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Printed Image Watermarking with Synchronization Using Direct Binary Search

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Abstract

In this paper, we reveal the impact of the fixed synchronization pattern on the halftone image under DBS processing; and an improved watermarking method is proposed to avoid this impact, which is extended from a previously developed DBS based watermarking method. The watermark and synchronization pattern is to be embedded into the appropriate region of the host image adaptively; and excellent image quality and decent watermark capacity is provided. The method has good resistance to a printing and scanning attack while only size of the watermark and host image is required additionally in the watermark detection. Experimental results are presented for some special host images, including a sketch and a round logo to prove the flexibility of the method.

Introduction

In the recent years, the technique of digital image watermarking has been widely studied because of its great contribution to protecting ownership rights, tracking content usage, and ensuring authorized access. Among different kinds of digital image watermarking techniques, halftone image watermarking is a very fascinating one. During halftone image watermarking, the watermark is embedded in the halftoning process by exploiting the characteristics of the halftone image. Because the halftoning process is a necessary step in printing, halftone image watermarking has an intrinsic advantage for watermarking printed materials.

There are a number of methods proposed for halftone image watermarking or data hiding. According to the halftoning techniques they employed, most of the methods can be classified into three categories[1]: ordered dithering (OD), error-diffusion (ED), and direct binary search (DBS) based methods. The basic idea of OD based methods, e.g. in [2], is to embed the watermark using a number of different dither cells in the halftoning process. The stochastic dithering based method, e.g. in [3] is a variant of OD based methods. They require low computation but have difficulty in achieving high visual quality or watermark capacity. Error diffusion is widely used for watermarking because of its good visual quality and moderate computational complexity. Many different schemes [4, 5] has been proposed.

Among all the halftone techniques, DBS [6] offers the best visual quality. Some DBS based halftone image watermarking methods try to take advantage of it. The DBS-based orientation modulation (OM) [7] scheme is a creative one. It utilizes different halftone texture orientations to carry different watermark data. In other words, it hides the watermark in the frequency domain. Because of it, precise printing and scanning correction is not necessary. In [8], a synchronization method without synchronization pattern inserted is proposed for the OM watermarking scheme. The OM method is robust to P&S attack and offers excellent visual quality. However, the watermark capacity is severely limited in such schemes. In [9], the watermark capacity of OM is quantitatively analyzed. A more straight-forward DBS based watermarking scheme is to hide the watermark in the spatial domain, e.g. [10]. Unfortunately, this method is rather time consuming and gray-scale host image is required while decoding. In 2016, Wang proposed a new DBS based watermarking scheme [1]. Wang's scheme jointly optimizes the halftone, watermark, and synchronization pattern. It offers excellent visual quality in many cases and requires less computational consumption. In his scheme, the spatially embedded watermark requires precise P&S correction and it is exactly the reason that synchronization patterns are inserted. Not like the way in [7], Wang's scheme inserts the synchronization pattern in the spatial domain. It degrades the visual quality to some extent. Wang hypothesizes that the synchronization pixels only take up a minor portion of all pixels, so their impact is negligible. But he doesn't show any experimental result.

In this paper, we will present an experiment that reveals the impact of the synchronization pattern after an DBS process. We prove that the impact is negligible only in the mid-tones. In order to avoid such impact, we propose a watermarking scheme as an extension of [1]. In our strategy, a well-defined synchronization dot is only inserted into the suitable region. The data embedding and synchronization define a specific structure in the space of halftones, and the optimal halftoning solution is to be searched within this restricted structured space. In the P&S correction, we use a local linear transformation to estimate the global nonlinear transformation.

The rest of this paper is organized as follows. Section 2 reveals the impact of synchronization pattern and describes our improved watermarking scheme. Some experimental results and conclusions are presented in Sections 3 and 4.

Improved method

In this section, we reveal the impact of the synchronization pattern firstly. Based on the rules we find, we propose an improved watermarking method based on [1], including data embedding, P&S correction and decoding.

Throughout this paper, we use $[\mathbf{m}] = [m,n]$ and $(\mathbf{x}) = (x,y)$ to represent discrete and continuous spatial coordinates, respectively. Let $f[\mathbf{m}]$ denote the continuous-tone host image, and $h[\mathbf{m}]$ the watermarked halftone. It is assumed that both $f[\mathbf{m}]$ and $h[\mathbf{m}]$ take values between 0 and 1, i.e. $0 \le f[\mathbf{m}] \le 1$ and $h[\mathbf{m}] = 0$ or 1, where 0 and 1 represent pure black and white, respectively.

Impact of synchronization pattern

The dashed line is a typical synchronization pattern. In this paper, we use $L \times L$ pixels dashed boxes as the synchronization

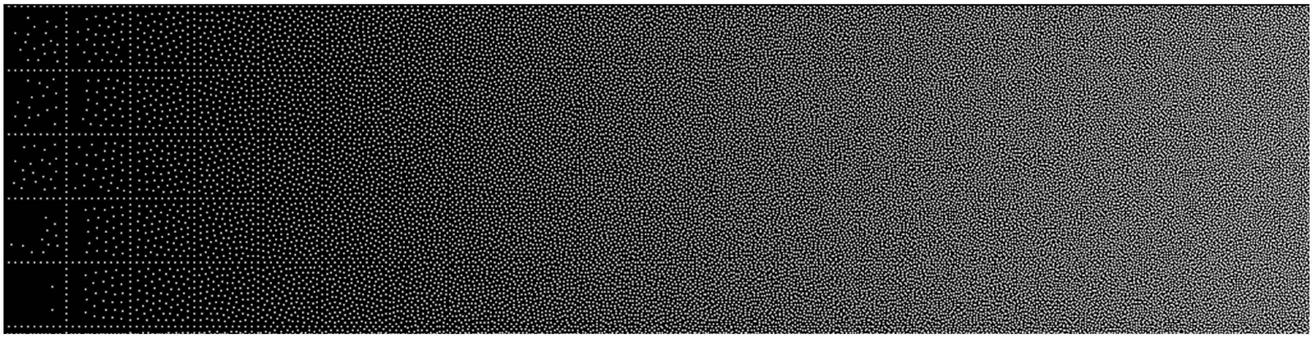


Figure 1. *The first ramp image*

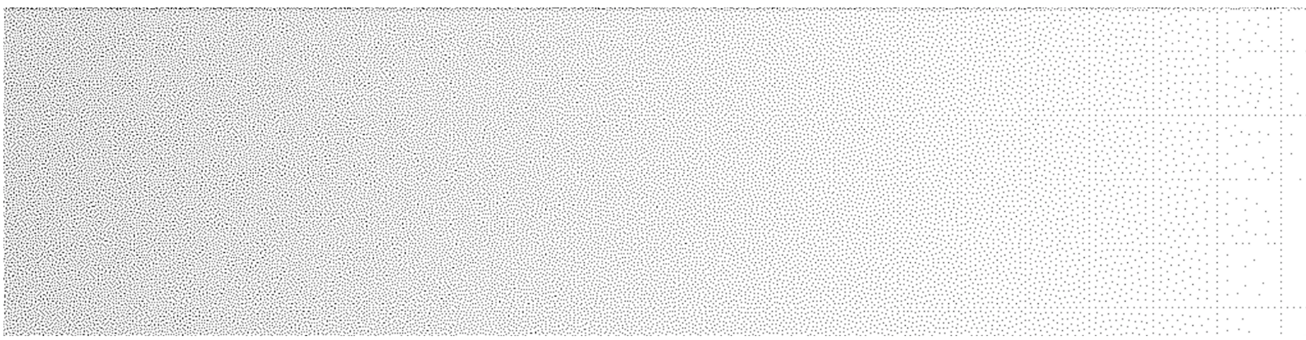


Figure 2. *The second ramp image*

pattern we focus on. The interval between two consecutive dots of a dashed box are r. The dashed boxes are to be inserted into the watermarked halftone. Here we use $L = 70$ and $r = 5$.

Let set S_i consist of all the coordinates of dots of the ith dashed box. Let $\mathbf{p_i} = [p_i, q_i]$ denote the coordinate of the left-up pixel of the ith dashed box. We have two kinds of dashed boxes: white and black. We denote $\bar{g}_i$ as the average gray level of the region within the ith dashed box in the host image, i.e.

$$\bar{g}_i = \frac{1}{(L+1)^2} \sum_{a=0}^{L} \sum_{b=0}^{L} f[p_i + a, q_i + b] \tag{1}$$

The type of the dashed box depends on $\bar{g}_i$, i.e.

$$h[\mathbf{m}] = \begin{cases} 1, \bar{g}_i \leq 0.5 \\ 0, otherwise \end{cases}, \forall \mathbf{m} \in S_i \tag{2}$$

In this way, the synchronization pattern pixels take the minor value among the pixels of the region within the dashed boxes in the watermarked halftone image so that it will be easier to detect the synchronization pattern in the decoding process.

Because the synchronization pattern is regular, it is perceptible if we insert the synchronization pattern after the halftoning process. Alternatively, we insert the synchronization pattern into a randomly generated image. Then we perform DBS on the pixels of the the image except the synchronization pixels based on the host image. The DBS spontaneously optimizes the pixels around the synchronization pattern to make it less perceptible.

However, let us imagine an extreme case. We insert some dashed boxes into a solid white image. We have enough reason to assume that the DBS process has no effect on this case in that there is no pixel that can be changed in the DBS process when it is a solid white image. What's more, the black dashed box is more conspicuous in a solid white image in nature. We can also expect a same outcome with a solid black image.

Furthermore, we come up with an assumption: After the DBS process, the visibility of the synchronization pattern depends on the local average gray level of the host image. To verify and analyze the relationship, we generate two ramp images. The gray level varies from 0 to 63/255 in the first ramp image and from 192/255 to 1 in the second ramp image. We perform DBS on them with consecutive dashed boxes inserted. The result is shown in Fig.1 and Fig.2.

We can see the dashed boxes in leftmost of Fig.1 and rightmost of Fig.2 are clearly visible. When we approach the middle part of both images, they begin to vanish. We can conclude that the synchronization pattern inserted in the mid-tone region only degrades the image quality slightly. Therefore, we should only insert the synchronization pattern in the mid-tone region and avoid doing it in the other regions. We determine two threshold: t_l and t_u. If a region R in the host image satisfies,

$$t_l \leq f(\mathbf{m}) \leq t_u, \forall \mathbf{m} \in R \tag{3}$$

we call it a safe region. We only embed the synchronization pattern into the safe regions. In this paper, we take $t_l = 30/255$ and $t_u = 220/255$ based on Fig.1 and Fig.2.

Data embedding

Before watermarking, we need to find all the safe regions in the host image, and then place as many dashed boxes as possible in the safe regions. The function of synchronization pattern (dashed boxes) is to recover the distorted watermarked image after printing and scanning (P&S). Apparently, the regions outside the dashed boxes cannot be recovered, which prevents decoding the watermark embedded in these regions. Therefore, we only embed the watermark into the regions within the dashed boxes. This is the hierarchy: whole image, safe regions, regions bounded by dashed boxes, pixels used for watermark.

During the data embedding process, the key is to generate a mask $W[\mathbf{m}]$ and an initial $h[\mathbf{m}]$, which both have the same dimension with the host image. If $W[\mathbf{m}] = 0$, $\mathbf{m}$ is a free pixel in the watermarked halftone. If $W[\mathbf{m}] = 1$, $\mathbf{m}$ is used for data embedding. If $W[\mathbf{m}] = 2$, $\mathbf{m}$ is used for synchronization. The mask is generated as the following steps:

1. $W[\mathbf{m}] = 0, \forall \mathbf{m}$
2. Find the safe regions in the host image. Scan each coordinate $\mathbf{m} = [m,n]$ that satisfies $m \mod 10 = 0$ and $n \mod 10 = 0$ from left to right and up to down. Set m to be the left-up coordinate of a dashed box and verify if the whole dashed box resides in the safe region. If so, calculate S, which is the set of the coordinates of the dots on the edge of the dashed boxes. Let $W[\mathbf{m}] = 2, h[\mathbf{m}] = 1, \forall \mathbf{m} \in S$ if it is a white dashed box and otherwise $W[\mathbf{m}] = 2, h[\mathbf{m}] = 0, \forall \mathbf{m} \in S$.
3. Repeat the step 2 until no dashed box can be placed. Note that the dashed boxes don't overlap with each other.
4. All $\mathbf{m}$ within the dashed boxes constitute a set A. Fig.3 shows an example of how elements in set A distributes and the location of the dashed boxes. With a given key, we randomly select n pairs of coordinates from A, where n is the length of the watermark. Define $b[i] \in \{0,1\}$ as the ith bit of watermark. For a pair $(\mathbf{m_i}, \tilde{\mathbf{m}}_\mathbf{i})$, we force them to be correlated according to its embedded bit $b[i]$ as

$$h[\mathbf{m_i}] = \begin{cases} h[\tilde{\mathbf{m}}_\mathbf{i}], & b[i] = 0 \\ 1 - h[\tilde{\mathbf{m}}_\mathbf{i}], & b[i] = 1 \end{cases} \quad (4)$$

and $W[\mathbf{m_i}] = W[\tilde{\mathbf{m}}_\mathbf{i}] = 1$

(a) Host image (b) Location of dashed boxes

Figure 3. *An example of data embedding process*

Afterwards, we can perform the modified DBS in [1] on the initial $h[\mathbf{m}]$. That is only toggle operation is allowed when $W[\mathbf{m}] = 1$. And $h[\mathbf{m_i}]$ and $h[\tilde{\mathbf{m}}_\mathbf{i}]$ toggle together. When $W[\mathbf{m}] = 0$, we can perform toggle and swap operations. When $W[\mathbf{m}] = 2$, we never change $h[\mathbf{m}]$.

P&S correction and decoding

During the printing and scanning process, the major geometric distortion is due to rotation, scaling and displacement. Fortunately, they are just linear transformations that can be easily dealt with. However, there exists minor global nonlinear distortion. The global nonlinear distortion can be caused by a different ratio between the horizontal and vertical directions both in printing and scanning, wrinkle in the paper and many other reasons. If the global nonlinear distortion is severe, the P&S correction is extremely hard. In this paper, we only consider the slight global nonlinear distortion case.

When the global nonlinear distortion is slight, we can assume it is almost linear distortion in the local region. So if we can detect the dashed boxes in the watermarked image, we can calculate the local linear transformation and correct the image locally. This is the key idea of our P&S correction method.

In the P&S correction and decoding process, only the scanned watermarked image (gray scale), the key, dimension of the host image, and watermark are available. The steps are:

1. Rough global correction: Detect the vertices of the watermarked image in the scanned image. Calculate the global projective transformation based on the four detected vertices and then restore the whole watermarked image with the homography technique. Finally, implement appropriate thresholding. An example is shown in Fig.4. Note that it is only a rough recovered bitmap of the watermarked image because of nonlinear geometry distortion. Then we convert the roughly restored watermarked image into a gray-scale image by calculating the mean value around each pixel. Find all the safe regions in it. The coordinates of the all the pixels of the safe regions constitute a set G.

(a) Scanned image (b) Rough recovered image

Figure 4. *An example of P&S correction: step 1*

2. Determine global image center $\mathbf{x_c}$ and rotation angle θ: From the scanned image, scratch the rough boundary of the printed dots from the blank background. The spatial coordinate sets of the four detected edges (i.e. top, bottom, left and right) are denoted as $E_i, i = 1,2,3,4$. Given $\mathbf{x_c}$ and θ, the line equations of four edges are known and can be denoted by

$$H^{(i)}_{(\mathbf{x_c},\theta)}(\mathbf{x}) = 0, i = 1,2,3,4 \quad (5)$$

where $\mathbf{x}$ is the spatial coordinate in scanned image. The parameters $\mathbf{x_c}$ and θ are given by

$$\{\mathbf{x_c}, \theta\} = \underset{\{\mathbf{x_c},\theta\}}{\arg\min} \sum_{i=1}^{4} \sum_{x \in E_i} ||H^{(i)}_{(\mathbf{x_c},\theta)}(\mathbf{x})||^2 \tag{6}$$

3. Find all possible locations of the dashed boxes: As for a coordinate set of a dashed box with left-up pixel $\mathbf{m}$ in the bitmap, we denote it as $S_{\mathbf{m}}$. The set $A_{\mathbf{m}}$ contains the coordinates of pixels within the $\mathbf{m}$ dashed box. We denote the length of a set S as $L(S)$. All possible $\mathbf{m}$ must satisfy:
   1. $m \mod 10 = 0$ and $n \mod 10 = 0$
   2. $\frac{L(A_{\mathbf{m}} \bigcap G)}{L(A_{\mathbf{m}})} \geq 0.8$
4. Estimation of local similarity transformations: The local similarity transformation of the $\mathbf{m}$ dashed box $T^{(\mathbf{m})}_{\mathbf{x_{c,m}},\theta_{\mathbf{m}}} : \mathbf{x}' \to \mathbf{x}$, from bitmap to scanned image can be written as

$$\mathbf{x} = T^{(\mathbf{m})}_{\mathbf{x_{c,m}},\theta_{\mathbf{m}}}(\mathbf{x}') = \mathbf{D}_{\theta_{\mathbf{m}}}(\mathbf{x}' - \mathbf{x}'_{\mathbf{c,m}}) + \mathbf{x_{c,m}} \tag{7}$$

where $\mathbf{x}'_{\mathbf{c,m}}$ and $\mathbf{x_{c,m}}$ denote the $\mathbf{m}$ dashed box center in bitmap and scanned image respectively, $\mathbf{D}_{\theta_{\mathbf{m}}} = \lambda[\mathbf{u_x}, \mathbf{u_y}]$, $\mathbf{u_x} = [cos\theta_{\mathbf{m}}, sin\theta_{\mathbf{m}}]^T$, $\mathbf{u_y} = [-sin\theta_{\mathbf{m}}, cos\theta_{\mathbf{m}}]^T$, and λ is the scale ratio. The parameters $(\mathbf{x_{c,m}}, \theta_{\mathbf{m}})$ are initialized as $(\mathbf{x^{(0)}_{c,m}}, \theta^{(0)}_{\mathbf{m}})$, where $\mathbf{x^{(0)}_{c,m}} = T_{\mathbf{x_c},\theta}(\mathbf{x}'_{\mathbf{c,m}})$ and $\theta_{\mathbf{m}} = \theta$. We refine the parameters by searching within in the neighbourhood of initial values. Write the refined estimator as $\mathbf{x_{c,m}} = \mathbf{x^{(0)}_{c,m}} + \Delta\mathbf{x_{c,m}}$, $\theta_{\mathbf{m}} = \theta^{(0)}_{\mathbf{m}} + \Delta\theta_{\mathbf{m}}$. Then we find

$$\alpha_1 = \min_{\Delta\theta_{\mathbf{m}},\Delta\mathbf{x_{c,m}}} \sum_{\mathbf{x}' \in S_{\mathbf{m}}} \frac{1}{L(S_{\mathbf{m}})} \bar{f_{PS}}[T^{(\mathbf{m})}_{\mathbf{x^{(0)}_{c,m}}+\Delta\mathbf{x_{c,m}},\theta^{(0)}_{\mathbf{m}}+\Delta\theta_{\mathbf{m}}}(\mathbf{x}')] \tag{8}$$

$$\alpha_2 = \max_{\Delta\theta_{\mathbf{m}},\Delta\mathbf{x_{c,m}}} \sum_{\mathbf{x}' \in S_{\mathbf{m}}} \frac{1}{L(S_{\mathbf{m}})} \bar{f_{PS}}[T^{(\mathbf{m})}_{\mathbf{x^{(0)}_{c,m}}+\Delta\mathbf{x_{c,m}},\theta^{(0)}_{\mathbf{m}}+\Delta\theta_{\mathbf{m}}}(\mathbf{x}')] \tag{9}$$

where $\bar{f_{PS}}[\mathbf{x}]$ denotes the gray-scale mean value of $\lambda \times \lambda$ square scanned image centered at $\mathbf{x}$. Then we find the final fit rate α by

$$\alpha = \min\{\alpha_1, 1 - \alpha_2\} \tag{10}$$

If $\alpha \leq 0.05$, we find the corresponding $\mathbf{x_{c,m}}$ and $\theta_{\mathbf{m}}$. Recover the local bitmap $\hat{g}[\mathbf{m}]$ within the $\mathbf{m}$ dashed box. Calculate the local average gray level of the recovered bitmap $\bar{g_{\mathbf{m}}}$. Then check

$$t_l \leq \bar{g_{\mathbf{m}}} \leq 0.5, \text{ if } \alpha_1 \geq 1 - \alpha_2 \tag{11}$$

$$0.5 < \bar{g_{\mathbf{m}}} \leq t_u, \text{ if } \alpha_1 < 1 - \alpha_2 \tag{12}$$

If it doesn't satisfy these conditions, we think it is a fake dashed box and discard the local recovery.
We process all possible locations of dashed boxes from left to up and up to down. Now We get the recovered bitmap within all the dashed boxes.
5. Decode the watermark from the recovered bitmap with the key. The method is just the reversed process of the step 4 of data embedding.

Experimental result

Watermark capacity, watermarked halftone image quality, and robustness to P&S attack are three aspects for evaluating the performance of our improved watermarking method. The capacity is represented by watermark rate (WMR), the watermarked halftone quality is evaluated by its HVS-based peak signal-to-noise ratio (HPSNR), and the robustness is by watermark decoding bit error rate (BER) after P&S. The exact definitions of WMR, HPSNR, and BER are listed as follows:

$$\text{WMR} = \frac{\text{number of bits of } b[i]}{MN} \tag{13}$$

$$\text{HPSNR} = 10\log_{10}\frac{MN}{E[f,g]}(dB) \tag{14}$$

$$\text{BER} = \frac{\sum_i \hat{b}[i] \oplus b[i]}{\text{number of bits of } b[i]} \tag{15}$$

where M, N is the size of the watermarked halftone, $E[f,g]$ is the total HVS-based perceived error.

We demonstrate our results on three host images of Lena, Logo, and Sketch, which are shown in Fig.5. Three watermark images shown in Fig.6 are to embedded into the host images. They have the 45×45, 100×100, and 150×150 pixels respectively.

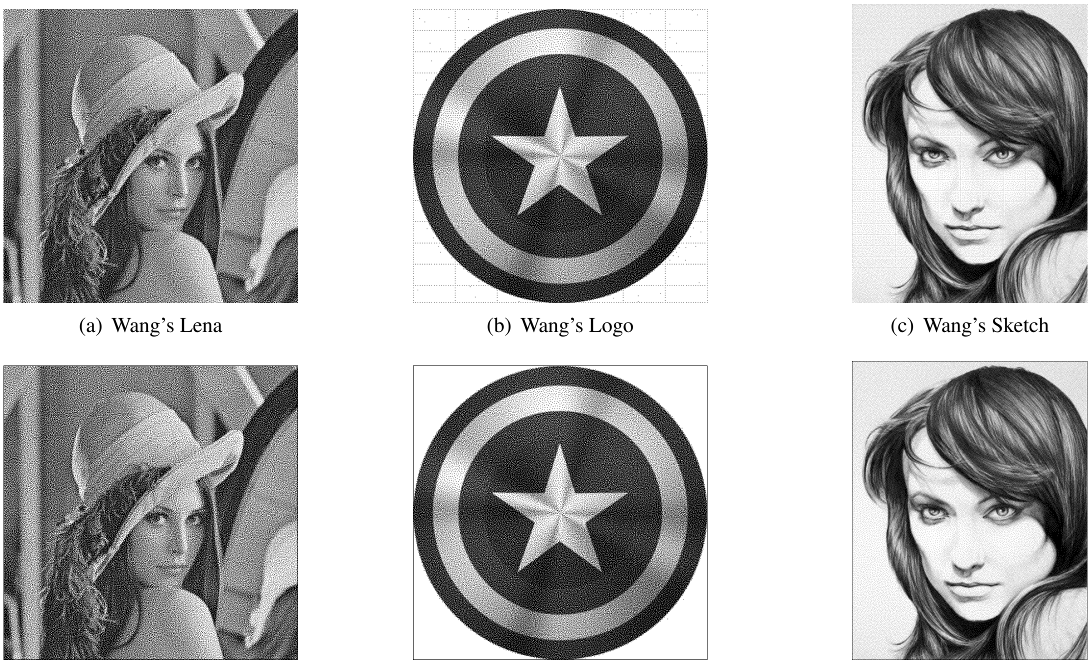
(a) Lena (b) Logo (c) Sketch

Figure 5. Host images

(a) 45×45 (b) 100×100 (c) 150×150

Figure 6. Watermark images

As an improved method based on Wang's watermarking scheme[1], we make an comparison with his work. We embed the 45×45 watermark into the three host images based on his method and ours respectively. The results are shown in Fig.7. We can see almost part of the Lena image is in mid-tone, so there is no conspicuous difference between our result and Wang's. The Logo image is an extreme case. The background of it is blank. In Wang's result, the dashed lines are clearly visible, but we can hardly see the dashed lines in our result. The Sketch image is a general case our method aimed to deal with. Obviously our method provides a better visual quality. In Table 1, we present the



(a) Wang's Lena (b) Wang's Logo (c) Wang's Sketch

(d) Our Lena (e) Our Logo (f) Our Sketch

Figure 7. *Comparison between Wang's method and ours in the electronic form*

Host	Method	Watermark size		
		45×45	100×100	150×150
Lena	Wang	40.7	40.6	40.4
	Our	40.7	40.5	40.1
Logo	Wang	37.4	37.0	36.9
	Our	41.6	41.1	38.9
Sketch	Wang	39.5	39.4	39.4
	Our	39.9	39.8	39.6

Table 1. Watermarked halftone quality HPSNR

visual quality (HPSNR). In our experiments, WMR varies from 0.3% to 8.6%, respectively.

To demonstrate our P&S correction and decoding process, we present the decoded watermark images from the three different watermarked images in Fig.7. The halftone is printed at 150 dpi with an HP Deskjet Ink printer and scanned at 600 dpi with an Epson Perfection V19 scanner. The BER of them are 0.35%, 0.85%, and 0.4%. The error rate is very low, which means the watermark can be extracted precisely using our method.

(a) From Lena (b) From Logo (c) From Sketch

Figure 8. *Decoding results*

Conclusion

In this paper, we reveal for the first time the impact of the fixed synchronization pattern on the halftone image under the DBS process. We propose an improved watermarking method. The watermark and synchronization pattern are only allowed to be embedded into the safe region, which resolves the impact of the synchronization pattern. And also, the watermark can be embedded to any shape of images. We use local linear transformation to estimate the global nonlinear transformation in the decoding process.

In the decoding process, we set some experimental parameters. When we change the printing and scanning equipment, we have to adjust the parameters, which decreases the robustness. A further direction of this work is to solve this problem.

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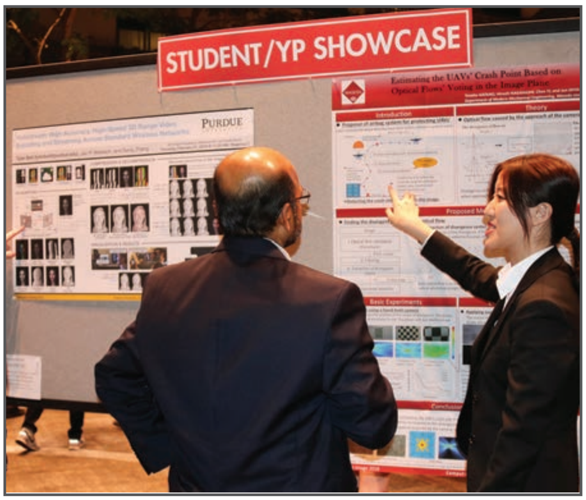

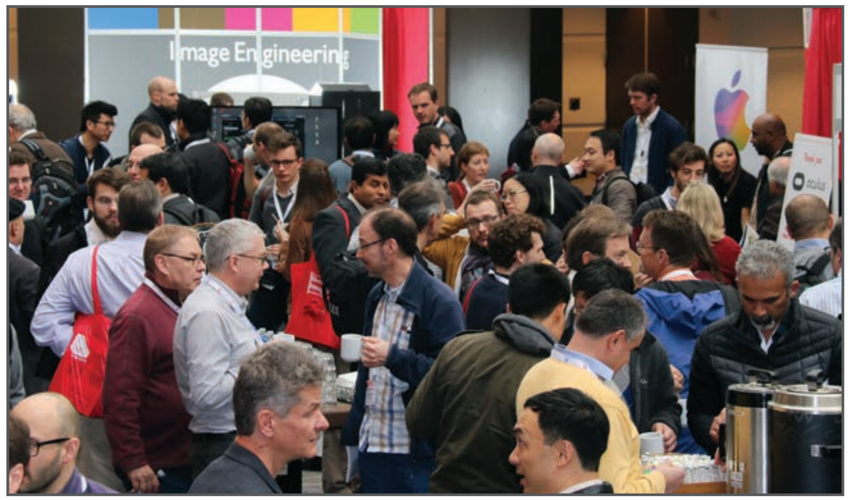

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