Edge Enhancement for Good Image Quality in Digital Halftoning

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Abstract

Digital halftoning algorithm is a method for representing a continuous tone image with a few discrete level of output-device. Most representative two methods of halftoning are screening (or dithering) and error diffusion. Specially, clustered screening has a fast processing speed and robustness to printer distortion and laser bean printer uses it generally. But, it has a poor quality in detail region, because of screen table's LPI geometry. In general, screen table mostly have 150~200 LPI. That LPI is not sufficient to represent a good quality at image edge. Our proposal improves the quality of detail region by using edge map and edge-optimized table at edge region differentiated from non-edge region. Edge-optimized screen is not a simple higher LPI screen than non-edge region. We have investigated the best dot-addition position for good edge image quality in visually at each screen table. And then, we composed the edge optimized screen table that makes it. If the image is edge region, edge-optimized screen is used. If not, we use default screen. We show the result screening images in simulated output and scanned image of real hard copy output in laser printer compared with previous methods.

Introduction

Screening is a representative method of digital halftoning. There are two type dither table: dispersed and clustered dither. Specially, LBP(LaserBeamPrinter) mostly uses clustered dither. Clustered dither has smoother tone linearity than dispersed dither type at LBP. And also, it robust against banding and dot gain of printing engine. But, clustered dither's weak-point is quality of edge sharpness. Because, clustered dither has lower LPI than dispersed dither. In fact, dispersed dither has not LPI concept in usual. To enhance the edge quality, previous several methods have been proposed. One of the simple methods is HPF(High Pass Filtering). It is widely known in image processing. HPF makes input source image's edge area more sharp. So, after dithering, halftone image's edge also has more clearness than before. Another method is High & Low LPI dithering at each edge & no-edge region. This method use more High LPI dither table at edge image region compare to no edge region's dither table. This method also has a better edge image quality. But previous this two also has tough quality at edge area. Specially, their hard copy printing result is insufficient quality then expected at digital image shown.

This paper focuses on that real hard copy printing output has a smooth edge quality than digital image output simulated. Because, hard copy output quality absolutely has a different from simulation output. Whereas simulated output is digital image, hard copy output is defected by engine characteristic like to dog gain or tone particle size. To resolve it, this paper analyzed what clustered dither table feature is to weaken edge quality. As a result, we found that image become smoother when we add a black dot to proper pixel location in edge region. Finally, we can make edge optimized new clustered dither table only used at edge region. This paper explains how we can make edge-optimized screen design method. And then, we compares out result to previous method in hard copy output.

Proposed algorithm

Flow

First, Flow-chart of proposed method is shown in Fig.4. Input pixel image I(x,y) is determined whether the current pixel is edge or not. (x,y) means image coordinate. In our research, edge determines method is not main point. So, we use Sobel Edge Detection method. And then, if the pixel is edge, we use edge-optimized dither table. If not, we use normal dither table. Edge-optimized dither comprise four varieties depend on edge direction. Fig. 2 shows 4 edge directions. In flow, "DIR" means four 4 direction. Namely, input image pixel is halftoned by edge-optimized 4 dither tables or normal dither table dependent on edge determination. This edge-optimized dither table has same rational vector with normal dither. Just it has different threshold value with normal dither tables' threshold values. And then finally two results of each dithering are merged. Merge process keep alive of dithering output of basic dither and supplement edge-optimized dithering output to it.

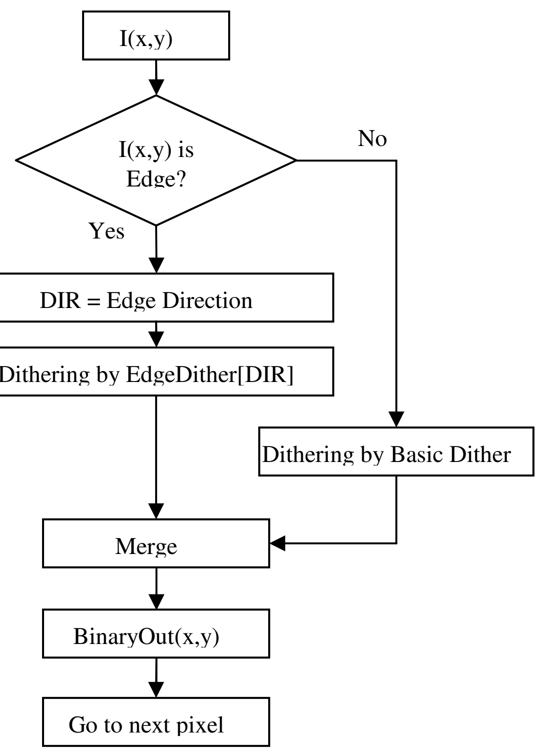
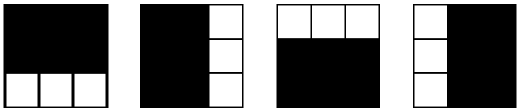


Figure 1: *Flow-chart of proposed algorithm*



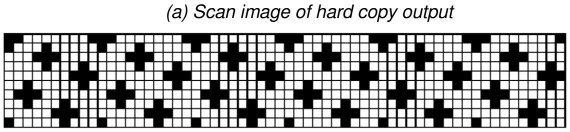
(a) (b) (c) (d)

Figure 2: *Edge direction (a) Up to down (b) Left to right (c) Down to up (d) Left to right*

Searching Dot addition location

From here, we will explain the method of searching best dot addition pixel position. For example, Fig.3 shows halftone result image by using 134LPI, 63degree clustered dither table. Fig.3(a) is scan image of hard output of laser printer. As in this figure, edge boundary has jaggy quality. Fig3(b) show expanded part of scan image (a) as digital image. In here, we can see that the reason of edge jaggy is white holes. This white hole is made by the distance of dot centers make clustered dots gathering. Generally, clustered dither's LPI is calculated by a distance of dot centers. Of course, there are holes in inner image region not edge region. But those inner holes are surrounded by other dots at 4 directions of clustered centers. So, inner image has not jaggy quality. But, at edge boundary, the hole is surrounded by just 1-side to edge direction. That makes image boundary has jaggier by the look of it. And, the white hole's size is bigger as LPI go down. And the white hole's shape is affected by screen Angle. Although, it may vary from person to person, under almost 150 LPI, visually human eyes can feel that there is a jaggy quality in edge area.

(a) Scan image of hard copy output



(b) Digital simulation of (a)

Figure 3: *Binary image of 134LPI,63 degree dither table*

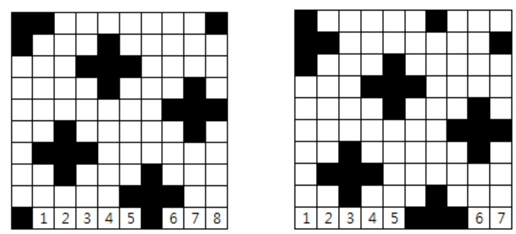
Our research focuses on that if we fill that white hole region by adding black dot, we can make more smooth edge. So, we have searched where the best pixel position of adding dot for best edge quality is and how we can add black dot in procedure of dithering process.

For experimentation, we select one edge direction among Fig.2's (a) edge directions (Up to down edge). Other direction case will be processed by same procedure. Halftone result of 85% input gray level by using 134LPI 63degree clustered dither is shown in Fig.4. Depending on combination of input image pixel coordinate and dither table coordinate, there are 2 cases of edge image formation like as each Fig4(a) and Fig4(b). These 2 formations are repeated in another edge positions at vertically. Namely, Fig.4.(b) is rotated 1 pixel shift of Fig.4.(a) at vertically to down direction. If, we shift again the Fig.4.(b), then that result will be same with Fig.4.(a). So, we have only to find a best dot addition location at each 2 edge case. In this description, we just describe only 1 edge case of Fig.4.(a). Another edge case also has same procedure. If screen vector geometry is changed, the edge case will be changed at several cases more than 2 or may be just one case.

Again at Fig4(a), we can see that there are 8 position of dot addition candidate. By adding black dot at each candidate position, we can make 8 new binary images. In here, left black dot of Num.1 position and left black dot of Num.6 are screening result of basic dither and we should not change a result of basic dither. And then, we have printed each 8 images of black dot added at LBP. After that, we have to evaluate the edge quality of each 8 case images. Fig.5. shows each 8 dot addition result in digital image. In here, we can assume (a) or (h) is better than others. But, as mentions above, simulation image has some different result with hard copy output. Because of this, we have to check what case is best quality by comparison of hard copy output results. With result of real hard copy outputs, we could select Fig5(a) case is best position. That is, if input image level is 85% and edge direction is up to down, edge-optimized dither table can have to reproduce black dot at the position of Num.1 of Fig4(a).

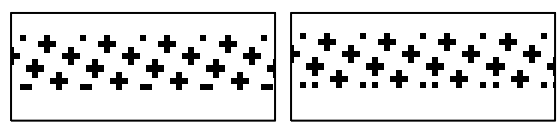
In quality evaluation, usually there are qualitative or quantitative method. In our paper, we use qualitative visual comparison.

Additionally, black dot addition counts will be 2 or 3dot not just only 1 black dot addition. It is dependent completely on output quality. At the case of 85% input level experiment, 2 black dot additions case made the output image to more noise at edge quality.

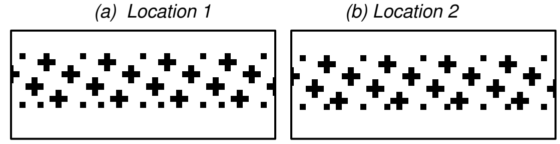


(a) Edge case 01 *(b) Edge case 02*

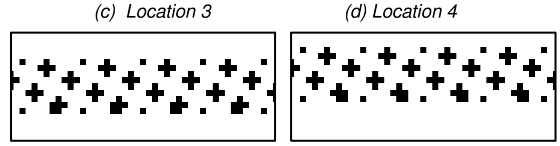
Figure 4: *Dot addition candidate of each edge case*



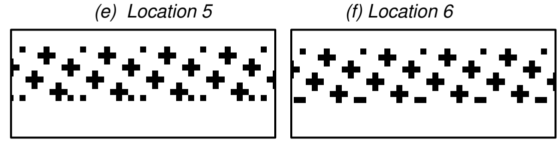
(a) Location 1 *(b) Location 2*



(c) Location 3 *(d) Location 4*



(e) Location 5 *(f) Location 6*

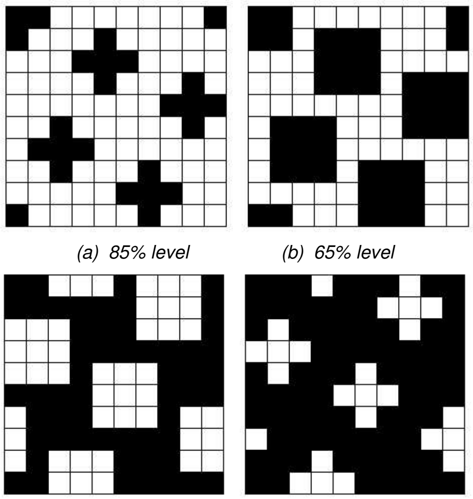


(g) Location 7 *(h) Location 8*

Figure 5: *Dot addition images at each candidate location of 1~8 of Fig4(a)*

Also, we have to examine of another edge case of Fig4(b), there are 7 black dot addition candidates. In our study, we have found that Num.2 is best position for better quality.

By the same method, we can make other input levels. Fig6 shows other levels of testing. In this paper, we designed dither tables for 4 level inputs (85%, 65%, 45% and 25%). Experimentally, 4 levels are sufficient to enhance the edge quality in 134LPI screen table.



(a) 85% level *(b) 65% level*

(c) 45% level *(d) 25% level*

Figure 6: *Dot shape of each representative level of dither*

After evaluations of 2 edge cases and 4 levels, we have to design edge optimized dither table of up to down edge direction for add a black dot at the pixel position we searched. It can be one of the tables for DIR at Fig1. And with the same flow, we can design edge-optimize dither table of other 3 direction edge. Remain direction's tables have also same vector position of centers. Fig7(a) is final designed edge optimized dither for edge case of up to down direction. In here, gray background box means the center pixels of 134LPI screen type. 134LPI, 63degree dither table have vector coordinate (x,y) = (2,4). 10x10 pixel dither size have 5 center pixels In table, threshold levels 216, 165, 64 and 10 are for each level of input 85% , 65% , 45% and 25%. In our study, 100% means all white and 0% means all black level. In previous experiment at Fig5, we have found Num.1 and Num.3 is best dot addition position for each edge case of Fig4(a). and (b) at input 85% level. We can see threshold level 216 in table(a) at last row line. The level of threshold 216 can turn on black dot if input pixel has 85%. As already mentioned, edge case are repeated in vertically rotated shifting. So, we can see that final edge-optimized dither table have 10 threshold levels of 216 in rotated shift pixel location that is calculated by multiplication of 2 edge cases and 5 dot centers. And, specially, threshold value of 165 concerned with input level 65% are two in same horizontal line serially. Because, in our study, 2 black dot additions had better quality than 1 black dot addition at input level 65%. Threshold value 1 concern with input level 0%. Namely, if input level is under 25%, all edge pixel of binary output will become black dot. Fig7(b)(c)(d) shows final edge optimized dither table at another edge direction as shown Fig2. Each tables have same threshold values with (a), but the location of threshold values are all different to each other. As we sow at Fig1 flow-chart, we will use 4 edge direction tables for edge-optimized dither.

Rational screen table size is times of minimum block size. 134LPI, 63degree screen's vector geometry has 10x10 minimum block size. So, we design edge-optimized dither has size of 10x10. In our research, there is no need of bigger size of dither table likely basic dither that has more big size for level reproducibility of tone like as multi center tables. If the screen vector is changed, minimum size also will be changed.

1	1	1	165	165	216	64	64	64	1
1	1	1	1	1	216	165	10	64	1
64	64	64	1	1	1	1	165	165	216
165	115	64	1	1	1	1	1	1	216
1	165	165	216	64	64	64	1	1	1
1	1	1	216	165	115	64	1	1	1
64	1	1	1	1	165	165	216	64	64
64	1	1	1	1	1	1	216	165	115
165	216	64	64	64	1	1	1	1	165
1	216	165	115	64	1	1	1	1	1

(a) Direction of up to down

1	1	216	216	1	1	10	115	165	1
10	10	165	1	1	1	10	165	1	1
10	115	165	1	1	1	216	216	1	1
10	165	1	1	10	10	165	1	1	1
216	216	1	1	10	115	165	1	1	1
165	1	1	1	10	165	1	1	10	10
165	1	1	1	216	216	1	1	10	115
1	1	10	10	165	1	1	1	10	165
1	1	10	115	165	1	1	1	216	216
1	1	10	165	1	1	10	10	165	1

(b) Direction of left to right

1	1	1	1	1	10	115	165	216	1
165	1	1	1	1	10	10	10	216	165
115	165	216	1	1	1	1	1	1	10
10	10	216	165	165	1	1	1	1	10
	1	1	1	10	115	165	216	1	1
1	1	1	10	10	10	216	165	165	1
216	1	1	1	1	1	1	10	115	165
216	165	165	1	1	1	1	10	10	10
1	10	115	165	216	1	1	1	1	1
1	10	10	10	216	165	165	1	1	1

(c) Direction of down to up

1	165	10	10	1	1	165	10	1	1
216	216	1	1	1	165	115	10	1	1
165	10	1	1	1	165	10	10	1	1
115	10	1	1	216	216	1	1	1	165
10	10	1	1	165	10	1	1	1	165
1	1	1	165	115	10	1	1	216	216
1	1	1	165	10	10	1	1	165	10
1	1	216	216	1	1	1	165	115	10
1	1	165	10	1	1	1	165	10	10
1	165	115	10	1	1	216	216	1	1

(d) Direction of right to left

Figure 7: *Final Edge Dither*

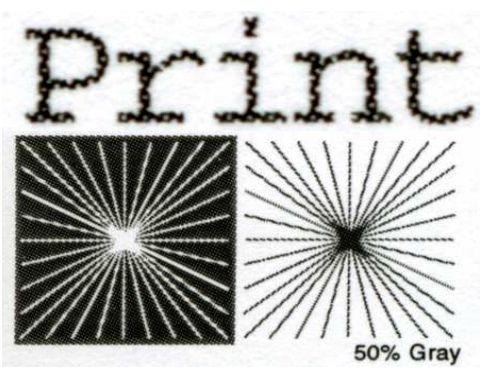
Experimental Results

Finally, we will show the result of comparison with other previous method at graphic and text object image. Fig8 show s the results. Fig8 is scan image of hard copy output printing not simulation image. We used Samsung CLP-620 laser printer and 134LPI 63degree screen. At first, Fig8(a) shows no enhanced image except just only dithering. We can see that image has very poor quality in edge area both of text and graphic object. Fig8(b) is High-LPI method. Edge area of each text and graphic is screened by HighLPI dither table. It's quality is some better than Fig8(a) in text object. But, there are still some rough at edge region. Although, edge boundary is screening by HighLPI, miss-match with High and Low geometry make edge quality poor. Fig8(c) is HPF method. It also some better quality than Fig8.(a). But, there is still some jaggy quality. HPF result is varies dependent on where input image's edge boundary coordinate is located at dither table black center or white center. Even if HFP result has same level, if that input pixel location is matched with dither table's black center, output binary output is more strength output compare to white hole matching case. Fig8.(d) is proposal method result. Our method is very clear at edge both of text and graphic.

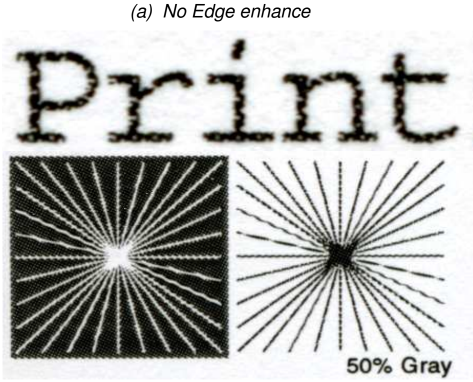
According to processing time, our method has similarly processing time with previous method in printing time. Just, our method needs to effort for design an edge optimized dither. But, it do not effect to printing time. And, edge-optimized dither table's size are very small, so it do not require big memory for edge optimized dither table saving.

Conclusion

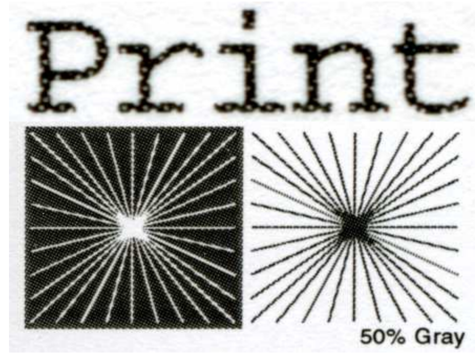
In this paper, we proposed the new dithering method for enhance edge quality of digital halftoning. The proposed algorithm has better quality than previous methods at edge boundary. For better than this time, we try to investigate more various dither type and broaden type of edge like as irrational type screen.



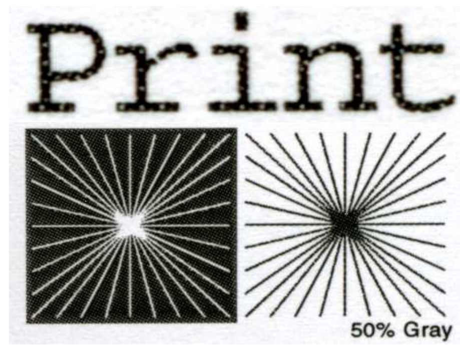
(a) No Edge enhance



(b) High LPI at Edge



(c) HPF



(d) Proposed

Figure 8 : *Result comparison*

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Author Biography

Hae Kee Lee received the B.S.,M.S. degree in electronic engineering from Inha university, Korea in 2002 and 2004, respectively. From 2004 to 2011, he worked at the Imaging Lab of IT Solution division, Samsung Electronics Inc. in Suwon, Korea, as a member of the research staff, doing research on the image processing algorithm at digital printing system.