1-24-2011

Descreening of Color Halftone Images in the Frequency Domain

C. J. Stanger
Boise State University

Thanh Tran
Boise State University

Elisa H. Barney Smith
Boise State University

Descreening of Color Halftone Images in the Frequency Domain

CJ Stanger, Thanh Tran and Elisa H. Barney Smith

Boise State University, 1910 University Drive, Boise, ID 83725
EBarneySmith@BoiseState.edu

ABSTRACT

Scanning a halftone image introduces halftone artifacts, known as Moiré patterns, which significantly degrade the image quality. Printers that use amplitude modulation (AM) screening for halftone printing position dots in a periodic pattern. Therefore, frequencies relating halftoning are easily identifiable in the frequency domain. This paper proposes a method for descreening scanned color halftone images using a custom band reject filter designed to isolate and remove only the frequencies related to halftoning while leaving image edges sharp without image segmentation or edge detection. To enable hardware acceleration, the image is processed in small overlapped windows. The windows are filtered individually in the frequency domain, then pieced back together in a method that does not show blocking artifacts.

Keywords: Descreening, halftoning, fast Fourier transform

1. INTRODUCTION

Color printers use three colors, cyan, magenta, and yellow, and sometimes black when printing color images. These colors are arranged in patterns of dots when a non-saturated color is desired. The perceived color depends on the size of the dots and the different combinations of the three colors at different angles. This type of printing is called halftoning.

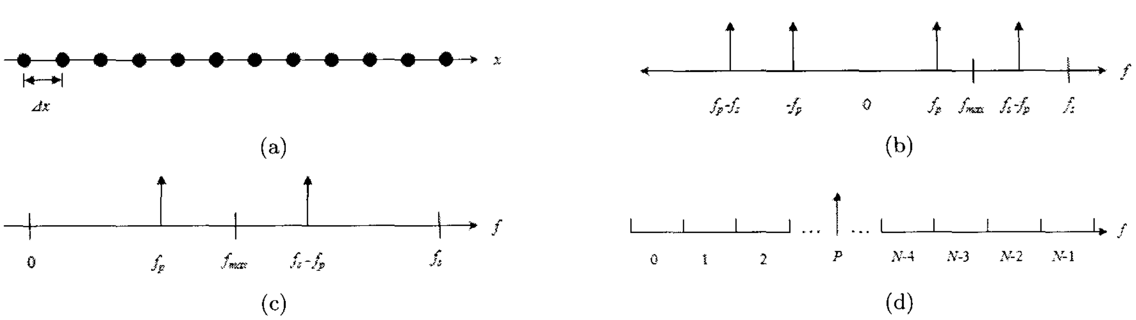
A problem arises when a printed halftone color image is scanned. It causes Moiré patterns to become visible and degrades the image quality to an unacceptable level. The degradation causes the image quality to be poor enough that it is easily noticeable by the naked eyes in most images. Steps must be taken to remove the Moiré patterns caused by the process of scanning a halftone document. This process is referred to as descreening. Past research has shown that descreening requires more than just using a low pass filter to smooth the image. A low pass filter removes the Moiré patterns but also cause blurring in the image. Various descreening methods have been developed including training-based descreening, hardware friendly descreening, and wavelet-based descreening that attempt to preserve image details.

Siddiqui and Bouman used a training-based denoising called Resolution Synthesis-based Denoising (RSD) followed by a modified Smallest Univalue Segment Assimilating Nucleus (SUSAN) filter to remove the halftoning.[1] The halftone artifacts have been successfully removed after filtering, however the sharpness of the edges has been lost. Shou and Lin used a Genetic Algorithm (GA) for different texture patterns that result from a scanned halftone image. Then, a cellular neural network (CNN) was used to classify the patterns. A specific filter was designed for each pattern to maximize the quality of the descreened image.[2] The filtered images are smoothed but some halftone artifacts are still present.

Hardware friendly descreening designs a filter that avoids expensive computations such as floating point operations and exponentials. Siddiqui, Boutin, and Bouman used a hardware friendly descreening algorithm that filters locally using gradient estimation, local averaging and local sharpening to calculate a descreened pixel value.[3] This descreening method performs well but has not yet been applied to color halftone images.

Wavelet-based descreening uses wavelets to decompose images into different frequency subbands and filter only the halftoning frequencies in the high frequency subbands. Kou, Tewfik, and Rao used wavelets as a way to segment halftone regions from text and then designed a two-stage color sigma filter to descreen the image.[4] This algorithm required preprocessing to segment halftoned regions from text. Zhang et al. converted an image to the CMYK color space and processed each channel individually. Wavelet-based descreening was used to decompose

Color Imaging XVI: Displaying, Processing, Hardcopy, and Applications, edited by Reiner Eschbach,
Gabriel G. Marcu, Alessandro Rizzi, Proc. of SPIE-IS&T Electronic Imaging, SPIE Vol. 7866
78661H · © 2011 SPIE-IS&T · CCC code: 0277-786X/11/$18 doi: 10.1117/12.872158



(a)

(b)

(c)

(d)

Figure 1: (a) halftoning in one dimension is a series of dots, (b) the corresponding frequency spectrum will have two peaks, (c) the range of frequencies under consideration is from 0 to f_s, (d) frequency spectrum quantized into N bins

each channel into different frequency subbands and filtered only the subbands in which halftoning occurred.[5] The halftone artifacts have been removed but the resulting images are very blurry. Kuo, Rao, and Thompson divided an image into 512 x 512 blocks and decomposed the blocks into smaller 128 x 128 subbands. A 2-D fast Fourier transform (FFT) was calculated for each 128 x 128 subband to try to identify peaks related to halftoning. The subband images in which the L^2 norm showed strong harmonics were identified as having halftoning frequencies present. A linear finite impulse response (FIR) filter was designed that had a frequency response of 1 at the DC component and 0 at the harmonics.[6] This algorithm also requires preprocessing to segment out the halftoned regions.

The methods described previously all filter in the spatial domain as opposed to the frequency domain. The algorithm proposed in this paper has similarities to what Kuo, Rao and Thompson developed. The key difference is that the proposed algorithm filters in the frequency domain using a series of band reject filters rather than using an FIR filter and without segmenting the image by subbands. Amplitude modulation (AM) screening is one type of halftoning that positions variable-size, equally spaced dots in a grid-like pattern. Due to this equal spacing in AM screening, there are frequencies related to halftoning that show a strong presence in the frequency spectrum. As opposed to an FIR filter, which is usually a low pass filter, a band reject filter is a better choice because it can isolate and remove a specific range of frequencies; in this case the frequencies resulting from halftoning, without causing blurring and keeping edges, such as in text, sharp. There is no need to segment halftoned regions from the rest of the image. Filtering in the frequency domain has not been widely used because computing the FFT for an entire image is not practical if the image is very large. However, the image can be broken down into small overlapping windows, filtered individually, then tiled together to reconstruct the entire image, processing manageable amounts of data at a time. These smaller blocks of data lend themselves to implementing the FFT in hardware.

Section 2 will describe the theory used to choose the cutoff frequencies for the band reject filter. Section 3 will discuss the descreening algorithm in detail. Section 4 will describe a window tiling process used to avoid blocking artifacts. Section 5 will show results from a test image with the proposed descreening algorithm applied.

2. THEORY OF HALFTONING FREQUENCY LOCATION

As stated in the introduction, AM screening is a type of halftoning that positions equally spaced dots in a grid-like pattern. Since the dots are equally spaced, AM screening is periodic. The frequencies of the dots can be calculated and used to predict the locations of the halftoning in the frequency spectrum. The theory of locating these halftoning frequencies will be presented first in one dimension to simplify the concepts and then extended to two dimensions to be applied on images.

A periodic series of dots can be used to represent halftoning in one dimension. Fig. 1a shows x as a spatially continuous function that produces this series of dots. The distance Δx is the period of the series of dots. The frequency for this series is found by taking the reciprocal of Δx to get $\frac{1}{\Delta x}$. This frequency is also called the printing frequency f_p. Taking the Fourier transform of x gives X. The plot of the frequency domain is shown

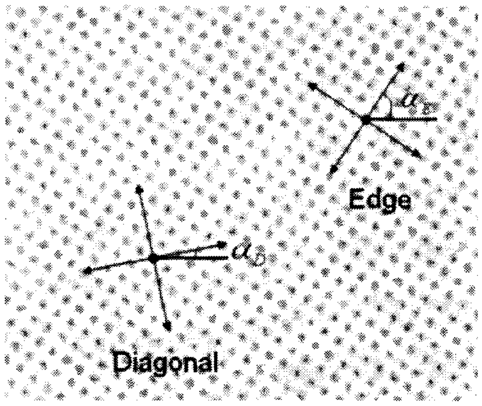


Figure 2: Magnified halftone image of a solid red color.

in Fig. 1b. The values of f_s and f_p represent the sampling frequency and maximum printing frequency that will satisfy the Nyquist theorem. Due to sampling, there will be an infinite number of peaks in the frequency spectrum. However, the arrangement is periodic so we only need to consider the range of frequencies from 0 to f_s as shown in Fig. 1c. The two peaks in this region are located at f_s and $f_s - f_p$. The values for f_p and f_s are not generally known a priori unless on a rare occasion one physically prints and scans an image with known settings. For this reason, theory has been developed to predict the halftoning frequency location so that it is not required to know f_p and f_s a priori. In discrete time, the frequency spectrum is quantized into N bins as shown in Fig. 1d. The bin number P in which the printing frequency is located is found using

$$P = round(\frac{f_p}{f_s}N). \tag{1}$$

This idea can be expanded to two dimensions. There is one more variable to include because each color is printed at a different angle, α, on the paper. Fig. 2 shows a magnified view of a uniform light magenta image. There are two primary frequencies that exist in every halftone color image: edge and diagonal. Since AM screening produces a square grid of dots, the distance between the dots along the diagonal is $\sqrt{2}$ units larger than the distance between the dots along the edge as shown in Fig. 3. From Fig. 2, two angles, α_D and α_E, are shown that correspond to the diagonal and edge frequencies. α_D is 45^o offset from α_E. In the frequency spectrum, the halftoning frequencies will each show up as four points. Therefore, the frequency spectrum shows four distinct bins of equal distance from the origin, spaced apart by 90 degrees. Eq. 1 with the addition of a printing angle now becomes

$$P_x = round((\frac{f_p}{f_s}N)cos(\alpha + \frac{k\pi}{2}) - \frac{N}{2}), \tag{2}$$

$$P_y = round((\frac{f_p}{f_s}N)sin(\alpha + \frac{k\pi}{2}) - \frac{N}{2}). \tag{3}$$

P_x and P_y give the coordinates of the bins in which the halftoning frequencies are located. The value $\frac{f_p}{f_s}N$ corresponds to the magnitude of the frequency. The value k is an integer ranging from 0 to 3 to account for all four bins corresponding to the two edge frequencies. The values are shifted $\frac{N}{2}$ bins because the origin in the 2-D spectrum has been shifted to the center of the frequency spectrum. Eqs. 2 and 3 can be applied for the diagonal frequencies, only with a smaller magnitude and a different printing angle than the edge frequencies. While the relative angles are known, a value for α_E or α_D has to be determined experimentally for each image.

3. DESCREENING OF HALFTONING USING A CUSTOM BAND REJECT FILTER

As the location of the bins in the 2-D FFT where AM halftoning should be present can be predicted, the halftoning frequencies can be located and filtered from the frequency spectrum. An algorithm has been developed

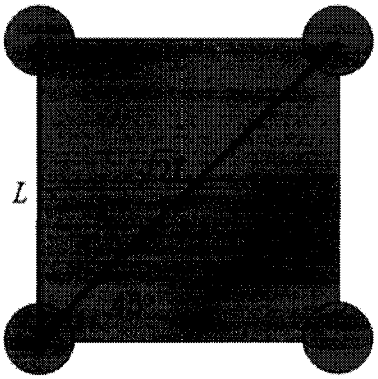


Figure 3: Relationship between the diagonal and edge halftoning frequencies, where L represents the distance between dots along the edge.

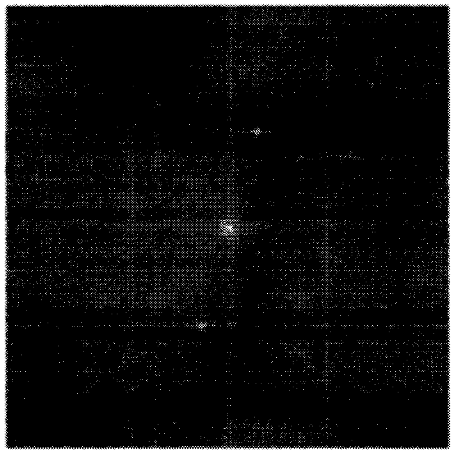


Figure 4: Log of frequency spectrum of a 128 x 128 window of an image.

that applies the theory discussed in Sec. 2 to design a band reject filter to remove halftoning frequencies. To locate the halftoning frequencies, an N x N square window is selected from the original image. A window has to be selected manually to ensure that it has at least one color with clear halftoning. The FFT of this window is computed. The log of the magnitude of the frequency spectrum is normalized so that the maximum peak is 1. Fig. 4 shows an example of the log of the frequency spectrum for a 128 x 128 window. The bright dot at the center of the image represents the DC component. The other bright dots are related to the edge and diagonal halftoning frequencies for the printing colors.

To ensure that only frequencies related to halftoning are filtered, the DC component and low frequencies near the origin are removed from consideration. After these frequencies have been removed from the spectrum, the maximum peak is located. This peak is located at a frequency corresponding to halftoning of one of the printing colors.

The locations of the other peaks can be calculated relative to the maximum peak. First, the three peaks corresponding to the maximum peak are located using Eqs. 2 and 3. Since the AM screening creates a square grid, the magnitude of the edge frequency is approximately 1.414 times larger than the diagonal frequency and the diagonal frequency is shifted 45^o from the edge frequency. Thus, the eight peaks corresponding to one color are located without searching the entire spectrum multiple times.

The peaks for the other colors can be calculated using the known relationships between the printing angles.

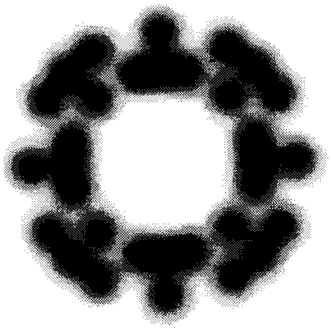


Figure 5: Example of a "Swiss Cheese" filter created using a frequency spectrum from a 128 x 128 window of an image.

The majority of color halftone printing uses the same relationship between printing angles of the different printing colors. This algorithm assumes the most common relationship: the angle between cyan and magenta is 30^o, and the angles between cyan & yellow and yellow & magenta are both 15^o. For printers that use black ink, the printing angle is 45^o. Knowing the relative angles allows the locations of halftoning frequencies to be independent of possible skew caused during scanning. Using these relationships to find the other halftoning frequency locations instead of searching the entire spectrum for all the other peaks significantly reduces the computational cost.

A custom band reject filter called a "Swiss Cheese" filter is created to descreen the N x N window. The name comes from the appearance of a slice of Swiss cheese after the band reject filter has been designed because of the various "holes" that are built into the filter. The "holes" are created by subtracting from 1 a 2-D Gaussian function, scaled such that the maximum value is equal to 1, centered at the location of each peak

$$H(u,v) = e^{-((u-\Delta u)^2+(v-\Delta v)^2)/(2\sigma^2)}, \tag{4}$$

where Δu and Δv are the coordinates for a given peak corresponding to a halftoning frequency and σ is the standard deviation or width of the "hole." A Gaussian filter was chosen because ideal filters cause ringing in the filtered image. The "Swiss Cheese" filter design consists of these Gaussian functions placed in series. Fig. 5 shows an example of a "Swiss Cheese" filter. The black circular regions represent the locations which will be filtered and the white region represents the frequencies that remain unaffected.

A Gaussian function requires computations that involve exponentials and could be computationally expensive. However, since halftoning frequencies do not change throughout an image this filter only needs to be created once and can be used for every window of the image. Therefore, the number of calculations is very small and the use of a Gaussian function for the filter is justifiable.

4. WINDOW TILING WITH OVERLAP

The large image is broken into a series of N x N windows. Each window is filtered using the "Swiss Cheese" filter design, then the inverse FFT is computed to show the window in the spatial domain. The filtered windows then need to be combined to show the whole image after filtering. Without overlapping each window, blocking artifacts result because pixels near the boundaries of each window do not get filtered well. A window overlapping method has been developed to overcome blocking artifacts.

First, an N x N window is filtered, and then Z pixels around the boundary are removed. Z must be large enough to remove the pixels near the border that did not get filtered. Instead of the next window starting at pixel $N+1$, it is shifted back by $2Z$ pixels. This shift is horizontal if the next window is to the right of the previous window or vertical if the next window is below the previous window. This window is taken from the original image and filtered just as the previous window. Z pixels around the border are also removed from this

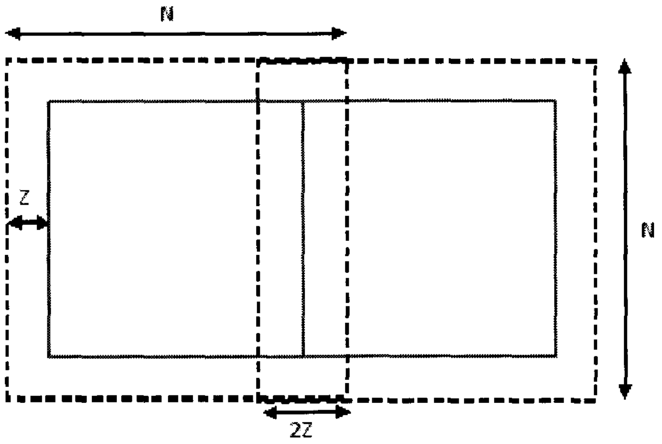


Figure 6: Example of a "Swiss Cheese" filter created using a frequency spectrum from a 128 x 128 window of an image.

window. Since the overlap is $2Z$, the smaller windows line up perfectly and blocking artifacts are avoided. Fig. 6 shows a diagram of the window overlapping method for horizontal overlap. The solid red squares show the remaining portions of the filtered windows. The dashed lines show the original windows.

5. RESULTS OF APPLYING "SWISS CHEESE" FILTER

For testing, several halftone printed color images were scanned. A window size of 128 x 128 was used. This window size was chosen because it was the smallest power of 2 that was able to separate halftoning from other frequencies when transforming to the frequency domain. Frequencies less than 15 bins from the original were excluded from the filtering process to preserve the DC component and low frequency components unrelated to halftoning. The printing angles were assumed to be 75° for cyan, 90° for yellow, and 105° for magenta. A value of 4 was used for σ in the "Swiss Cheese" filter design to compensate for quantization errors in the digital image.

Fig. 7a shows an original color halftone printed image after being scanned at a resolution of 600 dpi. Fig. 7b shows the same image after the "Swiss Cheese" filter was applied to the scanned image. Due to the high resolution of the images, it is difficult to see the difference when viewing the entire image. Fig. 7c shows a zoomed in portion of the original scanned image. Fig. 7d shows the same zoomed in portion after it was filtered.* The results show that the filter is able to remove halftoning significantly while retaining the original printed image quality. Also, there is no blurring or loss of detail caused by the filter.

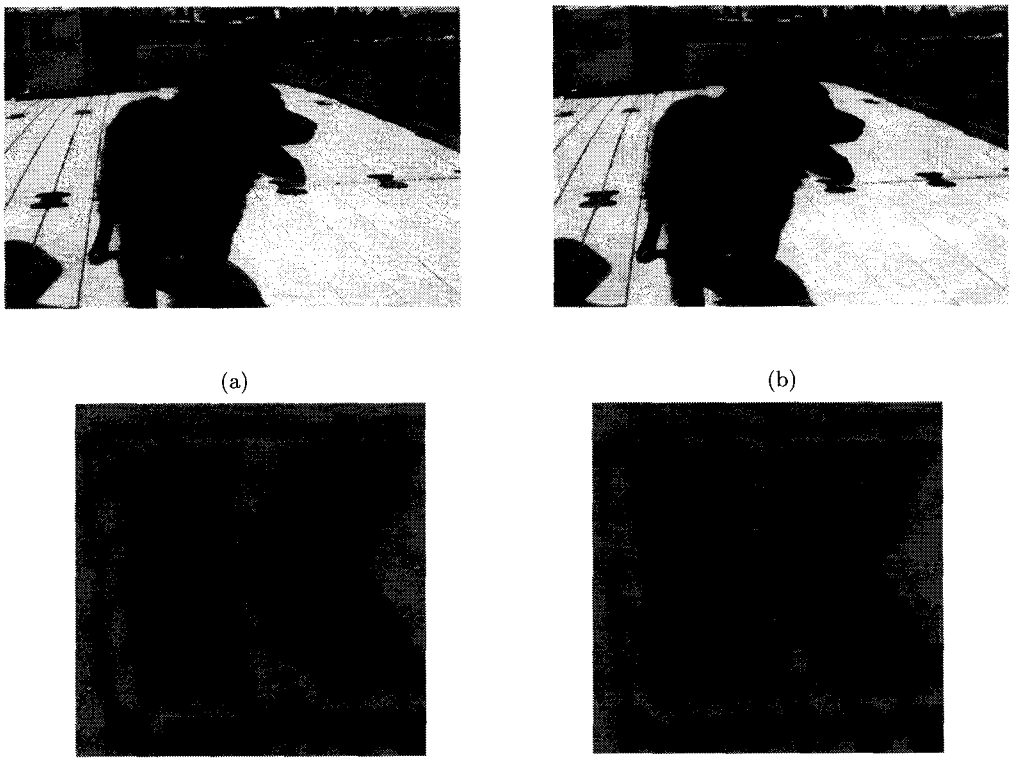
6. CONCLUSIONS

A special type of band reject filter called a "Swiss Cheese" filter was used to filter halftone color images. The filter was designed to isolate and remove the halftoning frequencies by placing "holes" at those locations. The "Swiss Cheese" filter showed a remarkable ability to remove only halftoning frequencies. The details of the original image were preserved. No blurring occurred as a result of filtering. A tiling process was developed to overlap each filtered window so that poorly filtered edges of each window were not included in the tiled image. The overall image quality was similar to the original halftone image. The FFT can be hardware suitable when an image is broken down into small windows. This method can be implemented in multifunction printers and also scanners as a solution to the halftoning Moiré problem.

Future work will fully automate this filtering process. An algorithm will be developed to automatically search for a window with clear halftoning of at least one color.

---

*Reprinting will cause the printer to add additional halftoning to the image and insert halftone dots after the algorithm has removed them. If this document remains as a soft copy, there will be no additional halftoning introduced.



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

Figure 7: (a) original color halftone scanned image, (b) filtered image using "Swiss Cheese" filter, (c) zoomed in region of original image, (d) zoomed in region of filter image.

ACKNOWLEDGMENTS

We would like to thank Hewlett Packard and Mark Shaw for their support on this project.

REFERENCES

[1] Siddiqui, H. and Bouman, C., "Training-based descreening," *Image Processing, IEEE Transactions on* **16**, 789–802 (March 2007).

[2] Shou, Y.-W. and Lin, C.-T., "Image descreening by ga-cnn-based texture classification," *Circuits and Systems I: Regular Papers, IEEE Transactions on* **51**, 2287–2299 (November 2004).

[3] Siddiqui, H., Boutin, M., and Bouman, C., "Hardware-friendly descreening," *Image Processing, IEEE Transactions on* **19**, 746–757 (March 2010).

[4] Kuo, C., Tewfik, A., and Rao, A., "Color halftone document segmentation and descreening," in [*Image Processing, 2001. Proceedings. 2001 International Conference on*], **2**, 1065 –1068 (October 2001).

[5] Zhang, E.-H., Ma, H.-B., He, M., Luo, B., and Duan, J.-H., "An improved descreening algorithm for color halftone image based on wavelet decomposition," in [*Image and Signal Processing, 2008. CISP '08. Congress on*], **2**, 242 –246 (May 2008).

[6] Kuo, C., Ravishankar Rao, A., and Thompson, G., "Wavelet based halftone segmentation and descreening filter design," in [*Acoustics, Speech, and Signal Processing, 2001. Proceedings. (ICASSP '01). 2001 IEEE International Conference on*], **3**, 1573 –1576 (May 2001).