Title	New dispersed-dot halftoning technique by elimination of unstable pixels for electrophotography
Author(s)	Sasahara, Shinji; Asano, Tetsuo
Citation	Journal of Electronic Imaging, 14(2): 023006
Issue Date	2005-04
Type	Journal Article
Text version	author
URL	http://hdl.handle.net/10119/4907
Rights	Copyright 2005 Society of Photo-Optical Instrumentation Engineers. This paper was published in Shinji Sasahara, Tetsuo Asano, Journal of Electronic Imaging, 14(2), 2005, 023006 and is made available as an electronic reprint with permission of SPIE. One print or electronic copy may be made for personal use only. Systematic or multiple reproduction, distribution to multiple locations via electronic or other means, duplication of any material in this paper for a fee or for commercial purposes, or modification of the content of the paper are prohibited.
Description	

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

Shinji Sasahara[a] and Tetsuo Asano[b]

[a]Fuji Xerox Co., Ltd,

430 Sakai, Nakai-Machi, Ashigarakami-gun Kanagawa 259-0157, Japan.

[b]Japan Advanced Institute of Science and Technology,

1-1, Asahidai Tatsunokuchi, Ishikawa, 923-12, Japan.

e-mail: shinji.sasahara@fujixerox.co.jp

e-mail: t-asano@jaist.ac.jp

ABSTRACT

Printing processes of electrophotography basically involve some instabilities of analog nature. These instabilities make small dot reproduction stochastic and degrade image quality. To overcome the analog instabilities in this paper, we have developed a dispersed-dot halftoning technique for high resolution electrophotography. Based on the characteristic of electrophotography, a combination of a Gaussian filter with a sigmoid nonlinear function was used to calculate the probability of toner transfer in print. We can obtain a predicted image in print using this nonlinear printer model. Halftone images having good image quality are formed under this model in a way so that the perceptive error with respect to an original gray scale image is small. To achieve this, unstable pixels that have their transfer probabilities within a band in our nonlinear printer model are eliminated as much as possible by an iterative improvement method. As a result, perceptive error was much improved compared to conventional cluster-dot halftoning.

Keywords: unstable pixels, stable printing, nonlinear printer model, iterative improvement

1. INTRODUCTION

Digital halftoning is a technique to convert a gray scale image into a binary image consisting of black and white dots. It is important that perceptive error which indicates visual difference between input gray scale image and printed image becomes low as much as possible. Since this error is measureable but incalculable, we

need to consider another calculable perceptive error A perceptive error between gray scale image and binary image is calculable. However, since binary bit pattern is reproduced stochastically because of its instability in electrophotography, perceptive image from binary image is different from printed image. Then we considered perceptive error between gray scale image and predicted printed image from binary image using device model. Our aim is to obtain good binary image which has few perceptive error between gray scale image and printed image. In this paper, this perceptive error is defined as "real perceptive error". And perceptive error between gray scale image and binary image is defined as "idealized perceptive error". A perceptive error between gray scale image and predicted printed image is defined as "predicted perceptive error"

Two types of halftone screen are generally used for this process. One is cluster-dot and the other is dispersed-dot. In the cluster-dot screen, clusters of pixels are formed so that their sizes are controlled by their corresponding gray levels. It has been widely used in the field of offset printing before the introduction of digital technology. Conventional cluster-dot halftoning, known as AM (Amplitude modulation) halftoning, reproduces continuous tone by changing the size of regularly arranged clusters. Printing is stable due to the large sizes of clusters. Since arrangement of pixels is restricted to form clusters, however, detail rendition of cluster-dot screen is rather poor than that of dispersed-dot screen. It can be recognized as perceptive error. On the other hand in dispersed-dot screen, pixels are arranged so that pixel density is controlled by level of an input image. These pixels need to be reproduced independently and ink-jet printer use this type of screen. Since there is no restriction for pixel arrangement, idealized perceptive error is smaller than the cluster-dot halftoning. However, the output quality nearly depends on instability of the device. One of the main reason why cluster-dot halftoning has been widely used in electrophotography is this instability, that is, difficulty to reproduce small dots independently form clusters. Some techniques that compensate these instabilities using device model which simulates characteristics of print process of the printer are proposed, and halftoning methods using these models are proposed.

Circled dot overlap model was proposed by Roetoling and Holladay.[1] In this model, the printer creates a circular dot with constant absorptance and multiple dot overlap is assumed by a logical OR. Stucki used this model for improving rendition of error diffusion.[2] An algorithm is proposed for minimizing perceptive error between original gray scale image and predicted image using iterative improvement methods such as DBS(Direct

Binary Search) algorithm.[3,4] Although these methods require high processing time, undesirable artifacts of halftone patten were reduced and image quality was drastically improved. Some models supposing the instability of electrophotography are also proposed. Flohr et al. proposed stochastic model for toner distribution.[5,6] This model assumed that pixels are constructed by several toner particles which are distributed in Gaussian distribution as a probability density function. Baqai et al. proposed an analytical model to consider dot fluctuation.[7] This model compensates parameters of circular-dot overlap model, based on the average and standard deviation of reflectance of printed dots . Kacker et al. proposed the model which simulates the electrophotographic process. This model defined the unstable region where pixel reproduction becomes stochastic, using simulated model of the electrophotographic process. Halftone image was created using 5 patterns such as 0%, 50%-Left, 50%-Middle, 50%-Right, 100% for coverage of line screen by DBS algorithm assuming 600dpi line screen halftoning. This paper reported that image noise was not increased in consideration of multi-level halftone pattern, in spite of including unstable pixels. These models with DBS algorithm contributed to compensate tone reproduction and to reduce undesirable artifacts by simulating dot shape and state of overlapping of printed dots.

Recently printer resolution has been dramatically improved, and 2400dpi high resolution printer was released. In case of such a printer, not only the shape of the dots but also the pattern of the dots is changed between halftone image and printed image. Smaller pixels become more difficult to reproduce. One such distortion is dot deficiency in the highlight or deep shadow regions of the image. Toner deposition takes place when laser light scans the photoreceptor and the accumulated light energy on the photoreceptor exceeds a threshold. Since the quantity of light accumulated in case of an isolated dot is below the threshold, chances of toner deposition taking place is negligible. The threshold fluctuates with the influence of parameters like size or shape of the toner particle, and conditions like temperature or humidity. So, when the accumulated energy of laser light on the photoreceptor is near the threshold, noise or unstable pixels are created because toner deposition proceeds stochastically. Using large pixel is an effective method for preventing the formation of isolated dots or unstable pixels, however image resolution becomes low. Therefore, in electrophotography, the cluster-dot halftoning technique has been mainly used for stable printing.

In this paper, a new halftone technique of dispersed-dot halftoning by elimination of unstable pixels is proposed for electrophotography which has high resolution of 2400dpi. Since size of pixels is about $10\mu m$ of the same order as the diameter of toner particles, one pixel is assumed to consist of one toner particle. Using a nonlinear printer model that is a simulation of the printing process of electrophotography, probability of toner deposition is calculated. Using this model, halftone image is created to arrange pixels so that perceptive error becomes minimum under the restriction of eliminating unstable pixels. Our work described in this paper has two distinct parts. We first propose a nonlinear printer model following the characteristics of electrophotography. This model uses a fluctuating threshold to simulate variation of condition such as temperature, humidity, etc.This fluctuating threshold creates unstable pixels. So in the next part, we propose a method to eliminate the unstable pixels to obtain better halftone images. Our nonlinear printer model simulates the printing process of the electrophotographic machine as follows. Based on the characteristics of electrophotography, a combination of a Gaussian filter with a sigmoid nonlinear function is used to calculate the probability of toner transfer for a given binary image. Thereafter, the reproduced image based on the toner distribution in print is predicted. A flowchart of the model is shown in Fig. 1. Next, our aim is to reproduce a halftone image which has a good image quality under nonlinear printer model. The image quality becomes poor if unstable pixels are included. To get rid of unstable pixels, if they are in the predicted image, we design an iterative improvement method over successive binary image patterns. This method is based on some conditions for each pixel of the binary image so that the perceptive error with respect to the gray scale image is minimized. This method eliminates the unstable pixels so that stable printing is possible.

The rest of the paper is organized as follows. In section 2, we describe our nonlinear printer model and its fluctuating threshold. In section 3, we show how the fluctuating threshold gives rise to unstable pixels and thereafter, discuss our method of iterative improvement of binary patterns. The discussion about selections of parameters and results are given in section 4. Section 5 has a conclusion and some indications of possible future work.

2. NONLINEAR PRINTER MODEL

In electrophotography, toner particles are electro-statistically transferred from the developer roll onto the photoreceptor drum. The photoreceptor drum has a latent halftone image against the negatively charged background formed by the scanning of a laser light. Negatively charged areas in the drum surface repel negatively charged toner particles while the toner particles deposit on the laser-exposed areas. Usually, the latent image is of binary nature. In case of halftone image having a resolution of 2400dpi, the laser light is exposed with a scan space of about $10\mu m$. The intensity distribution of the laser beam is Gaussian with an effective zone of about $50\mu m$. The scanning exposure is such that adjacent pixels are exposed with some overlaps. Toner deposition takes place when laser light scans the photoreceptor and the accumulated light energy exceeds a threshold. Since the required quantity of light is not accumulated in the case of an isolated dot, chances of toner deposition is very minimal. Since the threshold fluctuates with the influence of parameters such as size or shape of toner particle or environmental conditions such as temperature or humidity, when the accumulated energy of laser light is near the threshold, toner deposition proceeds stochastically, thus causing noise or unstable pixels. Therefore, in electrophotography, we need to arrange pixels so that unstable pixels do not appear. Below, we give the mathematical expressions of the described process.

Energy distribution of laser beam $i(r)$ is expressed as

$$i(r) = \exp\{-\frac{2r^2}{D^2}\}, \tag{1}$$

where D is the diameter of the Gaussian function at the level where the Gaussian filter has a value of $1/e$, and r is the distance of the point from the center of the beam.

Since, laser beam energy $i(r)$ of a pixel located at p is influenced by those of adjacent pixels, the accumulated energy $I(p)$ is given as follows,

$$I(P) = \sum_r i(r). \tag{2}$$

A sigmoid function is used instead of PIDC(Photoinduced Discharge Curve) and the intensity of the electric field $E(I(p))$ is calculated as follows,

$$E(I(P)) = \frac{1}{1 + \exp\{-S \cdot (I - K)\}}, \tag{3}$$

where S indicates a slope of I that is constant, and K is also a constant. Both S and K depend on the electrophotography machine. Fig. 2 shows the sigmoid function of our nonlinear printer model.

This intensity $E(I(p))$ indicates driving force of toner deposition, and when this exceeds a threshold th, the toner deposition takes place, as shown below.

$$\hat{b_s}(p) = \begin{cases} 1 & E(I(p)) \geq th \\ 0 & E(I(p)) < th. \end{cases} \tag{4}$$

The threshold fluctuates under the influence of parameters such as size or shape of toner particle or environmental conditions such as temperature or humidity. So, the pixel whose corresponding electric intensity $E(I)$ is close to the threshold becomes an unstable pixel. The threshold value th is assumed to follow a normal distribution with mean μ and standard deviation σ. Probability of $th = x$, is expressed as,

$$P(th = x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\{\frac{(x-\mu)^2}{2\sigma^2}\}. \tag{5}$$

Then, the probability of toner transfer is as follows,

$$Prob(p) = P(E(I(p)) \geq th). \tag{6}$$

Then we can obtain a simulated image of our nonlinear printer model using random numbers which has normal distribution as threshold.

3. MODEL FOR ELIMINATING UNSTABLE PIXELS

3.1. unstable pixels and fluctuating threshold

Our aim is to obtain a halftone image that produces a good quality image in print for electrophotography under our nonlinear printer model. To achieve this, unstable pixels that cause noise should be eliminated as much as possible.

Now, we can construct a halftone image whose unstable pixels are eliminated for stable printing. So, the predicted image $\hat{b_p}(P)$ in print is as follows,

$$\hat{b_p}(P) = \begin{cases} 1 & E(I(p)) \geq th_U \\ 0 & E(I(p)) \leq th_L \\ a & th_L < E(I(p)) < th_U. \end{cases} \tag{7}$$

where th_L, th_U indicate lower threshold and upper threshold respectively, and a indicates the index of unstable pixels.

The reader can refer Fig. 2 for seeing the band of the fluctuating threshold that causes the unstable pixels.

3.2. Iterative Improvement method for Eliminating unstable pixels

We construct a halftone image so that the perceptive error between the original image $g(p)$ and the predicted image $\hat{b_p}(P)$ is minimized.

Perceptive images and perceptive error between them can be shown using least square model proposed by Pappas et. al. as follows,[4]

$$g'(p) = g(p) * iVTF(p), \tag{8}$$

$$b'(p) = \hat{b_p}(p) * iVTF(p), \tag{9}$$

$$Err = \sum_p \{g'(p) - b'_p(p)\}^2. \tag{10}$$

where $iVTF(p)$ is the inverse Fourier transform of VTF(Visual Transfer Function). Using this model, we can also obtain a perceptive image $b'_s(p)$ of the simulated image $\hat{b_s}(p)$ and its perceptive error with respect to original gray scale image.

In order to obtain a good binary image whose perceptive error is minimized with respect to the original gray-scale image in reasonable time, DBS(Direct Binary Search) is a strong and general algorithm to solve such a kind of problem. In our case, since eliminating patterns that include unstable pixels are required, we use an iterative improvement method with local search on huge neighborhoods.[9] This is a method to replace the current binary pattern to the pattern whose perceptive error is minimum among candidate bit patterns in each local window*. When unstable pixels are included in the predicted image, the bit pattern does not become candidate. If the size of local window becomes larger, the total error approaches the minimum value, but the processing time increases.

Suppose that an original image A and a binary image B are given. Further, let $W(i,j)$ be a window of size $k \times k$ in B whose top-left corner is at (i,j). Our method is to check exhaustively all the $2^{k \times k}$ binary patterns

*The number of patterns increases exponentially with the neighborhood size.

in $W(i,j)$ and replace the current binary pattern by the best pattern that minimizes the total error. In other words, we find a binary image B' expressed by

$$B' = \arg\min \{Error(A,B) | B \text{ and } B' \text{ differ only in } W(i,j)\}. \tag{11}$$

Clearly, $Error(A,B') \leq Error(A,B)$ always holds. So, we can say that B' is an improvement over B to reproduce the original gray-scale image A. We use a Laser Beam Spread Function(LBSF) that is also a Gaussian filter of size $(2w_1+1) \times (2w_1+1)$. Now, if a binary pattern is changed in $W(i,j)$, an area of $(2w_1+k) \times (2w_1+k)$ of accumulated intensity of laser beam $I(p)$ is influenced. The reader should refer to Fig. 3 for illustration of a window, an LBSF filter, the Gaussian filter and their influence regions. Using eq. 3, we obtain an intensity distribution of the electric field in the area. And then, using eq. 7, toner distribution $b'(p)$ in this area is obtained. Now, if unstable pixels are present in this area, we try the next binary pattern. When unstable pixels are not included, we convolute an iVTF to this area. Since we use an iVTF filter of size $(2w_2+1) \times (2w_2+1)$, we are computing the total error of the influence region of size $(2w_1+2w_2+k) \times (2w_1+2w_2+k)$.

4. RESULTS AND DISCUSSION

In this section, we present some results of our models. We tried $512(= 2^{3\times3})$ bit patterns to perform iterative improvement with the model of elimination of unstable pixels using a 3×3 local window, a 7×7 LBSF filter and a 17×17 Gaussian as iVTF filter. The computed total error region is of size 25×25.

Figs. 4 and 5 show a halftone image and its halftone pattern which are obtained by our method. These images were created assuming 2400dpi high resolution electrophotography printer. In these images, pixels are arranged dispersively and we can find that these images include high frequency component or many isolated pixels. Figs. 6 and 7 show a predicted image and its enlarged pattern which are predicted by our nonlinear printer model. These images were formed so that perceptive error is minimized under the condition of eliminating unstable pixels. In these images, clusters that are constructed by several pixels join together mutually and form the maze-like pattern. High frequency component or any isolated pixels are not included. Figs. 8 and 9 show a printed image and its enlarged pattern which are printed by DocuColor 1256 GA[†]. These images were scanned

[†]DocuColor 1256 GA is a product of Fuji Xerox Co., Ltd .

by high resolution scanner which has 4800dpi resolution. These images were printed using halftone image which is created by our method. A noise is contained in these images, however reader could understand that similar halftone pattern to predicted image is obtained. It is thought that this noise can be reduced by optimizing the parameter of nonlinear printer model.

Now I will explain how to eliminate unstable pixels. Fig. 10 shows a example of a part of halftone image. 1 indicates ON pixel and 0 indicates OFF pixel respectively. The region surrounded by the thick line indicates 3×3 local window and when bit pattern of this region is changed, intensity of electric field in 9×9 region is influenced. Fig. 11 shows a intensity distribution of electric field. When this intensity is less or equal than the lower threshold, toner deposition dose not take place and when this intensity is larger or equal than the upper threshold, toner deposition takes place. We set values of 0.3 and 0.7 for lower and upper threshold respectively. In this bit pattern, since there are two unstable pixels included which are indicated by hatching background, we can not accept this bit pattern in local window. Now we try to change just one bit turning on as shown in Fig. 12, then the region surrounded by the dotted line is influenced and intensity of electric field in this region is changed as shown in Fig.13. Then, since value of unstable pixels is larger than the upper threshold and no unstable pixels are included in 9×9 region, we can accept this bit pattern. Next we calculate perceptive error of this pattern. We can obtain the halftone image by replacing current bit pattern with best pattern which has minimum perceptive error among accepted bit pattern.

I will show another feature of the halftone screen which is obtained by our method. Fig. 14 shows a simulated patch image of 128 Gray-Level using our nonlinear printer model. The simulated patch shows that clusters connect mutually and form a maze-like pattern. Fig. 15 shows the Fourier transform of the simulated image. It shows a doughnut-like form with mid frequency components of all directions. This means that it is an ideal halftone screen without anisotropy. Fig. 16 shows the amplitude of the frequency spectrum averaged over all angles for the simulated image. When the printer resolution is assumed to be 2400dpi, there is a peak on 11 cycle/mm and it is equivalent to 270lpi.

Figs. 18 show the perceptive error distributions of 200lpi conventional cluster-dot halftoning and predicted image obtained by

our nonlinear printer model. Fig. 17 shows original portrait image. In these figures, magnitude of the error is indicate by the color. In case of conventional cluster-dot, there are some large errors on the edge part, however it can be improved in our method. Although an average error is not so different, standard deviation and maximum error can be significantly reduced as shown in Table 1.

5. CONCLUSION AND FUTURE WORK

In this paper, we have presented a new dispersed-dot halftoning technique by elimination of unstable pixels for electrophotography. Based on the characteristics of electrophotography, a combination of a Gaussian filter with a sigmoid nonlinear function was used to calculate the driving force of toner particles in print with our nonlinear printer model. To obtain a halftone image which has good quality in print under nonlinear printer model, iterative improvement method for eliminating unstable pixels was adopted. In this method, unstable pixels, that have their driving force of toner particles within a band in our nonlinear printer model are eliminated as much as possible. The halftone image is constructed in such a way that perceptive error between the original image and the predicted image is minimized by an iterative improvement method. Although the halftone image made by our method includes high frequency components, they are reduced in the nonlinear printer model and then we can obtain simulated image in print. As the result of the Fourier analysis, it was found that predicted image has an ideal halftone screen without anisotropy.

In our results, the presence of high frequency components were more than anticipation in the output halftone image. It was because the used parameters did not sufficiently represent the characteristics of a real electrophotography machine. As a future work, we want to optimize these parameters to reproduce better characteristics of them. Also, it is necessary to check the validity of our model. Another drawback of our algorithm is that it needs long processing time. In our iterative improvement method, we tried all possible bit patterns. We want to examine whether we can improve the iterative algorithm using some algorithmic techniques.

REFERENCES

1. P.G.Roetling and T.M.Holladay, *Tone reproduction and screen design for pictorial electro graphic printing*, J. Appl. Photo gr. Eng., vol. 5, pp.179-182, 1979.

2. P.Stuck, *MECCA -a multiple-error correcting computation algorithm for bilevel image hardcopy reproduction*, IBM Res. Lab., Zurich, Switzerland, Tech. Rep. ROZ1060, 1981.

3. Anal92 M.Anal and J. Auerbach, "Model-based halftoning using direct binary search", Proc. SPIE/IS&T Symposium on Electronic Imaging Science And Technology, Vol. 1666, pp.96-108, 1992.

4. T.N.Papps and D.L.Neuhfohh, "Least-squares model-based halftoning", Proc. SPIE/IS&T Symposium on Electronic Imaging Science And Technology, Vol. 1666, pp.109-121 1992.

5. T.J.Flohr, J.P.Allebach and C.A.Bouman, "Halftoning via direct binary search with a stochastic dot model", in Proc. IS&T 3rd Tech. Sump. Prepares, Proofing Printing, PP.102-105, 1993.

6. T.J.Flohr, J.P.Allebach and C.A.Bouman, "An Efficient Implementation for Stochastic DBS", in SID Int. Sump. Tech Papers, 1994, pp.797-800.

7. F.A.Baqai and J.P.Allebach, "Halftoning via Direct Binary Search Using Analytical and Stochastic Printer Models", IEEE Trans. on Image processing, vol. 12, No.1, 2003.

8. D.Kacker, T.Camis and J.P.Allebach, "Electrophotographic Process Embedded in Direct Binary Search", IEEE Trans on Image processing, vol. 11, No. 3, 2002.

9. K.Nakano, *Halftoning Through Optimization of Restored Images -A New Approach with Hardware Acceleration*,IEICI Technical Report, Vol.102, No.733, pp.9-14 2003.

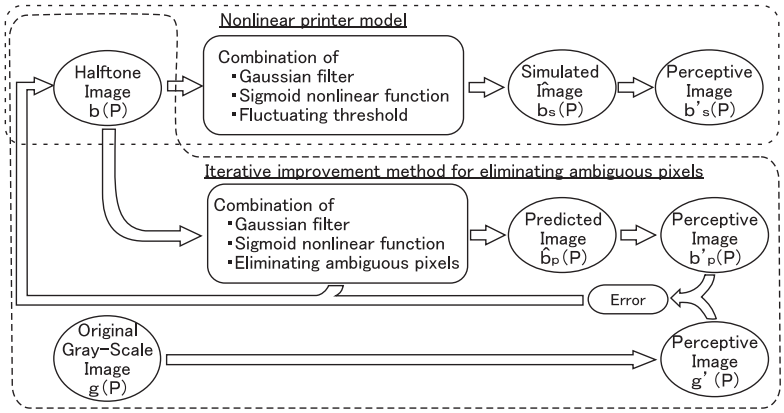

Figure 1. Schematic diagram of the nonlinear printer model and the iterative improvement method by eliminating unstable pixel model.

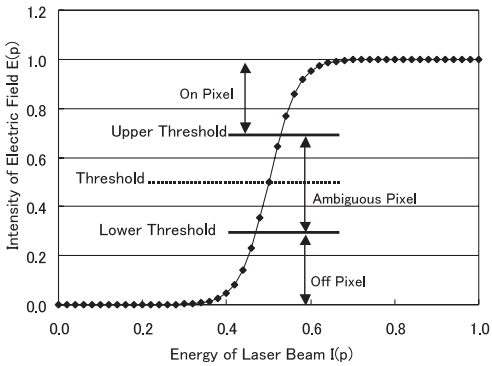

Figure 2. Sigmoid nonlinear function instead of a PIDC (Photoinduced Discharge Curve) shows the intensity of the electric field against the laser beam intensity.

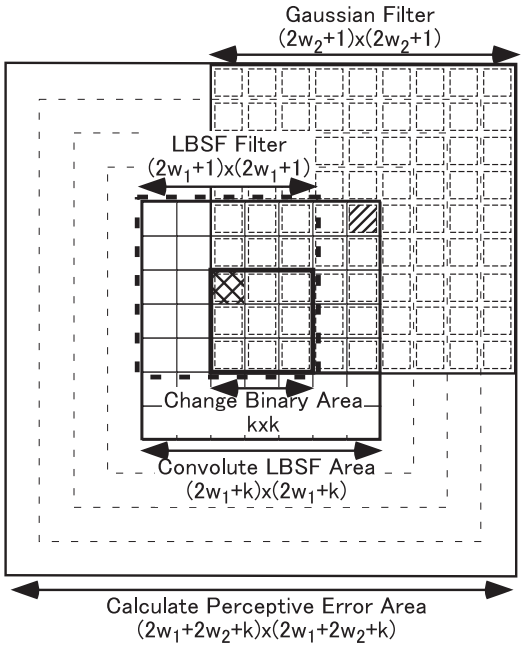

Figure 3. Illustration of a window of size $k \times k$, an LBSF filter of size $(2w_1+1) \times (2w_1+1)$, a Gaussian filter of size $(2w_2+1) \times (2w_2+1)$, the LBSF influence region of size $(2w_1+k) \times (2w_1+k)$ and computation of the total error region of size$(2w_1+2w_2+k) \times (2w_1+2w_2+k)$

Table 1. Comparison of Perceptive Error between cluster-dot and our model

	Average	Standard Deviation	Maximum
Cluster-dot	0.27	0.7	7.0
Our Method	0.26	0.4	3.6

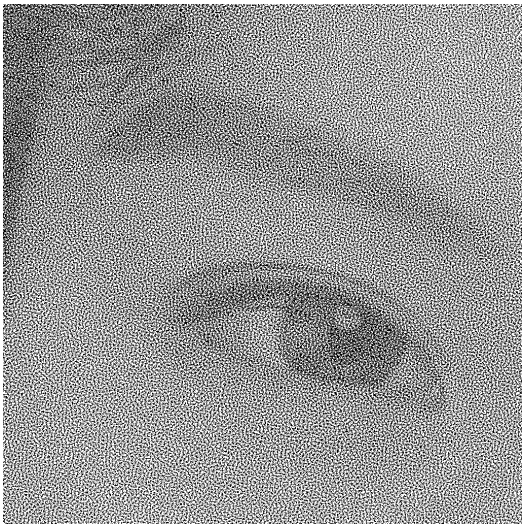

Figure 4. Halftone image of the portrait made by our nonlinear printer model

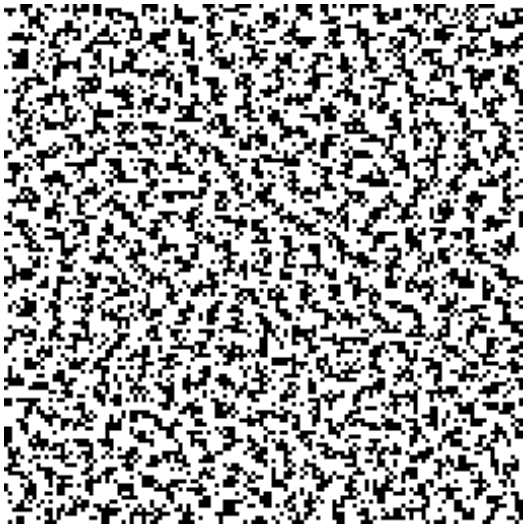

Figure 5. Dot pattern of halftone image

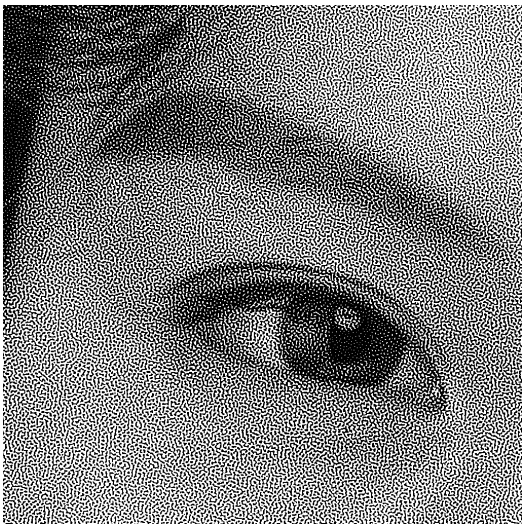

Figure 6. Predicted image of our nonlinear printer model

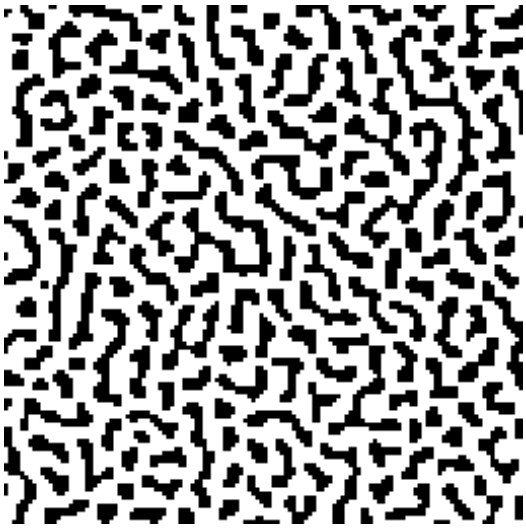

Figure 7. Dot pattern of predicted image

Figure 8. Printed image of high resolution electrophotography

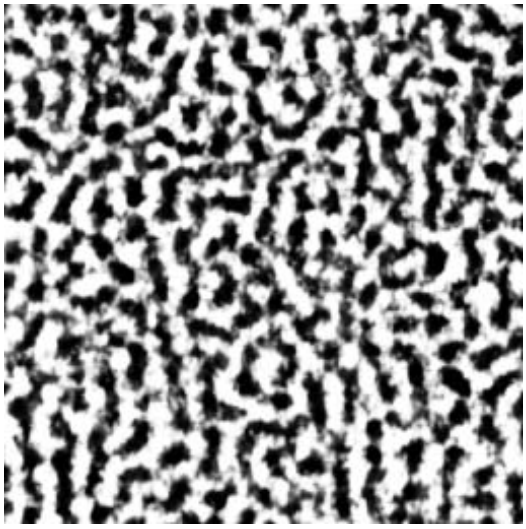

Figure 9. Dot pattern of printed image

0	0	1	0	0	0	0	0	1
0	0	1	0	1	0	1	0	0
1	1	1	1	1	1	1	1	0
0	0	0	0	1	1	1	0	0
0	0	0	0	0	1	0	1	1
0	0	0	0	0	0	1	0	0
0	0	0	0	0	0	1	0	0
1	0	1	0	0	0	1	0	0
0	0	0	0	1	1	0	0	0

Figure 10. Halftone image of the portrait made by our nonlinear printer model

.20	.04	.06	.03	.02	.02	.02	.01	.01
.77	.70	.90	.93	.93	.92	.79	.17	.01
.90	.85	.95	.99	1.00	1.00	1.00	.77	.01
.11	.04	.07	.58	.99	1.00	1.00	.90	.03
.00	.00	.00	.00	.21	.96	.98	.79	.06
.00	.00	.00	.00	.00	.17	.68	.29	.04
.00	.00	.00	.00	.00	.05	.24	.04	.01
.14	.01	.01	.05	.11	.22	.10	.00	.00
.17	.01	.06	.83	.97	.82	.06	.00	.00

Figure 11. Dot pattern of halftone image

0	0	1	0	0	0	0	0	1
0	0	1	0	1	0	1	0	0
1	1	1	1	1	1	1	1	0
0	0	0	0	1	1	1	0	0
0	0	0	1	0	1	0	1	1
0	0	0	0	0	0	1	0	0
0	0	0	0	0	0	1	0	0
1	0	1	0	0	0	1	0	0
0	0	0	0	1	1	0	0	0

Figure 12. Predicted image of our nonlinear printer model

.20	.04	.06	.03	.02	.02	.02	.01	.01
.77	.71	.91	.94	.93	.93	.79	.17	.01
.91	.88	.97	1.00	1.00	1.00	1.00	.77	.01
.12	.07	.30	.94	1.00	1.00	1.00	.90	.03
.00	.00	.00	.07	.74	.98	.98	.79	.06
.00	.00	.00	.00	.01	.26	.70	.29	.04
.00	.00	.00	.00	.00	.05	.24	.04	.01
.15	.01	.01	.05	.12	.22	.10	.00	.00
.17	.01	.06	.83	.97	.82	.06	.00	.00

Figure 13. Dot pattern of predicted image

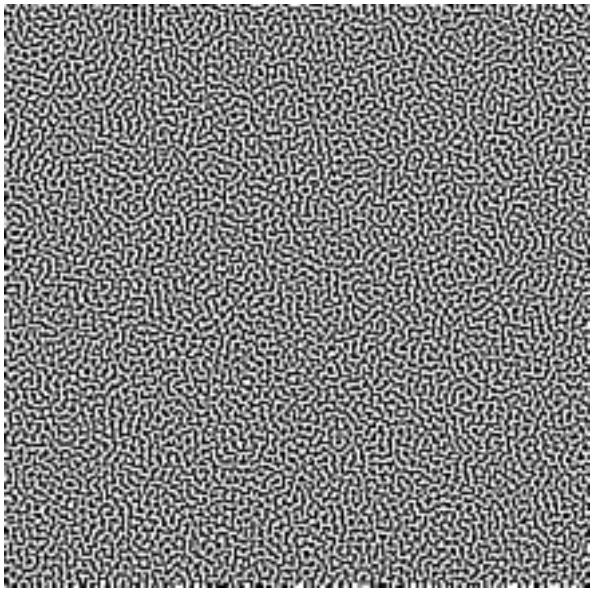

Figure 14. A simulated image of the nonlinear printer model of a 128 Gray-Level uniform patch.

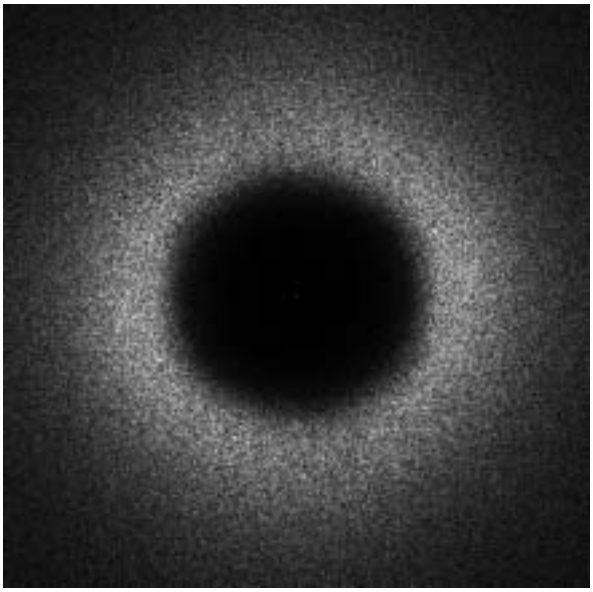

Figure 15. Fourier transform of the simulated image.

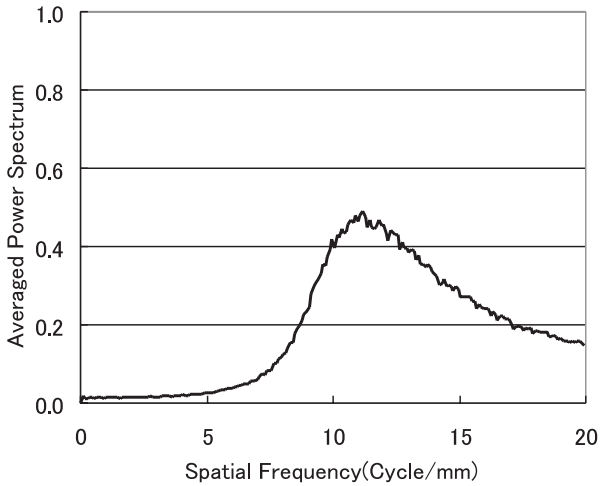

Figure 16. The amplitude of the frequency spectrum averaged over all angles for the simulated image of our nonlinear printer model.

Figure 17. Original gray scale image using evaluation perceptive error.

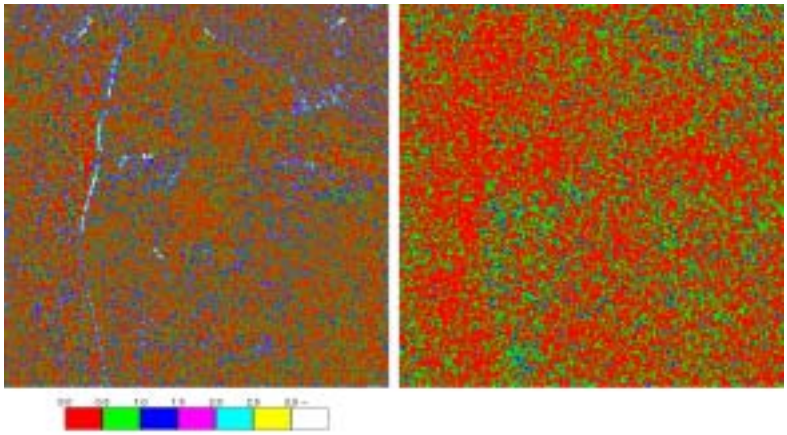

Figure 18. Comparison of perceptive error distribution between cluster-dot and our method(Left Cluster-dot, Right Our nonlinear printer model).