Border Enhanced Screening Technology (BEST)

Hwai-Tzuu Tai and Yee Ng
NexPress Solutions LLC
Rochester, New York

Abstract

In the commercial printing industry, customers demand crisp sharp text and line-arts as well as vivid color pictures printed consistently on the same media at the same time. This demand in image quality requires that the design of the text and line-arts of sharp edge elements be preserved without aliasing; and the larger pictorial areas have excellent tonal gradation without noticeable artifacts (i.e.; moiré, density contouring, appearance of course screening texture, etc). We have developed a multi-level screening method {Border Enhanced Screening Technology (BEST)} that utilizes an image structure classifier to identify pixels of different classes. Then a class-based adaptive screening technique (with multiple gray-level halftone choices), in combination with gray level anti-aliasing (GRET) method, is used to render stable, smooth and artifact free large area screens and accomplish anti-aliasing for pastel as well as saturated color edges at the same time. The BEST method has delivered excellent image quality.

1.0 Introduction

In the commercial printing industry, customers demand crisp sharp text and line-arts as well as vivid color picture printed consistently on the same media at the same time. This demand in image quality requires that the design of the text and line-arts of sharp edge elements to be preserved without aliasing; and the larger pictorial areas have excellent tonal gradation without noticeable artifacts (i.e.; moiré, density contouring, appearance of course screening texture, etc). However, stair-stepping edges in a text or line arts are a common problem associated with the printing of low resolution binary image data. Efforts have been made to reduce or overcome line jaggedness with anti-aliasing method by either moving the dot position, changing the dot sizes or dot density along the edges at the desired locations.

Digital halftoning is a widely used screening technique to reproduce pictures in printing. There have been many different halftoning methods developed in the past, each having its unique ways to create and to arrange dots on the image plane to preserve the tones and the details of the image. The human visual system integrates various dots to perceive a grayscale picture. Recently, a significant improvement on image quality has been made with multi-level screening & printing techniques. The multi-level screening & printing technologies have allowed superior image quality prints to be achieved at medium writer resolution. There are now many commercially available inkjet and high speed Electro-photographic color printing devices that utilize multi-level screening techniques to deliver excellent picture image quality.

In a specific digital printing architecture, a document that contains text and picture elements is composed electronically on a desktop. The electronic pages are then rasterized (without rendered) into bitmap form and sent to a writer. The characteristics of text and pictorial in the original contents have been lost in the bitmap representation. Image type information needs to be recovered from the rasterized bitmap representation for better renditions. The bitmap form is very common representation in the scanned documents that both text and picture are indistinguishable at pixel level. A lot of progress has been made in the past to develop intelligence using segmentation methods to identify and to segment image types on a page into text regions and picture regions.[1] Proper screening techniques are then applied to render text and pictures into its best rendition form.[2,3] However, due to the complex decisions need to be made with limited information, some errors are easily introduced and create subsequent screening artifacts on the page.

In this paper, we will introduce a multi-level screening method {Border Enhanced Screening Technology (BEST)} and its architecture. The BEST method utilizes local image features to identify pixels of different classes. A class-based adaptive screening technique (with multiple gray-level halftone choices), in combination with gray level anti-aliasing (GRET) method,[4] is then used to render stable, smooth and artifact free screens and also accomplishing anti-aliasing for pastels as well as saturated color edges.

2.0 Multi-level Screening

In multi-level halftone screening, each pixel has the capability to be rendered in several different dot sizes or densities, thus creating different gray levels for each pixel. This is significantly different from the binary halftoning that only has one dot size or density. This multi-level scheme enriches the halftone dot design with extra dimension of flexibility in dot choices. More complicated dot formations can be designed with multi-level scheme than the binary scheme. We have developed multi-level screening system using a high speed multi-level 600 dpi LED writer in the full color digital press printing system.[5,6,7]

2.1 Multi-level Dot Design

In the following, interactions of dot formation with the underlying Electro-photographic (EP) process are briefly described. There is a unique feature of the EP process for developing dots. More stable dots are developed when there are well-formed charge potential wells of the latent electrostatic image being produced. Less stable dots are developed when there are less-defined charge potential well being produced. In the paper,[5] two unique dot designs are described: full dot type and partial dot type. The two dot types show significant visual differences. The full dot type has a stable screen structure while the partial dot type has a continuous tone appearance.

It can be easily understood in the multi-level dot design that different dot building processes result in different dot formations. To analyze different dot formation behaviors influenced by the EP process, a design of dot formation chart is useful. This dot formation chart is a two-dimensional layout of various multi-level dot patches. The patches are arranged such that dot exposures are increased along one direction while dot sizes are increased along another direction. Each patch represents a unique dot formation. The layout is illustrated in Figure 1. The printed dot formation chart helps visually assess of how graininess varies with respect to dot formation and helps quickly identify the stable dot formation and unstable dot formation. Furthermore, as density and dot center are carefully measured from the printed dot formation chart, a physical multi-level dot model can be built for the multi-level screen design.

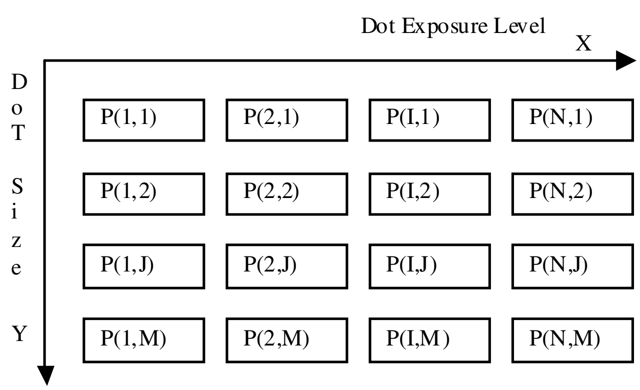

Figure 1. Illustration of Dot formation Chart. Each patch P(I,J) represents a dot formation at specific dot size and dot exposure.

One aspect of multi-level screening is the dot formation and image structure can be co-optimized. When dots are more stable on its own dot formation, it could be used to render in image area with less image structure. The internal structure of dot provides the stability for itself. On the contrary, when the dots are less stable on its own dot formation, it could be used to render in image area with fine image details and utilize the image structure to provide the stability. Therefore, an optimal image quality could be achieved with selected dot formations matching to image structure. This is the essence of adaptive screening. It will be described later.

2.2 Multi-level Color Screen Design

In a traditional 4-color CMYK printing process, due to registration requirements, the screen angle usually designed around 15, 45, and 75 degree with 30 degrees angle apart from each other to avoid unpleasant interference patterns. A good color screen design will ensure a better quality image to be rendered. A lot of efforts have been put in the multi-level color screen design.

Some common issues in color screen design must be addressed: (1) To achieve a rotated angle screen design such as 15, 45, and 75 degree screens. (2) To hold a specific relationship in screen ruling and screen angles between each color to avoid color overprint Moiré. (3) To accommodate cell sizes and cell shape differences of the select screens. (4) To build artifacts free screens (artifacts such as: unbalanced dots, auto-Moiré pattern, over-print Moiré, unpleasant screen textures and contouring). (5) To build a stable dot that has co-optimized with device marking process. (6) To build a specific tone characteristics in the full tone scale. (7) To build a desired dot shape (whether elliptical, circular, or line) in a small cell. (8) To maintain an accurate color reproduction and a consistent color appearance.

Several sets of high quality color screens in the range of 150 lpi to 200 lpi have been developed. They are optimized with EP process and integrated into the printing system.

3.0 The BEST Algorithm

The functional block diagram of the BEST architecture is illustrated in the figure 2. It includes two tightly coupled processors: adaptive screening and GRET anti-aliasing. Each processor is emphasizing improvements on different attributes of image quality. In the following, several image samples are used for illustration. It will be clear how the BEST algorithm performs after the following description.

3.1 Adaptive Screening Method

The objective of adaptive screening is to render image with appropriate dot formation that matches local image structure. There are several image processing steps involved in the adaptive screening: (1) Feature extraction: processing each pixel to extract out local image structures. (2) Feature mapping: maps the extracted features to an index value. (3) Membership function: generates the percentage dot formations of different classes. (4) Blending operation: sum up different classes of dots to construct the composite dots.

The feature is defined as the maximum of gray level differences between central pixel and neighboring pixels within 3×3 window. It is a simple local pixel difference measure. There are other sophisticate schemes could be implemented on this step. The extracted feature is mapped to an index value and then followed by a membership function process. The membership function generates an n-tuple value that represents the percentage of dot classes of the feature belongs. It is illustrated in figure 3. Through experimental design, the index is assigned such that it correlates image structures to the dot formations. A high index value correlates to text area, edges, high contrast, and fine pictorial details. Therefore, a matched dot type is rendered in those high index areas. Similarly, a low index value correlates to picture area, non-edges, and low pictorial details. Another matched dot type is rendered in those low index areas. There are index values that overlapping multiple dot types, these areas are then rendered with multiple dot types blended. The rendered output pixel O(X,Y) can be expressed as

$$O(X,Y) = \Sigma\, Dot_j\,(\, p_j(X,Y),\, q_j(X,Y),\, I(X,Y)\,) * M_j(F(X,Y))$$

While I(X,Y), and X,Y are input image pixel values and pixel positions; $Dot_j(\,)$ are dot functions (j = 1,2,..n); (p, q) are screened pixel positions; $M_j()$ are membership functions; and F( ) is the feature extraction function.

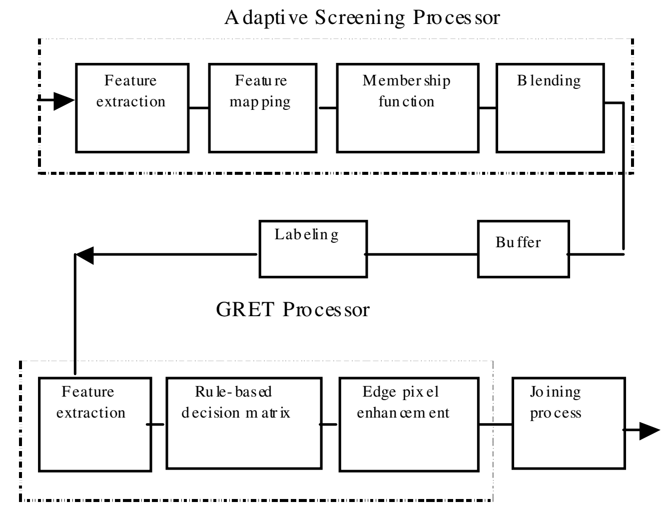

Figure 2. Functional diagram of the BEST algorithm.

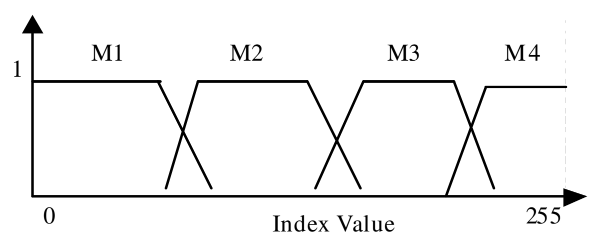

Figure 3. Illustration of typical membership functions of different dot types.

Therefore, appropriate dot formations, which match local image structure, were rendered within the image. The adaptive screening renders a better image quality.

3.2 GRET Anti-Aliasing Method

The author has described a GRET technology that improves the jaggedness of near-saturated text and line graphics in the NIP16 conference. The GRET function will be only briefly described here. Please refer to the original paper for more detail on architecture and implementation.[4]

The core of GRET is a rule-based decision matrix that guides the detecting pixels need to be treated. Pixels associated with specific edge transition patterns, which are captured in the rule database, will be altered. The GRET data flow starts a window operation to extract local image features (such as gradient amplitude and gradient direction). A rule-based decision matrix then finds the best match for the extracted features. If there is a match found, an enhanced gray value is then output for printer exposure. Otherwise, the pixel is unaltered for output. Those enhanced gray pixel values have been carefully designed to shape the edges, reduce aliasing but maintaining the line weight and design intent of the fonts.

In the data flow of BEST architecture, the image has been screened prior to the GRET processing. An extra labeling processing is introduced to separate screened dots from the saturated text and lines. This labeling process includes an adjustable thresholding process. Pixels are labeled into two classes: "need operation" and "by-passed". In the internal GRET operation, only those labeled as "need operation" pixels will be further processed as normal GRET operation. At the output of BEST algorithm, the "by-passed" pixels of the screened image are recombined with GRET enhanced image.

4.0 Image Simulation Results

Several images have specifically been chosen and they have been enlarged to visualize the effects of BEST algorithm. Two classes of dots are used in the adaptive screening for demonstration: Type A and Type B. Type A is an optimized pictorial screen that has stable screen structure and type B is an optimized text screen that has continuous tone structure.

Figure 4 is a saturated black text image; the adaptive screening processor has no effect on the image. It shows the enlarged image as being processed with and without GRET processing. The text is smoothed with anti-aliasing GRET processing. Figure 5 is a non-saturated color text image; the GRET processor at this time has no effect on the image. A portion of "P" has been magnified 10X for detailed illustration. It can be observed the effects of adaptive screening with type B dots rendered along the border of text. Those edge pixels are connected to each other and have preserved its original font shape. It improves the appearance and legibility of tinted text. In contrast to normal screening, they lose detail and have a more jagged appearance due to the screen structure. Figure 6 is a picture with fine texture, a Moiré pattern can easily be seen for a normal screening. However, it is invisible with BEST method because of type B dots that are blended in. Figure 7 is a typical picture rendered with BEST method. The color insert that contains figures 5, 6, 7 is created from NexPress2100 digital color press.

Figure 4. A saturated black text image "PIC2001". The character "P" has been enlarged 8X to illustrate the effects of enhancement with and without GRET processing.

5.0 Conclusion

We have illustrated the BEST algorithm and its architecture. Two processors: adaptive screening and GRET anti-aliasing processing are tightly integrated in the BEST architecture. The adaptive screening takes unique features of multi-level screening that is multi-level dot formations are able to co-optimize with both image contents and EP marking process. The GRET anti-aliasing processing smoothes out the stair-stepping edges while maintains the edge sharpness. Internally each processor is emphasizing improvements on different attribute of image quality. As the result, the BEST algorithm renders better image quality for all the image elements: text (either saturated or non-saturated text), line art, and image contents.

In a full process color printing, the BEST algorithm is used to render each separation independently. With proper color screen design, image qualities for the whole page are further improved.

References

1. Yee S. Ng, "Rule-based Image Segmentation Method for Continuous-tone, text and halftone in Electrophotographic Copier/Printer", *IS&T's PICS 2000, pp. 269-274.*
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.*
3. 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.*
4. Yee S. Ng, "Gray Resolution Enhancement Anti-aliasing Technology (GRET) for High speed Printing", *IS&T's NIP16:2000, pp. 810 – 813.*
5. Yee S Ng, Hieu P Pham, Hwai 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, pp 622-625, 1994.*
6. Yee S. Ng, Hieu T. Pham, Michael Mattern, "Non-Impact Printer Apparatus and Method of Printing with Improved Control of Emitter Pulsewidth Modulation Duration", *U.S. Patent 6,061,078.*
7. Isaac Ajewole and Yee S. Ng, "Quasi-Center-Weighted PWM Multi-level LED Printhead with Non-linear Exposure Uniformity Correction", *IS&T's NIP16:2000, pp. 287-291.*

Biography

Hwai-Tzuu Tai is a technical member of NexPress. He has been associate with NexPress since 1998. Before join to NexPress, he worked in R&D of Office Imaging within Eastman Kodak. He received his Ph.D in EE from University of Pittsburgh. His research interests are image processing related to digital halftoning and color printing, He holds 24 patents in the image processing field.

Yee S. Ng is a Chief Engineer of NexPress since 1998. He was a Project Chief Engineer and Science Associate at Eastman Kodak Company before that. He received his Ph.D in Physics from Pennsylvania State University and joined Kodak Reserach Laboratory in 1980. His research interests are in image quality, image processing, Electrophotographic processes, electronic Writer and Image Data Path design. He was a Kodak Distinguished Inventor and holds > 80 U.S. Patents. He received the Carlson Memorial Award in 2000 from IS&T.