Chapter 30
Halftone Image Quality Evaluation Based on Reconstruction Index Model

Xiao Zhou, Ruizhi Shi, Da Li, Shenghui Li and Yusheng Wang

Abstract Halftone algorithm is the medium of the conversion from continuous digital image to scattered dot image, and it is the core technique of RIP prepress. Different algorithms have different characters on image nonlinear reconstruction, while corresponding halftone images have different effects. The advantages and disadvantages of halftone algorithm will determine printing images' output quality. In this paper, founded reconstruction index models are used to make objective evaluation on halftone algorithms. Quantitative study is performed on the aspect of gray level index, contrast level index, and image entropy difference. Frequency domain analysis and power spectrum analysis are also performed on respective halftone images. Through halftone image quality evaluation, advantage and disadvantage comparison of halftone algorithms based on different indexes is obtained, which provides reference for the amelioration of halftone algorithm and finally improves vision quality of printing image.

Keywords Reconstruction index · Halftone image · Image quality · Objective evaluation · Frequency domain analysis

30.1 Introduction

In image processing, digital halftoning is the technique to realize the transformation from digital image to halftoning image, which reproduces original image tone and color through binary equipment. Halftone technique depends on algorithm. Through nonlinear transformation of different algorithms, it finally obtains halftone images with different dot distribution. Therefore, algorithm is the core of halftone

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technique. Algorithm quality will influence halftone image quality and visual effect. Since the generation of digital halftoning, various algorithms such as pattern dither, error diffusion, flat noise, blue noise, etc. are invented by people. Based on these algorithms, many ameliorated algorithms are created [1]. According to dot distribution shape, halftone technique can be divided into three groups, AM halftoning, FM halftoning, and Hybrid halftoning. They have different characters to reproduce and express image. Evaluating halftone image quality of different halftone algorithms is the method to test and compare halftone algorithms' characters, which can provide reference for algorithm development and finally improve image quality. In this paper, halftone algorithms are evaluated objectively under several basic evaluation models. Algorithms' gray level index, contrast level index, and image entropy difference are researched quantificationally. Meanwhile, frequency domain analysis and power spectrum analysis are done on the generated halftone images.

30.2 Evaluation Model Foundation of Halftone Reconstruction

Applying some objective method to evaluate halftone image can test and reflect halftone algorithm's capability objectively, which is not influenced by subjective factor. Objective evaluation's basic thought is to test and calculate the difference between halftone image and original image. In the aspect of image gray level, contrast level index, image entropy difference, frequency domain, and power spectrum, halftone algorithms and images are tested and evaluated.

30.2.1 Evaluation Model of Reconstruction Accuracy

The total level of halftone processing can be reflected on the visual quality of binary image, which should meet two conditions. First, gray level of halftone image's single part should be equal to original image's single part as much as possible. Second, halftone image should have feasible contrast level index. The two indexes are evaluated through gray level evaluation and contrast level index evaluation [2].

30.2.1.1 Gray Level Evaluation Model

Set P_m as gray level evaluation function. Original image is denoted as $g(x, y)$. Single $g(x, y)$ value stands for the gray level of the original pixel. After normalization, pixel gray level satisfies $0 \leq g(x, y) \leq 1$. Halftone image is denoted as

$b(x, y)$. Single $b(x, y)$ value stands for halftone image's pixel gray level. According to the characters of halftone image, $b(x, y)$ value should be 0 or 1, in which, 1 stands for black pixel, 0 stands for white pixel, as Formula 30.1 shows.

$$P_m = \sum_B \frac{1}{N_b^2} |g(x, y) - b_G(x, y)| \tag{30.1}$$

In Formula 30.1, B stands for the adding operation carried out in image's specific part. $b(x, y)$ is the part average gray level in the corresponding zone of the halftone image. N_b^2 is the pixel amount contained in the specific part [3]. Evaluation function P_m stands for the difference between the gray level of the original image's specific part and halftone image's corresponding part average gray level. The lower the P_m value, the closer the halftone image's gray level to the original image's gray level will be.

When the relationship between original image pixel and halftone image pixel is one-to-many, set halftone unit to contain $n \times n$ recorder grids. Original pixel gray level is A. According to gray level evaluation model (1), gray level evaluation model (2) is obtained.

$$P_m = \sum_B \frac{1}{N_b^2} \left| \frac{A}{256} - \left[A \cdot n^2/256\right]/n^2 \right| \tag{30.2}$$

30.2.1.2 Contrast Level Index Evaluation Model

Contrast level index evaluation function is used to evaluate visual contrast difference between original gray image and halftone image, which is denoted by P_c function, as Formula 30.3 shows. The lower the P_c value, the higher the contrast level index will be, and the greater the difference between original gray image and halftone image will be [4]. In this aspect, the higher the P_c value, the closer the halftone image to the original gray image will be.

$$P_c = \sum_B \frac{1}{N_b^2} |[g(x, y) - \bar{g}(x, y)] - b(x, y)| \tag{30.3}$$

In Formula 30.3, $\bar{g}(x, y)$ is the average value of pixel part $g(x, y)$. According to the definition of part average gray level, contrast level index model (4) under the relationship between original image pixel and halftone image pixel is obtained as one-to-many.

$$P_c = b_G(x, y) = \left[A \cdot n^2/256\right]/n^2 \tag{30.4}$$

30.2.2 Foundation of Reconstruction Image's Entropy Difference Model

Set the average gray value j of a certain pixel's neighborhood pixel as spatial signature value. The pixel's gray value is i, i and j constitute two tuples (i, j). Meanwhile, $f(i, j)$ is defined as the frequency of the two tuples (i, j). P_{ij} is defined as the comprehensive feature weight, in which i and j satisfy the condition $0 \leq i, j \leq 255$. P_{ij} is shown as Formula 30.5.

$$P_{ij} = f(i,j)/MN \tag{30.5}$$

Define two-dimensional entropy through the weight P_{ij}.

$$H = \sum_{i=0}^{n} p_{ij} \log_2 p_{ij} \tag{30.6}$$

Define image entropy difference through one-dimensional entropy which expresses the gathering feature of the gray distribution. Entropy difference is the absolute value of the difference between original image entropy and halftone image entropy, which reflects the ability of halftone algorithm to obtain image information. The closer the entropy difference to value 0, the more information the halftone image will obtain from the original image. The information amount of the two images will be closer [5]. The discrepancy between halftone image and original image will be smaller. Set the gray distribution probability of original image and halftone image as p_{i} and q_{i}, respectively. Then the image entropy difference H_c is shown as Formula 30.7.

$$H_c = \left| \sum_{i=0}^{n} p_i \log_2 p_i - \sum_{j=0}^{n} p_j \log_2 p_j \right| \tag{30.7}$$

30.3 Experiment and Analysis

30.3.1 Experiment Content

30.3.1.1 Halftone Algorithm and Experiment Objects Confirmation

Evaluation objects are Bayer pattern dither, error diffusion, and AM halftoning. In the experiment, 8 × 8, 10 × 10, 14 × 14, and 16 × 16 are chosen as the halftone unit accuracy. The experiment chooses color patches with symmetrical gray level. Gray levels are 25, 50, 75, 100, 125, 150, 175, 200, 225, and 250. For simple statistics calculation, set each color patches' size as 8 × 8 pixel, as Fig. 30.1 shows. Choose

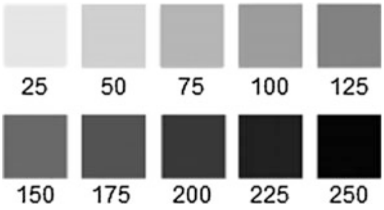

Fig. 30.1 Color patch scale

Fig. 30.2 Original image *goose* and *pepper*

original images *goose* and *pepper*, as Fig. 30.2 shows. The image *goose* has abundant color and relatively big tone contrast. The image *pepper* also has abundant color, which is used to compare.

30.3.1.2 Experiment Items

Some experiments are performed as follows:

(1) Use Bayer pattern dither, error diffusion, and AM halftoning to screen color patches. Bayer pattern dither applies extended 8 × 8 dimension threshold matrix and uses shift algorithm to realize threshold comparison. Error diffusion applies Floyd–Steinberg filter and uses median method to choose threshold. AM halftoning applies round shape dot, screen angle is set as 0°, halftone unit accuracy is set as 8 × 8, 10 × 10, 14 × 14, and 16 × 16. Do statistics calculation on the screened experiment color patches and get the data of gray level evaluation, contrast level index, and image entropy difference.

(2) Use Bayer pattern dither, error diffusion, and AM halftoning to screen original image *goose* and *pepper* with the same method as item 1. And halftone images under the three algorithms are obtained.

(3) Do Fourier transform on the *goose* and *pepper* halftone images and get frequency domain images and power spectrum images, and their characters are analyzed. In which, AM halftoning only choose 16 × 16 halftone unit accuracy.

30.3.2 *Evaluation Result*

30.3.2.1 Statistics Analysis of Color Patch Evaluation Index

After model calculating and data statistics, gray level evaluation index P_m value, contrast level evaluation index P_c value, and image entropy difference H_c value are obtained, as Tables 30.1, 30.2, and 30.3 show, in which I, II, and III are Bayer dither, error diffusion, and AM halftoning. The four numbers under AM halftoning are halftone unit accuracy 8 × 8, 10 × 10, 14 × 14, and 16 × 16.

According to the statistics results in Tables 30.1, 30.2, and 30.3, curve images are drawn. In each curve image, abscissa is gray level, and ordinate is index value, as Fig. 30.3 shows. A, B, C1, C2, C3, and C4 represent Bayer dither, error diffusion, and AM halftoning with 8 × 8, 10 × 10, 14 × 14, and 16 × 16 halftone unit accuracy.

(1) The index values of the two dither algorithms are higher than AM halftoning, which illustrates that two dither algorithms' halftone image is less closer to original image in gray level than AM halftoning. Two dither algorithms lose image tone while the AM halftoning will lose image tone in all the halftone unit accuracy other than 16 × 16. The higher the halftone unit accuracy is, the less loss will occur, but the extent of the tone loss is lower than the two dither algorithms. The index value of Bayer dither is lower than error diffusion in the gray level intervals of 0–135 and 180–240 while higher in other intervals. The AM halftoning index curve waves are in different gray level intervals, thus different halftone unit accuracies in different tones have different abilities to reproduce original image gray level.

Table 30.1 Gray level evaluation index P_m value

Gray level	25	50		75		100		125
I	0.011	0.055		0.043		0.016		0.050
II	0.051	0.070		0.059		0.078		0.098
Gray level	150	175		200		225		250
I	0.148	0.121		0.031		0.027		0.023
II	0.086	0.090		0.078		0.051		0.008
Gray level	25			50				
III	0.004	0.008	0.001	0	0.007	0.005	0.001	0
Gray level	75			100				
III	0.012	0.003	0.008	0	0	0.001	0.003	0
Gray level	125			150				
III	0.004	0.008	0.003	0	0.008	0.006	0.004	0
Gray level	175			200				
III	0.012	0.004	0.005	0	0	0.001	0	0
Gray level	225			250				
III	0.004	0.005	0.003	0	0.008	0.007	0.003	0

Table 30.2 Contrast level evaluation index P_c value

Gray level	25	50			75	100		125
I	0.109	0.141			0.250	0.375		0.438
II	0.047	0.125			0.234	0.313		0.391
Gray level	150	175			200	225		250
I	0.438	0.563			0.750	0.906		1.000
II	0.5	0.594			0.703	0.844		0.984
Gray level	25				50			
III	0.094	0.090	0.097	0.098	0.188	0.190	0.194	0.195
Gray level	75				100			
III	0.281	0.290	0.291	0.293	0.391	0.390	0.388	0.391
Gray level	125				150			
III	0.484	0.480	0.485	0.488	0.578	0.580	0.582	0.586
Gray level	175				200			
III	0.672	0.680	0.679	0.684	0.781	0.780	0.781	0.781
Gray level	225				250			
III	0.875	0.870	0.878	0.879	0.969	0.970	0.974	0.977

Table 30.3 Image entropy difference H_c value

Gray level	25		50	75	100			125
I	0.349		0.398	0.500	0.531			0.522
II	0.207		0.375	0.491	0.524			0.530
Gray level	150		175	200	225			250
I	0.522		0.467	0.311	0.129			0
II	0.500		0.447	0.357	0.207			0.022
Gray level	25				50			
III	0.321	0.312	0.326	0.329	0.454	0.455	0.459	0.459
Gray level	75				100			
III	0.514	0.518	0.519	0.519	0.529	0.530	0.530	0.529
Gray level	125				150			
III	0.506	0.508	0.507	0.505	0.457	0.452	0.455	0.452
Gray level	175				200			
III	0.386	0.378	0.380	0.375	0.278	0.280	0.279	0.278
Gray level	225				250			
III	0.169	0.175	0.165	0.164	0.044	0.043	0.036	0.033

(2) Contrast level evaluation index of all algorithms are progressive increase curves. In the gray level interval of 0–255, it increases along with the gray level, thus one single algorithm has different contrast level difference in different gray tone. The higher the gray level is, the bigger the contrast level difference will be. The index values of two dither algorithms are higher than AM halftoning algorithm, thus the difference in contrast level difference

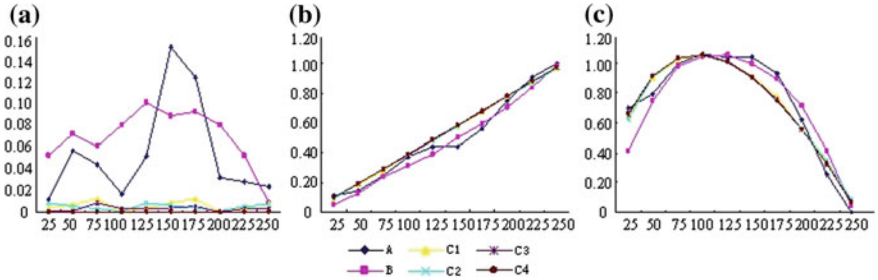

Fig. 30.3 Basic indexes evaluation curve images. **a** Gray level evaluation index. **b** Contrast level evaluation index. **c** Image entropy difference

between original image and halftone image obtained from the two dither algorithms is bigger than AM halftoning algorithm. The smaller the contrast level difference is, the smaller the visual difference between original image and halftone image will be. Therefore, the halftone image generated by AM halftoning is closer to original image in visual effect. In the gray level interval of 0–255, the index value of Bayer dither is higher than error diffusion, thus halftone image generated by error diffusion is closer to original image than Bayer dither.

(3) Image entropy difference of these algorithms increases with the increased gray level. When the value gets the maximum, it starts to decrease. The starting values are all higher than 0.4, the minimum values are all close to 0. With the increasing image entropy difference, halftone image's ability to obtain information from original image gets stronger. When the entropy difference gets to the maximum, the ability starts to get weak. In the gray level intervals of 0–110 and 130–180, image entropy difference of Bayer dither is bigger than error diffusion while smaller in other gray level intervals, which illustrates that error diffusion can get more information from original image and has stronger ability to get information than Bayer dither in gray level intervals of 0–110 and 130–180, and halftone image is closer to original image. In the gray level intervals of 0–30 and 100–210, image entropy difference of Bayer dither is bigger than AM halftoning while smaller in other gray level intervals, which illustrates that AM halftoning can get more information from original image and has stronger ability to get information than Bayer dither in gray level intervals of 0–30 and 100–210, and halftone image is closer to original image. In the gray level intervals of 105–240, image entropy difference of error diffusion is bigger than AM halftoning while smaller in other gray level intervals, and they are close in the gray level interval of 240–255, which illustrates that AM halftoning can get more information from original image and has stronger ability to get information than error diffusion in gray level intervals of 105–240, and the ability is close in the gray level interval of 240–255, and halftone image is closer to original image.

30.3.2.2 Halftone Image and Frequency Domain Analysis

Use Bayer dither, error diffusion, and AM halftoning to screen the M plate image of the experiment object in Fig. 30.2. As Fig. 30.4 shows, (a1) and (a4) are halftone images of Bayer dither, (a2) and (a5) are halftone images of error diffusion, (a3) and (a6) are halftone images of AM halftoning with halftone unit accuracy 16 × 16. Do Fourier transform on *goose* halftone image and then get frequency domain images and power spectrum images. As Fig. 30.4 shows, (b1) and (b4) are halftone images of Bayer dither, (b2) and (b5) are halftone images of error diffusion, (b3) and (b6) are halftone images of AM halftoning with halftone unit accuracy 16 × 16.

Halftone image of AM halftoning is more elaborate than two dither algorithms. Bayer dither has fixed mode added on the image. Bayer dither gets black and white dots through threshold value comparison, in which process, error is abandoned. Tone jump exists between black and white dots, which results in high frequency prominent in the frequency domain image. While the error generated from error diffusion through threshold value comparison diffuses to pixels around which one can obtain elaborate dots and relatively small tone jump. AM halftoning has more exposure dots and more data amount. Therefore, its frequency domain image has different color from the two dither algorithms. From the frequency domain images, AM halftoning is more elaborate and accurate and has better detail reproduction

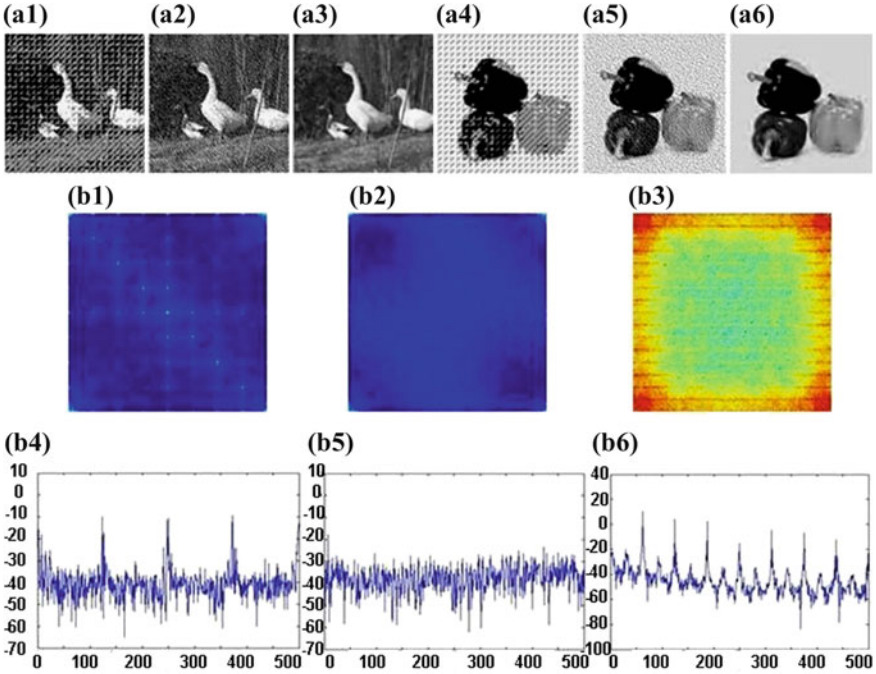

Fig. 30.4 Halftone images, frequency domain images, and power spectrum images of different algorithms

ability. In the power spectrum images obtained from periodogram method, power spectrum curve of AM halftoning is smoother than the two dither algorithms and has smaller average fluctuation.

30.4 Conclusions

Digital halftone quality evaluation is an important way to test whether halftone algorithm is good or not. On the basis of founded reconstruction index model, this paper does objective evaluation on halftone algorithms. On the aspect of gray level evaluation index, contrast level evaluation index, and image entropy difference, halftone images are researched quantificationally, meanwhile, halftone image's frequency domain character and power spectrum character are researched. Through comparison and analysis, advantage and disadvantage of each halftone algorithm are obtained, which can provide reference for the improvement of digital halftone technology.

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