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## ABSTRACT

A mathematical model of the electrophotographic printing process has been developed. This model can be used for analysis. From this a print simulation process has been developed to simulate the effects of the model components on toner particle placement. A wide variety of simulated prints are produced from the model's three main inputs, laser spread, charge to toner proportionality factor and toner particle size. While the exact placement of toner particles is a random process, the total effect is not. The effect of each model parameter on the ISO 13660 print quality attributes line width, fill, raggedness and blurriness is described.

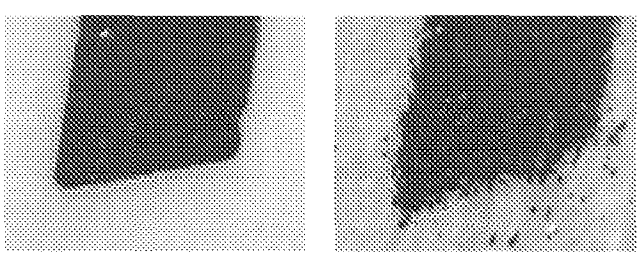
**Keywords:** electrophotographic printing, printer model, ISO 13660 standard, image quality

## 1. INTRODUCTION

The electrophotographic printing process is a common printing method used in printers. These printers can print documents of many forms. In this paper the bitonal images of text and line drawings are the focus. The source conceptual images for text and line drawings have smooth boundary contours and the text symbols and line components are filled with a solid uniform color. The printing process consists of small toner particles adhering to the paper in patterns to represent these forms. To a large degree the printer output matches the targeted shape, but the edges on the microscopic level will be rough, the interior of the symbols may not be solid and the exterior may not be clean, Figure 1. The ISO 13660 standard has been developed to measure these and other printing attributes.

The configuration of the print engine determines aspects of image quality.[1,2] A model of the electrophotographic printing process with both analytical and simulation components has been developed.[3] In this paper various tunings of the electrophotographic printing process are evaluated based on the objective image quality attributes defined in the ISO 13660 standard. The effect of each parameter or combinations of model parameters on several of the standard's metrics is considered.

In Section 2 the electrophotographic process and the model that describes it are introduced. The attributes from the ISO 13660 standard are described in Section 3. The observed relationship between the printer model and the ISO 13660 standard are presented in Section 4. The paper concludes in Section 5.



(a) (b)

Figure 1. Printed samples of the left leg of an A viewed with a microscope. (a) Photographically printed test chart (b) Laser print.

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## 2. ELECTROPHOTOGRAPHIC PRINTING MODEL

The electrophotographic printing process is used in laser printers, photo copiers and fax machines. The electrophotographic printing process starts by charging the photoconductor (PC) drum. This charge is spatially evenly distributed. A laser beam discharges the PC drum producing a pattern describing the image. The image is divided into rows and the laser traces each row. The laser beam has a Gaussian intensity profile. The spread on the x-axis (direction of motion) may be equal to the spread on the y-axis (circular), but often is less than the spread on the y-axis. Toner particles adhere to the discharged area proportional to the charge. The density of the toner particles is proportional to the intensity of the charge resulting from the laser beam. The toner consists of particles of size from 5 to 30 micrometers. The toner particles are distributed randomly and proportional to the charge. The toner particles are transferred from the PC to the paper. Rollers heat and compress the toner into the paper. This prevents the toner particles from being disturbed or relocating when the charge is removed. Excess toner particles are removed from the PC and the PC is neutralized to be ready for the process to repeat for another image.[4,5]

These steps are combined to form analytical and simulation models of the printing process.[3] The model takes as input the trace path of the laser needed to produce the desired image pattern. This consists of determining the start and stop locations of each row of pixels. The model and simulation can apply to any image printed by the electrophotographic process. For high contrast black and white images the laser turns on and remains on for the width of a stroke on each row. Then it turns off until the next stroke. In high contrast bilevel images the steps at the ends of the laser trace rows can produce a jaggie artifact on diagonal or rounded edges. This can be compensated for by turning the laser on and off in sub-pixel sections in adjacent rows. The model allows for this procedure. For gray scale images based on the desired half tone pattern the laser turns on and off frequently. For color images, the process would have to be repeated three or four times, once for each toner color. For the purpose of this paper, only high contrast black and white images are considered. Since the edges of a vertical stroke are produced by the ends of several laser traces whereas the edges of a horizontal stroke are bounded by a single laser trace, both types of edges are considered in this paper.

For a given laser trace the charge on the PC and the expected coverage on the paper by toner can be predicted.[3] The output of the printing process can be simulated as well. From the traces of the laser the expected charge on the charge roller is determined as a spatial function which is then converted into the number of toner particles as a spatial function. The initial PC charge, its discharge properties and the strength of the laser combine to produce a constant of proportionality which determines the number of toner particles to place per unit charge, *N Toner.* The width of the laser's Gaussian profile is denoted by $\sigma_x$. It is assumed[6] for this paper that $\sigma_y = (87.6/72)\sigma_x$. For each point on the trace of the laser the toner is placed with a Gaussian distribution in the x and y directions. The toner is then additionally placed in a uniform, but random x position along the laser trace, specified by the locations where the laser is turned on and turned off. Once the positions are determined, toner "spots" of the specified size and shape are placed at these positions. The size of the toner particles is the third parameter of the model. For the simulations reported on in this paper, the size is constant across any one image. The model allows for the size to vary according to a specified distribution. The implementation of the model as a simulation produces images of the "printed" output which bear strong visual similarity to the images seen on paper as output by a physical printer, Figure 2. The laser's spread, the number of toner particles and the size of the toner particles can be varied in reality and in simulation.

In this work the simulations are of 600 dpi printing and each $\frac{1}{600}$ inch unit is divided into 4 sub-pixels to approximate spatially continuous printing. This essentially makes an image designed and "printed" at 600 dpi, and "scanned" at 2400 dpi. Other print resolutions as well as finer sub-pixels (higher "scanning" resolution) are possible. The lines used were 100 pixels long and 10 pixels wide, or the equivalent of 4200 by 420 $\mu$m. Figure 3 shows examples of lines with variation in each of the three main model parameters individually. Changes of the model parameters in pairs produces a wider range of resulting outputs and are explored in Section 4.

## 3. THE ISO 13660 STANDARD

The ISO 13660 standard[7] compiles a list of attributes that are designed to correlate with human perception of print quality. Measurement methods for each attribute have been designed to work on high contrast bitonal

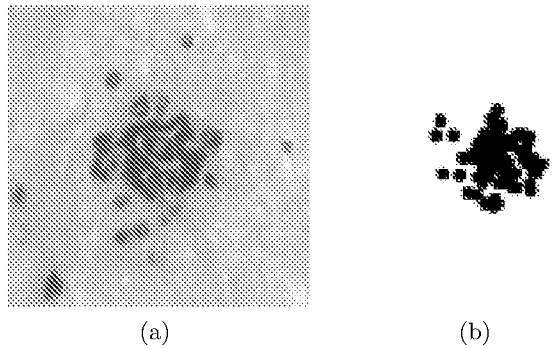

Figure 2. (a) magnified image of a actual printed pixel. (b) simulated image of a single pixel. The pixels are both at 600 dpi.

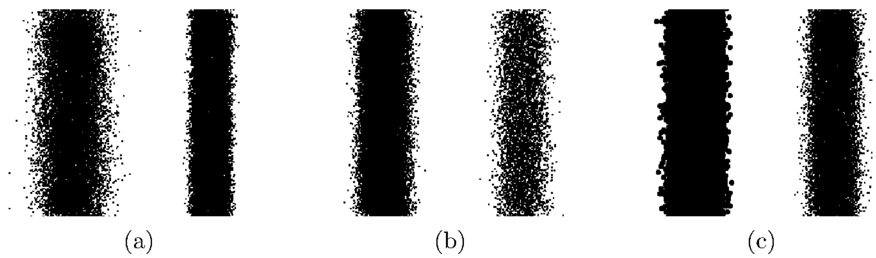

Figure 3. Effects of changing (a) laser spread, (b) number of toner particles (c) size of toner particles.

images. It is most effective for relating the attributes to perception within a single printing technology, which is the focus of this paper. The standard describes both large area density attributes as well as character and line attributes. Of the character and line attributes, this paper focuses on blurriness, raggedness, line width and fill. These attributes are defined as

- *Blurriness*: the average distance between the 90% reflectance and 10% reflectance boundaries of the image.
- *Raggedness*: the standard deviation of the residuals from a line fitted to the 60% reflectance threshold of the line.
- *Line width*: the average width of a stroke measured from 60% reflectance edge on one side to the 60% reflectance edge on the other side of the line.
- *Fill*: the ratio of the area with 75% or more reflectance within the 90% reflectance boundaries of an image.

Quantitative metrics designed to mirror the ISO 13660 print quality standard have been coded.

The ISO 13660 standard is designed to work on scans or other gray level images made of the printed document at high magnification where the local reflectance is collected. That imaging process produces a range of reflectances. For the simulation, the resulting document image contains only pure white paper and pure black toner as there is no need to use an imaging system to acquire these images. Without an imaging system to blur the image producing mid values, levels other than 0 and 1 are produced by taking local averages. The image shapes used in this paper are all straight lines. For blurriness the 10% and 90% reflectance lines and for line width the 60% reflectance are calculated by averaging the intensities in the direction of the stroke edge to produce a range of gray levels. Raggedness needs the 60% reflectance edge to maintain its positional variability, and the fill attribute needs to keep the spatial positions of the places which were and were not filled with toner, thus for raggedness and fill, the averaging is done through applying a square uniform averaging filter. In all cases it is assumed that there is a linear relationship between reflectance and gray scale value.

## 4. RELATIONS BETWEEN THE PRINTER MODEL AND THE ISO 13660 STANDARD

When printing, the three main inputs to the printer model (laser spread, charge to toner proportionality factor and toner particle size) can be varied in turn to produce a range of output images. Each parameter change will result in a change in the image output in a nondeterministic way. While the exact placement of toner particles is a random process, the total effect is not. Depending on the parameters, the characteristics of the resulting image will vary.

A series of tests were run to create vertical and horizontal lines with the three printer model parameters varied in pairs and to record their effect on the ISO 13660 attributes of line width, fill, raggedness and blurriness. Since toner size is discrete relative to the sampling grid, and contains a small number of likely values relative to the simulation resolution, the number of toner particles and the spread of the laser beam are varied for three fixed particle sizes: squares of $\frac{1}{4}$, $\frac{1}{2}$ and $\frac{3}{4}$ of the 600 dpi pixels. This is produced by using squares of 1x1, 2x2 and 3x3 units of the 2400 dpi sub-pixel sampling grid. In Figures 4, 5 and 6 the resulting attribute measurements for three different sized toner particles are displayed. Sample values of laser spread and number of toner particles along the various contours in Figure 5a-c were extracted. A set of lines to corresponding to the printer output for the model parameters along these contours were collected and are shown in Figures 7-9. To show the edges in higher detail, the full width of the stroke for blurriness and raggedness was not shown. In general there is a correspondence that the contours do accurately describe the visualized attributes. The raggedness, blurriness and line width are constant where designed to be, and from one contour to the next, a distinct change is seen.

Blurriness and raggedness mirror each other in their relationship to the model parameters. The isoclines for blurriness and raggedness slope in a different direction than line width. The fill attribute tends to saturate for larger unit number of toner particles and larger laser spread. If more toner particles are placed, they will totally fill a solid region. Likewise, if the toner particles are placed such as to overlap more from one trace to the next, that will also increase the net fill. While the fill plot in Figure 5d seems to not contain much information, what is notable is that a feeling for the relative amounts of these two parameters that is needed to achieve 100% fill can be determined. This does not include the possibility of toner chipping off due to some physical process.

From one toner size to the next the directional trends of the contour plots (Figures 4-6) are consistent. The change is in the numerical values associated with each contour. As the toner particle size increases, for the same laser spread and unit number of toner particles, the lines are wider. Blurriness decreases with an increase in toner particle size, but not linearly; the very fine toner particles produce a much more blurry edge. Raggedness, which is dependent on the 60% reflectance level stays mostly the same with changes in toner particle size, except at small number of toner particles. This corresponds to when fill is significantly less than 100%.

There is some variance in the measurements sample to sample, even with the same parameters due to the randomness in the toner placement, but not much. The variance in the measurements for all attributes was not dependent on the toner particle size. For blurriness and raggedness the standard deviation in the measurements was generally between 5 and 10 percent. For line width the standard deviation was less than 1 percent, but was higher for larger laser beam width and smaller number of toner particles. Likewise for fill, the standard deviation was less than 0.1 percent, but had the same parameter dependencies as for laser width. The higher variance for blurriness and raggedness leads to the contours for blurriness and raggedness in Figures 4-6 being less smooth than the contours for line width and fill.

The edges of the strokes are expected to have a different quality if they are horizontal versus vertical due to the trace of the laser proceeding in the horizontal direction. While the results were only shown for horizontal lines, the same qualitative trends were present for both types of edges. The line width is slightly wider for the same parameters on horizontal edges versus on vertical edges. For small laser spread the sizes are approximately the same, but for the larger laser spreads, the horizontal lines can be up to 5$\mu$m wider. Blurriness and raggedness increase more rapidly with respect to the width of the laser for horizontal edges than for vertical edges. Fill is largely unaffected by the edge orientation.

The attributes in the ISO 13660 standard are designed to be measured from images where a range of reflectances would be produced through the blurring that occurs in the imaging system optics. For the simulations there are no optics, so the images maintain their bilevel intensities. The 10%, 60%, 75% and 90% levels depend

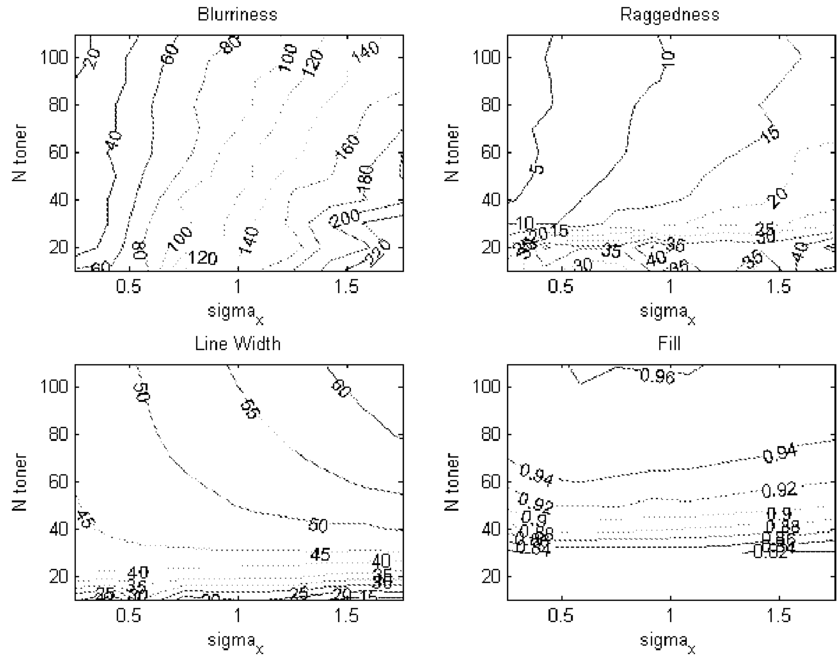


Figure 4. Attribute measurements for 1x1 toner particles at 2400 dpi sub-pixels.

on the averaging method used to create them. This is most visible in the blurriness versus raggedness measurements, especially for small toner particles in low quantities. While blurriness and raggedness are defined differently and are based on different measurements (average 10% and 90% reflectances versus variance of 60% reflectance lines) they have very parallel resulting measurements over a wide range of printer model parameter values.

## 5. CONCLUSIONS AND FUTURE WORK

The image quality attributes that have been measured were selected for inclusion in the ISO 13660 standard as they were measurable and correlated to quality attributes.[8] Through this study a sense of what factors in the image production relate to image quality has been described. A series of edges with equal measured attribute values will have similar qualitative effects in the printer simulated output. The ISO 13660 attributes do not include any measurements for the sharpness of corners. Corner sharpness can be adjusted by the laser trace pattern, but for the basic corner, the effect of these model parameters would also be interesting to determine.

The output of the simulation resembles the physical output of the electrophotographic printing process. The relationship between the model parameters and the image quality attributes can enable the production of a set of line or character samples with monotonically changing quality attributes. The INCITS W1.1 *ad hoc* team on text and line quality[9] is producing a set of printed pages samples with a monotonically decreasing range of image qualities to form a quality ruler.[10] A set of samples can be produced by using a wide variety of printers and print media, but the range of factors is too high to assure a monotonic quality relationship. Varying the raggedness and blurriness produces a form of controllable and measurable degradation that can be varied monotonically. The set needs to have a constant stroke width to give the perception of constant character darkness and not lead to extraneous perceptual quality factors. Through the use of a degradation process such as described in this paper, a large quantity of print samples can be produced in a controlled and reproducible fashion with a monotonically changing print quality. This is a key intermediate step towards the standard development.

Because the optical acquisition system was not included in the simulation, to get reflectances between 0 and 100% averaging of the simulated printer output was needed. The averaging method used could be tuned to more closely mimic the Point Spread Function (PSF) of a common optical system. Tests not reported on in this paper

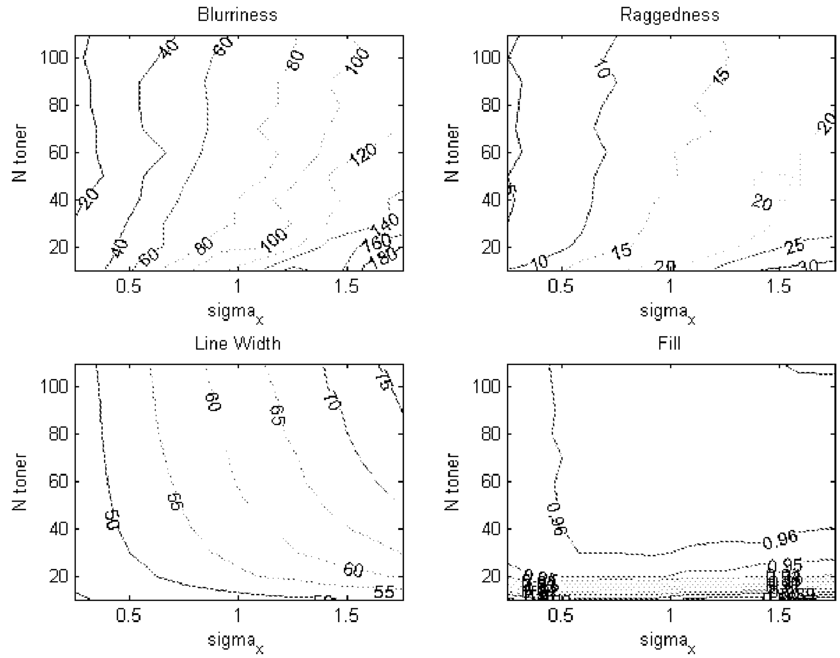


Figure 5. Attribute measurements for 2x2 toner particles at 2400 dpi sub-pixels.

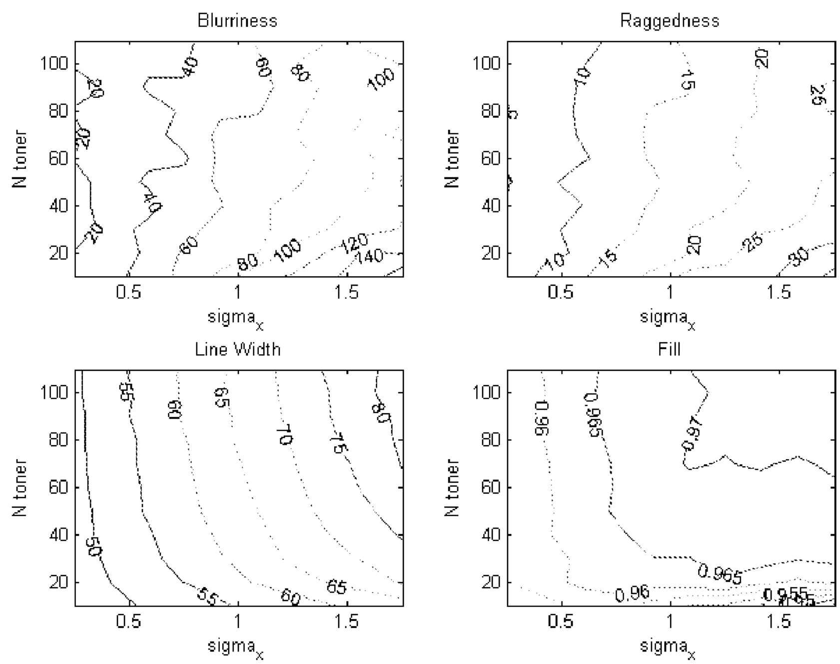


Figure 6. Attribute measurements for 3x3 toner particles at 2400 dpi sub-pixels.

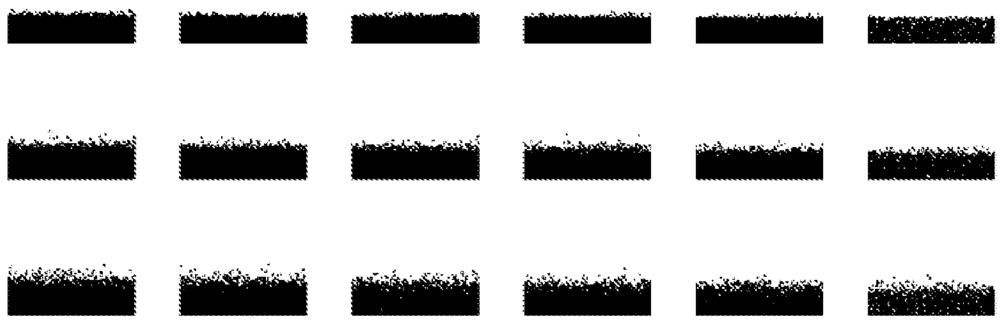

Figure 7. Edge samples for constant blurriness attribute. Top row samples have blurriness = 40; Middle row, blurriness = 80, Bottom row, blurriness = 120.

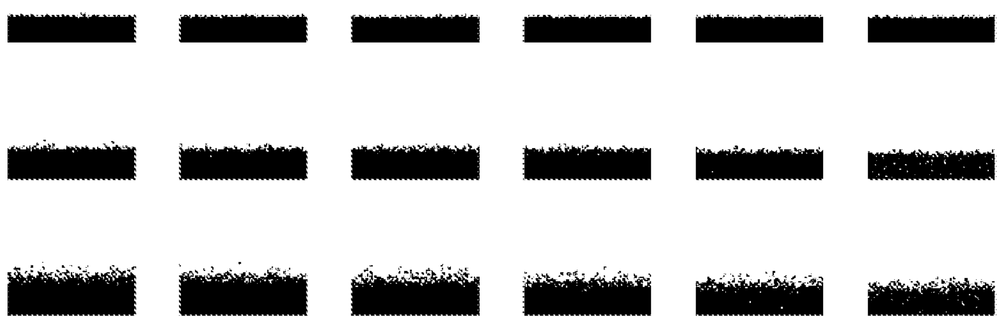

Figure 8. Edge samples for constant raggedness attribute. Top row samples have raggedness = 5; Middle row, raggedness = 10, Bottom row, raggedness = 20.

Figure 9. Stroke samples for constant line width attribute. Top row samples have line width = 50; Middle row, line width = 60, Bottom row, line width = 70.

have compared printing the simulated lines and measuring the ISO attributes with a camera system and the same trends reported on in this paper were observed.


## ACKNOWLEDGMENTS

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## REFERENCES


[1] Yamaguchi, C. and Takeuchi, M., "Influence of toner particle shape and size on electrophotographic image quality," *Journal of Imaging Science and Technology* **40**, 436–440 (Sept/Oct. 1996).

[2] Johnson, G. M., Patil, R., Montag, E. D., and Fairchild, M. D., "Image quality scaling of electrophotographic prints," in [*Proceedings SPIE Electronic Imaging, Image Quality and System Performance*], **5294**, 165–175 (2004).

[3] Norris, M. and Barney Smith, E. H., "Printer modeling for document imaging," in [*Proceedings of the International Conference on Imaging Science, Systems, and Technology: CISST'04*], 14–20 (June 2004).

[4] Williams, E. M., [*The Physics and Technology of Xerographic Processes*], Krieger Publishing Company (1993).

[5] Schein, L. B., [*Electrophotography and Development Physics*], Laplacian Press (1996).

[6] Yi, J., *A Xerographic Simulation Model*, Master's thesis, University of Idaho (May 1999).

[7] "ISO/IEC 13660:2001 Information Technology - Office equipment - Measurement of image quality attributes for hardcopy output - Binary monochrome text and graphic images," (2001).

[8] Briggs, J. C., Klein, A. H., and Tse, M.-K., "Applications of ISO-13660, a new international standard for objective print quality evaluation," in [*Proceedings Japan Hardcopy '99*], 281–285, Imaging Society of Japan (1999).

[9] Dalal, E. N., Barney Smith, E. H., Gaykema, F., Haley, A., Kirk, K., Kozak, D., Robb, M., Qian, T., and Tse, M.-K., "INCITS W1.1 standards for perceptual evaluation of text and line quality," in [*Proceedings SPIE Electronic Imaging, Image Quality and System Performance VI*], **7242**, 724203 (January 2009).

[10] Keelan, B. W., [*Handbook of Image Quality: Characterization and prediction*], CRC (2002).