Electrophotographic Ghosting Detection and Evaluation

Xiaochen Jing(1), Steve Astling(2), Renee Jessome(2), Eric Maggard(2), Terry Nelson(3), Mark Shaw(2), Jan P. Allebach(1), (1) Electronic Imaging Systems Laboratory (EISL), Purdue University, West Lafayette, IN 47907, USA. (2) Hewlett-Packard Company, Boise, ID 83714, USA.

Abstract

Ghosting is a well-known Print Quality (PQ) defect which may appear as a single or repetitive artifact presenting vestigial objects at a certain interval. The overall print quality will be limited if ghosting is present. Therefore, an algorithm that can accurately provide the information of both the ghosting source and its severity is greatly needed.

*In this paper, we propose an algorithm to detect and evaluate ghosting by first applying template matching in the CIE L*a*b* color space, and then calculating the color difference. The template matching step in the L* channel will indicate the position and the type (light or dark) of the ghosting. We then calculate the color difference among L*, a*, and b* channels to get the Delta E for the purpose of evaluation. Our algorithm can automatically detect, quantify, and label the severity of ghosting according to a final metric. Base on 82 samples in total, the accuracy of our algorithm is 92% compared with expert visual evaluation. Our algorithm is also suitable to be used as a quality control tool to set limits in production processing.*

Introduction

Electrophotographic (EP) ghosting is a well-known Print Quality (PQ) defect which may appear as a single or repetitive artifact presenting vestigial objects at a certain interval as shown in Fig. 1. The overall print quality will be limited if ghosting is present. Due to the complexity of the electrophotographic (EP) printing system, there are many sources that could cause ghosting. This situation increases the difficulty of diagnosing the root cause of ghosting. Therefore, an algorithm that can accurately provide the information of both the ghosting source and its severity is greatly needed.

Although there are many sources of ghosting, the most common cause is the residual toner particles that remain on the Organic Photo-Conductor (OPC) drum, which will then transfer to the media/transfer belt during a following revolution of the OPC drum. Under this situation, a ghosting will appear on the page along the processing direction. The distance between the original object and its ghost provides information about the circumference of the defective rotating component. Whether the ghosting is a positive (dark) or a negative (light) ghost can be helpful to trace back to the cause of the ghosting. The characteristic of ghosting has been well studied in [1]. The algorithm most commonly used to detect ghosting is simply measuring the difference in lightness reflectance between the ghosting region and the background. Based on this concept, a commercially available image analysis system to detect and quantify ghosting using Fourier analysis was developed in [2]. A technique that combines a human perception factor and a Fourier analysis metric to provide a final ghosting index that reflects the ghosting severity was introduced in [3]. A spatial analysis based on wavelet filtering and template matching in the lightness channel was described in [4]. Ghosting test patterns were also designed in these prior works [2, 3, 4]. Similar to [4], a template matching filter is also used in our algorithm. However, instead of using a single template bar, our template design is closer to the one used in [3]. In this case, our template with a periodic presentation of light and dark bars, can reveal the positive and the negative ghosting at the same time. Meanwhile, the final metric can also consider the impact of the sequence of ghosting bars along the scan direction on human perception. Furthermore, unlike [3] and [4] which operate in the lightness channel only, our algorithm performs in a full uniform color space.

In this paper, we first design a ghosting template with prior knowledge of our targeted EP printer, which can better reveal the ghosting issue. Base on the collected data, we then propose an algorithm to detect and evaluate ghosting by first applying template matching in the *CIE* $L^*a^*b^*$ color space, and then calculating the color difference. The template matching step in the L^* channel will indicate the position and the type (light or dark) of the ghosting. We then calculate the color difference among L^*, a^*, and b^* channels to get the Delta E for the purpose of evaluation. Details will be explained in the following sections.

This paper is organized as follows. Section 2 describes the test pattern design and the proposed algorithm for detecting and evaluating ghosting. Section 3 provides experimental result. We then conclude in Section 4.

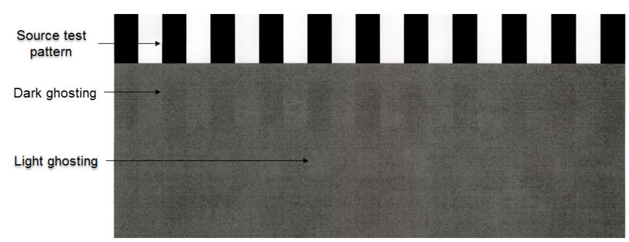


Figure 1. An example of test page with source test pattern and ghosting.

Measurement Methodology

Test pattern design

A well-designed test page is very important for the measurement of ghosting. The ideal test page should elicit the worst case ghosting for a printing system; and the test pattern should be suitable for future analysis. Ghosting test patterns were all designed in prior works [2, 3, 4]. Our template design is closest to the one used in [3], where the source pattern consists of a series of black rectangular bars, followed by a medium gray field. Compared with the single bar template in [4], our template with a periodic presentation of light and dark bars can reveal the positive and the

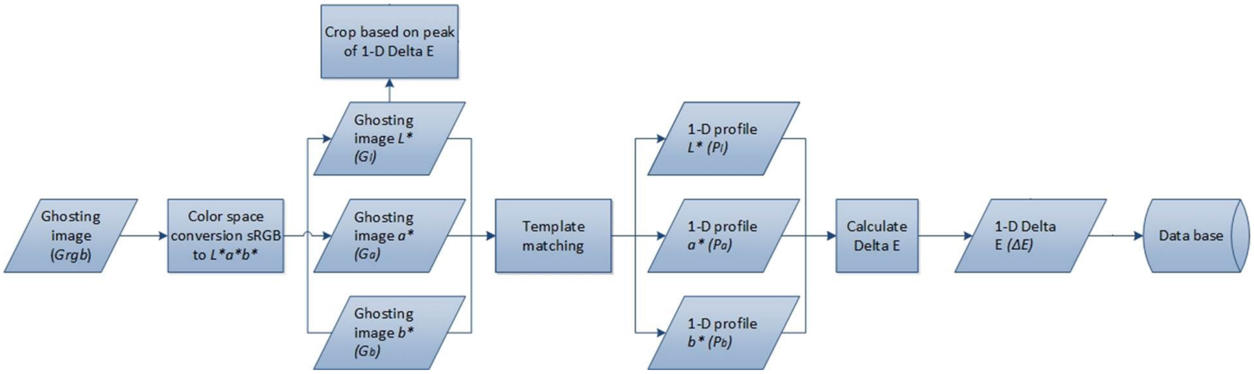
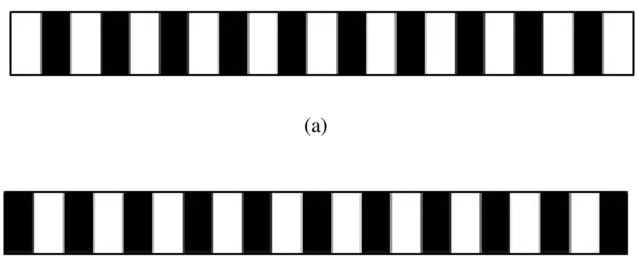


Figure 2. *Overview of the ghosting detection and evaluation algorithm.*

negative ghosting at the same time. Meanwhile, the final metric will also consider the impact of the sequence of ghosting bars along the scan direction on human perception. Furthermore, unlike [3] and [4] which operate in the lightness channel only, our algorithm performs in a full uniform color space.

The source test pattern, as shown in the top of Fig. 1, consists of 11 rectangular bars. The width of the margin between each bar is the same as the width of the black bar itself. The height of the rectangular bars is selected according to prior knowledge of the circumferences of the rotating components. So this test page can do the best to eliminate the possibility of overlapping between the ghosting caused by different rotating components. The test page is halftone and is printed at 600 dpi, then the printout is scanned at 600 dpi.



(a)

(b)

Figure 3. *Templates used in the template matching. (a) Template for potential ghosting region T_g; (b) template for background region T_b.*

Template matching

Figure 2 shows the process of the template matching algorithm. After we get the printed test pages, we first locate the Region of Interest (ROI), which is the flat medium gray field called ghosting image G_{rgb}. We then convert G_{rgb} from *sRGB* to *CIE* $L^*a^*b^*$ color space and get the ghosting images G_l, G_a, and G_b in separate L^*, a^*, and b^* channels. We apply template matching on G_l, G_a, and G_b separately to get the 1-D profile P_l, P_a, and P_b from each of them. Finally, we calculate Delta E based on these three 1-D profiles.

The major part of this algorithm is the template matching. For each ghosting image G_l, G_a, and G_b, we use the same method to process the image. There are two template as shown in Fig. 3. The top template T_g in Fig. 3(a) starts with a white bar, and looks like an inverse version of the source test pattern. The pixel value of white region is one, and the pixel value of black region is zero. By multiplying template T_g with the ROI and moving along the process direction, we are extracting the data from the potential region where ghosting might appear. To the contrary, the bottom template T_b in Fig. 3(b) starts with a black bar. By multiplying template T_b with the ROI and moving along the process direction, we will extract the average value from the background. Therefore, we define the 1-D profile P_j from G_j ($j = l, a, b.$) and T_k ($k = g, b.$) as

$$P_{jk}(i) = \frac{\sum\limits_{m=i}^{m=i+h+1}\sum\limits_{n=1}^{n=W} G_j[m,n]\cdot T_k[m-i+1,n]}{\sum\limits_{m=i}^{m=i+h+1}\sum\limits_{n=1}^{n=W} T_k[m-i+1,n]}, \tag{1}$$

and

$$p_j(i) = P_{jg}(i) - P_{jb}(i). \tag{2}$$

Where $i = 1,\cdots,H-h+1$; $j = l,a,b$; $k = g,b$. H is the height of the ROI, which in this case is the height of G_l, G_a, and G_b; W is the width of the ROI; h is the height of the source test pattern. By taking difference between P_{jg} and P_{jb}, we are actually subtracting the background value that surrounds the ghosting and getting the magnitude of the difference between the ghosting and non-ghosting regions. In this way, we can eliminate the effect of the noise and the low fluctuation in the background. The sign of P_l will indicate the type (light or dark) of the ghosting.

After getting the 1-D profile of each color channel, we then define the 1-D Delta E as

$$\Delta E(i) = \sqrt{\left(P_l(i)-\overline{P_l}\right)^2 + \left(P_a(i)-\overline{P_a}\right)^2 + \left(P_b(i)-\overline{P_b}\right)^2}, \tag{3}$$

where $\overline{P_l}$, $\overline{P_a}$, and $\overline{P_b}$ are the mean values of P_l, P_a, and P_b, respectively. The peak(s) in 1-D Delta E indicate(s) the start position of the ghosting, the sign of that point in P_l indicates the type of the ghosting. For the record, we focus on achromatic test pages for now. As we know, human eye is more sensitive to changes in gray levels, and a difference of 0.5 Delta E might be just noticeable to experts. Therefore, we then define one Delta E as the threshold of pass or fail. If the value of the peak in 1-D Delta E is less than 0.5, then the relative ghosting has a rank A; if it is between 0.5

and 1, then the relative ghosting has a rank B; between 1 and 1.5, then the relative ghosting has a rank C; if it is larger than 1.5, then the relative ghosting has a rank D. Test pages with rank A and B are acceptable and those with rank C and D are unacceptable.

Experimental Result

In this section, we show the experimental result. The algorithm of template matching and Delta E calculation is applied on a real sample with both dark ghosting and light ghosting. Figure 4, which is shown in the end of this paper, presents the final Delta E on the top of that real sample. On the top left of the evaluated result image, there are predicted score (Rank A, B, C, or D) and types of the ghosting defect are present in this target sample. The predicted score is the maximum Delta E observed along the process direction, as indicated in Fig. 4. If it is a dark ghosting the peak of the Delta E would point to left from the center black line of the image, and if it is a light ghosting the peak of the Delta E would point right from the center black line of the image. We locate the ghosting peaks by highlighting them, and pointing to the rulers along both the left and right sides. The number shown on the ruler indicates the circumference of the defective rotating component. The slope of the Delta E around the peak which highlights the ghosting indicate the sharpness of the ghosting along the top and bottom edges.

We further test our algorithm on 82 samples. The evaluation time taken by the expert was about two and half hours. On the other hand, our algorithm evaluated the ROI of samples with 638×825 pixels at 4 second/page running under Windows 7 on a computer with an Intel Core i7-2640 2.80 GHz CPU. Figure 5 shows the comparison of the evaluation result between our algorithm and the expert visual score. Each mark in Fig. 5 corresponds to a single test page, that the expert assigned Rank A, B, C, or D. The total number of correct acceptance and correct rejection is 92%. There is no further psychophysical experiments needed in this case.

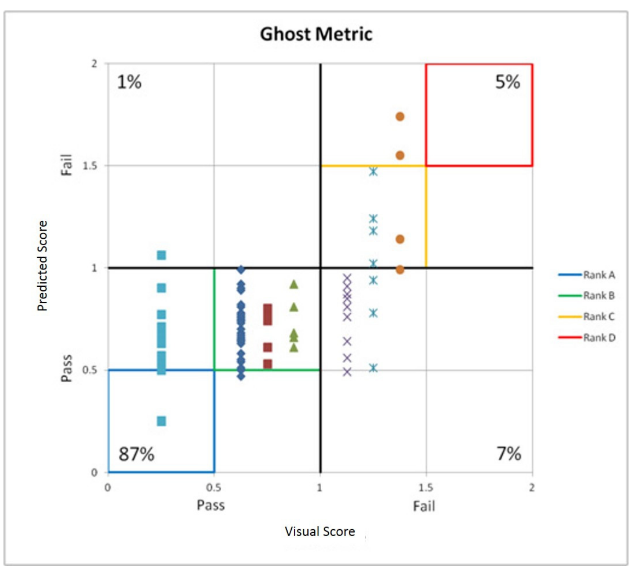


Figure 5. *Comparison of the evaluation result between our algorithm predicted score and the expert visual score.*

Conclusion

This paper presents an algorithm which can automatically detect, quantify, and label the severity of ghosting according to a final metric, as well as a test pattern design. By referring to the user report from this analysis algorithm, the operator can correlate the detected ghosting to the defective printer component. Furthermore, the time expense of evaluating one sample with our algorithm is 1/10 of that required by a human expert. Based on 82 samples in total, the accuracy of our algorithm is 92% compared with expert visual evaluation. Therefore, our algorithm is also suitable to be used as a quality control tool to set limits in production processing.

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Author Biography

Xiaochen Jing received her BS degree in Electrical Engineering from Tongji University in 2007. She received her MSEE and Ph.D. degree in Electronic Imaging Systems Laboratory of Professor Jan P. Allebach of Electrical and Computer Engineering from Purdue University in 2011 and 2013, respectively. Her research interests include image processing, image quality, computer vision, print quality, psychophysics, and human perception. She now works as a research scientist in KLA-Tencor, CA USA.

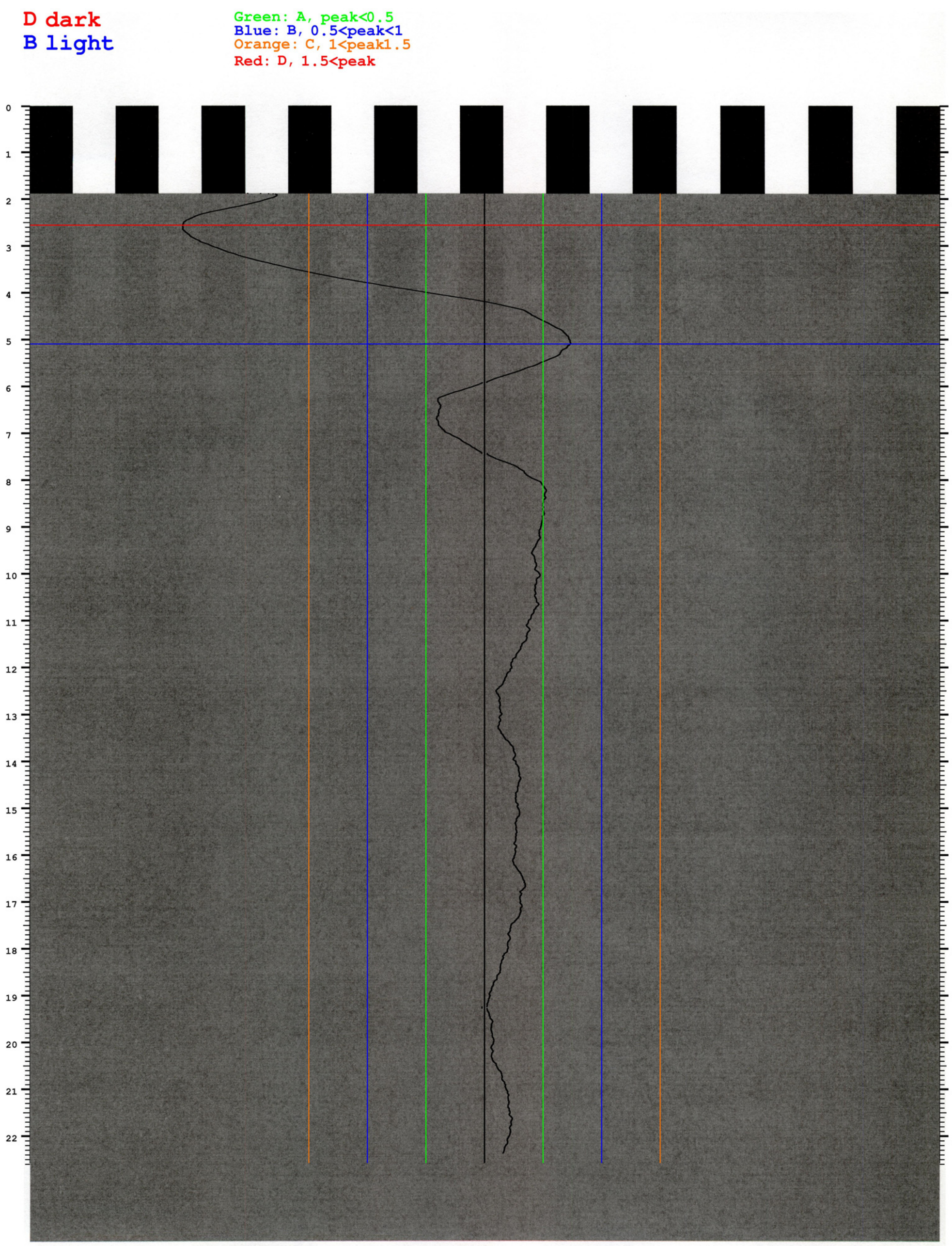

Figure 4. *Example evaluation result on a real printout document sample.*