Measuring the Imperfect Dot

Marguerite Doyle
Lexmark International, Inc.
Lexington, KY

Abstract

The printer dot is the smallest unit of a digital image. The shape, characteristic, and interaction of each dot play an essential role in the perception of image quality. This paper details a practical closed loop process for measuring the imperfect dot. The discussion will cover a minimum set of measurable attributes, the procedure to obtain data, show an example of results and correlate outcome to visual assessment.

Introduction

The dot is the smallest unit of an image. Dot size varies depending on the technology. While inkjet printers "jet" a spot of colorant ink at a specific point on the paper; electrophotography (EP) printers fuse colorant toner particles. Inkjets may have better defined dots than lasers. Yet they may exhibit more satellites. At times, in an EP mechanism (fusing), depending on the product, there is no guarantee that a single dot is created at a particular point. Therefore, for very small EP dots, the dots may deteriorate into resembling clumps of toner particles rather than well-defined dots. This can have adverse effects on dot statistics.

Dot quality is impacted by the printer mechanism, the characteristics of the ink or toner and the properties of the media. In inkjet printing the mechanisms impacting shape and size of dots include the printhead design and the absorption and spreading of ink drops.

Dot quality measurements evaluate both physical and spatial variations. Examples of physical measurements include average area, axis ratio, gray average, and roundness. Spatial measurements include dot placement accuracy in both the horizontal and vertical position.

How does dot quality correlate to perceived image quality? What dot attributes have the most impact? Which image quality attribute is most affected by dots? Answers to these and other questions will evolve over time as data from significant number of printers is obtained. Nonetheless, one would be inclined to think, the dot, the heart of any image, would be key in the perception of print quality. After all, it is the aggregation of dots that create lines, solid areas, and halftone patterns. Thus, the shape and characteristic of the individual dot must be important. Yet, at high resolutions, such as 600x600 dpi or 1200x1200 dpi, the human eye cannot resolve individual dots. Perhaps for that reason, it is arguable there is no need to produce the perfect dot since halftoning and color science can somewhat effectively account for its defects.

Fundamentally, the reason for measuring dots is to provide a set of useful parameters to engineers developing products. Another reason is to maintain a history of progression of the technologies from one project to another. Measuring dots is also useful in comparing competitive engines under consideration for new product development. Finally, dot analysis may be useful in manufacturing for monitoring the reliability of printhead builds. For these reasons alone, it seems important to develop methodologies for measuring dots. This paper addresses that aspect of the research. Ultimately, though, it is desirable to correlate measurements to visual attributes.

This paper is part of on-going observations in attempt to establish correlation between image quality parameters and measured attributes. Beginning with the dot, this document explores connections between dots to image quality. In particular this article is focused on the EP dot and its impact on graininess. Graininess, one of a set of observable attributes, is chosen because it should hypothetically be a good candidate to establish a relationship against measured attributes. In addition, to further narrow the focus and amount of information, only two printers are discussed in this paper. These two printers were singled out because they exhibited the largest difference in measurements. Thus if a correlation should exist, the analysis and conclusions would be better highlighted.

There is no doubt more research is required to reach conclusive correlation. The findings in this paper only suggest likely correlation not conclusions.

Defining the Ideal Dot

What defines an ideal dot? Should the ideal dot really be a square? Wouldn't squares logically fit better in cells defined in square units? However, given that printer dots are typically round, the ideal dot is defined as a sharp perfect circle, resolution dependent, and void of any satellites. The ideal dot would experience no optical or mechanical gain and be consistent in density. With this definition, the following dot parameters are measured:

- Physical Measurements:
  - Detection
  - Area & Dot Gain
  - Axis Ratio (elliptical shape/direction of travel)
  - Roundness (raggedness)
  - Gray Level (Optical Density) (darkness)
  - Extraneous Marks/Satellites
  - Sharpness (Contrast)
- Spatial measurements
  - Dot Coordinates (x,y)
  - Horizontal (rows) & Vertical (columns) Spacing
  - Fit to Line (pt-line in both Horiz. & Vert. directions)

Closed-Loop Measurement Process

Figure 1 shows the closed-loop process invoked in measuring dots. A rigid closed-loop process is necessary for repeatability, automation, and comparison accuracy. The target used is shown in Figure 2. The target is designed to be versatile, device independent to test both inkjet and laser technologies by encompassing dot patterns from a single dot to 25-dot clusters. Dots are created in CYMK on both the positive (color on white) and negative/reverse (voids on color) background. The data obtained results in 40 data sets per printer {(CMYK (4)* (5 positive + 5 negative))=40}. For simplicity and purposes of this paper, the discussion only addresses the CMYK, 4-dot cluster in the positive format. This limits the analysis to four data sets per printer. The rationale for picking the 4-dot cluster is because 1) the 4-dot cluster was the smallest printable structure that was comparable for all products under evaluation 2) The 4-dot cluster makes a "square pattern".

The equipment used to measure the dots is an ImageXpert automated visual system. Due to the small field of view of the camera, several measurements are taken for each square. In a post processing "sorting" program, the data is "stitched" together, sorted, and "extra" or "missing" dots are accounted for appropriately. The "sorted" data is then read into an Excel file. Automated visual basic routines are executed to obtain metrics corresponding to various parameters. Averages and standard deviations (a measure of consistency) are obtained for each parameter. Another automated program combines a choice of selected printers for comparison purposes. The routines apply pre-defined criteria to evaluate the "winners". A "winner" is selected based on a differential of values of >15%. Anything less is considered as being par and set to "same".

Additionally, dot images captured by a camera are magnified using PhotoShop as shown in Figure 3. Notice that Printer B is rounder, denser, has fewer satellites, and is more consistent overall in shape over Printer A. In this example, visually the enlarged dot images corresponded to the measured metrics.

Correlation of Graininess to Measured Parameters

Samples of images were printed and observers are asked specifically to focus on graininess and pick either sample "A" or "B". Printer B won overwhelmingly. The question now is which metrics had the biggest impact?

Limiting the analysis to positive dots (dots on white background), Printer A exceeded in only two parameters over Printer B. 1) Printer A created a 47 % smaller CMY dot size and 2) exhibited a closer dot to line row placement. In everything else, Printer B was a clear winner and was certainly more consistent in producing a rounder and less jagged dot with fewer satellites. In addition, Printer B maintained better density consistency (37% difference) and better point-line column placement. These measurements correlated with the magnified dot images.

Consistency emerged as an important factor. For example although printer A had smaller CMY dot, it is Printer B that consistently created the same size dot by a factor of 82% better than printer A is. For this purpose, an arbitrary scoring is invoked where "1" is given to the printer which exhibited the "better" attribute and "1.5" is given to the printer with better consistency. With this scoring, Printer B won with a score of seven compared to the Printer A's score of two. Recall that the initial tests enforced at least 15% difference in results. Therefore, in several categories both printers are scored as "same". In addition, since area and diameter are related, only the result of one contributed to the final scoring.

Although the methodology appears to work on this set of printers, validation on numerous other products is essential. For the moment, this first-pass scheme works until further refinement is applied as additional statistics is accumulated over time.

Illustrations

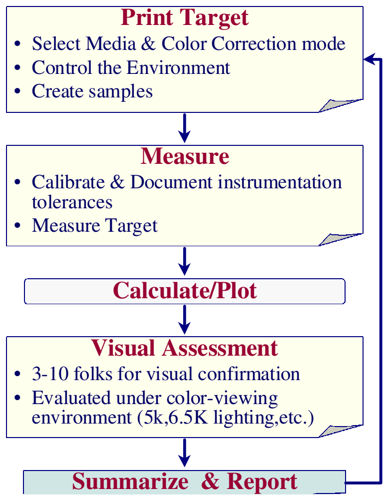

Figure 1: Closed-loop Measurement Process

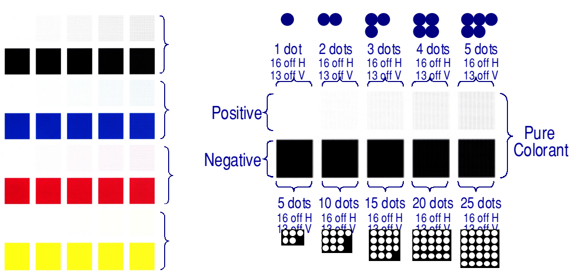

Figure 2: Dot Target

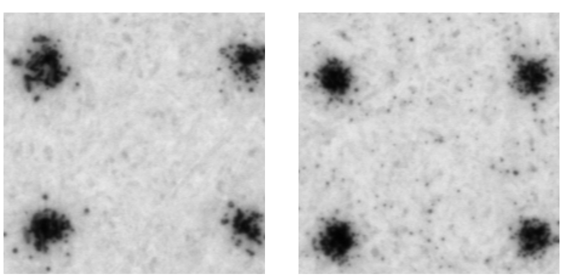

Figure 3: Dot magnification 4-dot clusters x300 from PhotoShop; Printer A (left) & Printer B (right)

Conclusion

The outcome of the experiment suggests there is a correlation between dot parameters and graininess. It is clear that the outcome is not based on any single but on the amalgamation of several dot parameters. To "equalize" the data, an allowable delta in the measurements is invoked. In this trial, it was set at a 15% delta. In future, more analysis is required to test the impact of the 15% clip and experiment with other points.

Consistency appeared as an important factor and thus had a higher power compared to individual parameter weighting (example: density/gray level).

The fact that the measured metrics correlated well with the visual test is promising. Of course, one needs to apply this theory on several printers, technologies, and people.

Biography

Marguerite joined IBM in 1977 as an electrical engineer in Lexington, KY in the Information Products Division where she held various engineering and management assignments. In March 1991, when Lexmark is formed, Marguerite went to France to launch technical support centers in Europe and Africa.

Marguerite's current mission is to generate image quality measurement specifications for ink jet and laser printers. Her goal is to institute automated and repeatable processes. Marguerite has developed a 2-day color science course for Lexmark International, Inc. which she regularly teaches internationally.

Marguerite holds a bachelor's Electrical Engineering degree from University of Illinois and a MSEE from the University of Kentucky.