulted from bit-interleaving has the property that the sub-image from the consecutive threshold value has increasing number of black pixels, there is still about 32% of NIPs. As shown in [1], the PSNR of the embedded image decreases as the number of additive pseudo pixels increases. Without this "and" operation, the PSMOD method needs much more pseudo-pixels to eliminate all the NIPs and thus will cause the performance of PSMOD method decrease in both the PSNR and robustness. In this paper, we present a novel method that not only needs less additive pseudo pixels to alter the NIPs into increased black pixel pairs, but also avoids false positive detection. Our method fully utilizes the NIPs in the embedding scheme so that there is no need to "and" with the original watermark in the decoder. Our method needs less additive pseudo pixels, so it has better PSNR performance. Also, the experiments show that our method is sufficiently robust to guard against the cropping and tampering attack.

2. Proposed scheme

The Proposed embedding procedure consists of three steps.

Step 1: Generate the sub-image pairs from the halftoned image.

In general, we can define the halftone screen as an M * N matrix array containing all the integers from 1 to m=N*M. Each pixel $f_{i,j}$ in the original gray-level image is compared with the corresponding value in the dither matrix and mapped to a white or black pixel $x_{i,j}$. Let $x_{i,j,1}, x_{i,j,2}, \dots, x_{i,j,m}$ be the sub-image sequence after bit-interleaving. Those pixels resulted from comparison with a given threshold value k of the dither matrix are combined to form a sub-image named $x_{i,j,k}$. We pair the two consecutive sub-images as $(x_{i,j,2t-1}, x_{i,j,2t})$, for t = 1, 2, ..m/2, to produce m/2 pairs of sub-images.

Step 2: Exclusive-or p_t with w_t, generating w_t'.

For all the pairs, we count their occurrence of the black pixel of each sub-image, and record the order of each pair. Let p_t , t = 1, 2, ..m/2, denote the order of each sub-image pair. The value of p_t is equal to 0 if $x_{i,j,2t-1}$ has less black pixels than $x_{i,j,2t}$, otherwise p_t is equal to 1. p_t equals to 1 means that pair $(x_{i,j,2t-1}, x_{i,j,2t})$ is a NIP and p_t equals to 0 means that it is an Increased black pixel Pair (IP). Each pair can embed a bit. Let w_t , t = 1, 2, ..m/2, denote the watermark we want to embed. w_t is exclusive-ored (xor) with p_t to generate w_t'.

Step 3: Embed w_t'.

If w_t' is equal to 1, $(x_{i,j,2t-1}, x_{i,j,2t})$ is swapped into $(x_{i,j,2t}, x_{i,j,2t-1})$. After swapping, The NIPs will become IPs except for those NIPs that have the same number of black pixels in the sub-images. In this case, it needs one additive pseudo pixel to make the pairs into IPs. The watermarked image is generated by inverse bit-interleaving of the swapped subimages.

To extract the wartermark from the embedded image, we can simply check the order of each sub-image pair of the watermarked image. If the pair is a non-increased black pixel pair, then the corresponding embedded watermark bit is 1, else it is 0. Let p_t', t = 1, 2, ..m/2, denote the order of each sub-image pair of the watermarked image. It can be proved that w_t is the same as p_t'.

To increase the embedded capacity, one can use the method that utilizes the strategy of further dividing each bit-interleaved sub-image into sub-sub-image (SSI) as described in [1].

Lemma:

$p_t' = p_t \text{ xor } w_t'$.

The proof of the lemma is immediate due to our embedding operation is to change the order of the sub-image pair if the corresponding embedded bit is equal to 1. This is equivalent to a logical exclusive or operation.

Claim:

If $w_t' = (w_t \text{ xor } p_t)$ then $p_t' = w_t$.

The proof of the claim is immediate. Since from the lemma

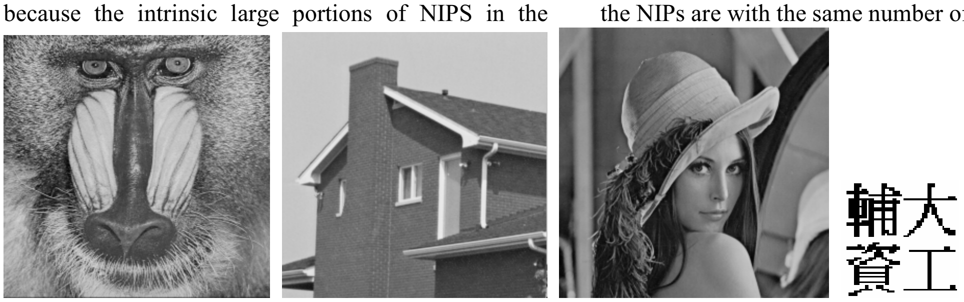
$$\begin{aligned} p_t' &= p_t \text{ xor } w_t' \\ &= p_t \text{ xor } (w_t \text{ xor } p_t) \\ &= w_t. \end{aligned}$$

And this completes the proof.

3. Experimental result

In the experiments, we used 512x512 halftone "Mandrill", "House" , "Lena" and a 64x64 watermark logo as shown in Fig. 1 to test the algorithms. The dither matrix is 4x4 as shown in Fig 2(a). The halftone image of "Lena" as shown in Fig. 2(b) is bit-interleaved into 16 sub-images as shown in Fig. 2(c) then every sub-image is divided into 16x32 sub-sub-images as shown in Fig. 2(d). Watermark of size 16x16x32/2, i.e. 64x64 thus can be embedded into the halftone image.

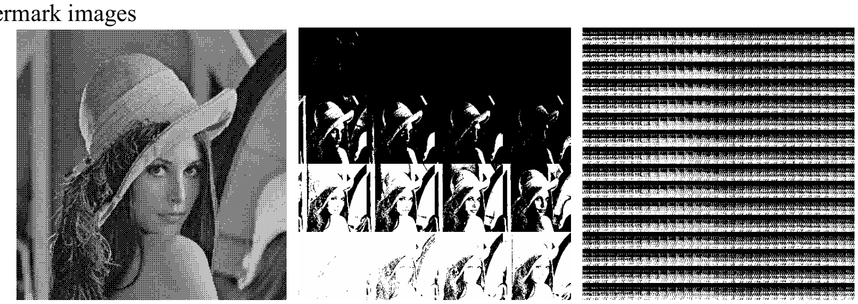
Table I. shows the number of NIPs of the algorithms and the associated number of additive pseudo pixels required to alter them into increased black pixel pairs. From Table I, The number of NIPs of the image itself is about 32%. Because of the “and” operation with the watermark in PSMOD [1], the number of NIPs required to be altered can be reduced. From Table I, it is reduced from 32% to 10% depending on the distribution of bit “1” in the watermark data. But because the intrinsic large portions of NIPS in the image, there are about 32% of the extracted watermark will be “1” within those un-watermarked images and will possibly cause a false positive detection after “and” with the watermark. Table II shows the false positive detection on the three halftone images. From Table II, the watermarks can be clearly identified from the extracted watermark of the original halftone images. Also from Table I, the NIPs of our method is slightly less than that of PSMOD. This tells us that most of the NIPs are with the same number of black pixel.



(a)Mandrill (b) House (c) Lena (d) Watermark image

Fig.1 The tested and watermark images

2	14	3	15
10	6	11	7
4	16	1	13
12	8	9	5



(a) 4x4 dispersed-dot dither matrix. (b) Halftoned Lena (c)Sub-images (d)Sub-sub-images

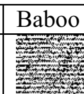
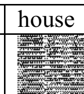
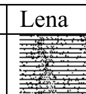
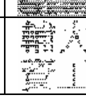
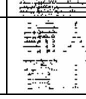
Fig. 2 (a) 4x4 dispersed-dot dither matrix. (b)Dithered Lena (c) Sub-images (d) Sub-sub-images

Table I. the number of NIPs and additive pseudo pixels

Method	PSMOD			PSMOD without "AND"			Our Method		
Image	Mandrill	House	Lena	Mandrill	House	Lena	Mandrill	House	Lena
Number of NIP	411	451	350	1641	1808	1364	356	414	333
Number of additive pseudo pixels	497	491	368	2086	1989	1458	356	414	333
Decoding error rate(without pseudo pixels)	10.03%	11.01%	8.54%	31.37%	34.03%	31.46%	8.69%	10.10%	8.12%

For the robust testing, all the 3 images are cropped by 1/4 portion and tampered. Two samples of the cropped and tampered images and their extracted watermark are shown in Fig. 3. The average correct decoding rate of 94.70% is obtained with the cropping attack and 86.42% is obtained with the tampering attack. Because of no “and” operation of our method, our correct-decode rate is not as high as that achieved by PSMOD.

Table II the false positive detection

	Baboo	house	Lena
Extracted Without “and” operation			
Extracted With “and” operation			

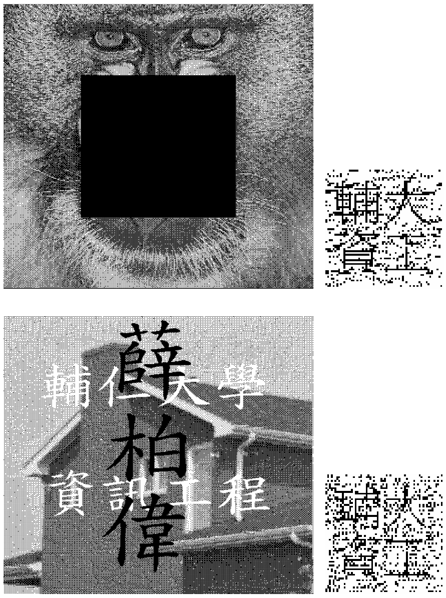


Fig. 3 Robust watermarking testing.

4. Conclusion

In this paper, we present a simple but novel method that not only needs less additive pseudo pixels to alter the NIPs into increased black pixel pairs, but also avoids false positive detection. Since our method utilizse the bit-interleaving in the same way as that used in [1] except the "and" operation and the additive pseudo pixels required, most of the experimental result in [1] are still true for us, so we did not doing all the experiments such as printed-and-scanned process. Our method meets the requirement of blindness and requires less additive pseudo pixels, so it has better PSNR performance. Because of no "and" operation of our method, our correct-decode rate is not as high as that achieved by PSMOD. This is what we plan to research in the future to increase the robustness of the algorithm.

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