Rule-based Image Segmentation Method for Continuous-tone, Text and Halftone in Electrophotographic Copier/Printer

Yee S. Ng
NexPress Solution LLC
Rochester, New York, USA

Abstract

In the area of digital copier/printer, when a document with mixed image types {continuous tone photographs, halftone pictures, text (gray as well as binary) and graphics} are used with one set of output printing algorithm at one time (error diffusion, gray level halftone screening, or thresholding etc.), there are some undesirable effects occurring. If an input halftone picture was printed with a lower screen frequency halftone output (such as a hard dot 150 lines/inch screen), moiré pattern shows up. If a text image is printed with a halftone output, the text quality (especially gray text and smaller font size text as well) degrades due to the screening. If a more continuous tone like output algorithm (like gray level error diffusion or a partial dot higher screen gray level halftone) is used, then the granularity of the continuous tone input image suffers in an Electrophotographic system. An image segmentation method using feature extraction, fuzzy logic and rule based processing on scanned input images (at 600 dpi) to identify the image type in a pixel basis for printing is used. Two different output printing algorithms (a 300 l/inch partial dot screen for text and a mixed dot 161 l/inch screen output for continuous tone input) were used for different segmented image type in printing to achieve good result.

Introduction

In the area of digital copier/printers, when a document with different image types (continuous tone photographs, halftone pictures, text ((gray, as well as binary) and graphics) are used with one set of output printing algorithm at one time (error diffusion, gray level halftone screening or thresholding etc), there can be some undesirable effects occurring. For example, if an input halftone picture is printed with a lower screen frequency halftone output (such as a full dot 150 lines/inch screen)[1] moiré pattern shows up. If a text image is printed with a halftone output, the text quality (especially gray text and smaller font size test as well) degrades due to screening. If a more continuous tone like output algorithm (such as gray level error diffusion or a partial dot higher frequency gray level halftone[1]) is used, then the granularity of the continuous tone input image suffers in an Electrophotographic system. Sometimes those different image types can even exist on the same page. One known solution to this problem is to provide the copier/printer with a manual selection device so that the operator, either through an on-screen editing function or by use of digitizing table, can identify various image types on the page before processing. So a different output algorithm can be used for different input image type.[2] However, this is very tedious and inefficient. It is more desirable to be able to segment the input image type in real time so a more appropriate output-rendering algorithm can be used for each image type.

Method using document image type analysis and region building approach was used for automatic image segmentation and rendering.[3] However, the process of assigning pixels to regions and then building regions is relatively slow and requires that the processor buffer substantial areas of the document page during the region building process. Further more, there are pixels or small regions of an image type that can be buried within a much larger region of a different image type that can be mis-classified. It is desirable to be able to segment image type down to per pixel area, so output rendering algorithms can be assigned on a per pixel basis so it can run more rapidly. An image segmentation method using feature extraction, fuzzy logic and rule based processing on scanned input images (at 600 dpi) to identify the image type in a pixel basis for printing is described here. In the case that the image type of a pixel cannot be determine with a degree of certainty (such as in the boundary between the two image types), an intermediate image type can be assigned with an output rendering algorithm that is intermediate in characteristic between the two other output algorithms to reduce the artifacts of transition (in terms of tone-reproduction and texture characteristic).[4]

Rule-based Segmentation Method

We are making use of the gray values of the input scanner images (at 600 dpi), the gradient amplitudes and gradient directions to form membership functions for the text, continuous-tone and halftone image. The output (fuzzy-data value) that the membership function generates then becomes an input to a rule evaluator which compares the fuzzy-data values and if one rule seems to be the dominant explanation for the fuzzy-data value, the input image type will considered to have been determined. This news is then passed on to a defuzzifier and selects a predominant output rendering method as its output (see Figure 1 for detail). In order to make the printing decision more robust towards decision error, some other intermediate rendering algorithms (like those that have an intermediate tone-reproduction curve, texture and screening) may be used in cases that are too close to determine. Due to this fuzziness involve in a per pixel bases, one can break up some boundary condition caused by hard switching between image type determination.

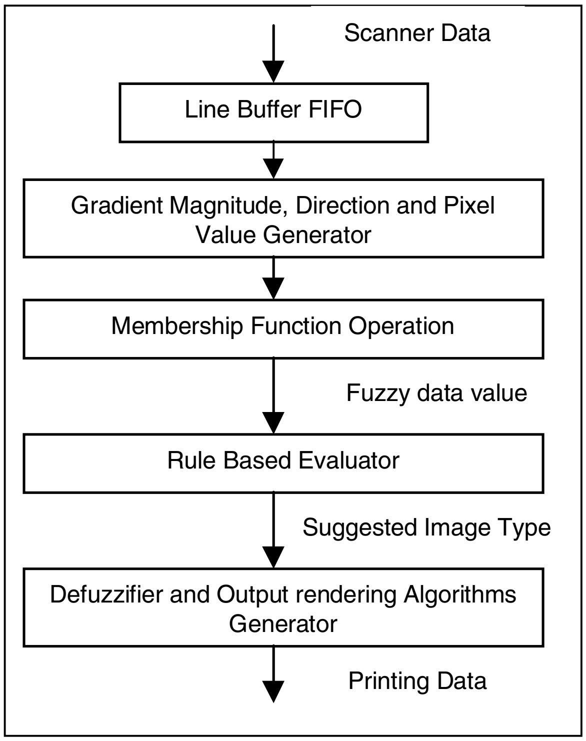


Figure 1. Block Diagram of Rule-based Segmentation Algorithm

In more detail, the 600 dpi gray level data (8 bits) from the scanner is first stored in a 9 line FIFO line buffer and then a 9x9 window image is used with a magnitude-direction operator to obtain a gradient magnitude (gm), gradient direction (gd) and the value (v) of the current and surrounding pixels in the Gradient Magnitude and Direction Generator (see Figure 1). Only some of the values within the 9x9 matrix are used for the segmentation operation. These values (gm, gd and v) are then passed to the Membership Function Operation.

The membership function determination of image type e.g. continuous-tone, text, halftone is based on an initial assessment of image type. As an example of this membership function determination operation consider the case of an image data input of text information such as text characters. Usually when the gradient magnitude (gm) of the current pixel is low, the chances or probability (TP1) of being text is relatively low. Conversely when the gm is high, the probability of the current pixel being text is higher. Table 1 provides probability-related value, TP1, of a current pixel, being text based on particular values of gradient magnitudes for the current pixel. The gradient magnitude of the current pixel is referred to as gm[5] and it is at the center of the 9x9 matrix. In Table 1, the values a, b, c, d are indicated and may be used as tunable parameters depending on scanner characteristics (such as sharpness, contrast etc.). In the particular 600 dpi input scanner that we did the experiment on, the values a, b, c and d are set to be 7, 16, 5 and 45 respectively. There are certain starting assumption such as b > a. Thus, in accordance with Table 1, the probability related value (TP1) of the current pixel being text using gradient magnitude value (gm[5]) criterion is 0 for a current pixel having a gradient magnitude that is low – for example < or = ‘a”. If the current pixel’s gm[5] is > or = “b” (that is a much larger value than a), then (TP1) has a higher probability of being text –(in this case, we assume the TP1 value of 1). When gm[5] has a value between “a” and “b”, TP1 has a value between 0 and 1 as shown in Table 1. An exception to the above is for gray text when gm[5] < c, then the neighborhood 9 pixels’ gm within a 3x3 matrix are used to help the assignment of value for TP1. Table 1 also shows a test condition weighting order. In a high-speed parallel process system, all the evaluation can be done at the same time. Also, if two or more of the test conditions are true, the one with the highest weighting order prevails.

Table 1

Test Condition Weighting Order (1 is highest)	TP1	gm[5]
1	2	gm[5] < c and (sum(gm[n]>d) for n=1 to 9
2	0	< a
3	1	> b
4	(gm[5] – a)/(b-a)	a<= gm[5] <= b

The membership function generation function also examines each current pixel’s probability related value (TP2) with respect to gradient direction (gd). In Table 2, it may be seen that in determining TP2, the gradient direction value for the current pixel, gd[5] is compared with gradient direction values of adjacent pixels, such as gd[3,4,6,7] which are aligned in the line direction of the current pixel. In this case, the probability of being text is higher when a larger number of pixels along the line direction of the current pixel has a similar gradient direction. Similar technique using test condition weighting order is used for the assignment for value for TP2 as in TP1.

Table 2

Test Condition Weighting Order (1 is Highest)	TP2	gd[5]
1	1	gd[5] = gd[6] = gd[4] = gd[7] = gd[3] and gd[5]not = 0
2	0.5	gd[5] = gd[6] =gd[4] and gd[5] not = 0 and {gd[5 = gd[3] or gd[5] = gd[7]}
3	0.25	gd[5] = gd[6] = gd[4] and gd[5] not = 0
4	0	None of the above

The same processing apparatus in the Membership Function Operation (MFO) also examines the current pixel for its probability related value of being derived from a halftone content (HP1 based on gm, HP2 based on gd) and a continuous-tone content (CP1 based on gm, CP2 based on gd). In considering the MFO continuous-tone fuzzy-data probability values CP1 and CP2, if the gradient magnitude (gm) for the current pixel is high, the probability that it is of a continuos-tone origin is less (except in a sharp transition situation which will be discussed below), thus reference may be made to Table 3 where CP1 is estimated based on gradient magnitude of the current pixel (gm[5]) as well as its surrounding pixels in a 3x3 matrix. A tunable parameter set of e, f and g are used here. In the particular scanner of choice, the value for e, f and g are set to 9, 5 and 45 respectively.

The MFO for the continuous-tone probability valuation CP2 are based on the fact that if the gradient direction of the current pixel is not changing and its gradient magnitude is small, there is higher chances that the current pixel is continuous-tone, thus Table 4 provides a relationship between the chances that the current pixel is of continuous-tone origin (CP2) using gradient direction values for the current pixel, gd[5]. In the other case condition, we are making use of the gradient direction of the neighboring pixels to gives us an indication of the likelihood that the current pixel is continuous-tone. In Table 4, M is the number of neighboring pixels to the current pixel in the 3x5 gradient direction matrix that have a gradient direction (gd) = 0. Thus for each neighboring pixel of the current pixel and which neighboring has a gradient direction of zero, there is added 1/14 points and CP2 equals the sum of these points in the all other cases condition.

Table 3

Test Condition Weighting Order (1 is the highest)	CP1	gm[5]
1	0	> e
2	1	< f and sum (gm[n] < g) for n = 1 to 9
3	1 – (gm[5]/e)	For all other cases

Table 4

Test Condition Weighting Order (1 is the Highest)	CP2	gd[5]
1	1	0 and gm[5] = 0
2	M/14	All other cases

The MFO fuzzy data probability valuations are also made for a halftone membership function content. For the halftone membership function, one makes use of the fact that gradient magnitude, gm are changing and usually tend to be higher values and the gradient direction, gd are usually changing. Thus the halftone MFO probability valuation for the current pixel using magnitude criteria, HP1, and probability valuation using gradient direction criteria, HP2, are provided in the Tables 5 and 6 respectively. In Table 5, the tunable parameter values of h and i for the scanner under test are 12 and 3 respectively. In Table 6, N is the number of neighboring pixels to the current pixel in the 3x5 gradient direction matrix that have a gd not equal to 0 and not equal to gd[5]. Thus for each neighboring pixel that has a gradient direction that is not the same as the current pixel and is non zero; that is the gradient direction is changing rapidly in the region, there is added 1/14 points and HP2 equals the sum of these points.

The respective probability valuations for text, continuous tone and halftone image type are respectively summed. Thus, a text fuzzy data value TP is calculated according to TP = TP1 + TP2. A continuous-tone fuzzy data value is calculated as CP = CP1 + CP2 and a halftone fuzzy data value is calculated as HP = HP1 + HP2. These respective fuzzy data values are input to a preliminary Rule-base Evaluator. This Preliminary Rule-base Evaluator examines the respective inputs and generates a numeric assignment value that represents the most likely type of assignment to the current pixel: i.e. is it most likely text, halftone or continuous tone origin. Table 7 shows the criteria used in determining the numerical assignments.

Table 5

Test Condition Weighting Order (1 is highest)	HP1	gm[5]
1	1	> h
2	0	< i
3	(gm[5] –i)/(h – i)	i< = gm[5] <= h

Table 6

HP2	gd[5]
N/14	N/A

Table 7

Test Condition Weighting Order Assignment (1 is highest)	Membership Function	Criteria Investigated	Preliminary Numerical
3	Text	TP > HP and TP > CP	0
1	Continuous-tone	CP > TP and CP > (HP + 0.25)	1
2	Halftone	HP > (CP + 0.25) and HP > TP	2
4	Indeterminate	None of the above applies	3

For those current pixels that when investigate in accordance with the above criteria and do not fall within the specific criteria conditions, these pixels are considered indeterminate cases. The numerical assignments are then output to a buffer that stores the numerical assignment of the current pixel and the assignments from seven neighboring pixels on the previous line and three pixels on the current line to help further determine in the case of a current pixel receiving an "indeterminate" rating whether the current pixel belongs to text, continuous-tone or halftone. Such further determination for the current pixel can be done according to criteria in Table 8. In Table 8, a tunable parameter "j" which, for example, may be j =2 is compared with a number "n" of neighboring pixels stored in the buffer that have numerical assignments indicating they have been determined to be a halftone pixel. The final numerical assignments from the Rule-base Evaluator represent a decision regarding a determined rendering algorithm for the current pixel. This decision is output to the Defuzzifier and Output Rendering Algorithms Generator.

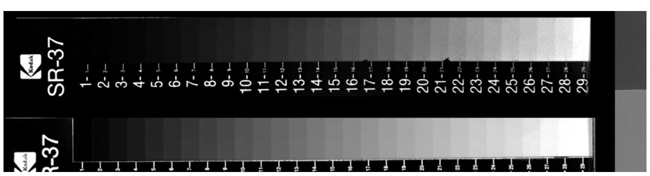
Table 8

Test Condition Weighting Order (1 is highest) Assignment	Indeterminate Case	Final Numerical
4	1. Most neighboring pixels have continuous-tone assignment	1 (continuous tone)
1	2. n >= j	2 (halftone)
2	3. Most neighboring pixels have text assignment but there are indeterminate pixels or continuous tone pixels around the line direction of current pixel and image data values along a direction perpendicular to the line direction indicates low density	1 (continuous tone)
3	4. Most neighboring pixels have text assignment	0 (text)
5	5. None of the above	3 (indeterminate)

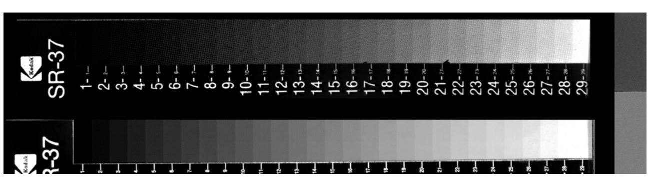
In rendering each pixel, the rendering block has inputs for receiving a signal of the input image density of the current pixel and a signal representing a final numerical assignment (suggested image type) from the Rule-base Evaluator. The input density will be screened with multiple screening algorithms at the same time, but the suggested image signal from the Rule-base Evaluator would determine which screening algorithm output would be sent for printing. A preferred rendering algorithm for continuous-tone image type printing by electrophotographic process is selected to be a medium screen frequency mixed mode dot screen and a tone reproduction curve characteristic for picture and low granularity. A current pixel indicated to be text might be processed using an algorithm more suitable for text such as a higher frequency partial dot screen with a tone reproduction curve suitable for text printing. A current pixel determined to be halftone is preferably rendered with a rendering algorithm chosen to reduce moiré patterns. Such pixels may be processed with multiple level error diffusion or a high screen frequency partial dot screen with a tone reproduction curve suited for halftone. For those pixels that remain indeterminate, a rendering algorithm is provided that includes a tone reproduction curve (TRC) intermediate that of the TRC for text and halftone. Such rendering algorithm may include error diffusion or a high frequency screen with texture compatible with the intermediate frequency mixed dot screen. This blending in when the fuzziness of the system cannot tell which image type to assign to the current pixel provides robustness and provide a distinct advantage in the use of fuzzy logic in an image segmentation system.

Experimental Result

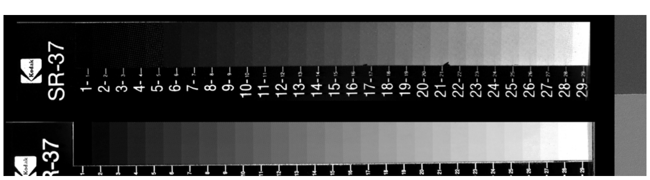
Input test image using a continuous-tone and a screened Kodak SR37 step tablet (on the same page) was used as a training input for parameter tuning (the parameters for this scanner have been discussed in previous pages) with a 600 dpi input scanner. Two output algorithms were finally chosen – a 161 lines/inch mixed dot halftone for continuous tone pictures (with a TRC suitable for picture), and a 300 lines/inch partial dot halftone for text (with a TRC suitable for text) and halftone (with a TRC suitable for halftone). It turns out the texture of the 300 lines/inch screen blends in very well with the 161 lines/inch screen, so the indeterminate case can just use the 300 line screen with a halftone TRC with satisfactory result. The output prints indicates significant moiré reduction of the input screened SR37 step tablet area compared with just using a 161 mixed dot halftone on the test page. At the same time, the continuous tone SR37 area indicates lower granularity compared with using a 300-line partial dot screen on the image alone. In the text region of the input images, better text reproduction is observed on the print.



Picture 1. Input Test Target

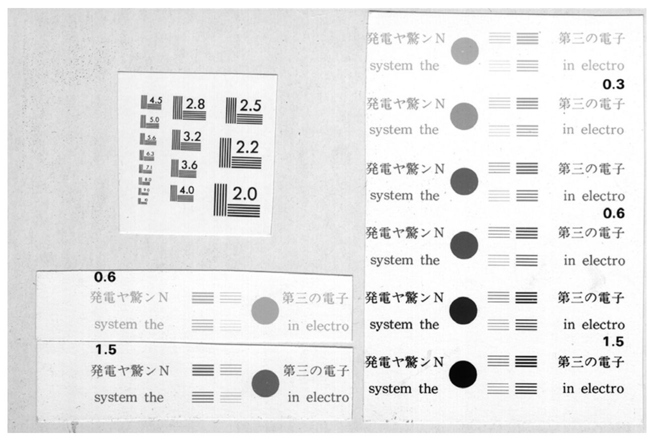


Picture 2. Halftone Rendered Test Target



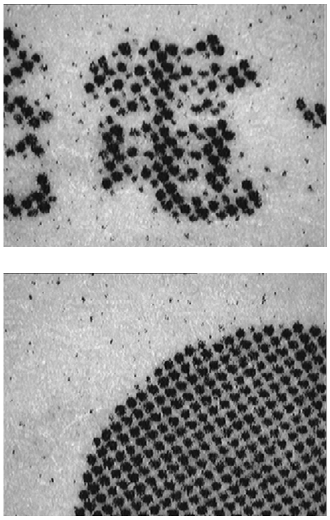
Picture 3. Segmented and Screened Test Target

This algorithm is then verified with a variety of input image types (continuous tone pictures, halftone pictures, text/graphics [including gray text]) with good results. Picture 1 shows the SR37 input test target (the top SR37 step tablet is halftoned and the bottom step tablet is continuous toned). Picture 2 shows the test target after it has been halftoned with a 161 lines/inch mixed dot screen. The moiré pattern shows up at the region with the halftoned input step tablet. The continuous toned step tablet region looks fine. Picture 3 show the test target after the image has been segmented using this method, so a 161 lines/inch mixed dot screen is used in the continuous toned input area and a 300 lines/inch partial dot screen is used in the halftoned input area. Moiré on the halftone input region has been significantly reduced and the granularity of the continuous toned input region is very similar to that of Picture 2.

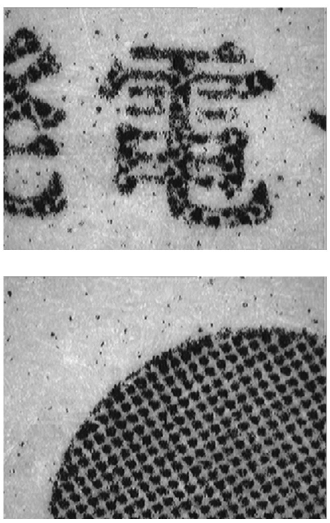


Picture 4. Gray Text Input Target

In Picture 4, we show a test target with a mixture of gray text and continuous toned circles of different densities that we use as an input test target. After the image has been scanned in, we processed the image in a traditional screening mode with a 161 lines/inch mixed mode screen and printed out the image in a 600 dpi multiple level printer. A magnified portion of the printed gray text is shown here in Picture 5. As one can see that traditional screening has degraded the text. In the same figure, we also show the magnified image of a printed circular dot (original is a continuous tone circular dot). The screened and printed output shows lower granularity on that dot than if 300 lines/inch partial dot is used to print that portion. In Picture 6, we are using the segmentation algorithm discussed here to process the image. A magnified portion of the printed gray text and continuous tone circular dot is shown in Figure 6. As one can see that the gray text shows less degradation. The edge of the circular dot is also smoother since a higher screen frequency halftone is used to reproduce the edge, but the low granularity of the interior of the dot is also preserved with the lower screen frequency halftone.



Picture 5. Magnified Traditional Screened Output



Picture 6. Magnified Segment and Screened Output

Conclusion

A rule-based image segmentation and selective screening method has been developed for scanned input mixed image type document. Printed output indicates moiré reduction for halftone input image type, low granularity for continuous tone image type and good preservation of detail for text image type (including gray text).

References

1. Yee S. Ng, Hieu T. Pham, H. T. Tai and Eric Zeise, Gray Level Printing Method with Embedded Non-Uniformity Correction Using a Multi-bit LED Printhead, IS&T's 47th Annual Conference Proceeding, pg. 622-625. (1994).
2. Hwai-Tzuu Tai, Method and Arrangement for Locally Switching Gray Dot Types to Reproduce an Image with Gray Level Printing, U.S. Patent 5,200,831. (1993).
3. Yee Ng, Hwai-Tzuu Tai, Mixed Screen Frequencies with Image Segementation, U.S. Patent 5,471,543. (1995).
4. Hwai-Tzuu Tai, Method and Apparatus for Locally Blending Gray Dot Types of the same or Different Types to reproduce an image with Gray level Printing, U.S. Patent 5,956,157. (1999).

Biography

Yee Ng received his M.S. degree in Electrical Engineering and a Ph.D. in Physics from the Pennsylvania State University. He joined Eastman Kodak Research Laboratory in 1980. He was a Kodak Distinguished Inventor and holds > 70 U.S. patents. His work has primarily focused on color proofing, electrophotographic processes, image rendering/ enhancement, image quality issues, electronic writer and image data path development. He is currently a Chief Engineer in NexPress Solution LLC. He is a member of the IS&T and the New York Academy of Sciences.