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Measuring CMYK color plane misregistration from scanned printed customer content image [1]

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Abstract

Print defect detection and measurement are critical for designing and improving high-quality printing systems. Color plane misregistration is considered to be among the most serious and common defects affecting the overall image quality within the printing industry. There has been some research on it, but mostly focused on measuring the defect on uniform color pages or specific test images. In this paper, we designed and developed a processing pipeline, and two measurement strategies for measuring color plane misregistration. The processing pipeline can automatically determine the direction, magnitude, and identity of the misregistered color plane for a scanned printed customer content image. The entire design pipeline can be directly used on the printed output without prior information on image content, allowing it to be widely used for printer troubleshooting.

1. Introduction

Misregistration of the color planes is a significant issue in printing technologies. Due to the fact that individual colorant planes are printed separately and independently, there will be color shifts in the printed image if there is no strict registration between the individual colorant planes. This limitation is particularly common with laser, electrophotographic printing technologies. The problem is illustrated in Figures 1 and 2. The right image in Figure 1 demonstrates that the magenta plane is not properly registered in the horizontal direction, and when compared to the reference image on the left, we can clearly see the impact of this issue on the image's boundaries. Additionally, in Figure 2, cyan moves downward in the right image, particularly around the fingers. This is due to the cyan plane being misregistered vertically.

The traditional solution to this problem, which is used in offset lithographic printing, where the printing plates are created using extremely high-resolution image-setters, is to rotate the screens to the most separated angles possible. However, achieving the desired angles with digital printers, which have a much lower spatial resolution, is difficult.

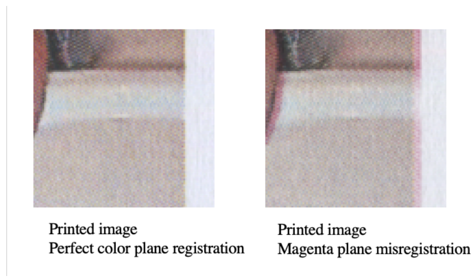

Figure 1. *Illustration of color plane misregistration: the Magenta plane of the right image moved in the horizontal direction.*

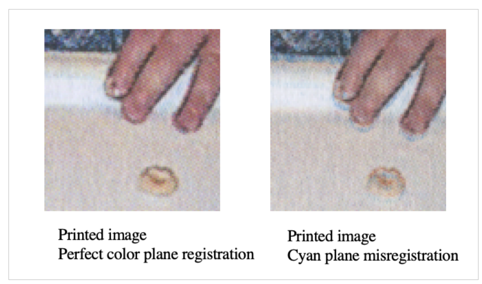

Figure 2. *Illustration of color plane misregistration: the Cyan plane of the right image moved in the vertical direction.*

Oztan, Sharma, and Loce addressed the issue by developing a quantitative method for determining the color difference [1]. When registration errors occur, their approach calculates the change in the fractional area of Neugebauer primaries and then uses it to predict color shifts. They established registration insensitivity conditions by identifying instances in which the fractional coverage of each Neugebauer primary remains constant in the presence of registration errors.

Kim and Chen define this issue in terms of the visual appearance of the halftone microstructure [2]. They concentrated on determining the sensitivity of halftone screens to registration errors and quantifying the effect of registration errors.

While all the previous studies were beneficial to this question, they were primarily focused on the hardware mechanical level, or halftone patterns and images, which cannot be used di-

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rectly on printouts. While some methods for measuring this problem on printouts do exist, they typically necessitate the creation of a uniform content image or a specific test image. Our contribution is that we will directly measure color plane misregistration using the customer's content images, which means we will have no prior knowledge of image content/texture, halftone images, or print quality, allowing the processing pipeline we designed to be more widely used by users or machines. Furthermore, we not only identify the misregistered color planes, but also estimate their direction and magnitude, which allows us to detect the problem more thoroughly and accurately.

2. Methodology

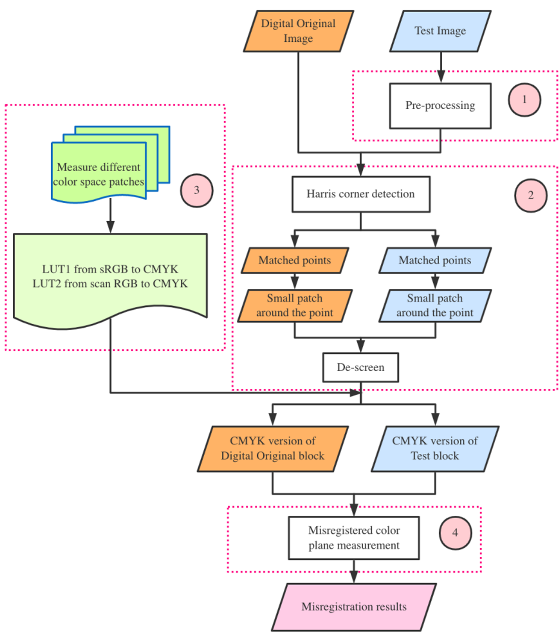

Figure 3. *Overall pipeline for color plane misregistration analysis.*

Our overall framework is depicted in Figure 3. Along with the scanned printed image of the customer content page (hereinafter referred to as the scanned image), our input contains the digital original image of the customer content page (hereinafter referred to as the digital original image). The digital original image is the image that was sent to the printer and is used as a reference to avoid confusion between color plane misregistration and the original texture of the image.

We first conduct preprocessing on the scanned image, which includes image resizing, edge skew correction, image registration, and image slicing. Following that, to ensure that the entire image is measured uniformly, we use keypoint extraction and feature matching [3] on each small region pair (scanned region and digital original region) to identify aligned point pairs, and then use the aligned point pairs as the center to extract the surrounding pixels to form aligned block pairs. We filter out block pairs that are not strictly aligned by computing the SSIM (Structural Similarity Index) [4] and setting a threshold. To remove halftone dots in different orientations (horizontal and vertical), we de-screen these aligned blocks using different 1-dimensional Gaussian filters.

Following that, we need to convert the block pair's color space, which requires enough data to generate LUTs (Look Up Tables). We start color space conversion by creating three color test pattern pages in three distinct color spaces (sRGB, scanned RGB, and CMYK). Each color test pattern pages is composed of over 1000 distinct color blocks, as shown in Figure 5. We take three lists of 1000 corresponding color values (RGB values list of RGB patch, RGB values list of scanned RGB patch, and CMYK values list of CMYK patch), then develop two mappings using tetrahedral interpolation [5], and create two LUTs. One LUT is a mapping from sRGB to CMYK for digital original blocks, while the other is a mapping from scanned RGB to CMYK for scanned blocks.

Our block pairs are now in CMYK space as a result of the above LUT mapping. To obtain the final color plane misregistration result, we use two strategies. One strategy is to calculate the MSE(Mean-Square Error) of the CMYK values in the horizontal and vertical directions, while the other strategy is to directly calculate the cross-correlation of the block pairs in the C, M, Y, or K channel.

The following sections will explain the details of each function.

2.1 Pre-processing

In general, the scanned image will be smaller in size, and resolution than the digital original image due to the printing and scanning processing. In addition, due to the possibility of paper skew during scanning, the scanned image may have irregular margins.

An example digital original image is shown in Figure 4(a), with a size of 6912 $\times$ 4768 pixels at a resolution of 600 dpi in sRGB space. Our initial scanned image, which is 3456 x 2384 pixels at 300 dpi and has uneven margins, is shown in Figure 4(b). Prior to image alignment, we trim and correct the skew margins introduced during the scanning process to eliminate the irregular margins, as illustrated in Figure 4(c). Then, using bicubic interpolation, the size and resolution of the test image are adjusted so that the scanned image is the same size as the digital original image, as illustrated in Figure 4(d).

We assume for our scanned images that the geometric transformation involves only a small skew angle rotation and a small translation along the x-axis and the y-axis, and thus we want to find several matched key points in order to compute the optimal transformation. To save computation, we convert RGB images to grayscale and then resample them at a 1/3 downsampling rate. Following that, we use histogram matching to match the gray values in the scanned image to those in the digital original image. Then we use Harris Corner detection to extract key points from

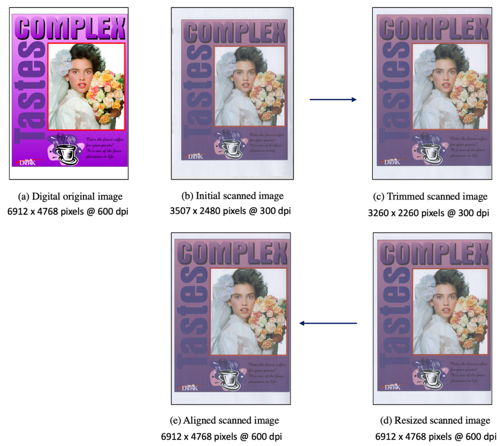

Figure 4. *Digital original image, original scanned image and pre-processed scanned image.*

the digital original image and scanned image, respectively. The feature descriptor is built using the 31 $\times$ 31 local areas that surround each key point. We find the best-matched key point pair by minimizing the sum of squared differences (SSD) and computing the ratio SSD. The optimal transformation is then determined by leveraging the Maximum Likelihood Estimation Sample Consensus (MLESAC). We use this transformation to transform the scanned image so that it aligns with the digital original image, as shown in Fig. 4(e).

After obtaining the aligned digital original and scanned image pair, we divide each image evenly into 100 small blocks to make the color shift more visible. Each block is a tenth of the original image's width and height. To ensure the alignment's accuracy, we perform block registration using the aforementioned method to generate the aligned digital original and test block pair.

2.2 Color space conversion

As mentioned previously, our scanned image is in scanned RGB space, the digital original image is in sRGB space, and the misregistered color plane is in CMYK space. As a result, two LUTs are required to convert the color space between sRGB and CMYK, as well as between scanned RGB and CMYK.

We create a color page with 1000 distinct color blocks that are ordered by the arithmetic difference of the three RGB channels. We obtain this color page in three different color spaces: sRGB, scanned RGB, and CMYK, as shown in Figure 5. We measure the start, end, length, and width of each small color block on the color page and use the average color values of the 0.6 Height $\times$ 0.6 Width area in the center of each color block to indicate the color. As a result, three lists containing 1,000 corresponding color values are created. The RGB values for the sRGB and scanned RGB pages are measured and recorded, as are the CMYK values for the CMYK pages.

Then, using tetrahedral interpolation, we create two LUTs from these data: one for converting the digital original image from sRGB to CMYK and another for converting the scanned RGB image to CMYK. As illustrated in Figure 6, prior to performing tetrahedral interpolation, we perform trilinear interpolation to augment the data.

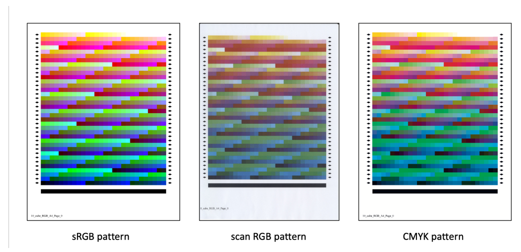

Figure 5. *The test pages in three different color spaces.*

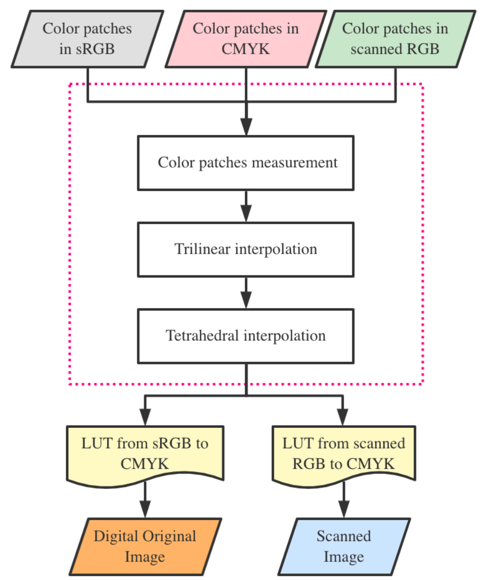

Figure 6. *Framework for color space conversion.*

2.3 Image de-screening

De-screening is required to remove halftone patterns from the input scanned image. While Gaussian filtering is commonly used to de-screen images, it has the potential to blur image details. We want to avoid weakening any useful details when measuring color plane misregistration, so we divide the problem into two problems in different directions. We de-screen only vertically when measuring horizontal color plane misregistration, and only horizontally when measuring vertical color plane misregistration.

This also decomposes the two-dimensional Gaussian filter into two one-dimensional filters. After conducting several tests, we determined that 15 $\times$ 1 and 1 $\times$ 15 1D Gaussian filters were more suitable for horizontal and vertical descreening, respectively, of our images. Figure 7 illustrates the performance of our descreening methods.

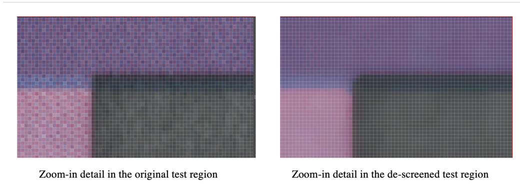

Figure 7. *Zoom-in detail in the original test image and de-screened test image.*

2.4 Color misregistration measurement and results

To obtain the final color plane misregistration result, we use two strategies. One strategy is to directly calculate the cross-correlation of the block pair in the C, M, Y, or K channels, while the another strategy is to calculate the MSE of the CMYK values in the horizontal and vertical directions.

2.4.1 Measurement using cross-correlation

The first technique starts with Fourier transformation. We transform the block pairs to the Fourier domain, use element-wise multiplication of the transform of one block with the complex conjugate the of the transform of the other block to compute cross-correlation in this domain, and then perform an inverse FFT to obtain the cross-correlation. Then we locate the maximum value of the cross-correlation and apply it to the original block of pixels to get the x and y axis offsets.

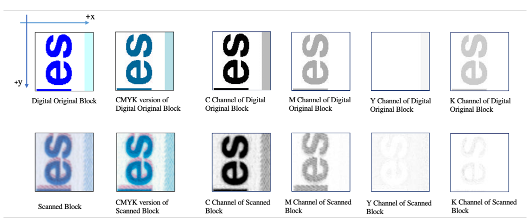

Figure 8. *CMYK channels of digital original block and scanned block pair.*

Table 1: Color plane shift results of Figure 8.

The amount of color plane shifts (pixel value)				
	Cyan	Magenta	Yellow	Black
x-axis	-1	0	0	-1
y-axis	0	-6	0	0

If color plane misregistration occurs, it indicates that the CMYK version of the scanned block is offset from its digital original block. As shown in Figure 8, from left to right are the digital original block (Row 1) and the scanned block (Row 2), the CMYK color space version of the digital original block and scanned block, and the block in the four channels of C, M, Y, and K, respectively. Table 1 shows the offsets of the scanned image relative to the digital original image based on their cross-correlation for each of the CMYK colors. Because it is imperceptible to the human eye when the offsets are less than or equal to 2 pixels, we collect only offsets larger than 2 pixels. From the results Table 1, the magenta plane has been shifted by 6 pixels in the -Y direction. This is our color plane misregistration measuring result, which is identical to the visual observation.

Additional results are shown in Figure 9 and Table 2, which indicate that the yellow plane has shifted 16 pixels in the -Y direction, which matches the visual observation.

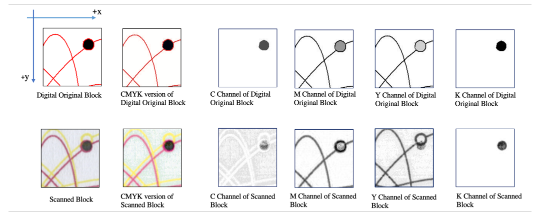

Figure 9. *CMYK channels of digital original block and scanned block pair.*

Table 2: Color plane shift results of Figure 9.

The amount of color plane shifts (pixel value)				
	Cyan	Magenta	Yellow	Black
x-axis	2	0	1	1
y-axis	1	1	-16	1

2.4.2 Measurement using MAE and MSE

The feature-matched small block pair typically contains key points, implying that it contains edges or texture variations. Thus, for a small block pair with a regular texture (rectangle or square), rather than performing color space conversion, Fourier transformation, and cross-correlation on the entire image, we can derive a color plane misregistration conclusion by computing color shift along a horizontal line and a vertical line that cross the edges.

We convert the digital raw blocks to grayscale and then convert them to a binary image using Otsu's binarization. Otsu's method derives the optimal global threshold from the image histogram. Following that, we do morphological opening (erode the image and then dilate) in order to eliminate symbols and details from the binary image while retaining the stronger contours. Then, using the Hough transform, we find horizontal and vertical lines. We refer to this open source function to implement Otsu's method and Hough transform [10]. Figure 10 shows the edge detection processing.

Figure 11 depicts an example of a regular texture (rectangle or square) that meets the MSE calculation requirements. Rather than performing color space conversion, Fourier transformation, and cross-correlation on the entire block pair, we only apply color space conversion to the pixels on the horizontal and vertical lines indicated by the arrows. Then, using the following formula, we compute the individual and sum MSE of CMYK on the lines.

$$indMSE_i = (i_{digital} - i_{scanned})^2 \tag{1}$$

where i is one of C, M, Y and K.

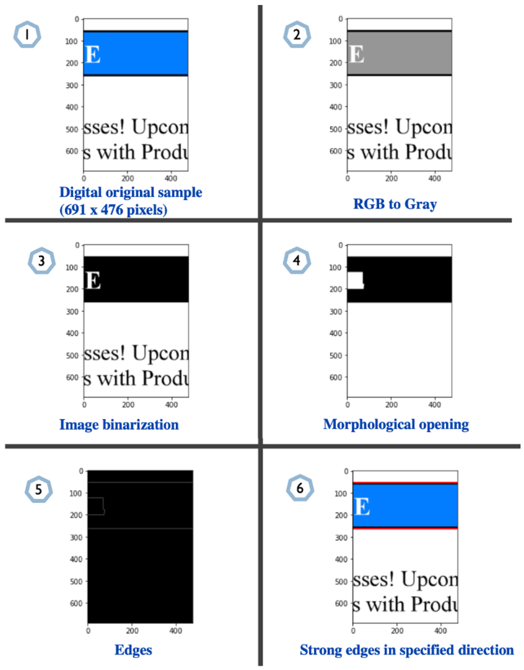

Figure 10. Sample results for Hough transform (Note: the edges of the last sub-image are highlighted with 6-pixel-wide red lines; the actual edges are 1 pixel wide lines.

$$sumMSE = (C_{digital} - C_{scanned})^2 + (M_{digital} - M_{scanned})^2 + (Y_{digital} - Y_{scanned})^2 + (K_{digital} - K_{scanned})^2 \quad (2)$$

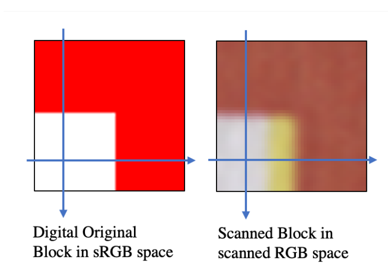

Figure 11. A digital original block and scanned block pair.

When color plane misregistration appears, the MSE of CMYK will significantly increase. We use a sample Figure 11 to illustrate the results measurement. The horizontal and vertical MSE values for this sample are shown in Figure 12. MSE values are scaled in the 0-1 range. We can see that the vertical MSE is always small and has no distinct peak, while the horizontal MSE has a distinct peak near the center, which corresponds to the yellow plane misregistration we see in the scanned block. We can determine the magnitude of the color plane misregistration by calculating the width of this peak, which is 9 pixels for this sample. The misregistered color can be determined by computing the four MSEs and determining the maximum value, which is Yellow, as shown in Table 3.

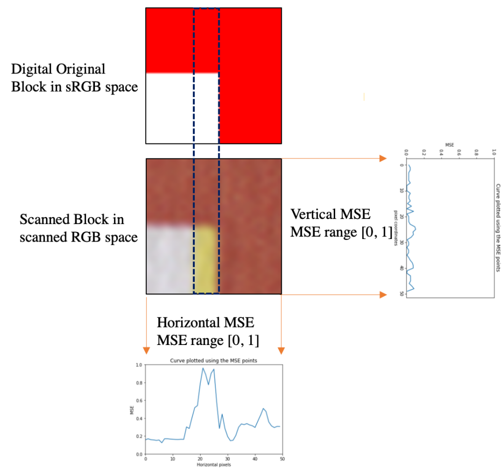

Figure 12. MSE plots of the block pair.

Table 3: MSE of each color plane.

MSE			
Cyan	Magenta	Yellow	Black
0.0075	0.019	0.972	0.002

3. Conclusion

In this paper, we designed and developed a processing pipeline for measuring color plane misregistration. The processing pipeline can automatically determine the direction, magnitude, and identity of the misregistered color plane for a scanned printed customer content image. We developed two measurement strategies: one measured using cross-correlation achieves subpixel accuracy and is thus preferred for high-resolution printed images. Although the other strategy, MSE calculation strategy is slightly less accurate than the former, it does not require the entire image's color space conversion, nor the entire image's FFT and IFFT transformation, which reduces the amount of computation. The entire design pipeline can be directly used on the printed output without prior information on image content, allowing it to be widely used for printer troubleshooting.

Acknowledgment

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