Model based printer linearization

Dror Kella[1], Lior Katz[1], Ayelet Pnueli[2]
[1]Hewlett-Packard, Indigo division, Rehovot 76101, Israel
[2]Hewlett-Packard Laboratories Israel, Technion City, Haifa 32000, Israel

Abstract

We introduce two novel methods for accurately predicting the conversion function from digital input to printed dot area. This conversion function is substantial for dot gain compensation. Dot gain compensation ("press linearization") is aimed at keeping the print color consistent while the press physical parameters drift. To achieve good and consistent print quality, this procedure should be done often. However, since it requires the printing of special jobs with color patches, it consumes both time and paper. This procedure is even more unwieldy in web presses that print on rolls of paper. The goal of this work is to achieve good print quality with much fewer print interruptions.

The first method is based on a physical model and the second is built on a complete heuristic model. Both methods use the digital data and a small set of measurements as an input. These methods provide the possibility to accurately and directly predict the conversion function. We further discuss the concept of a full physically predictive method. The methods were tested on an HP-Indigo digital press but the concept is applicable to any printer.

Introduction and problem statement

In order for a printer to reconstruct a required digital image on paper accurately, a conversion function is needed. The conversion function links the required color output with the input digital coverage per ink, taking into account both the mechanical dot gain (the final ink coverage versus the digital coverage) and the optical dot gain (the perceived "coverage" change of the image relative to the true coverage due to scattering of light in the ink, ink/media interface, ink/ink interface and in the media). For the HP-Indigo **L**iquid **E**lectro **P**hotography (**LEP**) presses the conversion is constructed in two stages.

The first stage is generating an ICC profile [1], which characterizes the press' color gamut based on a lookup table that links the CIELAB color coordinates and Dot Area coverage (**DA**) values of a large set of predefined printed patches. This profile is designed with some "art" in mind and is set to give pleasing results for a host of parameters such as, color accuracy, grey balance, resolution of features in highlights and dark tones etc. In HP-Indigo digital presses, this profile is fixed and does not change unless another profile is installed.

The second stage links the required **DA** per ink with the input digital coverage per ink.

In order for a printer to reconstruct a required digital image on paper accurately a conversion function is needed. This function links the measured coverage, or dot area, with the input digital coverage. This process is called "press linearization".

This conversion varies from press to press and in time. For the high level of accuracy required from industrial presses, such as the HP-Indigo digital press, this function must be periodically adjusted. A method used on the HP Indigo digital presses is to accurately measure a set of patches with different pixel density and using an in-line color sensor to correlate the input with the output. This is followed by a software procedure that defines a smooth conversion function based on the measurements. The drawback of this method is that it is time and material consuming. It further requires the press to stop production and engage in calibration.

In order to reduce time and material waste we have devised two different approaches for a model based prediction method that, using a small number of measurements, accurately predicts the linearization function.

The first approach is based on a physical model. The second approach is heuristic. Both methods are calibrated by few actual measurements.

Physical method:

For the Indigo Liquid EP press the printing process may be described as follows: a charged photoconductor (**PIP**) is discharged by laser light and thus a latent image is created on it. The **PIP** is engaged with a high concentration and high charge liquid ElectroInk in a development nip (Figure 1 left), with a

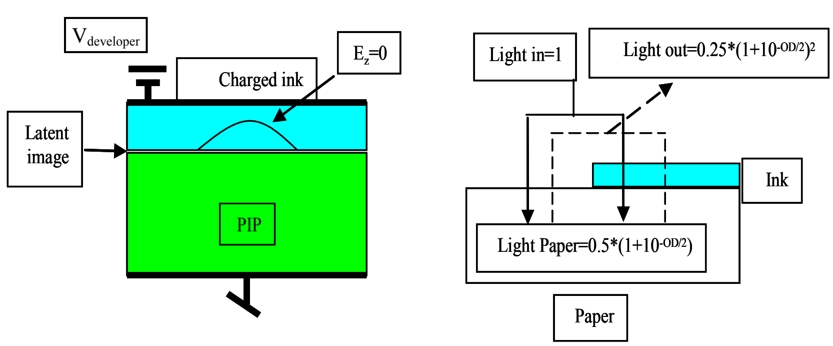

Figure 1: *Left: Model of ink development nip. Ink separates on the surface of zero field in the vertical direction. Right: Scattering in paper, model for half of the paper covered and full scattering in paper.*

developing potential $V_{developer}$ pushing the ink towards the PIP. The surface, where the electric field in the perpendicular direction changes sign, defines the splitting of the ink. Ink under this surface is attached to the **PIP** to form the image. The image on the **PIP** is transferred to an intermediate blanket and then to paper. To predict the image seen by the observer we begin with a physical model that predicts the ink coverage on the **PIP**. We assume that the ink shape on the paper is similar to the ink shape on the **PIP**. The ink coverage model solves the Poisson equation for the nip depicted in Figure 1 left: $-\nabla^2 \varepsilon\varepsilon_0 u=\rho$, where on the interface $n \cdot D=\sigma$, (ε is the dielectric constant, u the potential, ρ is the charge density in each region and σ the latent image charge). We use Dirichlet boundary conditions for the top and bottom, u= $V_{developer}$ and 0, and Neumann conditions $\sigma=0$ on the sides. The charge density on the ink/**PIP** interface is calculated by mapping the laser exposure to the Photo-Induced-Discharge curve using an equation of the form: $\sigma(x)=(\sigma_d-\sigma_l)\exp(-LP(x)/s)+\sigma_l$, where $\sigma(x)$ is the charge density on the ink/PIP interface, σ_d and σ_l are the dark and light charge (charge density without light and with constant illumination) and s is the sensitivity of the **PIP**.

Combining the full trajectory of light through ink and paper, we assume the light passing the ink cover undergoes full scattering in the paper (Figure 1 right), i.e. light traverses the ink once into the paper. In the paper light is homogenized and then traverses the ink back to the observer. This naïve assumption works reasonably well for high frequency screens. More elaborate point spread function schemes may also be used [2]. To compensate for un-modeled physical variables we use a modified Yule-Nielsen (YN) [3] scheme, by changing the parameter of the exponent (**n**) of the penetration function: $I_{out} = I_{in}\left(\int 10^{OD \cdot (z/hn)} dx\right)^n$, where OD is the optical density of a solid patch, z/h the normalized ink height, and x the space coordinate. Fitting the exponent n at few (3-5) points yields different values. We predict the linearization function using a linear interpolation of this parameter **n**. Thus the linearization function prediction is based on a rigorous physical modeling of the ink coverage on the **PIP** for each level of the screen followed by a fit with a small set of measured data.

Heuristic method:

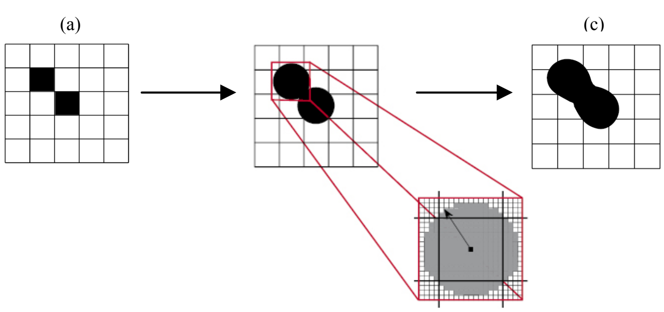

***Figure 2**: heuristic model main steps*

The heuristic model takes as input the digital screen matrix and the measured dot area (**DA**) of selected patterns. For each screen gray level, the method places the digital screen image (Figure 2a) on a fine mesh, placing a circle of radius R_0 in the center of each originally 'on' pixel (Figure 2b). R_0 can be calculated either by using a calibration pattern or by using one of the screen's low gray levels (Where the dots are separated). All the remaining 'off' sub-pixels are then assigned with a value that represents the probability of each sub-pixel to be 'on'. The probability of a pixel i to be 'on' is calculated according to

$$P_i = \sum_{j \in w} \frac{n(j)}{d(i,j)}$$

where w is the effective window, $n(j)$ is the number of times the pixel j was 'on' because of a drawn circle (i.e. an overlap function) and $d(i,j)$ is the distance between a pair of 'off' and 'on' pixels (i and j respectively). At this point we have a binary image with 2 groups of sub-pixels: sub-pixels with value 1 ('on' pixels), and sub-pixels with values 0 ('off' pixels) and their probabilities of being 'on'. The second group is sorted in descending order by their probability values. The first T sub-pixels are then turned 'on' (Figure 2c), where T is the difference between the measured **DA** of the halftone pattern and the digital image with primary drawn circles, multiplied by the mesh dimensions. By doing this, we set the model output **DA** of the selected pattern to be the same as the measured one. The value of the *T'th* sub-pixel is defined as the threshold. The next stage is to predict the thresholds of the remaining screen's gray levels. The prediction is done by passing an n degree polynomial between the thresholds acquired on a small set of measured patterns.

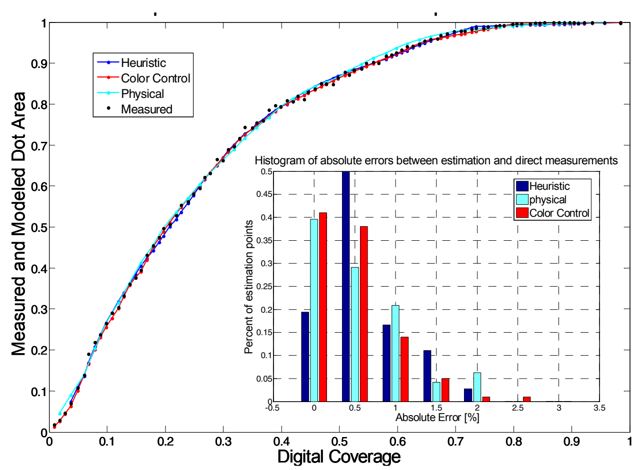

Figure 3: Comparison between the color control physical and heuristic linearization function predictions Vs. measured data

Experimental results:

To test the accuracy of our method under "worse case" conditions, we have chosen a synthetic low frequency screen. This screen is difficult in two senses. The first, relating to the physical model, is the low frequency (full scattering in paper is not assured), the second is the smoothness which is not optimal. Figure 3 displays the quality of prediction for the linearization function. The dots are the measured data (including 0% and 100% coverage) the red line, the simple straightforward method, is the interpolated linearization function based on 17 measured samples, cyan is the physical method curve and the blue is the heuristic curve, both with only 5 sample points. The image in the insert is a histogram of the absolute differences between the 3 predictions and the measured data with the same color coding as the main image.

Discussion and Conclusion

We have shown our capability to predict, via modeling and a small set of measurements, the press linearization function for an HP Indigo press, with results similar to the one obtained by the straightforward method of measuring a large number of patches and interpolating the values between them. In general, the physical method should be optimized to reduce the number or eliminate the measured patches. Comparing the two methods, physical and heuristic, the physical method has the potential to accurately predict the press but is not directly transferable to other printing devices. The heuristic method is not limited to a certain system but lacks the ability to accurately predict the press without direct measurements.

The idea, which surfaces from this research, is general and may be applied to all printing devices. It is to use physical prediction where possible and a heuristic method to compensate for un-modeled elements.

References

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Author Biography

Dror Kella received his BSc degree in Physics and computer sciences form Tel-Aviv University, Israel (1987) and his MSc and PhD in physics from the Weizmann Institute of Science, Israel (1989 and 1994). He was employed on a postdoctoral position at Aarhus University from 1994 till 1997. From 1997 to 2001 he was employed by Applied Materials, Israel in designing scanning electron microscopes. Since 2001 he is employed by HP-Indigo researching various aspects of LEP.

Lior Katz received his MSc in physics from Bar-Ilan University, Israel, in 2004. Since then he works in HP-Indigo. Part of his research interests lie in the field of color prediction models for digital printing.

Ayelet Pnueli received her Ph.D. in physics from the Technion, Israel Institute of Technology, in 1993. Since 2004 she is working for HP-Labs Israel.