Measurement of Electrophotographic Ghosting

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Abstract

Electrophotographic (EP) ghosting is a print defect, manifesting itself as the re-development of a previously printed image. It frequently appears when printing a mid-tone fill immediately following an area of solid fill. Within the mid-tone region, the previously printed solid fill gets imaged again as a ghost.

Today, several methods exist that measure ghosting. The most common method is measurement of the difference, in lightness or reflectance, between the ghost region and the background. However, this method does not fully correlate to the perception of the ghost defect. This paper describes a technique that allows for a perceptual measurement of ghosting. The procedure involves measuring several features of the ghost defect using a flatbed scanner. The combined set of features then yields a Ghost Index metric (GI), which correlates with human perception. This metric enables better definitions of product design goals and provides a tangible way for gauging progress towards the design goals.

Introduction

Ghosting can be produced by a number of factors. Common mechanisms are incomplete erasure of the electro-photographic drum or inadequate charging in the developer after the imaging of a high-density region. In printed copy, ghosting appears as an unwanted image developed further down the page in the process direction. A ghost image may show up as a single or repeated defect. The frequency depends upon the causal mechanism and the diameter of the offending printer component. The cause of the ghosting also determines whether the ghost prints as a positive or negative image. Figure 1 shows an example of ghosting, where two ghost images reside in what should be a uniform, gray field. The distance from the black box at the top of the image to the ghost provides information about the mechanism involved in producing the ghost. Other characteristics to note about the ghosts include the density (light versus dark), definition of the ghost boundary (blurry versus sharp) and density of the area around the ghost.

Ghosting susceptibility is one of many potential imaging system defects considered in the design process. Having an accurate measure of ghosting can directly effect the ability to assess design changes and trade-offs. In the past, reflectance based measurements have been used to measure differences between ghost areas and non-ghost areas. These measurements examine only one characteristic of the ghost phenomena. Trying to access the perceived level of ghosting using only a reflective measurement may provide a misleading representation of the defect level. This, in turn, compromises the optimization of an imaging device's overall print quality. A method is needed to accurately measure the perceived level of ghosting in an imaging system.

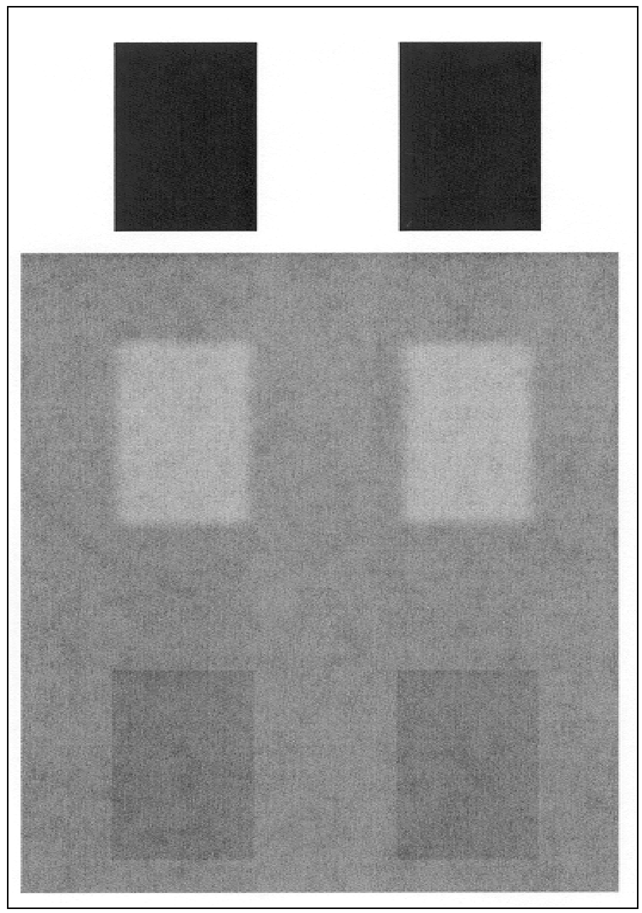

Figure 1. Example of two Ghost image

Measurement Methodology

An accurate measurement of ghosting must consider all aspects of the ghosting defect. Examining a large number of ghost defects provides a list of potentially significant characteristics:

- Magnitude of the lightness difference between ghost and non-ghost regions
- Sharpness of ghost edges
- Light or dark ghost
- Background lightness that surrounds the ghost

Integrating some or all of these qualities should yield a function correlating analytical measurements with perceived magnitudes of ghosting. The first step in determining this function is to measure each characteristic individually.

A custom designed test page enables the measurement of ghost images by eliciting the worst case ghosting for a printing system. The page includes a large solid area printed before a medium gray field.

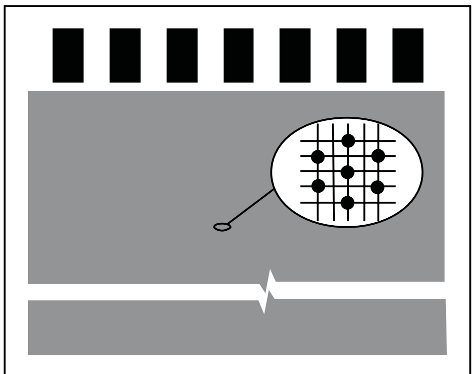

Figure 2. Ghosting test page

The test page, shown in Figure 2, consists of a series of seven black squares across the width of the page with a medium gray field printed for the remainder of the sheet. The gray area is generated with the illustrated dot pattern on a 600-dpi grid. In printer testing, this pattern has shown to generate worst case ghosting.

For this study a flatbed scanner is used for measuring ghost characteristics. The scanner is simple to operate and provides a large measurement area. All scans have a resolution of 300 pixels per inch and 8 bits of gray. A reflectance profile measurement 2048 pixels long is taken horizontally across the ghost region. The start of the profile is to the left of the first black block. Averaging 20 pixels in the vertical direction at each horizontal location reduces some of the unwanted print quality issues not related to ghosting, i.e. banding. Figure 3 shows a scan of a ghost region.

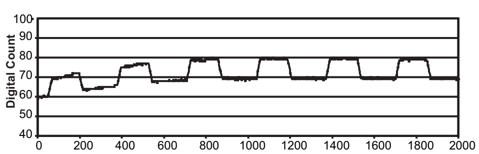

Figure 3 – Scanned data

The scanned data is then converted to an approximate lightness space using the following equation:

$$Lightness = 116 * (ScanVal)^{1/3} \quad (1)$$

Scaling of the scanned curve into a lightness like space allows for ghost defects of varying backgrounds to be compared on a visually similar scale. The scaled data appears in Figure 4.

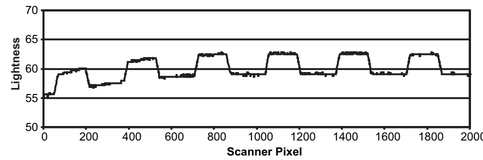

Figure 4. Data scaled in lightness

In Figure 3, the underlying curve in the data is not part of the ghost defect. It is caused by the non-uniformity of the scanner illumination. To remove this effect, a third order polynomial fit is preformed on the lightness profile (Figure 5) and subtracted from the measured profile, producing the curve in Figure 6.

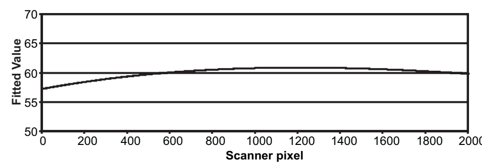

Figure 5. 3rd Order fit to lightness

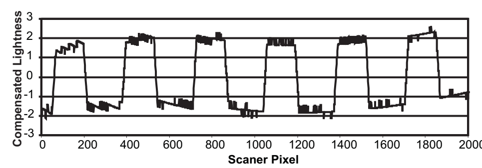

Figure 6. Scaled and compensated data

With lightness scaled data and scanner non-uniformity corrections determined, the ghost defect can now be accurately characterized.

Subtraction of the summed, above-zero values from the summed, below-zero values approximate the magnitude of the difference between ghost and non-ghost areas. The start of the luminance line was defined to be outside the measured ghosting region. Because of this the values measured at the start of the lightness profile can be used as a reference to determine the positive or negative nature of the ghost image. Calculations for the background of the ghost region entail taking the average value of the 3rd order fit to the luminance. These computations provide three of the four characteristics postulated as significant to the measurement of ghosting magnitude. The assessment of edge sharpness requires a different approach.

To begin, an FFT is performed on the scaled and compensated data (Figure 7).

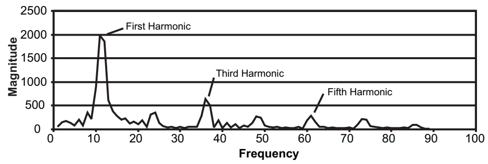

Figure 7. Luminance profile in frequency domain

If there is a ghost present in the luminance line it has been induced by the pattern at the top of the test page. The first harmonic shown in Figure 7 corresponds to the frequency of the black bars on the top of the ghost test page. An added benefit of this is that a ghost can be automatically detected in a scan. If the magnitude of the first harmonic is the maximum value in the frequency spectrum then the black bars have induced a ghost to occur in the gray field. A comparison of the third and square of the fifth harmonic magnitudes to the first harmonic magnitude renders information about the sharpness of ghost edges. The use of square of the fifth harmonic was determined by experimental means. Equation 2 generates a value for the sharpness.

$$Sharp = \frac{First}{third * fifth^2} \tag{2}$$

At this point, all the specified characteristics have an associated method for measurement. The next step involves merging the individual values to create a model approximating the perceived level of ghosting. This is accomplished with a psychophysical test.

Psychophysical Testing

A set of images containing simulated ghost artifacts was prepared for visual evaluation of the magnitude of the defect. Simulated samples were used instead of samples taken from normal machine output. This was done because the "real" prints may include other quality artifacts that detract from the evaluation of the ghost (e.g. banding, streaking). Also, normally produced ghost images may not include all combinations of interactions needed to adequately sample an appropriate range of ghost images.

A total of 42 test images was printed on paper and mounted on neutral colored cardstock. These samples vary in background density, magnitude of density difference between ghost and background, sharpness of ghost outline and positive or negative ghosting. A Rating Scale method was used for the visual scaling with seven categories anchored with range-establishing images at the extreme categories. Data were obtained from 27 observers. The charge to the observers follows:

> In this experiment you will be shown 42 images that contain some degree of ghosting phenomena. Your task will be to evaluate the degree of ghosting relative to two reference prints placed at the opposite ends of the seven point rating scale on the viewing tables. The reference prints define a total range of ghost intensity and are labeled 1 for the lowest amount of ghosting and 7 for the maximum amount. The other five categories divide the total range into equal parts. For example, if the print sample you are evaluating was judged to be equidistant in ghosting severity between the two reference prints it would b placed in the "4" category. All the prints in a given category will have the same level of severity of ghosting, as you perceive it.

All observations were conducted under 5000 Kelvin fluorescent lighting at a luminance level appropriate for critical viewing. In order to allow the observers to become familiar with the test methodology and the types of ghost defect, they participated in a short pilot experiment before evaluating the test image set. After completing the pilot experiment the observers were given the 42 test images in an order randomized with respect to the magnitude of defect. As each image was evaluated it was placed face up on a viewing table by the appropriate category label. As succeeding samples were rated the observer was permitted to make adjustments to previous decisions if a mistake had been made. At the completion of the viewing session the observer was asked in an exit interview to describe the scaling experience and to identify the characteristics of the images that were critical to the judgements made.

A model that estimates the perceived level of ghosting from objective measurements may be created by combining the visual ranking results with the objective measurements from the scanner. Based on information from the exit interview, the proposed model includes edge sharpness (*Sharp*) and ghost-background density differences (*Diff*) as it primary factors. Using regression analysis, a model for the ghost index (GI) was determined and appears as Equation 3.

$$GI = A * Diff + B\left(\frac{Sharp}{Diff}\right) + C * Sharp + D \tag{3}$$

The R-Squared statistic for this regression indicates that the model accounts for over 97% of variability in perceived rankings. This is deemed an acceptable model for use in the calculation of the metric. Figure 8 presents a comparison of measured values to computed values.

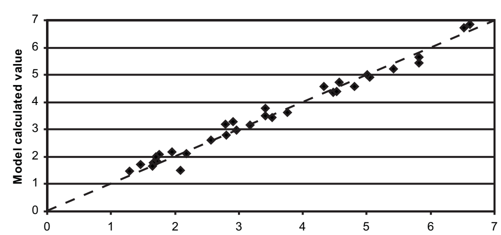

Figure 8. Comparison of model and actual data

Conclusions

The analytical model proposed has a close correlation to the perceived magnitude of ghosting. However, the complexity introduced with this model warrants a comparison to previously used methods.

To date, differences in lightness or reflectance prevailed as the most common ghosting measurement method. Though a quick and simple measurement, it does not fully describe the perceived magnitude of ghosting. Figure 9 compares the conventional difference and the newly proposed models on the same chart.

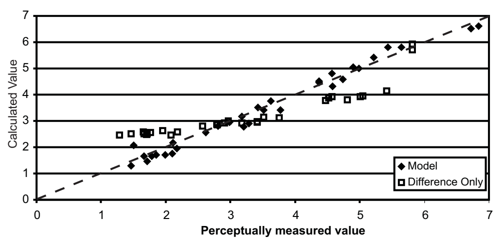

Figure 9. Comparison of Model and Difference measurements

It can be seen that while there is a correlation between the difference measurement and perceptual ranking it is not as accurate as the proposed model. Using just the difference in lightness would yield an R-Squared statistic just over 78%. Another examination of the data is shown in Fig. 10.

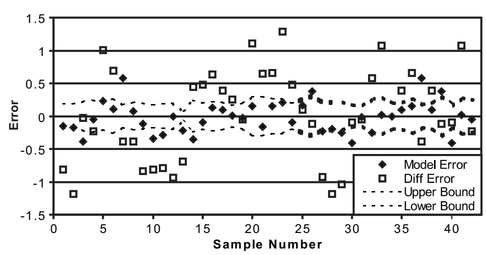

Figure 10. Error Comparison

In this graph the error is computed in terms of the absolute difference from the psychophysical ranking. The dashed lines represent the upper and lower confidence bounds calculated for the psychophysical testing. Both the proposed model and the measurement of the difference in lightness are shown. It can be clearly seen that the use of the proposed model is generally within the 95% confidence interval of the psychometric testing while the difference method does not.

In addition to the close correlation to perceptual measurement, the proposed model has one other benefit. The measurement method provides an indication of whether a ghost is present. For automated measurement this can prevent erroneous data from being collected.

References

1. John C. Briggs et al., Thermal Banding Analysis in Wide Format Inkjet Printing, Proc. IS&T NIP16, pp. 388-391 (2000).
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Biography

Paul Jeran joined Hewlett-Packard in 1992. During that time he has been involved in the development of new printing technologies, print quality measurement and printer reliability. Currently he is a member of the Advanced Technology Section working to establish print quality metrics for LaserJet printers. He is an active member in ISO/IEC JTC1 SC28 and ECMA TC34 standards committees. Mr. Jeran received his BS and MS degrees in Mechanical Engineering from the Rochester Institute of Technology.