New dispersed-dot halftoning technique by elimination of unstable pixels for electrophotography

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Abstract

◆ Problem about printing process of electrophotography
  – Analog unstableness
    • Stochastic reproduction of small dots
    • Degradation of image quality

◆ Proposal method
  – New dispersed-dot halftoning
    • Combining a Gaussian filter of with a sigmoid nonlinear function
      – Computing the probability of toner transfer
    • Using nonlinear printer model
      – Predicting an image to be printed out
      – Producing halftoned images with small perceptive error
Introduction

🔹 The purpose of digital halftoning
  – Obtaining a binary image looking similar to an input image
    • Minimizing a perceptive error

🔹 Implementation
  – Cluster dot
    • Arrangement of pixels
      – Restriction to form clusters
        » Recognition as perceptive error
  – Dispersed dot
    • No restriction for pixel arrangement
Previous work

- Considering the unstableness with DBS algorithm
  
  • Baqai
    - Deriving the error metric with mean and variance
      » The lower variance exists, the less unstable pattern happens
  
  • Kacker
    - Defining the unstable region
      » Range of the specific exposure
◆ Toner deposition
  – Scanning photoreceptor for laser light
  – Exceeding a threshold for the accumulated light energy on the photoreceptor
  – Being sensitive to change parameters
    • Sizes or shapes of toner particles
    • Environmental conditions like temperature or humidity

◆ Occurring cause of the unstable pixels
  – Being near the threshold for the accumulated energy of laser light on the photoreceptor
    • Becoming probabilistic for toner deposition
      – Being created for unstable pixels
Proposed method

- Assuming one pixel equal to one toner particle (10 μm)
- Using a nonlinear printer model
  - Combining a Gaussian filter with a sigmoid nonlinear function using fluctuating threshold
    - Probability of toner deposition
  - Predicting a image to be reproduced
- Using iterative improvement on a binary image to get rid of unstable pixels

Fig. 1 Schematic diagram of the nonlinear printer model and the iterative improvement method which eliminates unstable pixels.
Nonlinear printer model

◆ Formulating above-described process
  – Expressing energy distribution of a laser beam $i(r)$ at a point in the distance $r$ from the center of the beam
    $$i(r) = \exp\left\{ -\frac{4r^2}{D^2} \right\}$$  \hspace{1cm} (1)
    where $D$ is the diameter of the Gaussian function at which the Gaussian filter has a value of $1/e$
  – Taking the influence from the adjacent pixels into accounts, energy $I_p$ accumulated at a pixel $p$
    $$I_p = \sum_{q \in N(p)} i(||p - q||)$$  \hspace{1cm} (2)
    where $N(p)$ is a neighborhood of a pixel $p$ at which the energy is not negligible and $||p - q||$ denotes the distance between two pixels $p$ and $q$. 
Intensity $E_p$ of the electric field at a pixel $p$

$$E_p = \frac{1}{1 + \exp\left(-S \cdot (I_p - K)\right)}$$ (3)

where $S$ indicates a slope of $I_p$ that is a constant, and $K$ is a constant. Both $S$ and $K$ depend on the electrophotography machine.

$E_p$ indicates driving force of toner deposition at a pixel $p$.

Fig. 2 Sigmoid nonlinear function instead of a PIDC shows the intensity of the electric field of the electric field against the laser beam intensity.
- Probability of $\theta = x$

$$\Pr(\theta = x) = \frac{1}{\sqrt{2\pi} \sigma} \exp\left\{ \frac{(x - \mu)^2}{2\sigma^2} \right\}$$  \hspace{1cm} (4)

where threshold value $\theta$ follows a normal distribution with mean $\mu$ and standard deviation $\sigma$.

- Probability of toner transfer at a pixel $p$

$$P_{\text{trans}}(p) = \Pr(o_{bp} \geq \theta)$$  \hspace{1cm} (5)

- Obtaining a simulated image of nonlinear model with normal distribution as threshold.
Unstable pixels and threshold determination

- Terminology
  - Input gray scale image $g$, halftoned image data $B$
  - Printed image $Out(B)$, perceptive error $Err[Out(B)]$

- Unstable pixels
  - Being affected by the condition of a printer characterized by various parameters for an output image
  - Being unstable in this sense for output image $Out(B)$

- Stable image
  - Eliminating as many unstable pixels causing noise as possible
– Prediction of an output image
  • Assuming two thresholds $\theta_L$ and $\theta_U$ characterizing the behavior of a printer for unstable pixels
  • Being put at a pixel $p$ for toner particle
    – High probability when $E_p$ is at least the upper threshold $\theta_U$
    – No high probability when $E_p$ is at most the lower threshold $\theta_L$
  • Defining predicted image $\hat{B} = \left( \hat{B}_p \right)$
    
    $$
    \hat{B}_p = \begin{cases} 
    1 & E_p \geq \theta_U \\
    0 & E_p \leq \theta_L \\
    a & \theta_L < E_p < \theta_U
    \end{cases}
    $$
    
    \text{(6)}
    $$
    \text{where } a \text{ indicates that the pixel is unstable}
    $$
  \end{array}
Iterative improvement to eliminate unstable pixels

- Basic idea
  - Finding a binary halftoned image data minimizing the perceptive error given by $\text{Err}(g, \hat{B})$
  - Defining the perceptive error $\text{Err}(g, \hat{B})$

$\tilde{g} = g \ast iVTF$ \hspace{1cm} (7)

$\tilde{B} = \hat{B} \ast iVTF$ \hspace{1cm} (8)

$\text{Err}(g, \hat{B}) = \sum_p \left( \tilde{g}_p - \tilde{B}_p \right)^2$ \hspace{1cm} (9)

where $iVTF$ is the inverse Fourier transform of visual transfer function (VTF)

- Obtaining a perceptive image of $\hat{B}$ and $\text{Err}(g, \hat{B})$ about an original gray scale image $g$
– Proposed method
  • Replacing a current binary pattern with the pattern whose
    perceptive error is minimum
    – All candidate bit patterns in each local window
  • Process
    – Being given for an original gray scale image $g$ and a binary
      image $B$
    – Letting $W(i, j)$ be a $k \times k$ window
      » $2^{k \times k}$ different binary patterns
    – Examining all those patterns and replace the current binary
      pattern by the best pattern that minimizes the total error
      $B^* = \arg \min \{ \text{Err}(g, B) | \text{B and B differ only in } W(i, j) \}$ (10)
    – Using a laser beam spread function (LBSF) that is a
      Gaussian filter of size $(2w_1 + 1) \times (2w_1 + 1)$
– Affecting the $(2w_1 + k) \times (2w_1 + k)$ area centered at $(i, j)$ for a change of a binary pattern in $W(i, j)$ in the energy distribution
– Using Eq. (3) to obtain $E_p$ in the area
– Using Eq. (6) to acquire toner distribution in this area
– Existing for unstable pixels in this area
  » Trying next binary pattern
– Not including unstable pixels in the area
  » Convoluting $iVTF$ of $(2w_2 + 1) \times (2w_2 + 1)$
– Computing the total error
  » In the influence region of size $(2w_1 + 2w_2 + k) \times (2w_1 + 2w_2 + k)$

Fig. 3 Illumination of a $k \times k$ window, a LBSF filter of size $(2w_1 + 1) \times (2w_1 + 1)$, a Gaussian filter of size $(2w_2 + 1) \times (2w_2 + 1)$, the LBSF influence region of size $(2w_1 + k) \times (2w_1 + k)$, and computation of the total in the region of size $(2w_1 + 2w_2 + k) \times (2w_1 + 2w_2 + k)$. 
Results and discussion

- Environments
  - $512 (= 2^{3 \times 3})$ bit patterns, $3 \times 3$ local window,
  - $7 \times 7$ LBSF filter and $17 \times 17$ Gaussian $iVTF$ filter

- Results

Fig. 4 Halftoned image of a portrait reproduced by our nonlinear mode.

Fig. 5 Dot pattern in a halftoned image.
Fig. 6 Predicted image of our nonlinear printer model.

Fig. 7 Dot patterns in the predicted image.

Fig. 8 Printed image of high resolution electrophography.

Fig. 9 Dot patterns in the predicted image.
Application

- Part of a halftoned image
- Indicating ON pixel by 1 and OFF pixels by 0
- Representing a $3 \times 3$ local window for thick line
- Once changing a bit pattern in this region, the intensity of electric field in the $9 \times 9$

Fig. 10 Halftone image for the portrait reproduced by our nonlinear printer model.

- Setting to 0.3 and 0.7 for the lower and upper thresholds
- Indicating that the intensity of electric field exceeds threshold and toner deposition takes place for the dark shade pixels
- Representing unstable pixels for hatched patterns
- Not accepting the bit patterns containing unstable pixels

Fig. 11 Probability distribution of toner transfer in case of including unstable pixels.
• Trying to flip a single 0 pixel to 1 as shown by the dark shade

• Affecting the intensity of electric field at those pixels in the influence region shown by the dotted lines

• Becoming larger than the upper threshold for the values at those unstable pixels

• No containing unstable pixels in the $9 \times 9$

• Calculating the perceptive error of this pattern

• Updating a halftoned image data by replacing the current bit pattern with best pattern minimizing the perceptive error among accepted bit pattern

Fig. 12 An image predicted by our nonlinear printer model.

Fig. 13 An image predicted by our nonlinear printer model.
• Another features

Fig. 14 An image predicted by our nonlinear printer model of a 128 gray-level uniform patch.

Fig. 15 Fourier power spectrum of the predicted image.

• Being connected for ON pixels to form clusters
• Globally forming a maze-like pattern

• Showing a doughnut-like form with mid frequency components in all direction
• Meaning that it is an ideal halftone screen without anisotropy
Fig. 16 An image predicted by our nonlinear printer model.

Fig. 17 Comparison of perceptive error distribution between cluster dot and our method (left-cluster-dot, right-our nonlinear printer model.

- Indicating the magnitude of error by the color
- Tending to have large errors on the edge part in the cluster-dot algorithm

| Table 1 Comparison of perceptive error between cluster-dot model and our model |
|---------------------------------|-----------------|-----------------|-----------------|
|                                | Average | Standard Deviation | Maximum Error  |
| Cluster-dot                    | 0.27    | 0.7               | 7.0             |
| Our Method                     | 0.26    | 0.4               | 3.6             |
Conclusion and future works

◆ Result
  - Including high frequency components for the halftoned image data
  - Being reduced in the nonlinear printer model
  - Finding the predicted image has an ideal halftone screen without anisotropy by Fourier analysis

◆ Future works
  - Existing more than our expectation for high frequency components
  - Optimizing these parameters to reproduce better characteristics of a real electrophotography machine
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2) 문자 화상에 대응하는 빛으로 감광 드럼상에 정전 잠상을 형성합니다.
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