Image Analysis as A Tool for Printer Characterization and Halftoning Algorithm Development

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Abstract

- Using of image analysis to develop
- Parameterize printer model
  - Form the basis for modification to the print mechanism or rendering algorithm
Printer technologies and artifacts that impact print quality

- The two mainstream technology
  - Electrophotographic (EP)
    - Banding artifact
      - Due to fluctuations in the angular velocity of the optical photoconductor (OPC) drum
    - Developing detailed physics-based model
  - Inkjet (IJ)
    - Nonconstant paper speed
Resulting in non-uniform line spacing as the printheads move back and forth.

The source of artifacts are typically twofold:
- Dot irregularity
  - Ink coalescence or creation of satellites
- Dot placement error
  - Causing by misaligned nozzles in a print head.
Banding reduction via closed-loop feedback control

- To reduce banding
  - Designing a better mechanical system
  - Compensating the source of the banding through feedback
    - Having system that
      - directly compensate the line spacing error
      - directly govern OPC drum angular velocity
  - Having system that indirectly compensate the line spacing error
To characterize banding

- Using designed test pattern to produce banding
- Using image analysis as a tool to analyze it
Fig. 1. Layout of the test pattern used to characterize banding
Fig. 2. Waveforms and spectra of (a) scan line spacing, (b) horizontally projected absorptance before compensation, and (c) projected absorptance after compensation
Fig. 3. Portions of 1-inch-high printed images scanned at 150dpi
Halftoning via direct binary search and tone-dependent error diffusion

- Direct binary search
  - Iterative search-based halftoning algorithm
- Toggle
  - Switching a pixel
- Swap
  - Interchanging the state of two different pixels in search domain
• DBS seeks a halftone image that minimize

\[
\epsilon = \int |\tilde{g}(x) - \tilde{f}(x)|^2 dx
\]  

(1)

Where, \( \tilde{g}(x) = h(x) * g(x) \) and \( \tilde{f}(x) = h(x) * f(x) \)

Here, * : denote the convolution operation

\( h(x) \): represents the point spread function of the HVS

\( g(x) \): the continuous- parameter rendered halftone

\( f(x) \): the continuous- tone original image
- **DBS algorithm**
  - Implicitly based on an ideal printer model
  - The halftone image rendered by the ideal printer

\[
g(x) = \sum_m g[m] p(x - Xm)
\]  \hspace{1cm} (2)

where, \( p(x) = \text{rect}(x/X) \): the spot function of the ideal printer

\( X \): the periodicity matrix
The relation between $\tilde{g}(x)$ and $g[m]$

$$\tilde{g}(x) = \sum_m g[m] \tilde{p}(x - Xm) \quad (3)$$

where, $\tilde{p}(x) = h(x) \ast p(x)$ embodies the effect of cascading the ideal printer rendering and HVS model.

Error measure

$$\epsilon = \sum_m \sum_n e[m]e[n]c \tilde{p}\tilde{p}[m - n] \quad (4)$$
Tone-dependent error diffusion

Tone-dependent method

Using different weight sets for different input pixel values have been developed for error diffusion.

The binary output

\[
g[m] = \begin{cases} 
1, & \text{if } u[m] \geq t[m; f[m]], \\
0, & \text{otherwise}
\end{cases} \quad (5)
\]
- The continuous-tone pixel value

\[ u[(m + k)] \leftarrow u[m + k] - w_k (f[m])d[m] \] (6)

- The threshold matrix

\[ t[m; a] = \begin{cases} 
  t_u(a) & \text{if } p[m;0.5] = 0 \\
  t_l(a) & \text{otherwise}
\end{cases} \] (7)

where, \( t_u(a) \) and \( t_l(a) \) : tone dependent parameters satisfying \( t_u(a) \geq t_l(a) \)

The function \( p[m;0.5] \) : halftone pattern generated by DBS to represent a constant patch with absorptance 0.5
Robust halftoning for electrophotographic printers

- Using to generate the equivalent gray scale image
  - Hard circular dot (HCD) printer model
    - The printer can generate a circular spot
  - Overlap of multiple dots is resolved by a logical OR
Fig. 4. (a) Digital halftone $g[m]$, (b) HCD model output, and (c) equivalent gray scale image $\hat{g}[m]$ for HCD model.
To examine the validity of the HCD model for EP printer
  - Considering the output

Using measurement-based stochastic model
\[
E\{e[n]e[m]\} = \begin{cases} 
E\{e[n]\}E\{e[m]\} & \text{if } m \neq n \\
E\{e[m]\}^2 & \text{otherwise}
\end{cases}
\] (8)

\[
\phi^{EP} = \sum_{m,n} e[n]e[m]c_{\tilde{pp}}[m-n]+c_{\tilde{pp}}[0]\sum_m \sigma_e^2[m]
\] (9)
Fig. 5. (a) Digital halftone and 4000 dpi scan of its print sample resulting from HP LaserJet 4M printed at (b) 300 dpi, (c) 600 dpi
Fig. 6.
Robust halftoning for inkjet printers

- To characterize the target inkjet printer
  - Printing test pattern using magenta
  - The printed image is then scanned at 4000 dpi resolution
  - Analyzing the resulting scanned image
  - Computing the dot statistics
The goal of the training

- Minimizing the error measure by searching for the optimal $w_k(a)$ and $t[m; a]$

\[ \phi^{IJ} = \sum \sum E\{e[m]\}E\{e[n]\}c_{pp}[m-n] + \text{cov}\{e[m]e[n]\}c_{pp}[m-n] \]
Fig. 7. Measurement data for HP DeskJet 970Cx printer used in the 600 dpi, 10 in/sec, uni-directional print mode
Fig. 8. HP DeskJet 970Cx printer outputs (scanned at 4000 dpi) using DBS algorithm
To reduce banding
  - Using real-time information about fluctuation
To reduce the effect of stochastic dot interaction or dot placement error
  - Incorporating a printer model within the halftoning algorithm