Methods to Automate Print Quality Assessment

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Abstract:

This paper demonstrates how image processing techniques can be combined to automate print quality assessment and reduce the time to market. Typically, significant engineering resource is required to evaluate and optimize print quality over a range of environmental conditions. This method is not only tedious, but its subjective nature induces error. An automated process has been developed to quantify print quality for a variety of digitized print samples. The process uses neighborhood analysis and edge detection to automatically align the digitized image. Techniques such as gradient-based edge detection, neighborhood analysis, and thresholding are used to quantify print quality for each region of interest. Calibration curves are used to relate manually graded images to computationally graded images. Finally, a weighted normalized least-squares fitting routine transforms print quality metrics for each environmental condition into a table of optimized electro-photographic voltage settings.

Introduction

When developing a new color laser printer, it is important to adjust EP settings to optimize print quality over a range of paper types, environments, and speeds. Completing the entire process generates thousands of pages that require print quality evaluation. In the past, engineers have manually evaluated print quality using a pass/fail system. The passing print samples define the range of acceptable EP settings, and optimal EP settings are chosen somewhere in the middle of the range. This tedious print quality assessment process must be redone whenever a major hardware or software change is made. In addition, the subjective nature of this process has the possibility to induce error. Because a pass/fail system is used, a print sample that is barely acceptable receives the same score as a print sample with excellent print quality, increasing the risk of choosing non-optimal EP settings in extreme environments. In order to compete more effectively in the digital printing industry, it is critical to minimize design cycle time and produce excellent print quality. Automating the process of print quality assessment accomplishes both goals.

2. Body

2.1 Quantifying Print Quality

The first step in automating print quality assessment is to identify the various print defects that limit the range of acceptable EP settings. Solid area non-uniformities, halftone non-uniformities, and small white dots in solid areas are a few examples of these defects. A scanner is used to digitize thousands of print samples, and small regions cropped from these digitized print samples are sorted from best print quality to worst print quality and given a score from 0 (best) to 10 (worst) for each print quality metric. A small subset of these images is shown in figure 1. This process is repeated until several cropped images are identified for each print quality value between 0 and 10.

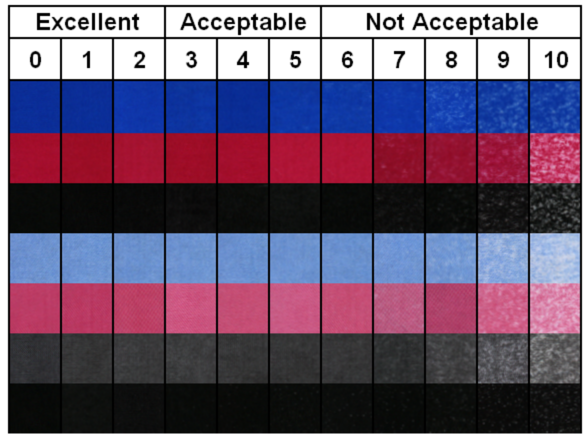

Figure 1: Print quality calibration scale

2.2 Computational Algorithms for Evaluating Print Quality

2.2.1 Solid and Halftone Uniformity

After defining a numerical print quality scale, the next step in automating print quality assessment is to identify algorithms to computationally measure print quality for each type of defect. The variance or standard deviation of a grayscaled digital image is a reliable metric to differentiate uniform print samples from non-uniform or under-transferred solid areas as illustrated by the histograms in figure 2a and 2b below. An averaging filter is applied to halftones before calculating the uniformity metric to minimize the effects of dot spacing.

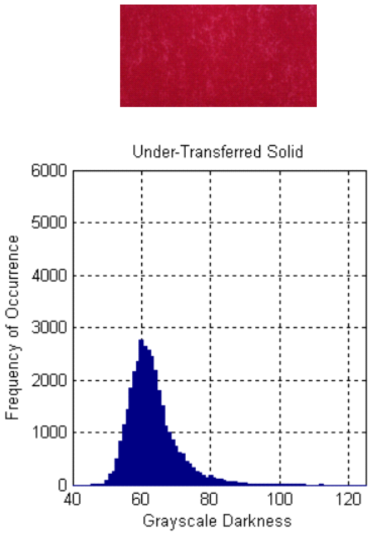

Figure 2a: Histogram for a non-uniform solid

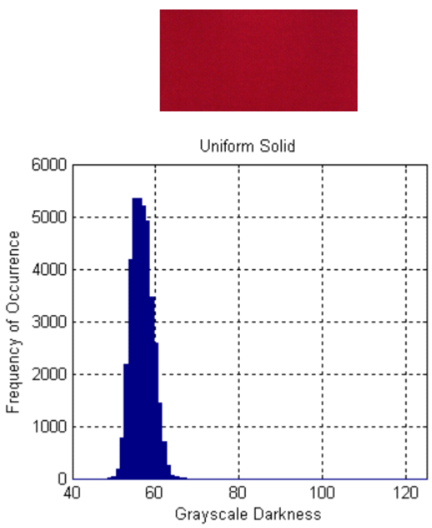

Figure 2b: Histogram for a uniform solid

2.2.2 Gradient-Based Defect Identification

When searching for small light gray dots within a predominantly dark gray image, it is difficult to determine an absolute darkness threshold to identify light defects. Objectionable defects tend to occur where there is a relatively large change in darkness over a short distance. In other words, defect edges tend to show up where the darkness gradient is highest. The Canny method for edge detection makes it possible to identify locations with large gradients in much the same way that the human eye sees defects. The Canny method determines the gradient by calculating the derivative of the Gaussian filter, and a gradient threshold can be specified to separate objectionable defects from acceptable defects. Figure 3 below demonstrates an application of the Canny method with a fixed gradient threshold by finding the outlines of light dots within halftones. The defects can be quantified by counting the number of white pixels in the black and white image on the right of figure 3 [2].

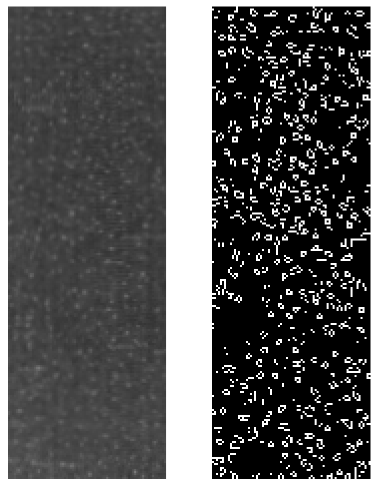

Figure 3: Demonstration of the Canny method for edge detection

2.3 Calibration

Algorithms defined in section 2.2 make it possible to objectively quantify print quality. However, in order to relate these quantities to subjective print quality defined in section 2.1, it is necessary to create a calibration curve for each metric. The calibration curves simply map the computed metric to a value between 0 and 10 representing the normalized print quality. Coefficients for calibration curves are determined through regression analysis using a constrained third order polynomial with a floor of 0 and a ceiling of 10. Figure 4 below illustrates one example of a calibration curve using standard deviation as the independent variable and the manually assigned print quality grade from 0 to 10 as the dependent variable. Average squared error can be calculated by summing the squared vertical error for each point and dividing by the number of points. A successful algorithm for determining print quality minimizes this squared error and also minimizes sensitivity to subtle changes of the independent variable.

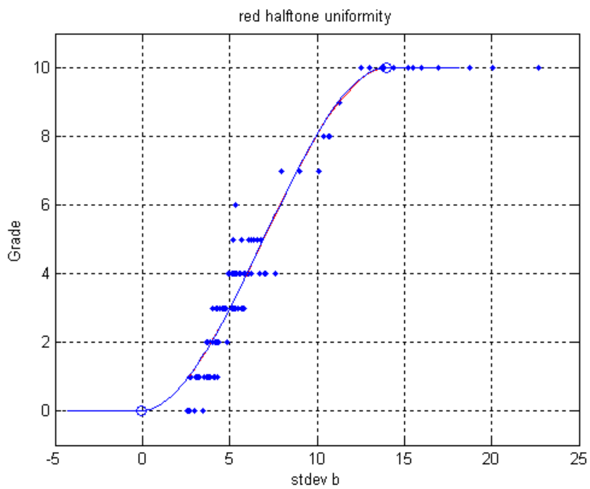

Figure 4: A calibration curve for red halftone uniformity

2.4 Coordinate Selection

After calibration curves are identified, a standard print file should be chosen to stress worst case printing scenarios. These usually include a combination of solid and halftone areas. Next, it is important to specify the coordinates of each region of interest, indicated by the outlined regions in figure 5 below.

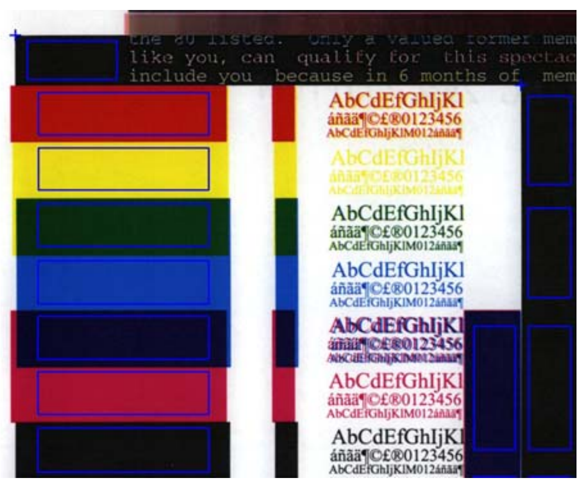

Figure 5: Print sample with regions identified

2.5 Corner identification and image transformation

To properly orient the page and adjust for skew and registration, it is important to specify the target coordinates of corners. The corner identification method works best with a black corner on a white background. The list below describes the steps taken to identify the corner coordinates and align the image.

- First define the region containing a dark corner on a relatively light background.
- Turn all reddish hues white to ensure that the corner for black is found instead of red or yellow, and convert the color image to grayscale. Refer to figure 6a.
- Use Otsu's method to convert the grayscale to image to black and white [1]. Use neighborhood analysis to keep only the largest white area and largest black area. Refer to figure 6b.
- Use the Canny edge detection method to identify maximum gradients to create an edge image. Refer to figure 6c.
- Rotate the coordinates of the edge image -135 degrees so that the corner of interest is at the minimum value. Use linear regression to fit two perpendicular lines to the rotated corner and calculate the correlation coefficient for each line. Refer to figure 6d.
- If the correlation coefficient for each line is close to 1, the intersection of the two perpendicular lines is rotated back 135 degrees to define the corner of the image. If the correlation coefficient for each line is not close to 1, no corner is identified.
- After corners are found at various locations across the page, the image is rotated, translated, and scaled to ensure the proper location of each print region of interest from figure 5.

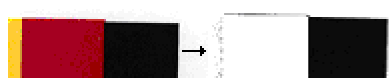

Figure 6a Elimination of reddish hue and conversion to grayscale.

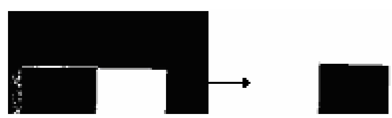

Figure 6b: Conversion to black and white regions of interest using Otsu's Method and neighborhood analysis.

Figure 6c: Creation of edge image using the Canny Method.

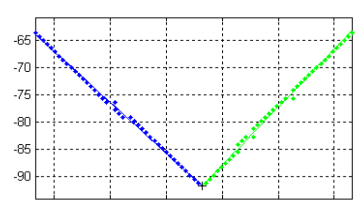

Figure 6d: Corner rotation and perpendicular line fitting routine.

2.6 PQ Assessment Output

After corner identification and image transformation is completed on each digitized print, calibration curves are used to calculate print quality metrics for each region of interest. Figure 7 shows the print quality metric for 25 pages. The print voltage was increased a fixed amount for each page beginning with page 1. According to figure 7, the print quality metric begins to level out after page 4 and remains fairly constant through the last page. A graph similar to figure 7 must be generated for each environment, paper type, speed, and EP parameter. Because print quality is now objective and quantifiable, the process of determining optimal EP settings can now be completely automated, reducing development time, cost, and human-induced error.

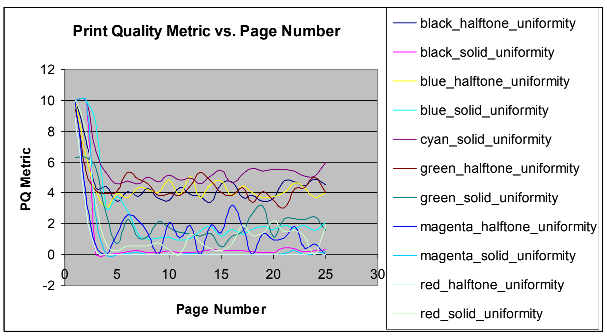

Figure 7: Print quality metric evaluated over a range of EP settings.

Conclusion

To reduce development time and optimize voltage settings, it is helpful to automate the process of print quality assessment. The first step in this automation process is to define the common print defects that limit the range of acceptable EP settings. Sample images for each print defect should be identified and numbered according to defect severity. Next, a series of algorithms are used to quantify each print defect. One such algorithm utilizes the Canny method for gradient-based edge detection to identify localized defects. Sample images for each print defect are graded manually and computationally. Constrained cubic calibration curves relate manual grades to automated grades. Corner identification methods make it possible to re-orient skewed and misaligned pages so that region coordinates can be specified in the correct location. Finally print quality metrics are calculated for each specified region and remapped to a normalized print quality scale based on the calibration curve coefficients. The normalized print quality metric ultimately makes it possible to automate print quality assessment.

References

[1] Otsu, N., "A Threshold Selection Method from Gray-Level Histograms," IEEE Transactions on Systems, Man, and Cybernetics,Vol. 9, No. 1, 1979, pp. 62-66.

[2] Canny, John, "A Computational Approach to Edge Detection," IEEE Transactions on Pattern Analysis and Machine Intelligence,Vol. PAMI-8, No. 6, 1986, pp. 679-698.

Author Biography

Robert Booth is a mechanical hardware engineer at Lexmark International with experience in transfer technology and fuser technology in color electro-photography. He is currently applying image processing techniques to automate the process of print quality assessment. He holds a bachelor's degree in mechanical engineering from the University of Kentucky and is currently pursuing a master's degree in mechanical engineering from the Georgia Institute of Technology.