

Analysis of Ghosting in Electrophotography

John C. Briggs, Eugene Hong and David Forrest
QEA, Inc.
Burlington, MA/USA

Abstract

A common print quality problem in electrophotographic (EP) printing is ghosting. Ghosting refers to a vestigial image repeated at regular intervals down the length of a page and appearing as light or dark areas (negative or positive ghosting, respectively) relative to the surrounding field.

There are many sources of ghosting, including most EP printer subsystems and many of their components. Subsystems from charging, development, photoreceptor, to fusing can all produce ghosting. The ghosts can be both positive and negative (darker and lighter). Having multiple ghosting sources can make the sources of ghosting difficult to determine, pointing to the need for reliable diagnostic tools.

This paper demonstrates how a commercially-available image analysis system is used to quantify ghosting and diagnose its causes. The system utilizes test targets specifically designed to reveal ghosting problems and are optimized for automated inspection. The analysis method uses frequency domain techniques that make it possible to isolate ghosting from other print quality problems. The method can also correlate observed ghosting to the printer component or components causing it. In addition to its role in R&D, the method is suitable for production environments as a quantitative tool for setting acceptance limits and performing quality control prior to shipping the product.

Introduction

At the present time, there is a significant interest in ghosting and the mechanism of ghost formation in EP printing. Ghosting is one of the problems that limits the overall print quality of EP prints.

Although there are many sources of ghosting, problems with the development system are a common source of ghosting. Figure 1 shows a sample image. Recent research[1] has pointed to charge accumulation on the development roller and metering blade as a source of ghosting. Other research showed that inconsistency of particle size across the development roller surface is a source of positive ghosting.[2,3] Other development subsystems such as fusing,[4] charging, and OPC can all be sources of ghosting.

Precise quantification of ghosting severity and identification of the root-cause is of significant value to manufacturers of EP printers or components. Unfortunately, sample prints are often difficult to evaluate, as there are many sources of ghosting. Additionally, unless the ghosting is very severe, the ghosting problem can be difficult to isolate from other image artifacts. What is needed is a clever technique to isolate the ghosts and facilitate automated measurement.

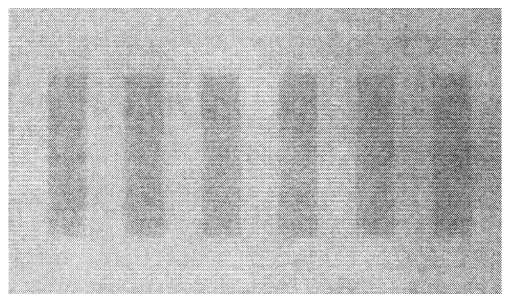

Figure 1: Scanned image showing ghosting problem. This region was intended to be uniformly gray. The dark rectangles are ghosts of black rectangles printed at the top of the page. Contrast has been increased to ensure reproducibility.

Measurement Method

Test Target

To be able to quantify the severity of ghosting, it is important to print a well-designed test target that highlights the ghosting problem. Although there are many ways to design a test target, the authors have developed a target that is suitable for automated inspection, see Figure 2.

The test target is designed as follows. At the top of the page is a pattern of forty-four 2×10mm black and white bars (stripes). This will be referred to as the *initial pattern* in this paper. Following the *initial pattern* is a large 50% gray halftone field. If ghosting does occur, it can be observed and measured in this field. On the printer used in our testing (HP LaserJet 4), the top of the page is printed first.

There are a number of black bars (2×10mm), on the left edge of the test target, that indicate the locations where ghosting may occur. For example, the development roller diameter is 16mm (HP LJ4) and has a circumference of 50.27mm. If ghosting is related to the development process, it will be located at a distance of 50.27mm from the *initial pattern*. There may also be a ghost at 2×50.27mm or 100.54mm. If the ghosting is due to some other process, the location of the ghost will be different. For example, ghosts related to the OPC are located at 94.25mm (30mm diameter OPC roller) from the *initial pattern*.

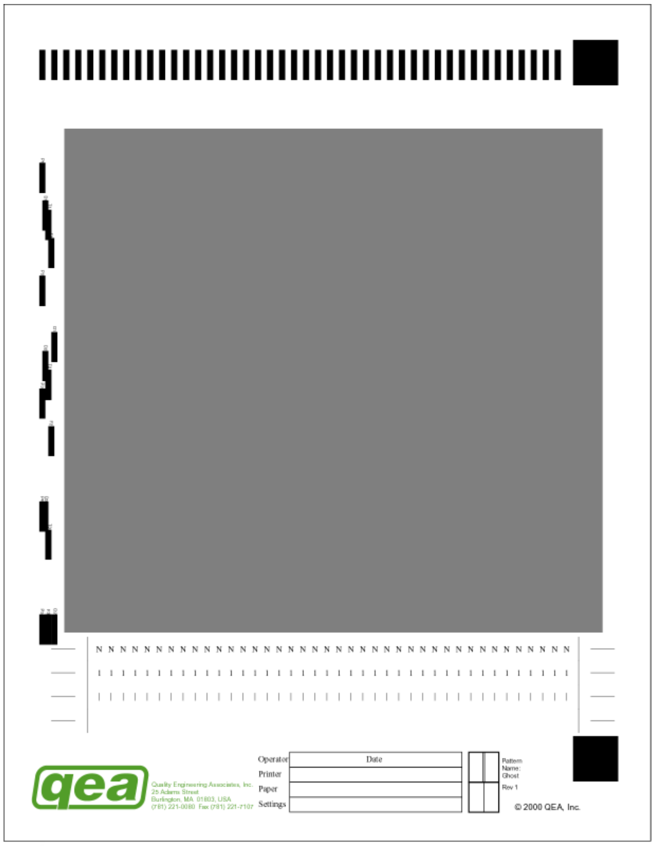

Figure 2: Test target used for evaluating ghosting.

Having a priori knowledge of where ghosts will occur for a given printer is a key piece of diagnostic information. By determining the location where the ghost occurs, it can be deduced which printer subsystem is causing the ghosting. Unfortunately, some printers use the same roller diameter in two different sub-systems (e.g. same fuser and OPC diameters) confounding efforts to uniquely determine the subsystem responsible for the ghosting.

Sample Measurement

Once the test target has been designed and samples printed, quantification of the ghosting severity is the next important step. While subjective evaluation of ghosting is possible, objective evaluation via image processing offers many benefits, including fast, automated, consistent, numerical quantification.

The ghosting samples were quantified using a commercially available image analysis system (IAS-1000 by QEA, Inc). This is a camera-based system that includes a PC and a vacuum table with an X-Y stage to hold down and move the sample. For quantifying ghosting, the system's "banding analysis tool" was used. The tool was instructed to measure the reflectance profile for an area 5mm high by 160mm wide in the areas where ghosting is expected, starting at the left edge of the gray area.

The ghosting data from one sample will be used to illustrate the technique. The reflectance profile data taken from a ghost area is shown in Figure 3. The graph shows just the first 16mm of a 160mm long reflectance profile. The reflectance profile is developed by first averaging CCD camera data together across a certain width (e.g. 5mm) into one data point then repeating this process for each point along the length (160mm) with sample spacing of 10μm. Unfortunately, the reflectance profile data is extremely noisy as a result of many other printing problems that exist in the print in addition to the ghosting problem. To create the graph in Figure 3, multiple forms of averaging need to be applied to the data making it difficult to automatically determine ghosting severity directly from the reflectance profile. Frequency domain techniques greatly facilitate this process.

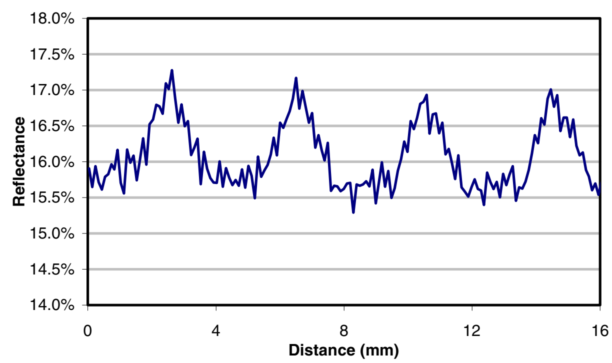

Figure 3: Reflectance profile showing the variations in reflectance due to ghosting. Note that the ghost period is 4 mm

The data in Figure 3 shows the key features of the ghost. The average reflectance was about 16.1% (0.79 OD). The dark area of the ghost is about 15.7% and the light area is as high as 17%.

The design of the test target is such that one of the black bars in the *initial pattern* is lined up with the left edge of the large gray area. Since the left edge of the gray area corresponds to position 0 (in Figure 3), this is a positive ghost. In other words, an area on the development roller that had previously printed a dark area, prints more densely than an area on the roller that had previously printed a white area.

To make progress with ghosting problems, a clear metric (or measure) of ghosting severity is needed. The magnitude of the periodic signal in Figure 3 is such a measure. The best way to get this information is to use frequency domain techniques.

Frequency Domain Analysis

A frequency domain analysis helps isolate features of the print. To get the frequency domain data, an FFT (Fast Fourier Transform) is applied to the raw reflectance profile data. The magnitude portion of the FFT is shown in Figure 4.

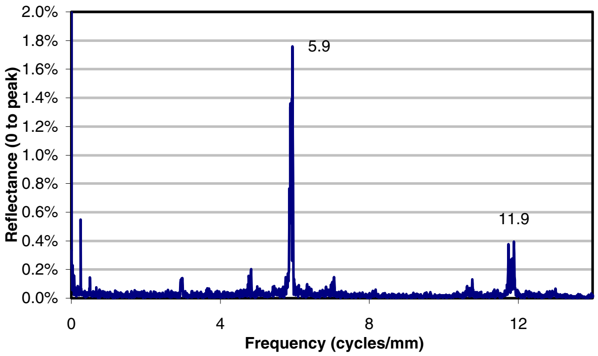

Figure 4: FFT of reflectance profile showing peaks at 5.9 and 11.9 cycles per mm due to halftoning.

The large peaks in the Fourier transform are due to the halftoning used to produce the gray field. For this printer, the fundamental frequency of halftoning occurs at 5.9 cycles/mm (150cycles/inch). The ghosting frequency occurs at 0.25cycle/mm and is well separated from the halftoning frequency at 5.9 cycles/mm. As a result, in the frequency domain, the halftoning information is easy to isolate from the ghosting information. By contrast, it is very difficult to separate out these two signals in the reflectance profile.

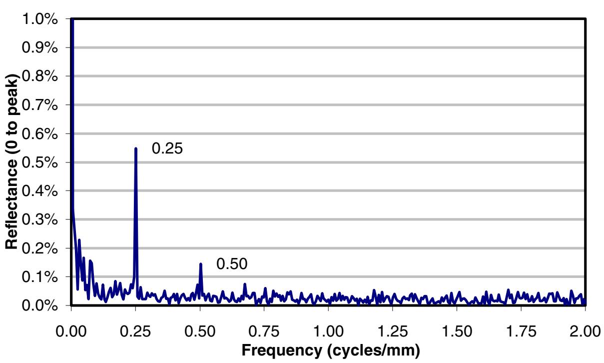

Figure 5: FFT of reflectance profile in the low frequency region showing peaks due to the ghosting.

The severity of ghosting can be judged by the magnitude of the 0.25cycle/mm peak in Figure 5. Because the original print pattern consisted of a square wave with a frequency of 0.25cycle/mm, the ghost also consists of a square wave at the same frequency. Figure 5 shows clear peaks at 0.25 and 0.50cycle/mm. This is expected since square waves consist of a large peak at the fundamental frequency (in this case 0.25) and then a smaller peak at the 2nd harmonic (in this case 0.50). There should also be still smaller peaks at higher harmonics (0.75, 1.00,…), but these peaks are buried in the noise of the signal. Subjective evaluation of ghosting severity has been shown to have a strong correlation with the magnitude of the 0.25cycle/mm peak.

There are two key points about using this technique. First, the frequency at which the ghosting occurs is controlled by the *initial pattern* used in test target design. This is a valuable tool to help isolate ghosting from other periodic and non-periodic sources of reflectance variation, e.g. halftoning, laser speed jitter. These other noise sources can confound a human observer trying to look for the presence of ghosting in among other sources of image noise. Using the test target design to force the ghost to contain a known frequency allows the image analysis system to accurately assess ghosting severity even if other noise sources are present. Secondly, for frequency domain techniques to work well, data needs to be available from many cycles, e.g. 10 or more. Measurements over many cycles are needed for the technique to give an accurate indication of ghosting severity. Use of the automated image analysis system makes this analysis very simple and easy.

Case Study

In order to test the usefulness of this measurement technique and understand more about the nature of ghosting, a simple case study was devised. A HP LaserJet 4 printer was selected for testing primarily due to its availability to the authors. This printer employs a monocomponent magnetic jumping development system. Three different print cartridges were purchased from a local office supply store. Two cartridges were OEM and one was aftermarket. The objective of the case study was to determine if there was much difference between the different brands of cartridges in terms of their ghosting performance.

After printing a few test samples, it was clear that there was a significant ghosting problem. A clearly visible ghosting pattern was observed on most of the prints at a distance of approximately 50mm from the *initial pattern*. Given this distance, the ghosting was attributed to the development sub-system.

For each of the three cartridges, ten sheets of paper were printed with the test target shown in Figure 2. Prior to printing each test target, a completely black sheet and then a completely white sheet were printed. These sheets were intended to put the printer in a consistent state, and make the print quality on the test sheet less dependent on the printing history. Each sheet was analyzed on the image analysis system to quantify ghosting. This data is shown in the top half of Table 1 and the left side of Figure 6.

Table 1: Data from ghosting analysis on LaserJet 4 printer with three different commercially available cartridges.

cartridge	roller	graph label	average reflectance	Mag. of 0.25cyc/mm peak
cart 1	roller 1	c1r1	19.1%	0.005 0
cart 2	roller 2	c2r2	15.6%	0.008 4
cart 3	roller 3	c3r3	17.4%	0.002 0
cart 1	roller 1	c1r1	19.3%	0.003 9
cart 1	roller 2	c1r2	19.6%	0.003 7
cart 1	roller 3	c1r3	17.1%	0.003 2

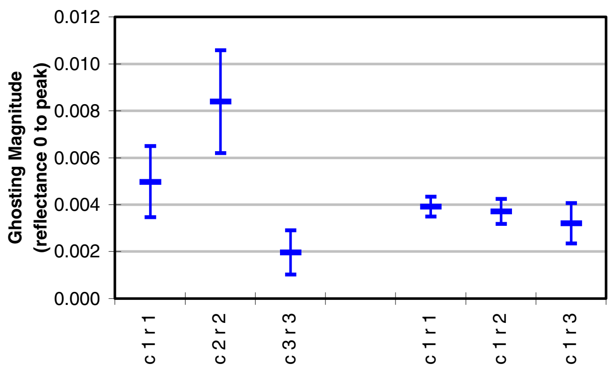

Figure 6: Magnitude of the 0.25 cycle/mm peak in the frequency domain data. Large marks are the average value of 10 print samples. Smaller marks are at +/- 1 standard deviation.

Clearly the different brands of print cartridges had significant differences in the severity of the ghosting. *Cart 3* has the lowest ghosting. The *Cart 3* prints had an average reflectance value of 17.4% in the area measured for ghosting. In the frequency domain data, there was a peak at 0.25cycle/mm of only 0.0020 reflectance (0 to peak). Thus a first order approximation to the reflectance profile is a sine wave with a DC value of 17.4% that has a maximum value of 17.6% and a minimum value of 17.2% with a period of 4mm.

The other two cartridges had a significant and visually objectionable ghosting problem. *Cart 2* had the worst ghosting with a value of 0.0084 reflectance (0 to peak). *Cart 1* was slightly better with a value of 0.0050 reflectance (0 to peak). There was a large variation in the magnitude of ghosting from one print sample to the next. It is therefore necessary to measure a large quantity of print samples to get an accurate assessment of ghosting severity on any given cartridge.

In an attempt to isolate the cartridge component responsible for the ghosting, components were swapped between the different cartridge brands. The mag-roller (development roller) sleeve from each of the three cartridges were placed one at a time into *cart 1*. Ten print samples were again obtained from each cartridge/roller combination and measured. This data is shown in the lower half of Table 1 and the right side of Figure 6.

When the mag-roller sleeves were placed in the same cartridge, the ghosting severity became more consistent. For this second group of prints, the peak at 0.25cycles/mm ranged from 0.0032 to 0.0039 reflectance (0 to peak). So despite initial suspicions that the mag-roller was to blame for the ghosting, this measurement technique was able to show that the mag-roller by itself was not the source of the problem. The ghosting may be due to the interactions between the mag-roller and the other development components.

One inconsistency in the data is that cartridge 1 with its own roller was used in both the first and second batch of testing, but the amount of ghosting was slightly different. In the first test, the ghosting was 0.0050 and in the second it was 0.0039 reflectance (0 to peak). Additionally, there was much less print-to-print difference in the magnitude of the ghosting on the second group of prints. Perhaps this is related to the fact that the samples were printed on different days and probably under different RH (relative humidity) conditions. The printing test conditions may need to be well controlled to get consistent ghosting.

This testing highlights a number of key issues about ghosting. First, ghosting is a significant problem with some brands of cartridges having more of a problem than others. Secondly, the testing shows the value of the measurement technique as a quantitative diagnostic tool which can assist in isolating the cause or causes of the ghosting.

Conclusions

Ghosting in electrophotographic printing continues to be a challenging print quality problem. The technique explained in the paper enables precise quantification of the severity of ghosting. The techniques involved a test target designed to reveal ghosting problems (if they are occurring) in a way that is optimized for automated quantification on an image analysis system. The measurement technique uses frequency analysis to isolate ghosting problems from other printing problems.

A case study of three different brands of LaserJet 4 cartridges showed that significant differences in ghosting severity do exist between brands. The data also showed the usefulness of the measurement techniques as a diagnostic tool to track down the source of the problem.

References

1. Inan Chen, Toner Charging and Deposition in Single-Component Development of Electrographic Images – A Theoretical Analysis, IS&T JIST V41 N6, p611-617, (1997).
2. Iwamatsu et al. Ghost Mechanism of Single-Component Contact Development. IS&T NIP 14:, pp 413-416, (1998).
3. Takaya et al. The Characteristics of Ghost Mechanism in a Non-Magnetic Single Component Process Depends on a Diameter of the Toner Particle. IS&T NIP 14:, pp 422-424, (1998).

4. Tse, Ming-Kai et al., A Fusing Apparatus for Toner Development and Quality Control, IS&T NIP13, Nov 2-7, (1997).

Biography

Dr. John C. Briggs joined QEA in January 1998. He is responsible for new product development and application research. He is the author of numerous technical papers on digital printing and print quality. Previously at Iomega Corporation, he was a key contributor to the design and development of the Zip™ drive. Dr. Briggs holds eleven patents. He received his BS, MS, and PhD degrees in Mechanical Engineering from the Massachusetts Institute of Technology.