Halftone-independent calibration of black&white printers

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ABSTRACT

Halftone calibration of a black&white printer is known process that involves printing and measuring patches for many different halftone levels. It is a tedious process that has to be repeated for every halftone dot or algorithm to be used. A new calibration procedure will be described that uses a halftone-independent characterization of the printer and a pixel overlap model to predict the tone response of any halftone algorithm. This enables all halftone dots and algorithms to be calibrated with only one set of printer measurements.

1. INTRODUCTION

Halftone calibration, as it is currently implemented, involves printing and measuring test patches at several different gray levels for a given halftone dot or algorithm. These reflectance or density measurements describe the tone reproduction of the halftone dot or algorithm. After determining the actual reflectance for each halftone bitmap pattern, it is a simple matter to adjust the thresholds of the halftone dot, or equivalently to modify the input image, so that halftone bitmap pattern with the proper reflectance is printed for each input gray level. There are several references in the literature[1-5] describing this process. The major problem with this method is that it needs to be repeated for each halftone algorithm to be used, making the addition of new halftone dots or algorithms very difficult and time consuming.

In this paper, we introduce a new method for halftone calibration that requires many fewer printer measurements and makes the calibration of halftones much simpler. The new method first characterizes the printer using measurements from a specific set of patches. These measurements are used to calculate least squares optimized values for parameters in a non-linear overlap model that describes the printer. These parameters can then be used on any desired halftone dot or algorithm to predict its tone reproduction for that printer. The key to the method is the new model that predicts the average reflectance or absorptance of an arbitrary bitmap pattern.

2. ABSORPTANCE MODEL

For an ideal printer with no dot gain, the normalized reflectance is proportional to the number of white pixels in the bitmap. The reflectance is normalized by making white paper, 1.0, and a black page, 0.0. The normalized absorptance, 1-R, would be proportional to the number of black pixels, for the idealized printer. For actual printers, the normalized absorptance is proportional to an average area coverage of the printed bitmap pattern. It is this average area coverage that the models try to predict.

The area coverage model in our calibration method is an extension of the circular dot overlap model, modified to include the effects of scattering of light in paper. The darkening of a halftone due to scattering of the light in the paper substrate is referred to as the Yule-Nielsen effect[6], or as optical dot gain.

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The circular dot overlap model has been used[1,4,5] to compensate for the darkening of a halftone due to physical dot gain, i.e. oversized black pixels. Many printers, laser, ink jet, etc., when marking a single black pixel, put down a circular region of ink or toner that is larger than the idealized square area corresponding to one pixel. This physical dot gain can cause a significant darkening of an image, especially when the creation of the halftone bitmap was based on the assumption that the pixels are ideal squares.

The circular dot overlap model compensates for the excess darkness by determining the actual area that is covered by the ink or toner. In Figure 1, the regions of the pixel that overlap into the neighboring pixels are identified with the symbols alpha, beta and gamma. When two black pixels are placed next to each other, the portions of the two pixels that overlap with each other do not result in increased area coverage. Only those portions of black pixels that overlap into white pixel regions increase the area coverage beyond that given by simply counting the number of black pixels.

For desktop printers, the circular dot overlap model does a reasonable job of predicting the amount of physical dot gain of the printer. This model, however, cannot predict the effects of optical dot gain. Comparisons of the model with experiment[4], show that while the circular dot overlap helps to compensate, it does not describe the complete tone response of typical halftone dots.

In the new area coverage model, six features are defined. They are named pixels (p), horizontal sides (h), vertical sides (v), corners (c), fillets (f) and bridges (b) and are illustrated in Figure 2. These features are related to the alpha beta and gamma features of the circular dot overlap model. A "pixel" is simply the number of black pixels within the halftone cell. The number of sides, corners, fillets and bridges depends on the configuration of the black pixels with the cell. A side is an edge that separates a black pixel from a white pixel, either horizontally or vertically. A black pixel can have as many as four corners. A corner is counted if it is adjacent to three connected white pixels. A fillet is the indentation in a group of three black pixels. It consists of a corner of a white pixel surrounded by three connected black pixels. A bridge is the intersection of two black pixels that touch diagonally.

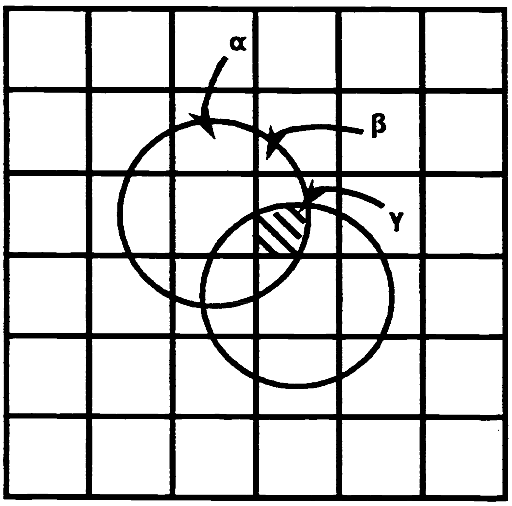

Fig. 1. The circular dot overlap model describes the locations and sizes of regions in which black pixels overlap .

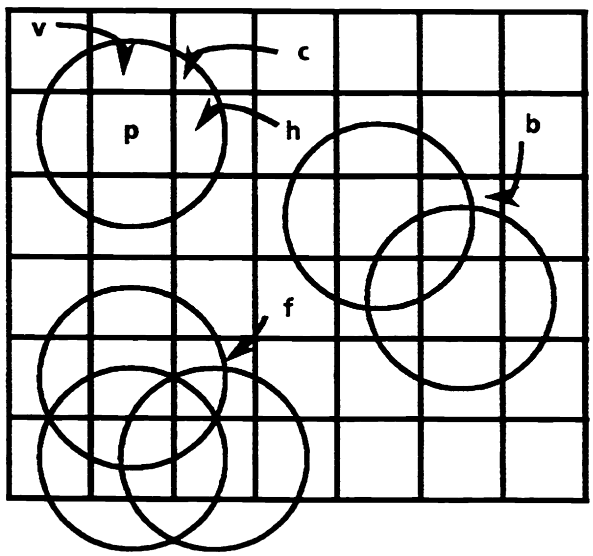

Fig. 2. There are 6 basic features in the new area coverage model. The average absorptance of a bitmap is predicted by these features.

The six features of the model can be calculated for any bitmap pattern. The model represents the absorptance, A, of a bitmap pattern as a linear combination of these features and cross products of them. The linear terms produce the same result as the circular dot overlap model. The additional non-linear cross products are included in the model to take into account the effects of light scattering in the paper.

Mathematically, the expression for the absorptance of the pattern becomes:

$$A = a_1 p + a_2 h + a_3 v + a_4 c + a_5 f + a_6 b + a_7 p^2 + a_8 h^2 + a_9 v^2 + a_{10} c^2 + a_{11} f^2 + a_{12} b^2 + a_{13} ph + a_{14} pv + a_{15} pc + a_{16} pb + a_{17} pf. \quad (1)$$

The constants a_1 - a_{17} are free floating parameters that are determined in the printer characterization step by a least squares fitting to this model of measurements from a set of test targets. The numbers, p, h, v, etc. are the number of times that those features occur in the bitmap. From these 17 parameters and 6 features, the reflectance (absorptance) of any arbitrary bitmap pattern can be determined.

3. PRINTER CHARACTERIZATION -- PHYSICAL MEASUREMENT

The characterization of the printer involves the fitting of the model to a set of measured responses of the printer. The fit will produce estimates for the a_1 - a_{17} parameters in Equation 1. The 17 parameters can be saved and used later to predict the tone response of that printer to an halftoning dot or algorithm.

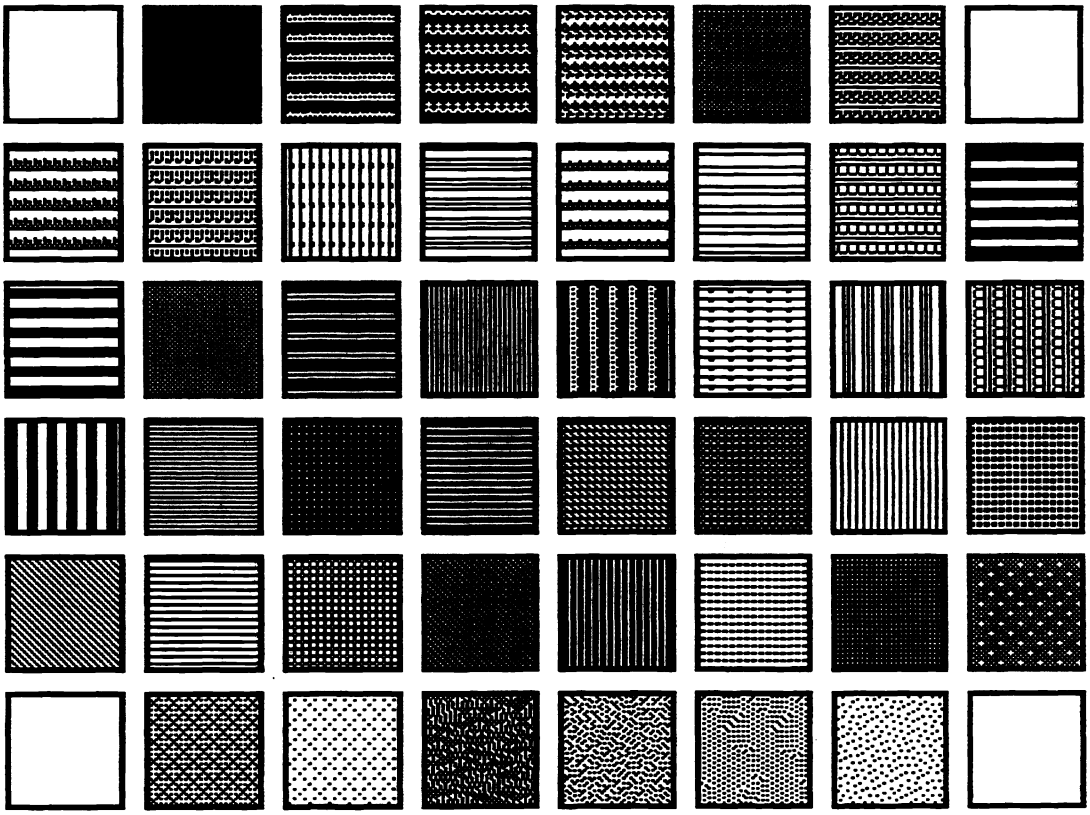

Fig. 3. Test Patterns. Shown here are the 45 test patterns that are used to characterize the interactions between black pixels in the area coverage model. These particular patterns were chosen to span the six dimensional space defined by the 6 features of the model.

The set of 45 test patches that are used to characterize the printer are shown in Figure 3. The patches are printed and their reflectances measured with a densitometer. The reflectances are normalized to lie between 0.0 and 1.0 for black ink and white paper.

For each of the 45 patterns, the 6 features, p, h, v, c, f and b can be calculated and combined in Equation 1. Each pattern yields one equation relating its measured absorptance with its calculated features and the 17 parameters, a_1 - a_{17}. These 45 equations can be combined into one matrix equation:

$$A = M x \, , \tag{2}$$

where A is the vector of 45 absorptance measurements, M is a 45 row x 17 column matrix of the features from the test patches, and x is the 17 element vector of model parameters.

In this printer characterization step, the model parameter vector, x, is the unknown. It can be estimated from the measurements using standard least squares techniques and the pseudoinverse[7], i.e.

$$x = (M^T M)^{-1} M^T A \, . \tag{3}$$

The range of values for the parameters is on the order of unity and they can be either positive or negative, depending on their nature. Note that the horizontal and vertical sides parameters (a_2, a_3) will be different, if the process direction is important for that particular printer.

4. HALFTONE CALIBRATION -- PREDICTION

Once the printer has been characterized, any halftone dot or algorithm can be calibrated. For this calibration method, the model can be used to predict the halftone response of the printer. No patches specific to the halftone have to be printed or measured. The halftone dot can be used directly to create several bitmaps, which are analyzed to predict the printer response.

The traditional halftone dot consists of several canonical patterns, called template dots. Each template dot is a pattern that can be analyzed for its features. A matrix, M, can be constructed, where each row of the matrix is the set of features for one of the template dot patterns. The size of the matrix will depend on the size of the halftone dot. There will be one row in matrix, M, for each unique template dot. If a halftoning method, such as error diffusion, is being analyzed, then the number of patterns, or gray levels, can be chosen to achieve any degree of accuracy desired.

When the matrix of features, M, has been determined from the bitmaps for the halftone process, the predicted tone response of the printer can be calculated from Equation 2. The tone response is the vector of absorptances, A, which is found by multiplying the matrix, M, by the already determined vector of printer parameters, x.

An experimental comparison between predicted and measured halftone responses is shown in Figures 4a and 4b. Figure 4a shows the response of a write-black printer (oversize black pixels) to two different halftone dots. Figure 4b shows the responses for a write-white printer (oversize white pixels). In both figures, each X records a measurement of a printed halftone patch. The solid lines are the predicted responses of each pattern for that printer, based on the experimentally determined 17 model parameters for each printer. The figures show very good agreement between the experimental measurements and the predicted tone reproductions. Note that almost all the X's lie on the predicted curves.

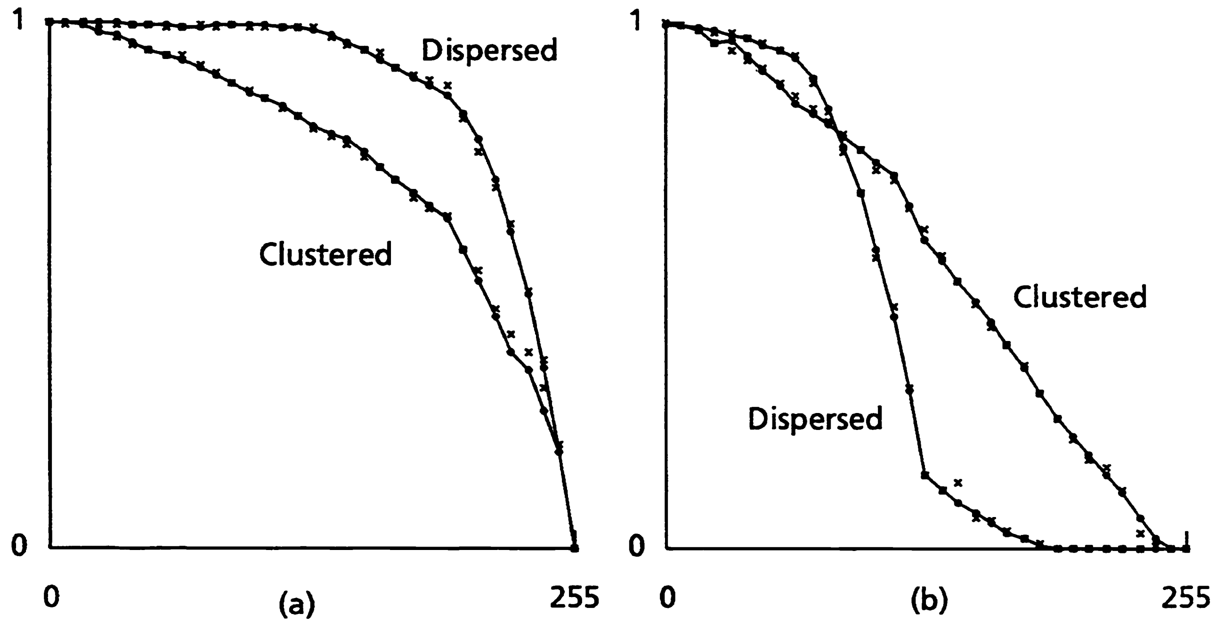

Fig. 4. Predicted (solid lines) vs. experimental (x's) tone reproduction curves for dispersed and clustered halftone dots. The printers used in the two examples above were (a) awrite-black printer that prints oversized black pixels and (b) a write-white printer that prints oversized white pixels.

5. CONCLUSIONS

A new model has been developed that accurately predicts the average reflectance of an arbitrary bitmap. The model enables a printer characterization method for halftones that is independent of the halftone dot structure. This enables a single characterization of the printer to predict the expected tone response of any arbitrary halftone dot or algorithm, thereby greatly reducing the number of measurements necessary to print calibrated halftone pictures.

6. REFERENCES

1. P. G. Roetling and T. M. Holladay, "Tone Reproduction and Screen Design for Pictorial Electrographic Printing", Journal. Appl. Photo. Eng., 5/4, 179-182, 1979.

2. C. J. Rosenberg, "Measurement Based Verification of an Electrophotographic Printer Dot Model for Halftone Algorithm Tone Correction" IS&T Adv. Non-Imp. Print., 286-291, 1992.

3. J. Shiau and L. C. Williams, "Semiautomatic Printer Calibration with Scanners", Journal Img. Sci. and Tech., 36/3, 211-219, 1992.

4. T. N. Pappas and D. L. Neuhoff, "Model-Based Halftoning", in Human Vision, Visual Proc. and Digital Display II, Proc. SPIE 1453, 244-255 1991.

5. P. Stucki, "MECCA - a Multiple-Error Correction Computation Algorithm for Bi-Level Image Hardcopy Reproduction", IBM Research Report, RZ 1060,1981.

6. J. A. C. Yule and W. J. Neilsen, "The Penetration of Light into Paper and Its Effect on Halftone Reproduction", Proc. TAGA, 3rd Ann. Tech. Mtg., 65-76, 1951.

7. C. W. Press, et al., Numerical Recipes in C, Cambridge University Press, 60-71, 1988.