Show-through Cancellation for Duplex Scanning

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Outline

• Show-through in Duplex printing
• Analysis of show-through
• Linearizing Simplification
• Algorithm for Show-through Correction
• Experimental Results
• Conclusions
Show-through in Scans of Duplex Printed Pages

- **Scan of Duplex Printed Page**
  - Paper not opaque
  - Printing on back side shows-through
  - Objectionable
Characteristics of Show-through

- Low contrast
- More visible in light regions of front page
- Blurred in comparison to printing on front side
- Transposed
Thresholding

- Removes show-through from black and white-text
- For Images/grayscale text:
  - Also removes low-contrast front-side information
  - Show-through still visible in some regions

Convert regions with reflectance above a threshold to white
Image Processing based Show-through Removal

- Scans from both sides available
  - can help distinguish low contrast front-side information from show-through
  - need to be able to predict “how-much” is contribution of show-through
Show-through Analysis

- Simple Model of Scanning Process
  - 3 layers and scanner backing between lamp and sensor
  - analysis using first physical principles
    - paper scattering and transmittance
    - transmittance of each “print-layer”
    - backing reflectance

![Diagram of scanning process with layers and directions]
Show-through Analysis

- Reflectance “seen” by sensor for front side scan

\[ R^s_f(x, y) = T^2_f(x, y)\left(S_p + T^2_p R^*_{bk} T^2_b(x, y)\right) \]

- Dependence on \( T^2_b(x,y) \) represents show-through
- Similarly for back-side scan

\[ R^s_b(x, y) = T^2_b(x, y)\left(S_p + T^2_p R^*_{bk} T^2_f(x, y)\right) \]

- Desired output \( T^2_f(x,y) \) and \( T^2_b(x,y) \)
- Two Equations in two unknowns
  - nonlinear equations
  - interaction not strictly point-wise
Show-through Analysis: Linearization

- Transform to density domain (logarithm)
  - approximation: $\ln(1-x) \approx -x$ for small $x$, using $S_p >> T_p$

$$D^s_f(x, y) \equiv -\ln\left( \frac{R^s_f(x, y)}{R^w_p} \right)$$

$$= D_f(x, y) - \ln\left( 1 - \frac{T_p^2 R_{bk}}{S_p + T_p^2 R_{bk}} \left( 1 - T_b^2(x, y) \right) \right)$$

$$\approx D_f(x, y) + \frac{T_p^2 R_{bk}}{S_p + T_p^2 R_{bk}} A_b(x, y)$$

- Scan density is desired density plus a small fraction of back-side absorbance
Show-through Point Spread Function

- Back-side Image is blurred in transmission through paper

\[
D_f^s(x, y) \approx D_f(x, y) + h(x, y) \otimes A_b^s(x, y)
\]

- \( h(x, y) \)
  - Show-through point spread function (PSF)
  - represents the term \( \frac{T_p^2 R_{bk}}{S_p + T_p^2 R_{bk}} \)
  - small in magnitude at all points

- Show-through correction ??

\[
\hat{D}_f(x, y) = D_f(x, y) - h(x, y) \otimes A_b^s(x, y)
\]
Show-through Cancellation Algorithm

- Adaptive filter to estimate and track show-through PSF
- Filter adapted in “far-end single-talk”
  - printing on back-side and none on front side
  - desired output density is zero
- Least-Mean-Squares (LMS) algorithm
  - nonnegativity imposed on coefficients
- Image processed in serpentine scan to preserve adjacency
- Large support allows “tracking” of relative mis-registration between front and back side scans
Show-through Cancellation Algorithm

Overview of Algorithm

- Current Pixel (to be processed)
- Back-side image scan Absorptance
- Predicted show-through for current pixel
- Adaptive filter support
- Front-side image scan density
- Corrected output pixel value
- Front-side image corrected density
- Adapt filter coefficients
- Front-side silence (un-printed) detection
Experimental Results

- Duplex printed page
  - text on one side, image on other
- Scan on UMAX Powerlook desktop scanner
  - gamma=1.0 (output linear in reflectance)
  - grayscale mode
  - 600dpi resolution
- Approx. alignment determined using features
- 31x31 Adaptive filter
- LMS adaptation
  - adaptation parameter 0.0001
  - 15x15 neighborhood for detecting “far-end single talk”
Filter Coefficient Views

- Mesh Plots of coefficients at two locations
Conclusions

- Show-through is an interesting image degradation encountered in scanning duplex printed originals
  - lends itself to physical analysis from first principles
- The algorithm presented here is an effective method for image processing based correction
  - similarities with speech echo-cancellation
  - better at removing show-through in low contrast image regions than simple thresholding
Experimental Results

• Complete Example

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Side 1

Side 2

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Side 1: Corrected

Side 2: Corrected