Abstract: Digital multitoning is an extension of half toning for rendering more than two tones at each pixel for higher image quality. A significantly improved homogeneity of clustered dots can be achieved by the proposed screening method based upon the new inter-iterative clustered-dot direct multi-bit search algorithm. A screening method for yielding green-noise dot clusters, yet noisy multitone texture was accompanied. The high-quality output proves it as a very competitive candidate for EP printers, e.g., laser printers. The first multitone screening method to generate stochastic clustered-dots for a much better visual quality. The pixel validation map is mainly utilized to restrain the possible dot growing region to form dot clusters. In this method, the quantization error at each pixel was diffused to neighbors for error compensation. A clustered dot multitoning method to yield stable dots for the EP printers.

Keywords: Clustered Dot Screen, Multi Toning, Half Toning, Screening Methods.

I. INTRODUCTION

Digital halftoning [1] is a technique for converting continuous-tone images into binary images. These binary images resemble the original images when viewed from a distance because of the low-pass nature of human visual system (HVS). This technique has been widely used in devices of limited tones rendering capability to yield the perceptual illusion of more tones. So far, many related commercial applications have been introduced, such as document printing and electronic paper (e-paper) displays. In general, there are two ways of improving the quality of the rendered images [2], i.e., increasing the spatial resolution for less visibility to artifact of halftone textures and offering more tones at each addressable pixel location for a greater signal similarity. The latter approach is the purpose of multitoning techniques which generates >2 possible tones for each pixel.

II. BACKGROUND WORK

A. Bi Level Half Toning With Stochastic Screen

Recently we have seen a newer and expanding role of stochastic screen in digital printing [1, 2, 3, 4] because of its implementation simplicity and visually pleasing output. The implementation of screening employs a simple point wise comparison,. An input image value is threshold by a corresponding screen value to turn the output pixel on or o. Halftone patterns from stochastic screen contain “blue noise” [5] characteristics, similar to those of error division method. Because the human visual system is less sensitive to high-frequency content (blue noise), halftone patterns generated from stochastic screening are less visible to a human observer. When devices have multilevel outputs, such as a multilevel inkjet printer, stochastic screen technique can easily be generalized to utilize this new capability [3]. It can be seen that this is equivalent to the binary implementation, except that the screen is rst scaled to certain intermediate range before the comparison is taken, and the output is set to one of those output levels based on the comparison result and corresponding intermediate range. For example, assume the device has 4 output levels, 0, 85, 170 and 255, respectively; also assume the original stochastic screen has 256 levels from 0to255. If the input pixel value is 128, the screen is rst scaled to the 85 and 170 range, then, based on the scaled screen value at that specific location, we either output 170 or 85. We call this simple extension the conventional multitoning scheme.

B. Conventional Multilevel Halftoning With Stochastic Screen

Digital halftoning [1] is a technique for converting continuous-tone images into binary images. These binary images resemble the original images when viewed from a distance because of the low-pass nature of human visual system (HVS). This technique has been widely used in devices of limited tones rendering capability to yield the perceptual illusion of more tones. So far, many related commercial applications have been introduced, such as document printing and electronic paper (e-paper) displays. In general, there are two ways of improving the quality of the rendered images [2], i.e., increasing the spatial resolution for less visibility to artifact of halftone textures and offering more tones at each addressable pixel location for a greater signal similarity. The latter approach is the purpose of multitoning techniques which generates >2 possible tones for each pixel. Digital multitoning can be divided into two categories in terms of the spectral properties, i.e., blue- and green-noise to render the spatial frequency of dot appearance for various printers. For instance, inkjet printers exploit the advantage of blue-noise methods for their rather reliable rendering of a given shade of color [3], [4]. Contrarily, laser printers prefer the green-noise methods for their inherently unstable printed dots of
the electrophotography (EP) printing process [5]. Currently, devices are capable of accommodating more ink intensities to approximate the original continuoustone images [4], [6]–[9]. For this, Blum [4] further investigated the relationship between droplet counts to the values of screens for rendering multitone with inkjet printers.

Couwenhoven et al. [9] also developed an ink depletion process to modify the input image before halftoning/multitoning for avoiding possible artifacts which might happen when excessive amount of colorants are printed in a small area of a page. Another perspective of the multitoning classification considers their processing types: 1) Point process - screening [2], [10], [11] and 2) neighborhood process - error diffusion [3], [8], [12]–[14]. Normally, these schemes are with tradeoff between processing efficiency and image quality. In Chandu et al.’s direct multi-bit search (DMS) [10], all possible absorptance states at each pixel are tested for the minimum perception error. Aiming at its low processing efficiency during the screen construction, Trager et al. [11] parallelized the generation process for speed-up. In contrast to the above screening methods which utilize simple thresholding method for multitoning, Gentle et al. [12] proposed an error diffusion based method for multitoning. In this method, the quantization error at each pixel was diffused to neighbors for error compensation. In addition, the output was determined by searching over all possible absorptance states for the minimal error. Although this approach yielded a greater image quality, some artifacts such as the line pattern and worm effect were still apparent. To solve these artifacts, Katsavounidis and Kuo [13] modified the processing path, in which the pixel with a larger error is processed with a higher priority. Based upon these advantages, Sarailidis and Katsavounidis [14] further improve the image quality. Beyond that, Yu and Spaulding [8] combined the error diffusion, screening, and over-modulation to deal with the texture contour artifact at certain rendered absorptance levels.

In summary, all of the above schemes generate dispersed dots to render rich details and less grainy perception, yet the required stable isolated dots printing is hard to be achieved by the inherent restriction of laser printers which utilize EP process. To solve the above issue, Brodlin and Deschuytere [15] proposed a clustered dot multitoning method to yield stable dots for the EP printers. In their work, bands are defined to render multiple parallel lines for presenting different pixel intensities. However, these periodically arranged line patterns still have artificially unnatural textures. In 2014, Chandu et al. [16] proposed the first multitone screening method to generate stochastic clustered-dots for a much better visual quality. In their method, the pixel validation map is mainly utilized to restrain the possible dot growing region to form dot clusters. In this design, some of the isolated dots are first generated as the seed pattern and then grow to form clusters. The allowable growing regions in the pixel validation map are enlarged with the Euclidean distance.

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C. Multi-Tone, Duotone

A duotone is the generic name for multitone printing, which can be done with two, three or four inks. This process requires that the press be set up with special inks, usually PANTONE-designated colors, instead of the standard CMYK inks used for process color printing. Usually the images are printed with a dark base color and a lighter second color, overprinted to fill in, tint and tone the photo or graphic. There are 4 types of multitone images in all. Each one contains the number of inks as the name implies:

- Monotone grayscale images printed with a single ink
- Duotone grayscale images printed with two inks
- Tritone grayscale images printed with three inks
- Quadrone grayscale images printed with four inks

III. PROPOSED METHODOLOGY

The method of generating stochastic clustered-dots for a green-noise property preferred by laser printers is first introduced. Subsequently, the screen construction which exploits the benefits of generated homogenous multitone outputs is detailed. A. Inter-Iterative CLU-DBS Figure illustrates the algorithm for better understanding. In which, each of the the inter-iterations (gray blocks) consists of many intra-iterations (white circles), and one intra-iteration stands for accessing all the pixels of a given image. At the end of entire process, the converged image gKinter of the Kinter-th inter-iteration is the output of the proposed algorithm. Details are introduced below. Formerly, CLU-DBS [17] generated halftone clusters for a green-noise property with the use of two-component. cost function, which was majorly formulated by both initial filter ci p p′ [m, n] and update filter cu p p′ [m, n]. Its purpose is to minimize the perceived errors between the continuoustone image f [m, n] ∈ [0, 1] and the multitone image g [m, n] ∈ {ai}0 ≤ ai ≤ 1S i=1. There are two main stages, trial and update, involved in the iterative process for each pixel of an image. Prior to these stages, an initialization stage is required to form an initial

\[ c_{p\epsilon}^{i} [m, n] = e_{0} [m, n] * c_{p}^{i} [m, n], \]  

Where

\[ e_{0} [m, n] = g_{0} [m, n] - f [m, n], \]

Where the operator ‘∗’ denotes convolution, and g0 [m, n] denotes the initial multitone pattern for being optimized. Subsequently, the trial and update stages are performed with a different filter cu p p′ [m, n] in opposed to the use of ci p p′ [m, n] in Eq. (2).

This design plays the vital role of approaching the green-noise property since ci p e0 [m, n] does not truly represent the filtered version of e [m, n] during the optimization process. Related discussions and detailed derivations can be found in Goyal et al.’s work [17]. In the trial stage of each pixel, it attempts some changes of multitone states in set \{ai|0 ≤ ai ≤ 1\}S i=1 and record their corresponding influences for minimizing the cost formulated below,

\[ \phi = \sum_{m,n} e [m,n] c_{p\epsilon}^{i} [m, n]. \]  

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Where
\[ e[m,n] = g[m,n] - f[m,n], \] (3)

And a general formula of k-th updated \( c_{i}^{\text{th}}[m,n] \) can be defined as bellow
\[
\begin{aligned}
    c_{i}^{\text{th}}[m,n] &= c_{i}^{\text{th}}[m,n] + \sum_{i} g_{i} c_{i}^{\text{th}}[m-n, n-n] \\
    &= c_{i}^{\text{th}}[m,n] + \sum_{i=0}^{k-1} \sum_{g_{i}} c_{i}^{\text{th}}[m-n, n-n].
\end{aligned}
\] (4)

During the iterative process, multitone dots are changed with two different ways to minimize the cost: 1) toggling at the current position \([m0, n0]\): This operation change the current absorptance state \(a_i\) to another one in the set \(\{0 \leq a_i \leq 1\}\) \(S = i\), and 2) swapping between pixels at \([m0, n0]\) and the one of its eight neighbors at \([m1, n1]\). As previously modeled in Chandu et al.’s DMS [10], \(a_i\) can be defined as below for a toggle operation,
\[
a_0 = g^{\text{mod}}[m0, n0] - g[m0, n0] \] (5)

And \(a_1=0\). In addition, the definitions of \(a_i\) for a swap operation are
\[
a_0 = g[m1, n1] - g[m0, n0] \] (6)

And
\[
a_1 = g[m0, n0] - g[m1, n1] \] (7)

where \(g[m, n]\) and \(g^{\text{mod}}[m, n]\) denote the original multitone pixel and updated multitone pixel, respectively. This enlarges the pool size of the absorptance states from two for the halftone case [17] to \(S\) for multitone case, and it also increases the number of trials of altering each multitone pixel.

Specifically, eight swaps and \(S - 1\) toggles are involved in each trial. As defined in Eq. (6), two individual filters, \(c_{i}^{\text{th}}[m, n]\) and \(c_{i}^{\text{th}}[m, n]\), affect the optimization, and their difference induces a phenomenon, termed inversion, which turns the clusters into voids, or voids to clusters. To prevent from this phenomenon which disturbs the typical screen algorithm design with the stacking constraint as introduced in Section 3.2, the cost function as proposed in Goyal et al.’s work [17] is formulated as below, \(\theta = \theta_{\text{homog}} - \theta_{\text{clust}}\) (10) where \(\theta_{\text{homog}} = \phi u\) as defined in Eq. (4) and it controls the dot homogeneity; the variable \(\theta_{\text{clust}}\) controls the dot clustering degree as defined below,
\[
\theta_{\text{clust}} = 2 \sum_{m,n} e[m,n] \Delta c_{i}^{\text{th}}[m,n] \] (8)

Clustering is the task of dividing the population or data points into a number of groups such that data points in the same groups are more similar to other data points in the same group than those in other groups. In simple words, the aim is to segregate groups with similar traits and assign them into clusters.

IV. SIMULATION RESULTS & DISCUSSIONS

Simulation results of this paper is as shown in bellow Figs.1 to 3.

Fig.1. Input Image.

Fig.2. Internal Image.

Fig.3. Output Image.

V. CONCLUSION AND FUTURE WORK

In this report, we present a novel over-modulation scheme to improve multilevel rendering around intermediate output levels. A more smooth transition of visual error has been achieved, the inter-iterative CLU-DMS is proposed to design screens for the generation of stochastic clusteredmultitone results. For the optimization, the tactic of
coordinating intra-iteration and inter-iteration is proposed to circumvent the potential issue of trapping in a local minimum cost in the conventional approaches such as DBS [19] and CLU-DBS.

VI. REFERENCES