Hybrid Resolution Enhancement Technique based on LookUp Tables

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Abstract

Recently, performance of electrophotographic printers has been significantly improved. Image quality and printing speed are major factors that determine performance of electrophotographic printers. Increase in the spatial resolution and multi-bit printing capability would result in the improved quality of printed images. However, when halftoning (or multi-toning) is performed by the printer driver, transmission time from computer to printer and the memory size required to store the image data will be increased. In order to reduce the size of image data transmitted from computer to printer, a LUT based method to enhance both of the spatial and bit-depth resolution is presented in this paper. The proposed LUTs are designed in advance using the training samples and stored at printer. When the haftoned image data is received from the computer, number of black pixels in 4x4 window is compared with number of black pixels in the 4 neighboring windows to select LUT. Spatial and bit-depth resolution are then simultaneously increased by applying the selected LUT. Various factors affecting performance of a LUT based resolution enhancement are analyzed.

1. Introduction

Image quality and printing speed are primary factors that determine performance of electrophotographic printers. Increase in the spatial resolution and multi-bit printing capability would result in the improved quality of printed images. Of course, image processing and screen design techniques are also contributing to the image quality. Overall printing speed is determined by the processing time at the computer, data transmission time from computer to printer, and processing and printing time at printer. In the past, the overall printing speed is determined mainly by the printing time at printer engine.

However, in the case of high resolution and multi-bit printing for a GDI printer, transmission time from computer to printer could be important factor that determines the overall printing speed. In order to increase the throughput, various resolution enhancement techniques have been proposed. Resolution enhancement techniques can be classified into the spatial and bit-depth resolution enhancement techniques. Spatial resolution enhancement can be regarded as the binary image resizing problem. Enhancement of the bit-depth resolution can be called as the inverse halftoning.

Previous works on the spatial resolution enhancement can be summarized as follows; In [1-3], pairs of binary pattern and its enlarged version were utilized as training samples. For a input binary pattern, its enlarged version was searched by the k-nearest neighbor scheme[1]. Instead of the k-nearest neighbor scheme, binary tree constructed based on the aforementioned pairs was utilized in [2-3]. Of course, a LUT can be constructed to replace the binary tree. Dot division was proposed in [4] to reduce the staircase artifacts due to the zero-order replication.

Bit-depth resolution enhancement or inverse halftoning can be utilized for the binary-to-gray level conversion in multi-level printing. One of the simplest bit-depth resolution enhancements would be the low pass filtering[5-6]. However, the simple low pass filtering would results in image blurring. In [7-9], pairs of binary pattern and its gray level version serve as training samples to construct binary to gray level LUTs. In [9], LUTs are constructed in 2 steps. Gray level image is first generated from the halftoned image by the method in [8]. Edges are detected from the gray level image. LUTs for the inverse halftoning are then constructed according to the type of detected edges. A wavelet based approach [10] and vector quantization technique [11] are also applied for the inverse halftoning.

In this paper, a novel hybrid resolution enhancement technique based on LUTs is proposed. The proposed hybrid resolution enhancement technique simultaneously increases the spatial and bit-depth resolutions. Objectives of the proposed techniques are to reduce the data size for transmission and memory capacity to store the transmitted data. The proposed technique can be utilized for a GDI printer where the halftoning is performed by printer driver. Five different LUTs are constructed by the offline procedure. Once constructed, LUTs are stored at printer for the online processing. After halftoned image is received from the printer, the number of black pixels within a 4x4 window is compared with the numbers of black pixels in four neighboring windows. Based on this comparisons, one of five LUTs is chosen to apply for the spatial and bit-depth resolution enhancement. Various factors affecting performance of a LUT based resolution enhancement are also analyzed.

In section 2, the proposed hybrid resolution enhancement technique is described. Offline LUT design method is explained and online procedure for the resolution enhancement is described. In section 3, experimental results of the proposed technique are presented. Effect of major factors on the performance of the proposed method is analyzed. Finally, conclusion is addressed in section 4.

2. Proposed hybrid resolution enhancement technique

Figure 1 shows the data flow when the proposed hybrid resolution enhancement technique is applied for a GDI printer. It is assumed that printer is capable of multi-level printing. Gray level image is halftoned by the printer driver. The halftoned image can be directly sent to printer. Alternatively, the halftoned image can be compressed for data reduction. At printer, the received data is decompressed if necessary. The proposed hybrid resolution enhancement method is applied to the (reconstructed) halftone image. After applying the proposed method, the size of image will quadrupled and each pixel will have 8 bit information. It will be printed through electrophtographic printing engine. Offlline procedure for constructing LUTs will be described.

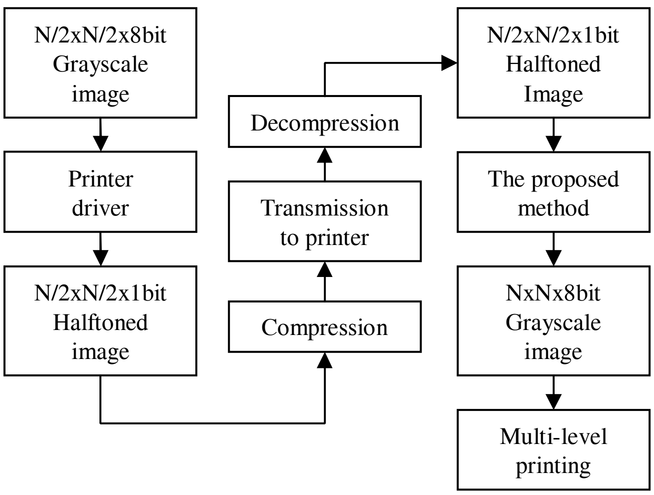


Figure 1. *Data Processing flow with the proposed hybrid resolution enhancement technique.*

A. Design of LUT (Offline)

In order to design LUTs for the hybrid resolution enhancement, the zoom factor and template should be determined in advance. The proposed LUT construction method is described for the zoom factor of 2 and a template of size 4x4 as shown in Figure 2. In Figure 2, pixel location marked as "X" denotes the pixel under processing.

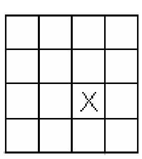


Figure 2. *A 4x4 rectangular template*

Flow chart of the proposed LUT design procedure is shown in Figure 3. A N/2xN/2x8bit image is halftoned to yield N/2xN/2x1bit binary image. A N/2xN/2x8bit image is then resized to yield NxNx8bit gray image. Up-scaling is employed in this paper because the down-scaling of the gray level image would deteriorate the quality of small sized fonts. Pairs of NxNx8bit gray images and the corresponding N/2xN/2x1bit halftoned images serve as the training images for LUT construction.

In the proposed method, the halftoned patterns are classified according to the number of black pixels in four neighboring windows. In Figure 4, the 4x4 window marked with bold lines indicates the neighboring window. It is overlapped with the 4x4 rectangular template shown in Figure 2. For convenience, 4x4 rectangular template is called as a processing pattern. First, the numbers of black pixels are counted for the processing pattern. Also, number of black pixels in each of four neighboring windows in Figure 4 is counted. Next step is to calculate the absolute difference in the number of black pixels. Among the four calculated differences, the maximum value is chosen. If the maximum difference is smaller than the predetermined threshold value, it is assumed that the processing pattern is contained in smooth area. This case is regarded as *class 0*. Otherwise, the processing pixel is determined that it is contained in the non-smooth or edge area. In this case, it is further classified as one of *class 1, 2, 3, and 4* as shown in Figure 4. In other words, processing pattern is classified as one of five classes depending on the number of black pixels.

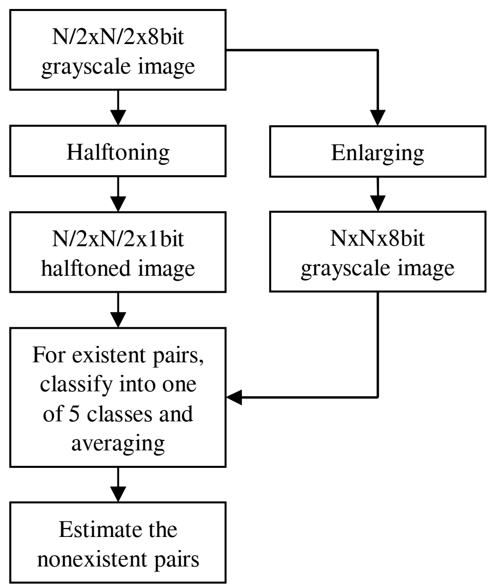
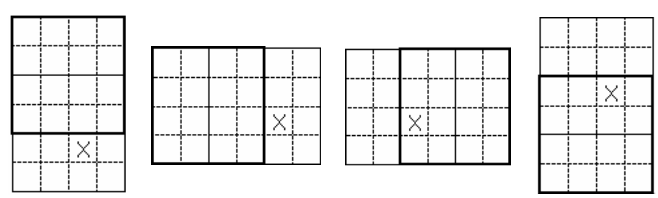


Figure 3. *Flow chart of the proposed LUT design procedure.*



(a) class 1 *(b) class 2* *(c) class 3* *(d) class 4*

Figure 4*. Four neighboring 4x4 windows for LUT construction*

For each of five classes, a LUT is constructed. Since size of the processing pattern is 4x4, there are 2^{16} different patterns. Thus, a LUT having 2^{16}x2x2 gray level patterns are constructed for each class. This procedure is repeated for all the pairs of training samples. When there are multiple gray level patterns are available for a given processing pattern, their average is utilized as LUT content. When there are no pattern existed, it is called as a nonexistent pattern. The best linear estimator is applied to estimate the 2x2 gray values for the nonexistent patterns [8].

B. Proposed hybrid resolution enhancement method (online)

Figure 5 shows flow chart of the proposed hybrid resolution enhancement method. Only the halftoned image is transmitted to the printer. Each of 4x4 rectangular templates on the haftoned image is classified to one of five classes by the same procedure described for the LUT construction. The classification is simple to implement, as it requires subtraction, absolute value calculation, and comparison operation. After classification, 2x2 gray levels are searched and extracted from the corresponding LUT. This procedure is repeated until all the pixels of the halftoned image are processed.

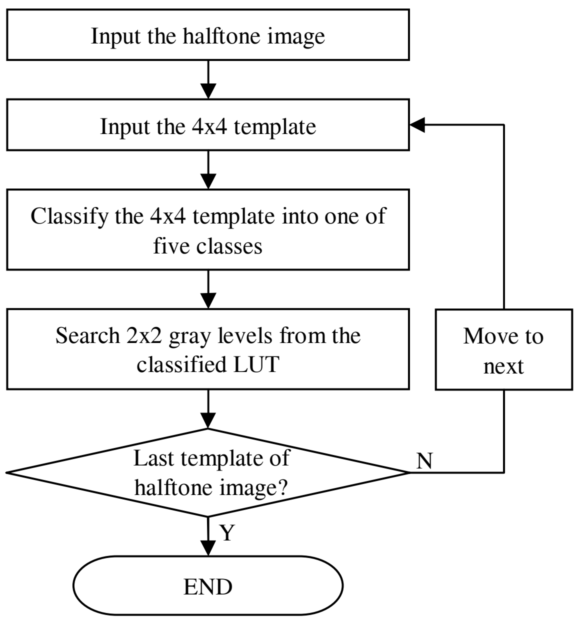


Figure 5. *Flow chart of the proposed hybrid resolution enhancement method*

3. Experimental results

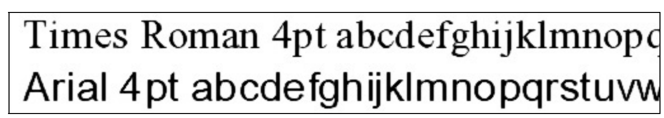
In order to construct five LUTs for the proposed hybrid resolution enhancement, the training images in [8] are employed. The training set contains both low and high frequency contents. The size of training image in [8] is defined as N/2xN/2x8bit. It is halftoned to yield N/2xN/2x1bit binary image. A N/2xN/2x8bit image is resized to yield NxNx8bit gray image. For the LUT construction, the error diffusion with Floyd-Steinberg kernel is applied for halftoning.

Performance of the LUT based resolution enhancement method depends on various factors. They include the size and shape of template, selection of training images, halftoning method applied to generate halftoned training image, estimation procedure for non-existent pairs, number of LUTs, and method of LUT construction. Effect of theses factors are analyzed next.

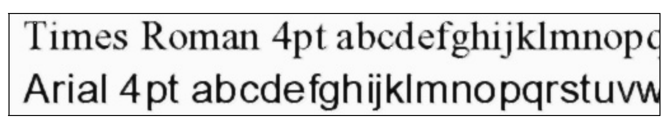
A. Effect of training Images

Pairs of N/2xN/2 binary images and NxN gray level images are used as training images. Effect of training images on the performance of resolution enhancement is shown in Figure 6. Suppose there are two separate training sets containing high frequency and low frequency contents. Figure 6 (a) and (b) show examples of a high frequency image generated by the training set representing high and low frequency contents, respectively. Figure 6 (c) and (d) represent the examples of low frequency image reconstructed by the training set representing high and low frequency contents, respectively. Effect of training images can be noticed in Figure 6. When the training images having low frequency contents are applied to the text images, the resulting images appear blurred. As shown in Figure 6 (b), when the training images having high frequency contents are applied to Lena image, it looks quite noisy.

In order to remedy this problem, a single training set containing various frequency contents can be considered as an alternative. However, the following experiments indicate that training set covering broad range of frequencies still generates problems. Figure 7 (a) shows a 4x4 binary pattern to be processed for the hybrid resolution enhancement. Training set containing wide range of frequencies is applied to the template pattern in Figure 7 (a). Figure 7 (b) shows the distribution of the gray level values of the upper left pixel in the 2x2 gray level window generated after the hybrid resolution enhancement. As shown in Figure 7 (b), the gray level values have wide distribution. Group 1 and 2 shown in Figure 7 (b) represent the distribution of the existent pairs from smooth and edge areas, respectively. When the output gray level values corresponding to a 4x4 binary template are determined by averaging over the whole existent pairs, high frequency contents will appear blurred due to the averaging procedure.

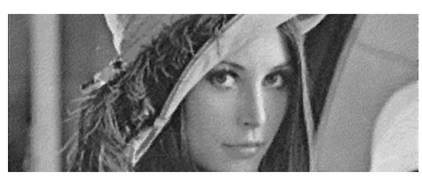


(a) Reconstructed high frequency image (using high frequency training set)



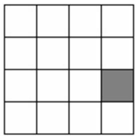
(b) Reconstructed high frequency image (using low frequency training set)

(c) Reconstructed low frequency image (using high frequency training set)

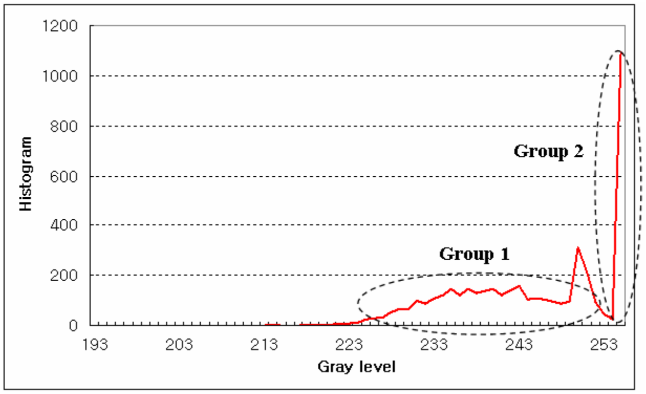


(d) Reconstructed low frequency image (using low frequency training set)

Figure 6. *Comparison of two training sets .*



(a) Example of input 4x4 binary template



(b) The histogram of existent pairs corresponding to (a) (upper left pixel only)

Figure 7. *Distribution of existent pairs*

In order to avoid blurring or over-enhancement, five LUTs are constructed in this paper. The number of black pixels within a 4x4 window is compared with the numbers of black pixels in four neighboring windows. Based on this comparisons, one of five LUTs are chosen to apply for the spatial and bit-depth resolution enhancement.

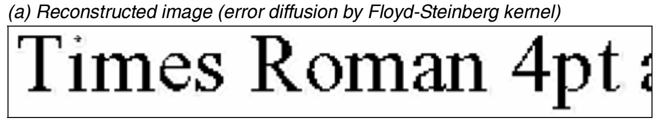
B. Effect of halftoning method

Haftoning method utilized for the generation of training samples also affects the performance of the LUT based method. In order to construct LUTs for the hybrid resolution enhancement, pairs of N/2xN/2 binary images and NxN gray level images are needed. Figure 8 shows the text images generated by the hybrid resolution enhancement. Four different halftoning techniques are utilized to generate N/2xN/2 binary training images. As shown in Figure 8, training images generated by the Bayer dither mask and error diffusion yield better image quality than those by the blue noise mask and AM ordered screen. Figure 9 shows a portion of smooth image area generated by the hybrid resolution enhancement. In this case, training images generated by the error diffusion method gives the best results among 4 halftoning techniques tested. In both of Figure 8 and 9, test images are generated by the same halftoning method utilized for constructing binary training images. Based on these experiments, it was found that the error diffusion is the best choice for constructing binary training images for the hybrid resolution enhancement. Also, it is desirable to employ the error diffusion for the halftoning in printer driver. Of course, after the hybrid resolution enhancement is performed at printer, the gray level image can be multi-toned by the AM ordered screen.

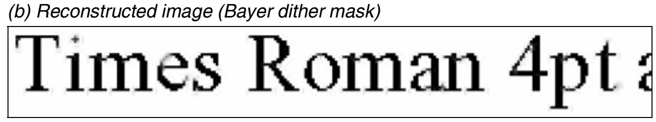
C. Effect of non-existent pairs

For the non-existent pairs, the best linear estimator described in [8] is applied to estimate the 2x2 gray values. Performance of estimation may affect the image quality. Instead of analyzing the effect of the estimation method on the image quality, percentage of search made for the non-existent pairs is examined. Table 1 indicates the percentage of the nonexistent pairs searched from the LUTs for seven test images, namely airplane, barbara, boat, goldhill, lena, mandrill, and peppers. A 4x4 rectangular template shown Figure 2 is used. The numbers in Table 1 indicate the percentage of nonexistent pairs searched from the LUT. The average percentage of the nonexistent pairs search for 7 test images is smaller than 0.2%. Therefore, it may be said that the effect of the estimating method for the nonexistent pairs on the image quality can be negligible.

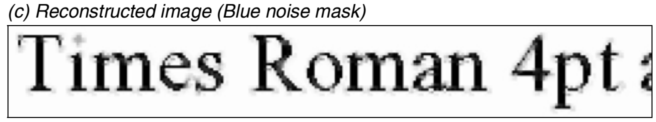
(a) Reconstructed image (error diffusion by Floyd-Steinberg kernel)



(b) Reconstructed image (Bayer dither mask)

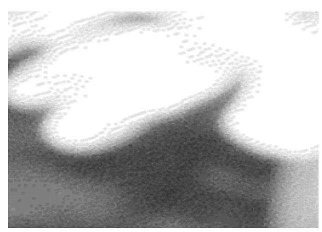


(c) Reconstructed image (Blue noise mask)

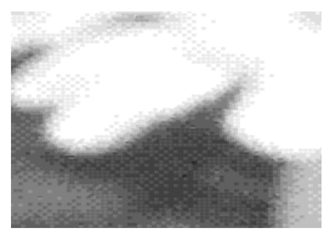


(d) Reconstructed image (AM ordered screen)

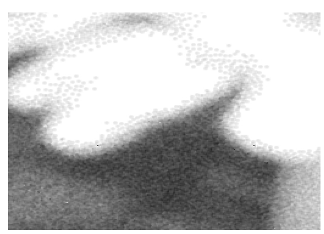
Figure 8. *Comparison of text area in reconstructed image according to halftoning method.*



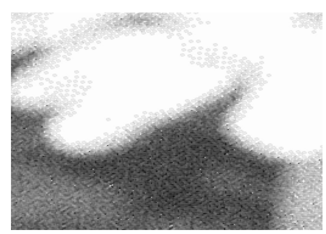
(a) Reconstructed image (error diffusion by Floyd-Steinberg kernel)



(b) Reconstructed image (Bayer dither mask)



(c) Reconstructed image (Blue noise mask)



(d) Reconstructed image (AM ordered screen)

Figure 9. *Comparison of smooth area in reconstructed image according to halftoning method.*

Table 1. Percentage (%) of nonexistent pairs search

	Class 0 (%)	Class 1-4 (%)	Total (%)
airplane	0.029	0.061	0.090
barbara	0.065	0.060	0.125
boat	0.013	0.032	0.045
goldhill	0.006	0.011	0.017
lena	0.011	0.035	0.046
mandrill	0.202	0.288	0.490
peppers	0.006	0.018	0.024
average	0.054	0.072	0.119

4. Conclusion

In this paper, a fast and efficient hybrid resolution enhancement technique is proposed. Objectives of the proposed techniques are to reduce the data size for transmission and memory capacity to store the transmitted data. The proposed technique can be utilized for a GDI printer where halftoning is performed by the printer driver. Five different LUTs are constructed by the offline procedure. Once constructed, LUTs are stored at printer for the online processing. After the halftoned image is received from the printer, the number of black pixels within 4x4 window is compared with the numbers of black pixels in four neighboring windows. Based on this comparison, one of five LUTs is chosen and applied for the spatial and bit-depth resolution enhancement. Various factors affecting performance of a LUT based resolution enhancement are analyzed.

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