

# Measuring Margin and Skew Errors in Scanned Printed Customer Content\*

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## Abstract

Print margin and skew describe an image placed crookedly on the printed page. It is one of the most common defects in electrophotographic printers and dramatically affects print quality. It primarily might occur when using a two-sided printing module on the printer. To solve or correct the print margin and skew error, we should first accurately detect the print margin and skew on the printed page. This paper proposes a method to accurately detect the print margin and skew based on the Hough Lines Detection algorithm [1]. There are three steps of this print margin and skew detection method. We first project the digital master images into the scanned test image with master image edges. The second step is the most challenging part of designing this method because all of our scanned test pages had only two or three and barely visible edges of the printed paper to the naked eye. We use an image processing method and Hough Lines Detection algorithm to extract the paper edges. The third step uses the projected master images edge and the extracted paper edges to calculate the print margin and skew result. Our algorithm is an efficient and accurate method to detect print margin and skew errors based on factual scanned image verification.

## 1. Introduction

Skew and margin defects occur when the movement of the paper in the mechanism is not square with print cartridge movement. The result is inconsistent print margins along the paper's edge (printing appears tilted on the page). These print defects are prevalent in electrophotographic printers, and significantly affect the print quality. This paper proposes a method to detect the skew and margin on the printed page. There are two input images in this print margin and skew detection method: one is the original master image (original digital image saved in PC), as shown in Figure 1 (a); another is the scanned test image, as shown in Figure 1 (b). The most challenging part of designing this method is all of our scanned test pages had only two or three and barely visible edges of the printed paper to the naked eye, as shown in Figure 1 (c). The input master image is 300 dpi letter size, and the other input scanned test image is printed as an A5 image and scanned as letter size.

In the previous study, researchers used distance to describe the margin and angle degree to describe skew [2]. In this paper, the skew and margin are calculated based on the

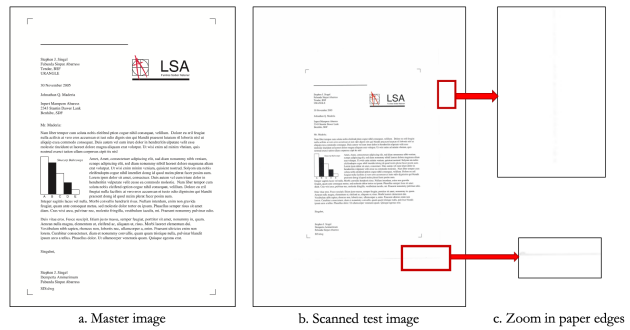


Figure 1: Print margin skew detection method input images.

distance between the print area corner points to the paper edges, as shown in Equation 1 and Figure 2. There are no other distortions in the printed and scanned images, and when we calculate the top margin, we will know the bottom margin, we don't need to calculate all the top, bottom, right, and left margins and skews. So for each test image, we only need to calculate the margin and skew for a set of mutually perpendicular edges. In Equation 1, we show the top and left margin skew calculation. We also can use a similar method to calculate the margin skew result of any two mutually perpendicular edges. This article is a continuation of our previous printing defect detection analysis [3, 4].



Figure 2: Print margin skew calculation sample image.

$$\begin{aligned} SKEW_{top} &= d_2 - d_1 & SKEW_{left} &= d_4 - d_3 \\ MARGIN_{top} &= \frac{d_1 + d_2}{2} & MARGIN_{left} &= \frac{d_3 + d_4}{2} \end{aligned} \quad (1)$$

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## 2. Print margin skew detection pipeline

This section introduces the details of the print margin and skew detection procedure. Figure 3 shows the overall pipeline of the proposed method. This method includes three main parts: master image projection with image edge, printed paper edge detection, and print margin skew calculation.

The first part is to project the master image to the scanned test image with the original boundary of the master image. In this part, we need to extract the corresponding interest points between the master image and the scanned test image. Then, we can calculate the transformation matrix to project the resized master image to the scanned test image with the original boundary. The second part is to detect the paper edge on the scanned test image. In this part, we use the Hough Line Detection algorithm [1]. The third part uses the projected master image boundary and the detected paper edge to calculate the print margin and skew.

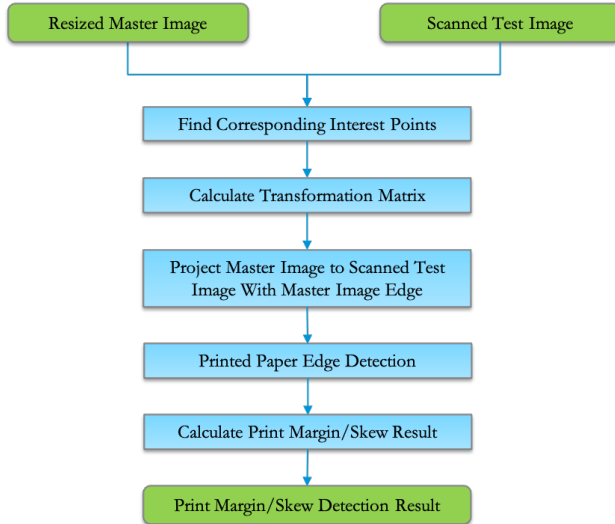


Figure 3: The overall pipeline of the print margin skew detection.

We will introduce the details of the print margin and skew detection process in the following sections.

## 3. Master image projection

To detect margin skew, we need to calculate the distance from the projected master image corner points to the real paper edge. So as the first step, we need to find the master image corner points on the scanned images. This module introduces how to project the master image into the scanned test image with the original master image boundary and extract the projected master image corner points.

### 3.1 Resize the master image

Before we project the master image into the scanned test image, we need to resize the master image first. For example, our master image is letter size, and the scanned test image is printed in A5 size scanned on letter size, as shown in Figure 1. In this condition, we first resize the master image from letter size ( $2500 \times 3200$  pixels with 300 dpi) to A5 size

( $1748 \times 2480$  pixels with 300 dpi), and put on the letter-size background, as shown in Figure 4. Figure 4 (a) is the original master image with letter-size, Figure 4 (b) is the resized master image in A5 size, Figure 4(c) is the resized A5 master image attached to the letter-size background, and Figure 4 (d) is the real scanned test image.

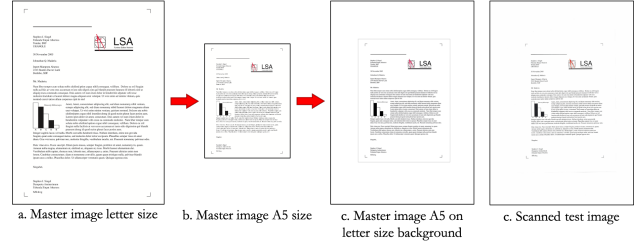


Figure 4: Process for resizing the master image.

### 3.2 Master image projection

In the master image projection process, the first step is to convert the scanned test image and the master image to grayscale. For the next step, we use the SIFT method to detect the scale-space interest points [5] with a 128-element descriptor in both master and test images. In the SIFT method, we use the Difference-of-Gaussian (DoG) pyramid to find all the local extrema, as shown in Equation 2. The  $G(x, y, k\sigma)$  is a variable scale Gaussian expressed in Equation 3;  $k$  is the scale parameter and it usually is 2;  $ff(x, y, \sigma)$  is Laplacian-of-Gaussian (LoG) [6] of image  $I(x, y)$ . We use these functions to find locally maximum or locally minimum points in the three-dimensional space  $(x, y, k\sigma)$ . We need to consider 26 neighbors in 3D neighborhoods for one extrema point.

$$D(x, y, \sigma) = [G(x, y, k\sigma) - G(x, y, \sigma)] * I(x, y) = ff(x, y, k\sigma) - ff(x, y, \sigma) \quad (2)$$

$$G(x, y, k\sigma) = \frac{1}{2\pi\sigma^2} \exp(-(x^2 + y^2)/2\sigma^2) \quad (3)$$

Because we use different scales  $\sigma$  across the DoG pyramid to detect the extrema point, we want to achieve greater precision in the localization of the extrema pixel-to-pixel with respect to the original image. To achieve this goal, we estimate the second-order derivatives of  $D(x, y, \sigma)$  at the sampling points in the DoG pyramid. We can localize the extrema point with the “sub-pixel” accuracy in where the DoG pyramid finds the extrema point. The Taylor series expansion of  $D(x, y, \sigma)$  in the vicinity of  $\vec{x}_0 = (x_0, y_0, \sigma_0)^T$  is used to find the location of an extremum in the DoG pyramid, as shown in Equation 4. The  $\vec{x}$  is the incremental deviation from  $\vec{x}_0$ ;  $J$  is the gradient vector estimated at  $\vec{x}_0$ , as shown in Equation 5;  $H$  is the Hessian at  $\vec{x}_0$ , as shown in Equation 6. Taking the derivative of both sides of the Taylor series expansion concerning the vector variable  $\vec{x}$  will get the result, as shown in Equation 7. Figure 5 shows the interest points from the master and scanned test images.

$$D(\vec{x}) \approx D(\vec{x}_0) + J^T(\vec{x}_0)\vec{x} + \frac{1}{3}\vec{x}^T H(\vec{x}_0)\vec{x} \quad (4)$$

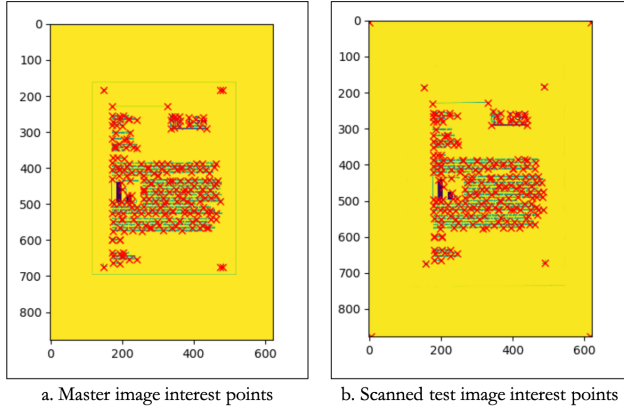


Figure 5: The interest points from the master image and the scanned test image.

$$J(\vec{x}_0) = \left( \frac{\partial D}{\partial x}, \frac{\partial D}{\partial y}, \frac{\partial D}{\partial \sigma} \right)^T \quad (5)$$

$$H(\vec{x}_0) = \begin{bmatrix} \frac{\partial^2 D}{\partial x^2} & \frac{\partial^2 D}{\partial x \partial y} & \frac{\partial^2 D}{\partial x \partial \sigma} \\ \frac{\partial^2 D}{\partial y \partial x} & \frac{\partial^2 D}{\partial y^2} & \frac{\partial^2 D}{\partial y \partial \sigma} \\ \frac{\partial^2 D}{\partial \sigma \partial x} & \frac{\partial^2 D}{\partial \sigma \partial y} & \frac{\partial^2 D}{\partial \sigma^2} \end{bmatrix} \quad (6)$$

$$\begin{aligned} 0 &\approx J(\vec{x}_0) + H(\vec{x}_0) \vec{x} \\ \vec{x} &= -H^{-1}(\vec{x}_0) \cdot J(\vec{x}_0) \end{aligned} \quad (7)$$

We use the Normalized Cross-Correlation (NCC) method [7] to establish the correspondences between interest points in the image pairs, as shown in Equation 8. Here, we assume that the test image is skewed by only a small angle relative to the master image. We use an  $(S+1) \times (S+1)$  window around the corner pixel in the gray level master image and use the same window around the corresponding pixels in the scanned test image. We can minimize the NCC to establish correspondences between master and scanned test images.

$$NCC = \frac{\sum_{i=-S/2}^{S/2} \sum_{j=-S/2}^{S/2} (I_1[i,j] - m_1)(I_2[i,j] - m_2)}{\sqrt{\sum_{i=-S/2}^{S/2} \sum_{j=-S/2}^{S/2} (I_1[i,j] - m_1)^2 \sum_{i=-S/2}^{S/2} \sum_{j=-S/2}^{S/2} (I_2[i,j] - m_2)^2}} \quad (8)$$

In Equation 8,  $S$  is the size of the window.  $I_1$  and  $I_2$  are the gray levels of each pair of interest points in the master and test images.  $m_1$  and  $m_2$  are the average gray level of the windows in the master and test symbol ROIs. The NCC value will be between  $-1$  and  $1$ . Being  $1$  means a perfect match between two interest points within the comparison window.

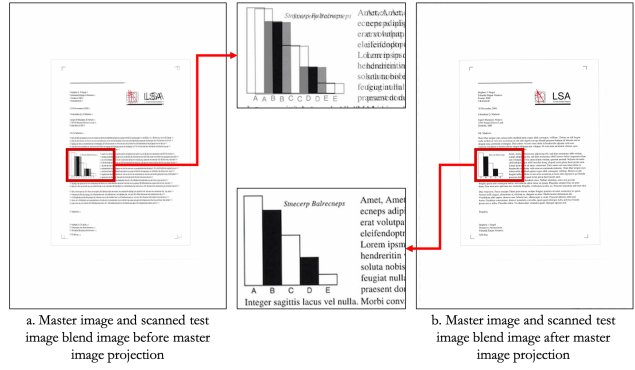


Figure 6: The blending images between master and test images before and after image registration.

The matched interest points are a set of 2D coordinates. We calculate the geometric matrix to transform the interest points from the test symbol ROI to the corresponding interest points in the master symbol ROI. The  $3 \times 3$  transformation matrix can remove the skew angle and translation distortion in the test symbol ROI. Four pairs of interest points can solve this matrix. We prefer to use more matched interest points to get a more accurate transformation matrix. We use the random sample consensus (RANSAC) algorithm [8] to calculate the best transformation matrix. We process the master image using the transformation matrix and project the master image with boundary into the scanned test image. Figure 6 (a) shows the blend image of master and scanned test images. The zoom-in detail image shows the considerable misalignment between the master and the scanned test images. Figure 6 (b) shows the blend image of the projected master and the scanned test images. There is no misalignment in the zoom-in detail image, and the master image print area boundary is also launched on the scanned test image. In our previous ROI extraction for image quality analysis work [9], we used a similar method for image registration.

## 4. Paper edge detection

The second important part of print margin skew detection is identifying the printed paper edge. This is the most challenging part because all of our scanned test pages had only two or three edges of the printed paper that were barely visible to the naked eye, as shown in Figure 1 (b).

### 4.1 Paper edge pixels extraction

With the aid of the projected master image, we can extract the content of the digital test image. Figures 7 (a) and 7 (b) show the gray value master image and the gray value scanned test image. So we use the black border in the projected master image to locate and remove the customer content in the scanned test image, therefore to obtain the masked scanned test image, which only includes the printed paper edges, as shown in Figure 7 (c). To extract the paper edge pixels in this masked test image, we set the fixed threshold 250. If the pixel value is less than the threshold, we will label it as a paper edge pixel, as shown in Figure 7 (d).

Then we use the Sobel Edge Filter [10] to detect the edges in the scanned image by determining where the pixel

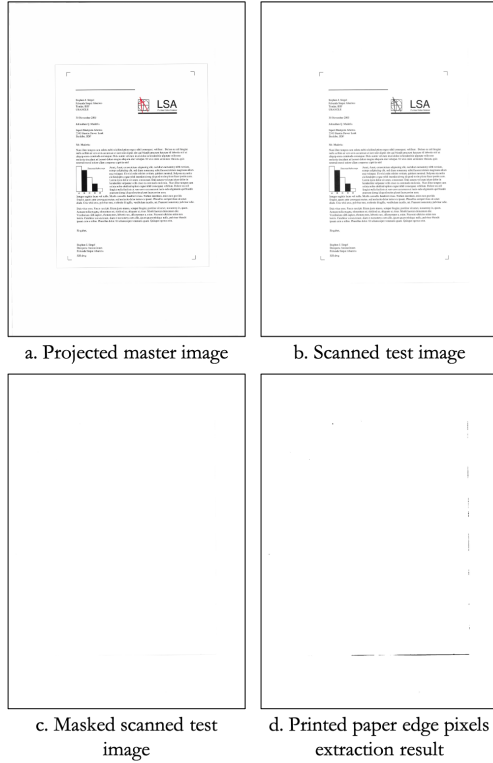


Figure 7: Paper edge pixels extraction process.

values of the image change drastically. This process can detect the horizontal and vertical directions of paper edges. The detection result is shown in Figure 8 (a). Because some of the edges are discontinuous and very short, we use the dilation method [11] to expand the edge area by 3 pixels, as shown in Figure 8 (b).

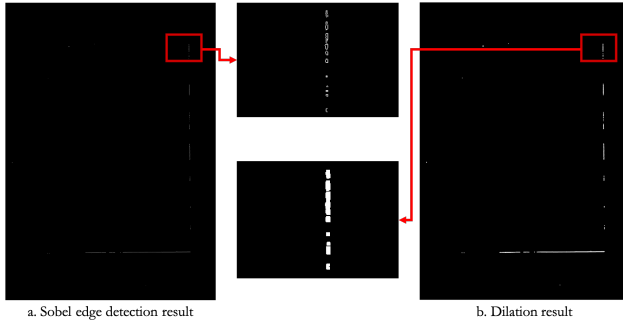


Figure 8: The Sobel edge detection and dilation result.

#### 4.2 Paper edge detection

The Hough Line detection algorithm [12] is applied to the edge image after dilation to define the location of paper edges accurately.

Generally, we use the form  $y = ax + b$  to represent a line in planar coordinates. In contrast, we represent any points on a line with  $\rho$  and  $\theta$  in the Hough Space, where the horizontal axis is the value of  $\theta$ , which is the angle between the normal line and the x-axis. The vertical axis is the value of  $\rho$ , which is the length of the normal line. The form of the normal line

can be represented by  $\rho = x \cos(\theta) + y \sin(\theta)$ .

In the Hough Space, any edge point produces a cosine curve. So we know that two edge points stay on the same line, then their corresponding cosine curves intersect on a specific  $(\rho, \theta)$  pair. So, the lines can be defined by finding the  $(\rho, \theta)$  pairs with some intersections larger than a certain threshold.

For our application, we map every edge point from the edge image after dilation to Hough Space with the accuracy of angles  $\pi / 1800$ . We set the Hough space intersection threshold to 3000, then we obtain a lot of lines, as shown in Figure 9 (a).

To further determine the location of the boundary of the paper precisely, we combine lines that have similar  $\rho$  and  $\theta$ . We then select the lines with the highest number of intersections in Hough space and remove all adjacent lines for which  $\rho$  is less than 100 pixels, and  $\theta$  is less than  $\pi / 1800$  (10 degrees) [13].

Figure 9 (b) shows the position of the extracted letter edge.

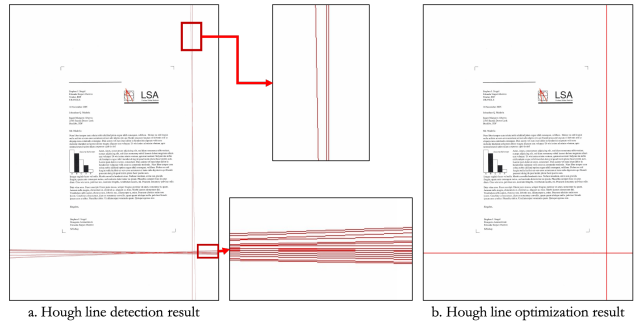


Figure 9: The Hough line paper edge detection.

#### 5. Margin and Skew Calculation

Equation 1 shows that margin is related to the distance from corner points of printing boundary to paper edges, essentially the distance from an end to a line. Here, we use the method of calculating the area of a triangle to compute the distance from a point to a line.

The most common way to calculate the area of a triangle is to take half of the base side times the height. Another way to find the area of a triangle is to calculate the dot product of the vectors of two adjacent edges [14].

Figure 10 shows three points A, B, and C, where A is a corner point at the boundary of the printed content, B and C are the two ends of the found paper edge. These three points can form a triangle ABC, and  $d_{A-BC}$  is used to represent the perpendicular distance from point A to line BC. So, we first calculate three sides of the triangle, then compute the triangle ABC's area using Equation 9.

Equation (9) shows that  $d_{A-BC}$  is equal to the dot product of the vectors of two adjacent sides divided by the base side of the triangle.

$$S_{ABC} = \frac{|\vec{AB} \cdot \vec{AC}|}{2} = \frac{|\vec{BC}| \cdot d_{A-BC}}{2} \quad (9)$$

$$d_{A-BC} = \frac{|\vec{AB} \cdot \vec{AC}|}{|\vec{BC}|}$$



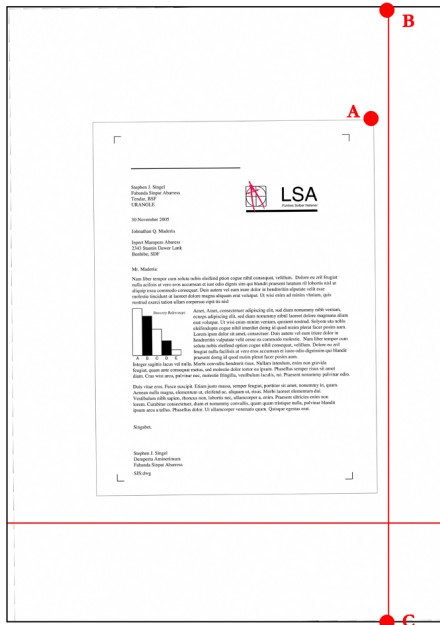


Figure 10: The distance from master boundary corner point to paper edges.

By the same logic, we can compute the distance from the other three corner points of the boundary of the print content to the corresponding paper edge. Therefore, we further calculate the margin and skew of the scanned test image by carrying all the computed distances into Equation 1.

Considering that we can detect only the right and bottom paper edges of the scanned test image shown in Figure 10, we calculated the margin and skewed on the right and bottom sides of the image, respectively. For the 300 dpi, letter-size scanned test image shown in Figure 10, the calculated margins on the right side and the bottom side are 74 pixels / 0.25 inch and 164 pixels / 0.55 inch, respectively; the calculated skew on the right side and the bottom side are 14 pixels / 0.05 inch, and 11 pixels / 0.04 inch, respectively.

## 6. Conclusion

In this paper, we proposed a print margin and skew detection method. The inputs of this method are the digital master image and the scanned test image. The output is the margin and skew detection result. We design three parts in our procedure to achieve this result: master image projection, printed page edge detection, and margin skew detection. In the first part, we use an image registration algorithm to project the master image with its boundary to the scanned test image. Then, we use an image processing method to extract the printed paper edges area and use the Hough Lines Detection algorithm to extract the optimal printed paper edges. In the third part, we use the triangle area function to calculate the distance of the print area corner points to the print page edges. We use these corner points to calculate the print margin skew result to paper edges distance values.

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**Mark Shaw** received his B.S. in Printing and Publishing Technology from University of Herfordshire in 1997 and his M.S. in Color Science from Rochester Institute of Technology in 1999. Then he went to Boise State University to take Electrical Engineering classes to meet the pre-requisites to study under Prof. Jan Allebach at Purdue. Finally he received his Ph.D. in Electrical and Computer Engineering from Purdue University in 2015. He is now a principal color and imaging master architect at HP Inc.

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