Printing Quality Enhancement by Detection of Printhead Defects In Single-pass Inkjet Printing

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Abstract

Banding and doubling are two of the most common problems in inkjet printing, which are caused by printheads defects including blocked nozzle and poor registration. It is expensive and inefficient to solve the problems by enhancing device accuracy or replacing the defective printhead, since the device or printhead may degrade over time. In this paper, we propose an economical and efficient method for banding and doubling reduction by detection of printhead defects without requirement of hardware renewal. We design a test pattern composed of specially organized dots to diagnose status of each nozzle by image processing. Specifically, after analyzing the printed and scanned test pattern, halftone images are modified according to the detected information for banding and doubling reduction. We adjust the size and placement of dots based on human perception in order to improve the printing quality. The detection and reduction are carried out in CMYK printing colorant channels separately. Thus, it could overcome the inter-channel interference which may affect the detection accuracy. Experimental results show that the proposed technique is flexible, highly precise and has extensive self-adaptability for various devices, halftone styles, substrates and inks.

Introduction

In recent years, people are paying more and more attention to printing quality. Among the common problems in inkjet printing, banding and doubling are the most frequent, especially in the single-pass process. The major causes for banding and doubling are defective nozzles and registration misalignment, both of which can be considered as printheads defects.

Banding usually appears as light or dark lines across the printed substrate in the direction of paper pass. In multi-pass inkjet printing process, banding can be minimized because different nozzles are used in different passes and thus it can help to hide the defects if one of the nozzles is mis-directed or is not firing [1]. However, multi-pass printing takes much longer time than single-pass printing. Nowadays, single-pass printing is widely used for its high efficiency. Therefore, it is beneficial to develop a technique to reduce banding in single-pass inkjet printing to achieve both good printing quality and high speed at the same time.

Doubling often occurs as slight shift in the position of the printing elements between different colorant channels and can make the printed characters blurred and hard for reorganization. It is mainly caused by registration misalignment. In color printing, registration is the method of correlating overlapping colors on one single image. Registration marks often appear as circles centered on the crosshairs. Figure 1 shows a commonly used registration mark. Although it seems black, it refers to 100% coverage in each of the four colorants: cyan (C), magenta (M), yellow (Y), and black (K). Unfortunately, registration is hard to be done accurately. It is a difficult task to adjust printheads of different colorant channels to ensure that they are parallel to each other. Thus, registration is accurate in the center of printhead but not at the ends. In addition, nozzles would be mis-directed during usage. Skewed nozzles also cause doubling and it is hard to fix them throughout registration process or to adjust the hardware device.

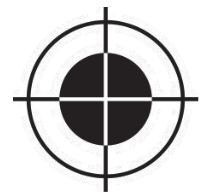


Figure 1. A commonly used registration mark.

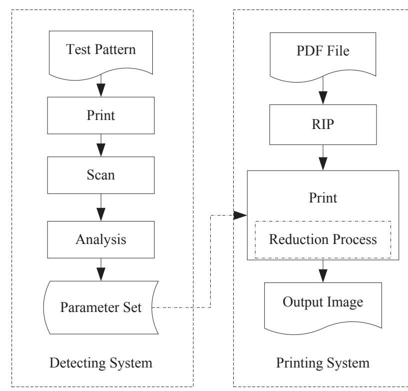


Figure 2. Framework of the proposed method.

It is possible to reduce banding and doubling by enhancing device accuracy or replacing the defective printhead, but it is an expensive endeavor without necessarily fixing the problem, since the device or printhead may degrade over time and produce banding and doubling problems which did not exist at the beginning. In this paper, we propose an economical and efficient method for banding and doubling reduction by detection of printhead defects without requirement of hardward renewal.

Much research has been done on this subject. Using sensors to monitor the working state of device to guarantee high printing quality is effective but it is associated with different hardware systems [2, 3]. On the other hand, the methods using image processing technique as a tool to analyze both banding and doubling are more adaptive. Studies have been reported on reducing banding and doubling in electrophotographic processes, focusing on designing better transmission, deflecting the laser beam, modulating the laser power, etc. [4, 5, 6, 7]. In inkjet printing, banding reduction methods combined with halftone techniques are popular

[8, 9]. Research on visibility assessment of banding and doubling and the attempts of improving image quality based on human visual model greatly inspired our work [10, 11, 12].

In this paper, we mainly concentrate on detecting defects of printhead and enhancing printing quality according to the detection result. Figure 2 shows the framework of our proposed method. After analyzing the test patterns, halftone images are modified according to the detected information for banding and doubling reduction. This technique is flexible, highly precise and has extensive self-adaptability for various devices, halftone styles, substrates and inks. Hence, it can be easily integrated into the existing printing system with different kinds of halftone algorithms.

The rest of the paper is organized as follows. In the next two sections, we describe the proposed method of defects detection and reduction of banding and doubling in detail. Then we show our experimental results. Finally we draw some conclusions and discuss our future work.

Printhead Defects Detection

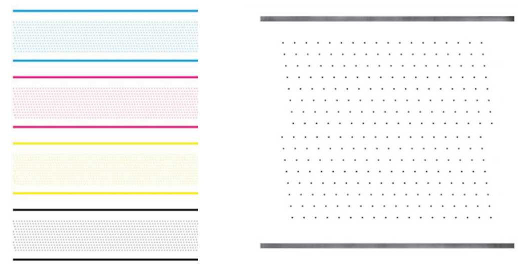
As we want to find the specific causes of banding and doubling, a detection system is proposed to obtain the information of printhead defects shown in Figure 2. First, we print a specially designed test pattern with the printer we want to fix. Second, we scan the printing output for further processing. Then, we analyze the digital image scanned above to get the information of defects and store it into a parameter set file which will contribute to the reduction process in printing system. When starting printing with new devices, it will take some time to get the information of defects. Once the parameter set is calculated, it can be reused in the following printing period until a new defect appears.

Design of Test Pattern

We design a special test pattern composed of specially organized dots to diagnose the status of each nozzle by image processing. Figure 3(a) shows the test pattern used in the detection system and Figure 3(b) is a sketch of the test pattern. Owing to the design, the locations of ink droplets propelled by adjacent nozzles are far from each other ensuring the independence of dots during the spreading of ink. Every dot in the test pattern corresponds to a nozzle in the printhead. During the detection, each nozzle fires more than once so we can get the exact direction of paper pass. Also, it keeps the stability of our technique. The bold straight lines help to position the test pattern in the right direction automatically. The detection is carried out in the CMYK printing colorant channels separately. Thus, it could overcome the interchannel interference which may affect the accuracy of detection.

Defects Analysis

In the detection system, we print the test pattern and scan it for analysis. After image graying and denoising, we could get the placement of droplets shown in Figure 4. Consider the direction of paper pass as longitudinal direction and the direction perpendicular to longitudinal direction as lateral direction. Then we draw grids along the longitudinal and lateral directions to keep the droplets in the supposed areas. Notice that, grid operation should include some exceptional cases such as impurity marked with the arrow at the top-right corner or missing dot marked at the bottom-right corner. The coordinate of each droplet dot is calculated. The distribution of pixel values in the corresponding grid of each nozzle for the original image can approximately reflect the status of nozzle. After the steps of analyzing, we stored the status information of nozzles into a parameter set file including the blocking state, the longitudinal offset and the lateral offset of the nozzles.



(a) (b)

Figure 3. *The designed pattern used in the proposed detection system. (a) The actual test pattern. (b) A sketch of the test pattern.*

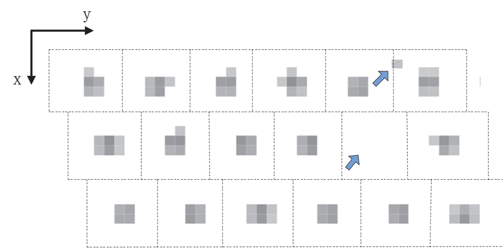


Figure 4. *The scanned test pattern after graying and denoising. The x-axis represents the longitudinal direction and the y-axis represents the lateral direction.*

Halftone Image Modification

Banding Reduction

Bandings are results of blocked nozzles and different drop volumes between nozzles. As we know, banding is related to human perception. Perceived severity of banding is dependent upon the spatial frequency of bandings and the contrast between bandings and the surrounding field [1]. Thus, by appropriately introducing dot placement variations in the banding regions and decreasing the contrast between the bandings and their surrounding field, it is possible to reduce bandings without visually affecting the current image quality. We mainly concentrate on reducing bandings caused by blocked nozzles. After detection, the index number of every blocked nozzle is definitely obtained. The halftone image is processed to reduce bandings by adjusting the size and placement of dots around the banding regions. An example of the reduction process is shown in Figure 5. Figure 5(a) is a normally printed image with the related nozzles working well. Figure 5(b) is a printed image with one nozzle blocked using the same original image as Figure 5(a). In the column of the blocked nozzle, all the corresponding dots are not printed, forming a region with a smaller grayscale value than that of the expected case. The basic step of reduction is to compensate the grayscale value of the blocked region by increasing grayscale value of the adjacent region as shown in Figure 5(c). Then we analyze the distribution character of the dots in the surrounding region and adjust the dot placement for a better spatial transitivity as shown in Figure 5(d).

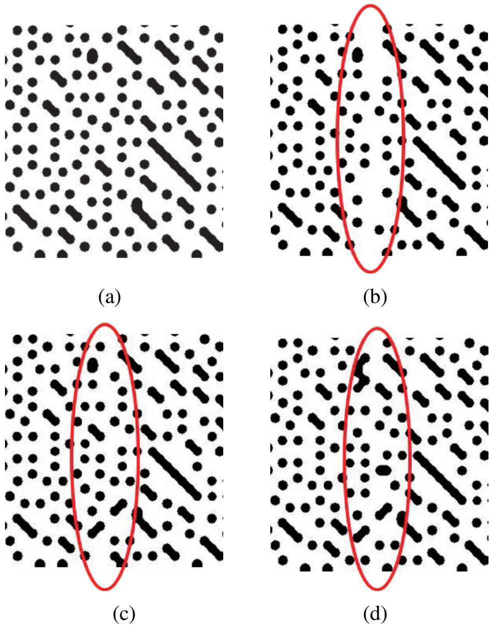


Figure 5. An example of reduction process. (a) A normally printed image. (b) An image printed with a blocked nozzle. (c) Banding reduction by compensating the grayscale value. (d) Further reduction by adjusting dot placement.

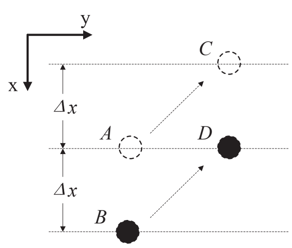


Figure 6. Schematic of doubling reduction in longitudinal direction (x).

Doubling Reduction

As we know, registration of colors is crucial for producing a sharp image such as lines and characters. Even a slight position shift in one of the four colors will make the printed image appear blurred or fuzzy, which is commonly called doubling or ghosting. According to the parameter set obtained above, we propose a method to reduce doubling based on halftone image. For longitudinal doubling, we move the position of dots, and for lateral doubling, we adjust the droplet volumes of adjacent nozzles by changing both size and quantity of dots. Figure 6 shows the processing procedure of doubling reduction in longitudinal direction. Suppose that point A is the ideal location of an ink droplet. When the corresponding nozzle is mis-directed in longitudinal direction, the actual landing ink droplet would appear on point B with a shift to the ideal location expressed as Δx. In halftone image, A is moved by Δx in the reverse direction to point C. Its location is not changed in y axis and the figure is just for better illustration. Due to the shift caused by the defected nozzle, the actual location of the landing drop would be at point D, which is the same as point A. After the procession of four colorant channels of the halftone image, the precision of registration can be significantly enhanced.

Experimental Results

The experiments were conducted according to the flowchart shown in Figure 2. Next, we will present our experimental results in two subsections. Firstly, the detection result will be demonstrated. Secondly, the reduction of banding and doubling will be discussed. The experiments are performed on a Founder EagleJet C4200 inkjet printer and an Epson Expression 10000XL scanner.

Figure 7 shows the detection result of longitudinal offset of nozzles. Points colored in blue, magenta, yellow and black represent the results of CMYK colorant channels, respectively. The abscissa represents the index number of nozzles in each printhead and the ordinate represents the offset value measured in pixels. At the beginning of our experiment, printheads were aligned carefully using the traditional manual registration method. Figure 7 demonstrates that registration is accurate in the middle of printhead but not at the ends which is consistent with our analysis in the introduction. Besides, the four circles presented in Figure 7 indicate obvious shift of the corresponding nozzles.

Figure 8 shows the banding reduction result by comparing images printed with and without our technique. When printing

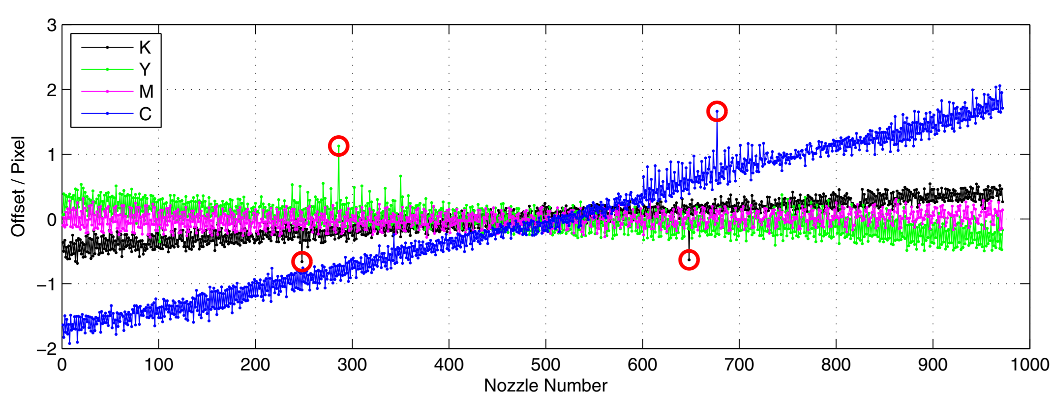
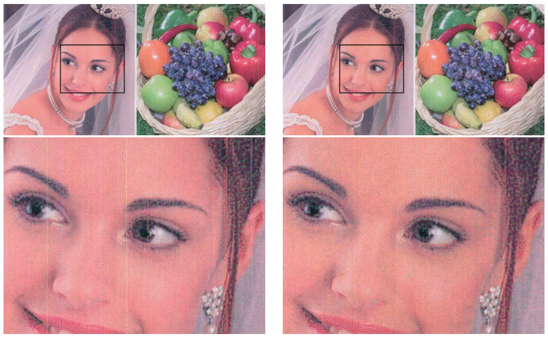
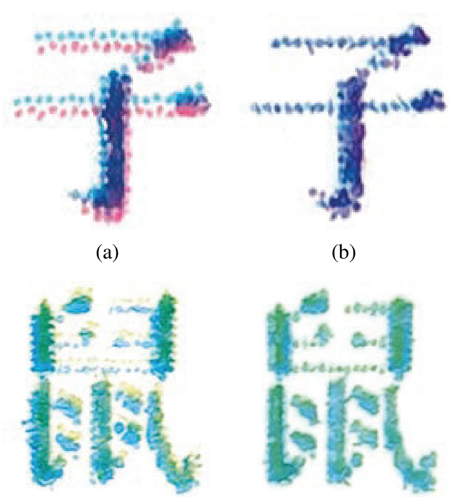


Figure 7. Longitudinal offset of nozzles of four colors.



(a) (b)

Figure 8. *Banding reduction result. (a) Image printed without our technique. (b) Image printed with banding reduction.*



(a) (b)

(c) (d)

Figure 9. *(a) Chinese character "Zi" printed with C and M colorants without doubling reduction. (b) Chinese character "Zi" printed with C and M colorants after doubling reduction. (c) Chinese character "Shu" printed with C and Y colorants without doubling reduction. (d) Chinese character "Shu" printed with C and Y colorants after doubling reduction.*

images using printheads containing blocked nozzles, bandings caused by blocked nozzles could be seen clearly in Figure 8(a). Figure 8(b) is the same image printed using our banding reduction technique with halftone image modified around the bandings region based on human visual model with the same printheads. It is obvious that there is a significant printing quality improvement.

Figure 9 shows the doubling reduction result. Hundreds of characters have been tested and two of them are selected for presentation as examples due to the limit of space. One is the simple Chinese character "Zi" and the other is the complex character "Shu". Figure 9(a) and 9(c) present the printed character "Zi" and "Shu" without doubling reduction. It is obvious that ink droplets are not accurately overlapped between different colorant channels. However, after the utilization of our proposed doubling reduction, the registration is much more accurate and the printed characters are more distinct, which can be clearly observed from Figure 9(b) and 9(d).

Conclusion

This paper presents an efficient technique to reduce banding and doubling in single-pass inkjet printing process without renewal of hardware device. A designed test pattern is used to examine the status of printheads. Halftone images are modified to compensate the defects of nozzle. Thus banding and doubling are visually reduced. This technique would shorten the time of repairing printheads and extend service of printheads. This technique is hardware-independent and does not rely on specific halftone algorithms. Therefore, it can be easily integrated into current printing systems. The effectiveness of this technique is experimentally verified. In the future, we will examine different drop volumes between nozzles and figure out the reduction of tiny bandings caused by the inconsistency of drop volumes between different nozzles.

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Yongtai Zhang received his B.S. degree of computer science at HUST (Huazhong University of Science and Technology) in 2008. And he is studying for a M.S. degree at Peking University after graduation from HUST. His current research areas include image process, printing system and machine vision.