A New Edge Enhancement on Halftone Image

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Abstract— This paper presents a new algorithm for improving the qualities of edge in halftone image. The algorithm is designed to diminish discontinuous and jaggy artifact on edges of halftone image without original image data. And our proposed algorithm does not depend on the special halftoning scheme since no inverse halftoning is included. It provides a possible way of low-cost processing directly on the halftone image which is independent of the original image. This algorithm can be typically applied to improve print quality for printers. The performance of the algorithm is demonstrated on various samples. It has been implemented and embedded into some printing apparatus.

Keywords-- Digital halftoning; Halftone image; Edge enhancement; Image processing

I. INTRODUCTION

Digital halftoning [1] is a technology widely applied in press and print field. By this process, original image with continuous tone can be transformed into a binary image (or of limited gray levels), known as halftone image. Generally speaking, the reason of involving this process is that, for one pixel, ink cannot represent continues gray levels but just differentiate between inked and not inked.

In halftone image, middle tone (neither 100% nor 0%) is represented by the density of inked dots (FM) or the size of inked dots (AM). Thus, some white pixels will exist inside a color area and special texture of halftoning will be formed. Discontinuousness and jag (Fig. 1) arise in edge areas due to the halftoning texture. These defects impact print quality and need to be diminished by special process. We propose an algorithm of edge enhancement post halftoning to solve this problem.

To improve the print edge quality, various methods have been proposed. A commonly used approach is to optimize the halftoning algorithm [2]. For edge enhancement on halftone image, various methods have been provided. Edge information is considered to modify the halftoning [3] [4] or applying different halftoning methods in different areas [5]. However, these technologies require change or even redesign for existing hardware. Another approach is process the halftone image resulted from the halftoning procedure. But typically the original image data is needed [6] [7]. As a result, partly modification of the hardware cannot be avoided and much memory is required to buffer original image data. Similar method is to gain continuous-tone image approximate to the original one by inverse halftoning. Inverse halftoning [8] [9] [10] is high-cost in time and hardware resource. Moreover, inverse halftoning depends on the special halftoning coefficients (frequency, angle of the halftoning). Besides, the result generated by this method is much different to the original image. As a result, the practicality of this method is limited. Template matching is another widely used method for edge enhancement without the original image data [16]. But the predefined patterns will aggravate the burden of processer and memory depending on the complexity of templates.

Figure 1. Discontinuous and jaggy edge in halftone image.

This paper presents an algorithm of improving the edge qualities in halftone image, which does not depend on any information of the original image data. This algorithm has features proper for hardware realization without any modification of existing hardware.

The article is outlined as follows: Section II describes the algorithm in detail step by step. Result is presented in section III, and section IV finishes with a conclusion.

II. ALGORITHM

In halftone image, the color of a pixel is not only determined by itself but also by pixels in a certain neighborhood. In other words, some statistic result instead of the precise gray value is taken as the pixel value. Actually this is the general idea of inverse halftoning. The algorithm in this paper is designed to take use of neighboring information as much as possible in order to get the satisfying result. In addition, some special correction and adjustment are introduced according to the character of halftone image.

The original printing pipeline and pipeline of improved

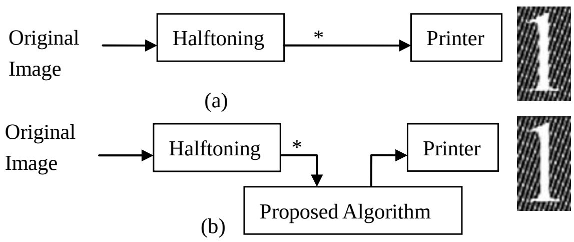

Figure 2. The pipeline of printing. (a) Original printing pipeline (b) Modified printing pipeline. *halftone image data

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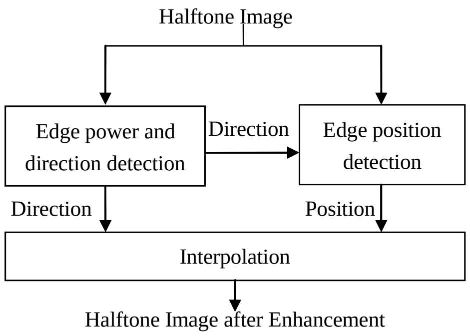

Figure 3. The flowchart of the algorithm

printing with edge enhancement presented in this paper are illustrated in Fig. 2.

Considering the distinguishing features of halftone image, we designed the general process of the algorithm as follow. The first step is to get precise edge direction; the second step is to detect precise edge position using edge direction as guide information; the final step is interpolation in certain edge positions. The flowchart of the algorithm is presented in Fig. 3.

A. *Edge direction detection*

Due to the halftone texture, edge in halftone image is discontinuous. Being different from the edge detection methods on ordinary image [15], in our proposed algorithm edge direction is detected together with edge position. The edge direction is used in the edge position detection as accessory information.

In halftone image, the color is represented with the density of inked pixels, so the color information has a statistic character. As a result, we designed the edge direction detection method based on vector calculation.

Using vector mask, the gray value V of each pixel within the mask is converted into vector information (a, b). The length of the vector $\sqrt{a^2+b^2}=V$ and the direction of the vector accords with its position relative to the central pixel. Fig. 4 illustrates a 3×3 mask by the colored area, the pixel marked blue is the center pixel, and the vector is calculated for the green one.

The response of the mask indicates the sum of vectors calculated above. That means get a vector set D and calculate the sum of them:

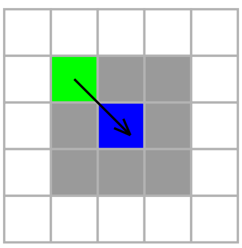

Figure 4. Vector Mask

$$\text{Sum} = \sum_{(a,b)\in D} (a,b) \quad (1)$$

Sum= (S_x, S_y) represents the edge information (including edge direction and edge power). The edge power (P) is calculated as follow:

$$P = \sqrt{{S_x}^2 + {S_y}^2} \quad (2)$$

The edge direction (Dir) is defined in Eq. (3)

$$\text{Dir} = \arctan(S_x / S_y) \quad (3)$$

This falls into one of predefined 16 directions in a circle.

Before thresholding, the edge power P is normalized in the way of being divided by the pixel number covered by the mask.

B. *Edge position detection*

The edge direction detected above is considered as instructive information to get precise edge position. In order to get higher response, different detection masks are chosen with respect to different directions to ensure negative coefficients on one side and positive coefficients on the other side along the edge direction. Using the NMS (non-maxima suppression), only the pixel with maximum response is reserved on the normal direction (perpendicular to the edge direction).

Ordinary mask used for edge detection [15], such as Sobel or Gaussian (negative and positive in each half) cannot achieve the satisfying result on halftone image due to the impact of halftoning. The main defect is discontinuousness in horizontal or erect edge and imprecise position for gradient edge. Take the Gaussian as an example shown in Fig. 5.

The discontinuousness is caused by the unstable area near the edge. The sums of gray value for every column are illustrated in Fig. 5 (c). The right and left columns indicate the unstable area, especially the right one which is much different from others. When response of the mask is calculated on the edge position, the biggest coefficients correspond exactly to the unstable area. So the response of

Figure 5. The edge position detection result and analysis. a) The position result detected by the Gaussian template. Red pixels are edge position result and black pixels are image data. b) The unstable area enclosed by red line. c) The statistic information of the gray value within the area enclosed by blue line in b)

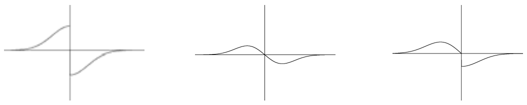

Figure 6. a) Gaussian (half negative and half positive). b) One-dimensional SOG. C) One-dimensional Gaussian-SOG.

the edge pixel is not much higher than two adjacent pixels, which is then omitted through the NMS.

To adapt to the unstable area, a new mask is required with the highest coefficient corresponding to the adjacent area of the edge instead of exact edge position (the highest coefficient corresponds to the stable area). Thus a new asymmetric edge detection filter (NAEDF) is introduced for edge position detection. The construction of NAEDF is as follow. Shift a standard Gaussian to right and left with one unit respectively. Then calculate the difference of these two shifted Gaussian, as the one-dimensional NAEDF. As shown in Fig. 6, peak value is one unit away from the center, therefore it is satisfying. Two-dimensional NAEDF is generated by convolving one-dimensional NAEDF with standard one-dimensional Gaussian.

For horizontal and erect direction, the result of NAEDF is not smooth because the response decreases slowly from light side to the dark side across the edge. The improvement is increasing the negative coefficients near the center of the mask. That is on the negative side of mask we use the negative coefficients from Gaussian instead. Using new mask, which is a combination of NAEDF and Gaussian, shown in Fig. 6 (c), the smooth and continuous edge position can be detected.

Finally, an adjustment was introduced to smooth edge position further. Edge pixel marked as P is adjusted if there is certain number of edge pixels with the same direction as P existing in its neighborhood. Statistic information of their position relative to P can be used to adjust the position of P as shown in Fig. 7.

C. Interpolation

This is the final step. A new gray value will be interpolated for pixel on edge position if its original value below a certain threshold. For example, the threshold can be set as 2 in the case of gray value ranges from 0 to 4 (limited gray level contained in halftone image).

Our goal is to interpolate some new pixel naturally along the edge position. As a result, a new interpolation value is calculated based on pixels in neighborhood. In order to get an approximate value of the original image, smoothing filters can be used. As a simple example, the interpolation value can be set as the average grey value in its neighborhood.

Finally, less jagged edges are expected after interpolation step.

Figure 7. Adjustment of edge position. a) The adjustment. Blue line as the edge direction, red line as the normal direction and the red square is the new position post adjustment; b) Edge position before adjustment; c) Edge position after adjustment

III. RESULT OF THE EXPERIMENT

The performance of the algorithm is tested on images with text of various sizes, fronts and gray levels. The case of lighter text on darker background is also taken into consideration. And it is tested on four color planes (CMYK) for every image.

Take the most widely used front, namely Times New Roman, as an example. The first set of test targets is developed using the gray level of 75% and font size of 6-8. Fig. 8 presents the result of our proposed algorithm. After the edge enhancement discontinues edge, such as horizontal and erect edge of the character "T", are smoothed. Also big-jag inclined edge, such as the inclined stroke of character "N", is smoothed.

Fig. 9 illustrates the test result on the character at gray level of 50%. Fig. 10 presents result of lighter text on darker background. Edge quality improvement can be observed after edge enhancement. Thus the performance of algorithm is satisfying in these cases.

Figure 8. From left to right: the original image, halftone image, result of enhancement. C: 75%; M: 0%; Y: 0%; K: 0%, Character "T" of font size: 6 and "N" of font size: 8

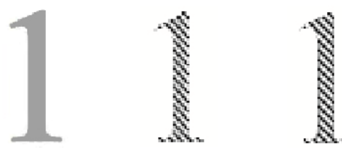

Figure 9. From left to right: the original image, halftone image, result of enhancement. C: 0%; M: 0%; Y: 0%; K: 50%.

Figure 10. From left to right: the original image, halftone image, result of enhancement. The case of lighter text (font size: 10) on darker background. C: 0%; M: 75%; Y: 0%; K: 0%.

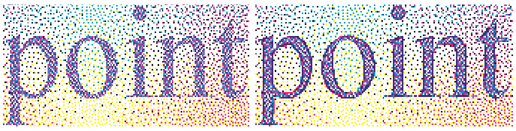

Figure 11. From left to right: the halftone image and the enhanced one. This result displays the robust of algorithm under complex background

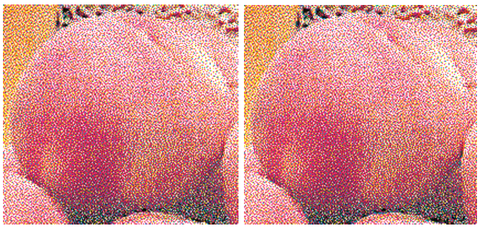

Figure 12. The left is halftone image, after enhancement the image has got little change (the right one). This result illustrates that the proposed algorithm is safe for the images without acute edges

Figure 13. The enhanced result of proposed algorithm and the result of another algorithm required original image

In application of this algorithm on some printers, the quality of printed text is improved obviously due to the enhancement process.

IV. Conclusion

This paper presents a new edge enhancement algorithm on halftone image. The method has shown an improved edge quality of halftone image. A significant feature of our proposed algorithm is that it does not depend on any original information or inverse halftoning process. The experiment result indicates the algorithm is very effective for improving edge quality. In addition, only a few local image data are involved so it is fit for hardware realization without any change on existing hardware.

V. Acknowledgment

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