Documentat Image Segmentation and Quality Improvement by Moiré Pattern Analysis[§]

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Abstract

Moiré patterns are distortions on the results of scanning printed documents. However, the patterns can be utilized in document image segmentation and quality improvement. The moiré phenomenon comes from sampling periodical structures in images, such as halftone screens, color components, and text galleys which often appear in printed magazines and newspapers. The generated moiré patterns appear in the scanning result in the form of obvious periodical patterns, color skew, and color noise on the edges of artworks. The moiré pattern degrades the scanning result and makes document analysis more difficult. A new approach to document image segmentation and quality improvement by moiré pattern analysis is proposed. A scanning resolution, called the conductor of screen sharing, is proposed to control the moiré pattern. With the resolution, moiré patterns are generated and enhanced in certain designed areas in the frequency domain. Then, a logical filter, called the comb filter, is proposed to detect the moiré pattern. The new method, which is based on the sampling theory and moiré analysis in the frequency domain, is actually performed in the spatial domain by re-sampling and logical filtering. The proposed method can efficiently extract gray or color pictures, artworks, and text paragraphs in printed documents. Moreover, the moiré patterns on the segmented document components can be easily suppressed. The suppression yields better image quality for further analysis and image compression. Experimental results are shown to demonstrate the feasibility of the proposed approach.

Key Words: Moiré pattern, Halftone screen, Printed document, Document segmentation, Image scanning, Quality improvement, Fourier analysis, Conductor of screen sharing, Comb filter, Sampling, Logical filter.

1. Introduction

Document image segmentation and quality improvement is necessary for most document analysis processes. The major purpose of segmentation is to identify meaningful areas on document images for further processing such as image compression and optical character recognition. The techniques for document analysis have been studied for many years, yielding results such as run-length smoothing [1], projection profile cutting [2], etc. Recently, some approaches using neural networks were also proposed for document analysis [3]. For printed document analysis, knowledge related to page composing and printing techniques can be utilized to perform segmentation. According to the special characteristics of document printing, a new method is proposed here to accomplish document image segmentation and quality improvement.

Periodical structures such as halftone screens and character lines in text paragraphs often appear in printed documents. The periodical structures of halftone pictures are dense and difficult to detect by human eyes. It is used to represent tones on printed documents. The text paragraphs in printed document contents include repeating text lines, namely, text galleys. The distances between the text lines in text galleys are normally designed according to character size and reading comfort considerations. In magazines and newspapers, both of the frequencies of halftone images and text lines are not changed to keep constant styles.

The tones on the articles in printed documents are not inherently gray. It is a combination of very dense binary, black or white, tiny dots [4]. The density of the dots creates the illusion of tones on the printing. This kind of image is named halftone image to distinguish from the continuous tone image which is the source gray-scale image. Limited by image rastering devices and printing machines, the tiny dots are clustered together to form

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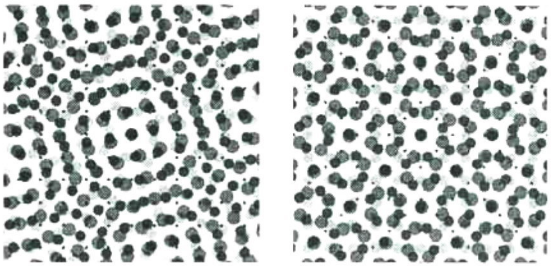
larger features, namely, halftone dots. Halftone dots are arranged uniformly and orthogonal as arrays, called halftone screens, to comfort human eyes. A thresholding process, called screening process, is employed to accomplish the conversion. All the tones, including pictures and tinted areas, which appear in the printed document are printed by the same technique. One example of pictures and tinted areas are shown in Fig. 1(a). When scanning the halftones of printed articles, aliasing is unavoidable and moiré patterns are created [5]. Fig. 1(b) demonstrates the phenomenon. Moiré patterns are distortions [6] which appear as periodical noise patterns on the scanning result. Many studies on the analysis of moiré patterns [7]-[10] have been conducted. Shu and Yeh [8] proposed the gauging function of the moiré pattern. Applying the theory to the screening and scanning process, Fukuda [9] modeled the superimposed moiré phenomenon of using many screens in printing and Morimoto [10] proposed a moiré suppression method for use in printing.

(a) Halftone pictures and tinted areas on printed document.
(b) Moiré patterns generated in scanned result of (a).

Fig. 1. Moiré patterns are generated when scanning halftone images.

Printed color images are produced from four separate halftone images, one for each of the ink colors: cyan, magenta, yellow, and black. The superimposition of the four halftone images also causes the moiré phenomenon which yield moiré patterns. By adjusting the screen angles of the four halftone images, the generated moiré patterns may be changed. Usually, people adjust the screen angles to make the generated moiré patterns as dense as possible to make the patterns undetectable by human eyes. Screen angles of 45° for black, 90° for yellow, 105° for cyan, and 165° for magenta are normally selected to avoid producing visible moiré patterns on printed articles. Fig. 2(a) demonstrates an example of moiré patterns which are generated by bad selection of screen angles for the four halftone images. Fig. 2(b) shows a better result of common screen angle combination used in color printing. Scanning color images on printed documents yields colorful moiré patterns. The analysis of the moiré patterns on the results of scanning color images is much harder than the analysis of those on scanned gray scale images, because the moiré patterns are generated by re-sampling the printed document which already has moiré patterns.

In this research, we utilize moiré patterns as features for document segmentation. A brief analysis of the moiré pattern is included and the result is shown helpful in the segmentation of color pictures and artworks on the scanning result of color printing. The main idea is to detect the periodical structures yielded by the moiré patterns. The new method, which is based on the sampling theory and moiré analysis in the frequency domain, is actually applied in the spatial domain by the techniques of re-sampling and convolution. We will also propose methods to suppress the patterns to improve image quality.



(a) arbitrarily selection of the combination of screen angles may generate obvious printing moiré.
(b) combination of screen angles to make the printing moiré as high frequency as possible.

Fig. 2. Examples of combination of screen angles on color printing.

More specifically, Fourier analyses are employed in this study to describe the moiré phenomenon. According to the analysis, a scanning resolution, called the conductor of screen sharing (CCS), is proposed to control the moiré pattern. Using the resolution, moiré patterns can be generated and enhanced in certain areas in the frequency domain. Then, a logical filter, called the comb filter, is proposed to detect the moiré patterns. After that, the periodical structure with a certain frequency on the scanned image can be detected efficiently. The method can be utilized to detect pictures and tinted areas in the scanning result of halftone images. The proposed method can be generalized to detect all kinds of periodical structures. For document segmentation, the period of text lines in text galleys is fixed, so the method can also be modified to detect text galleys. Compared with traditional documentation segmentation methods, the new method is simple, fast, and definitely suitable for analyzing the mass scanning results of magazines and newspapers.

The remainder of this paper is organized as follows. In Section 2, we formulate the screening and scanning processes. By Fourier analysis, we show how moiré patterns are generated during the process of scanning screened halftone images. In Section 3, we illustrate our discovery of the screen signal sharing phenomenon in the frequency domain. The proposed scanning resolution, the conductor of screen sharing (CSS), is described. In Section 4, the comb filter is proposed to detect the periodical variation of the scanning result. Using the results of the detection, the segmentation of the printed document is obtained. In Section 5, the proposed method for suppressing moiré patterns is described. In Section 6, some discussions and some experimental results are given by conclusions in Section 8.

2. Formulation of Screening and Scanning Process

2.1 Screening and scanning of gray-scaled halftones

Moiré patterns appear in images which result from scanning screened halftone images. The patterns vary when the scanning resolution is changed. The moiré patterns are shown to be caused by aliasing in frequencies in Rosenfeld and Kak [5]. They are generated by high frequency screen signals which are shifted into the low frequency area in the frequency domain. In the following, an analysis of the signal of the scanning result of screened halftone images is given.

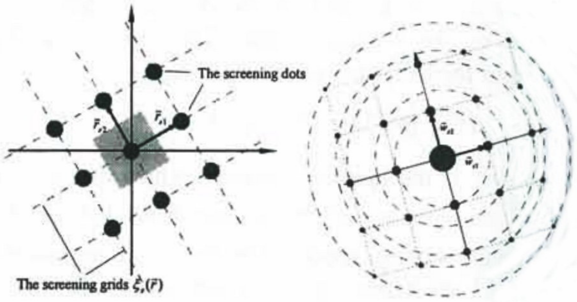
A screened halftone images is assembled by screen dots. Screen dots are clustered black pixels which are centered on a certain screening grid. A screening grid $\xi_s(\vec{r})$ can be defined as

$$\xi_s(\vec{r}) = \sum_{m=-\infty}^{\infty}\sum_{n=-\infty}^{\infty}\delta(m\vec{r}_{s1} + n\vec{r}_{s2}), \qquad (1)$$

where vector $\vec{r}$ specifies a position on the source halftone image; $\vec{r}_{s1}$ and $\vec{r}_{s2}$ are two orthogonal basis vectors of the screening grid; and m and n are integers. According to the local tone value at position $\vec{r}$ on the source gray-scale image, the sizes of the screen dots are varying. Darker or lighter tone areas have larger or smaller black screen dots, respectively. The generation of the screened halftone image is a threshold operation that gives a bi-level black and white result, by comparing the source gray-scale image and the screen generation function. The screen generation function is a repeating hill function which is a result of convolving the screen dot function with the screening grid. Yang and Tsai [11] includes a complete analysis of the screened halftone image, which indicates that the Fourier transform of the screened halftone image has significant screen signal components on the reciprocal screening grid $\Xi_s(\vec{w})$. The reciprocal screening grid is defined as

$$\Xi_s(\vec{w}) = \sum_{k=-\infty}^{\infty}\sum_{l=-\infty}^{\infty}\delta(\vec{w} - k\vec{w}_{s1} - l\vec{w}_{s2}), \qquad (2)$$

where $\vec{w}$ specifies a frequency in the frequency domain; k and l are integers; and $\vec{w}_{s1}$ and $\vec{w}_{s2}$ are the reciprocals of the screening bases, $\vec{r}_{s1}$ and $\vec{r}_{s2}$, respectively. Both the spatial and the frequency domains of part of a screened halftone image are shown in Fig. 3.



(a) Screening dots and screening grids in spatial domain.

(b) Screen signal components and reciprocal screening grid in frequency domain.

Fig. 3. The screen signal components and the screening grid.

The screen frequency and the screen angle are two factors of the screening halftone which are both determined by the screening grid $\xi_s(\vec{r})$. The length of the bases, $|\vec{r}_{s1}|$ and $|\vec{r}_{s2}|$, are the period of the screen grid, so the frequency of the screen is defined as the lengths of reciprocal bases in the frequency domain, $|\vec{w}_{s1}|$ and $|\vec{w}_{s2}|$. The angle of the screen is given by

$$\theta = \cos^{-1}\left(\frac{\vec{r}_{s1}\cdot\vec{i}}{|\vec{r}_{s1}||\vec{i}|}\right)$$

where $\vec{i}$ is a base vector of the Cartesian coordinate system. According to Gonzalez and Woods [12], the rotation of the spatial domain is identical to the rotation in the frequency domain. The angles of the reciprocal bases $\vec{w}_{s1}$ and $\vec{w}_{s2}$ change in accordance with those of the bases

$\vec{r}_{s1}$ and $\vec{r}_{s2}$ in the spatial domain. 45° is the most frequently used screening angle because it is most comfortable for human eyes. For this case, the screen signal components are located on a grid of 45° in the frequency domain.

Images are scanned and converted into digital signals by scanners. As well known, the scanning process is a sampling process and the scanning result is an array of pixels. Each pixel comes from a sampling point. The sampling points are located on a orthogonal grid. The scanning resolution is the density of the sampling points on the source article. A higher resolution results in a smaller scanning grid and a larger quantity of pixels. On the other hand, a scanner collects the reflected light from the source article though an optical system. The aperture and the focus of the lens of the optical system have influence on the scanning result. The process can be modeled by the following equation:

$$g(\vec{r}) = \left[h(\vec{r}) * a(\vec{r})\right] \times \xi_n(\vec{r}), \tag{3}$$

where $a(\vec{r})$ is the *aperture function* which defines the aperture transmittance of the scanner lens; $h(\vec{r})$ is the source halftone image produced by the screening process and printed on paper; $g(\vec{r})$ is the gray-scale image resulting from scanning; and $\xi_n(\vec{r})$ denotes the scanning grid which is defined as

$$\xi_n(\vec{r}) = \sum_{m=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} \delta(\vec{r} - m\vec{\alpha}_1 - n\vec{\alpha}_2), \tag{4}$$

where $\vec{\alpha}_1$ and $\vec{\alpha}_2$ are the basis vectors of the scanning grid, and m and n are integers.

The first part in the right hand side of (3), the convolution $h(\vec{r}) * a(\vec{r})$, models the optical process of the scanning process, in which the light is reflected from the printed halftone image and collected by the optics structure of the scanner. After that, the light is sampled at the scanning grid $\xi_n(\vec{r})$ at positions $m\vec{\alpha}_1 + n\vec{\alpha}_2$. The aperture function $a(\vec{r})$ is a distance function. The larger the distance from the sampling point, the less the light can be transmitted. The Fourier transform of Equation (3) is

$$G(\vec{w}) = \left[H(\vec{w}) \times A(\vec{w})\right] * \Xi_n(\vec{w}), \tag{5}$$

where $H(\vec{w})$ is the Fourier transform of $h(\vec{r})$, $A(\vec{w})$ is the Fourier transform of $a(\vec{r})$, and $\Xi_n(\vec{w})$ denotes the reciprocal scanning grid defined as

$$\Xi_n(\vec{w}) = C \sum_{k=-\infty}^{\infty} \sum_{l=-\infty}^{\infty} \delta(\vec{w} - k\vec{u}_1 - l\vec{u}_2), \tag{6}$$

where $\vec{u}_1$ and $\vec{u}_2$ are the reciprocal basis vectors derived from $\vec{\alpha}_1$ and $\vec{\alpha}_2$; k and l are integers; and C is a constant. The them $H(\vec{w}) \times A(\vec{w})$ in (5), the product of the aperture function and the original halftone image in the frequency domain, is shown in Fig. 4 for the one-dimensional case. According to the previous discussion, the halftone image $H(\vec{w})$ has signal components at the reciprocal screening grid $\xi_s(\vec{r})$, i. e., at $m\vec{w}_1 + n\vec{w}_2$. The product $H(\vec{w}) \times A(\vec{w})$ should also have corresponding signal components at these positions.

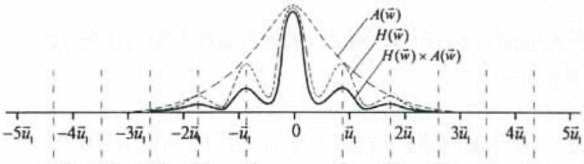


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Fig. 4. $H(\vec{w}) \times A(\vec{w})$ in the frequency domain.

By convolution, the signal components of $H(\vec{w}) \times A(\vec{w})$ centered at $m\vec{w}_1 + n\vec{w}_2$ are reproduced at each node of the scanning grid. An illustration of the result of such convolution for the 2-dimensional case is shown in Fig. 5 in which we see some screen signal components are shifted into the low-frequency area (the shaded square area). It is such screen signal components that introduce additional moiré patterns.

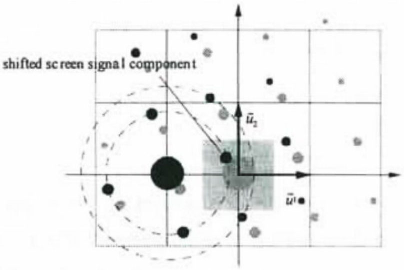


Fig. 5. Moiré signal is generated from screen signal components shifted into the low frequency area.

2.2 screening and scanning of color halftones

Color halftones are produced by four separate halftone processes of the cyan, magenta, yellow and black color components individually. The halftone images of the four colors are printed together to make color illusion. The screen angles of the halftones are carefully selected to make the moiré patterns resulting from printing as dense as possible. Usually 105°, 165°, 90°, and 45°, are used respectively for the cyan, magenta, yellow and black color screens. From the understanding of the behavior of gray halftone images which is described earlier, we know that the screened halftone images are assembled screen dots which spread on the nodes of the screening grid $\xi_s(\vec{r})$. For color printing, four screening grids are used for the four color screens, namely, $\xi_s^c(\vec{r})$, $\xi_s^m(\vec{r})$, $\xi_s^y(\vec{r})$, and $\xi_s^k(\vec{r})$ for the cyan, magenta, yellow and black screening grid, respectively. Normally, the selected screening grid use the same frequency but different angles. The reciprocal screening grids $\Xi_s^c(\vec{w})$, $\Xi_s^m(\vec{w})$, $\Xi_s^y(\vec{w})$, and $\Xi_s^k(\vec{w})$ in the frequency domain are illustrated in Fig. 6. The signals of the cyan, magenta, yellow, and black screens actually should be illustrated separately. Here, we put the four diagrams together to make a global view of the four signals. The black color which can be treat as dark cyan, magenta, or yellow is dependent on the other three colors in the CMY color space. According to the color printing technique, the black screens are printed on the other three color screens. These superimposing causes convolutions of the black signals with the three color signals. Fig. 7 (a)-(c) illustrate the convolutions of the black screen with the other three color screens, respectively. The three illustrations are mixed and shown in Fig. 7(d) to display the entire distribution of color halftone signals in the frequency domain. Comparing Fig. 6 with Fig. 7(d), we notice that some additional signals are generated by the convolution in the lower frequency area (shown as the dashed circular area in Fig. 7(d).) The signals introduce moiré patterns. In this case, screen angles are carefully selected. The angles of the major sensitive colors (cyan, magenta, and black) are arranged to differences of 30°. For this ordinary angle combination, the signals of the moiré patterns can be placed in the highest frequency. For other angle combination, the moiré signals are placed in the lower frequency area which generate larger moiré patterns and make the printing result worse. This is the reason why most of the color printing are normally use the ordinary screen angle combination.

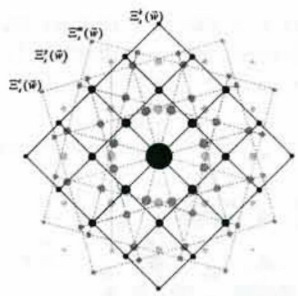
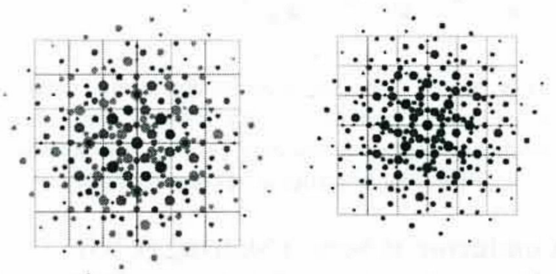
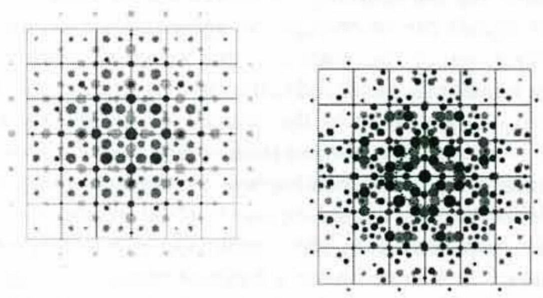


Fig. 6. Reciprocal screening grids $\Xi_s^c(\vec{w})$, $\Xi_s^m(\vec{w})$, $\Xi_s^y(\vec{w})$, and $\Xi_s^k(\vec{w})$ of color printing in the frequency domain.



(a) Cyan signals of color halftone in frequency domain.

(b) Magenta signals of color halftone in frequency domain.



(c) Yellow signals of color halftone in frequency domain.

(d) Signals of color halftones in frequency domain and additional printing moiré signals in dashed area.

Fig. 7 Signals of color halftone in frequency domain.

The signals are then sampled by the scanning process. According to the discussions in the previous section, the scanning operation causes another convolution of the color halftone signals with the scanning grid in the frequency domain. Obviously, the convolution may shift the halftone signal components as well as the moiré signals produced in printing into the low frequency areas and introduce additional moiré patterns. The situation is illustrated in Fig. 8.

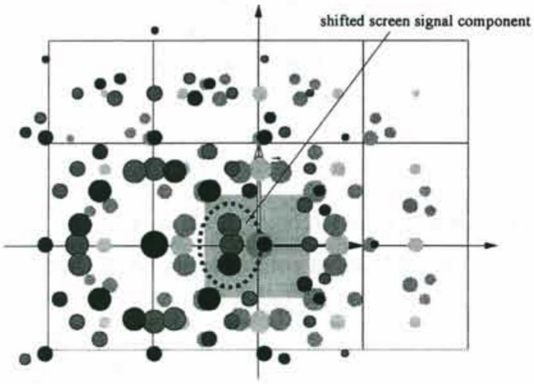


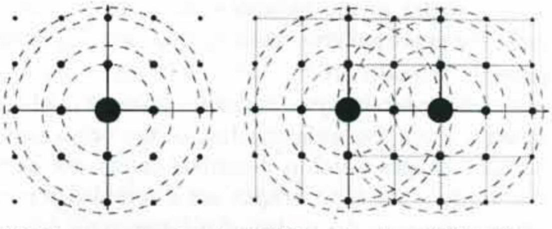
Fig. 8. Screen signal components and moiré signals produced by printing may shift into low frequency area in frequency domain in scanning process and causes additional moiré patterns of color halftones.

3. Conductor of Screen Sharing (CSS)

Moiré signals are high frequency screen signal components that come from convolution and are shifted into neighboring scanning grid in the frequency domain. By adjusting the scanning resolution, the location of the moiré signals can be changed. In some cases, with some combinations of the scanning and screening grid, the moiré signals may be placed in the same frequency areas in the frequency domain as the original screen signals are placed. We call this phenomenon *screen signal sharing*. To make the phenomenon happen, a calculated scanning resolution which is named the *conductor of screen sharing* (CSS) is proposed in this study for a given screen frequency and angle. After a halftone image is scanned using the CSS, no signal with a new frequency is added; only the amplitudes of the signals on the screening grid are changed. Fig. 9 illustrates the situation which happens on scanning a halftone image with 0° screens. We define the CSS for 0° halftone screens as

$$n \times \textit{screen frequency}, \qquad (7)$$

where n is an integer. In Fig. 9, it is noticed that the resulting moiré signals perfectly match the original screen signals on the original screening grid. No additional moiré signal is found in the frequency domain because the screen and moiré signals share common frequencies.



(a) The screen signal components of 0° halftone.

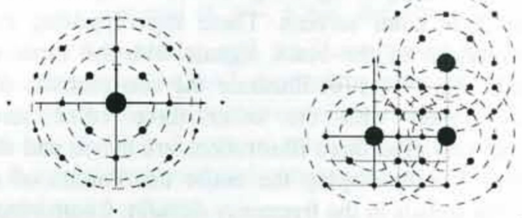
(b) The signals of 0° halftone on image obtained from scanning (a) by CSS(0°) using n=2.

Fig. 9. Screen signal components of 0° screen.

For the most commonly used 45° screens, we define the CSS(45°) by the following formula:

$$\mathrm{CSS}(45^\circ) = n \times \sqrt{2} \times \textit{screen frequency}, \qquad (8)$$

where n is an integer. By using this resolution, the resulting moiré signals also perfectly match the screening grid in the scanning result. Hence the screen signals are enhanced and no additional moiré pattern is introduced. In Fig. 10, n=3 is used for calculating the CSS.



(a) The screen signal components of 45° halftone.

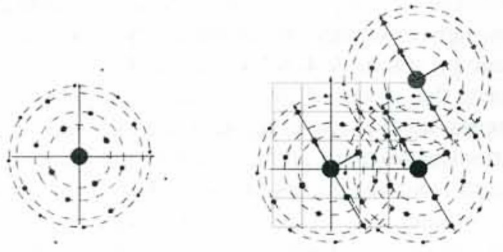
(b) The signals of 45° halftone on image obtained from scanning (a) scanned by CSS(45°) using n=3.

Fig. 10. Screen signal components of 45° screen.

Not all screens have corresponding conductors to make the moiré signals perfectly match the original screening signals in the frequency domain. For cases different from 0° and 45°, the convolved moiré signals can only share frequency bands in the frequency domain. Here we generalize the definition of the CSS for all the screening frequencies and angles as follows:

$$\mathrm{CSS}(\theta) = n \times \cos\theta \times \textit{screen frequency}, \qquad (9)$$

where θ is the screen angle and n is an integer. One result of scanning using the above free angled CSS is shown in Fig. 11.

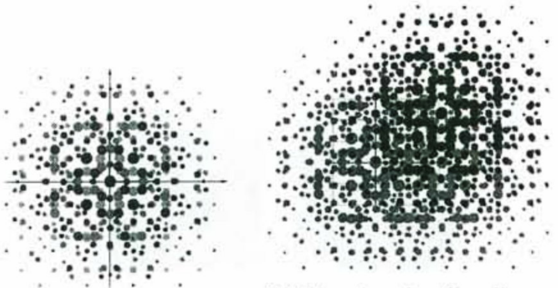


(a) The screen signal components of 30° halftone.

(b) The signals of 30° halftone on image obtained from scanning (a) scanned by CSS(30°) using $n=3$.

Fig. 11. Screen signal components of 30° halftone screens.

For color halftones, the moiré signals come not only from the screen signal components but also from superimposed color halftones in the printing process. By using the CSS(45°) defined above, the moiré signals of the black screen perfectly match the screening grid. For the scanning result of ordinary color halftone in this case, we found that the moiré signals produced in printing du to the superimposition of the four color halftones also share some frequency band in the frequency domain. This situation is shown in Fig. 12.



(a) The screen signal components of ordinary color halftones.

(b) The signals of ordinary color halftones on the image scanned by CSS(45°) using $n=3$.

Fig. 12. Screen signal components of color halftone screens.

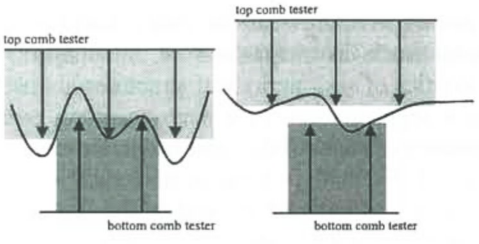
In short, for halftone images, by using the CSS, the moiré signals can be controlled to appear at certain locations in the frequency domain. This makes the detection and suppression of the moiré pattern easier.

4. Document Segmentation and Comb Filter

Halftones are generated during the printing process. Only the picture and tints which are printed by the screening technique have such periodical signals. On the other hand, in text galleys, text lines repeat. Both of these two types of structures can be easily found on printed documents such as magazines or newspapers. Some characteristics of such periodical structures are useful for document segmentation. In a mass scanning process, a large quantity of pages of the same magazine or newspaper are scanned. Normally, characteristics such as the angle and frequency of halftone screens or the line spacing of text galleys, are not changed in the pages. If this is the case, we can measure the halftone frequency, halftone angles, and the period of text lines in text galleys before performing segmentation of the image of the pages of the documents. Using the CSS proposed in the previous section, the moiré signals can be "conducted" to appear at certain controlled frequency locations. To detect the periodical screen signals, a spatial logical filter, called *comb filter*, is proposed in this study. The filter is simple and fast. It is suitable for document segmentation of large quantities of pages.

4.1 Comb filter

The comb filter is designed to detect periodical structures with certain frequencies. The result of the comb filter operation is a binary value, 0 or 1, indicating the periodical structure is detected or not. The comb filter includes two comb testers, the top comb and the bottom comb. The two combs are interlaced and the operations of the comb testers are similar to the applications of a pair of gears. As shown in Fig. 13 and Fig. 14 which illustrates the operation of the comb filter for the 1D case, the combs are applied to the image to go as "deep" as possible until one of the "tips" of the comb reaches the signal. The top comb takes the highest signal value of the signal valleys as the result of its operation and the bottom comb takes the value of the lowest hill as the result of its operation. When the signals have periodical structures and the period matches that of the tips of the combs, the top and bottom testers become "closed". If no periodical structure is found in the signals or if the period of the signals does not match that of the combs, the two combs become widely "open". The result of the comb filter operation is a binary value, 0 or 1, indicating the result of comb opening or closing, respectively. The segmentation result is the area with the values of 1. The opening and closing of the comb filter is shown in Fig. 13. Since no periodical structure can be found on a single value, we need one segment of signals to detect the periodical signal structure. The comb filter is a periodical area signal detector which operate on scanned images.



(a) Combs are close. (b) Combs are open.

Fig. 13. Opening and closing of comb filter.

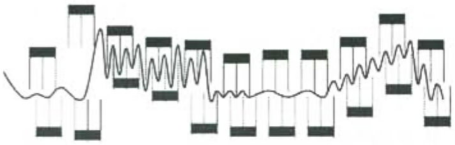


Fig. 14 Operation of 1D comb filter.

If an image is scanned using the CSS resolution proposed in the previous section, the moiré pattern in the scanning result may be conducted to appear in certain frequency areas in the frequency domain. In the spatial domain, the effect is that the obtained image has certain periodical structures. For example, the periodical structure will repeat every 3 pixels on the image which is scanned from a 45° halftone image using the CSS(45°) with n=3. The comb filter should be designed to fit the periodical structure. The organization of a comb filter is shown in Fig. 15. The comb size is the dimension of a test window which is a pixel array. The comb size is usually selected as several times of the number of pixels of the repeating structure. The comb gap indicates the distance between the comb sampling points. Here, we use five parameters to define a comb filter: w-h-g-sx-sy, where w indicates the width of the test window, h indicates the height of the test window, g indicates the gap of the combs, sx and sy define the displacements of the top comb tester with respect to the bottom comb tester in the a and y directions, respectively. In this case of Fig. 15, the organization of a 6-6-3-2-1 comb filter is shown.

Fig. 16 demonstrates the result of a comb filtering operation which detects the periodical structure on a scanned image of a 45° halftone image. The source image is shown in Fig. 16(a) which is scanned from a 45° halftone image using the CSS(45°) with n=2. The scanning result has periodical structures in half of the scanning frequency, i. e., the period of the signal is a double of the sampling points. Identical signal high-low or low-high structures repeat for every two pixels on the scanning result. A 4-4-2-1-1 comb filter is employed to detect the screened areas. According to the previous discussion, the screening grid are orthogonal. So, the periodical structure of the signals of the scanned halftone image have repetitions in both the horizontal and the vertical directions. The results of the operations of the top and bottom comb testers are shown in Fig. 16(b) and 16(c) respectively. The operation result of the comb filter is generated by comparing the computed operation results of the top and bottom combs. If the value of the result of the top comb is smaller than the corresponding value of the result of the bottom comb, the comb is close and a periodical structure is detected. The result of the detection for Fig. 16(a) is shown in Fig. 16(d).

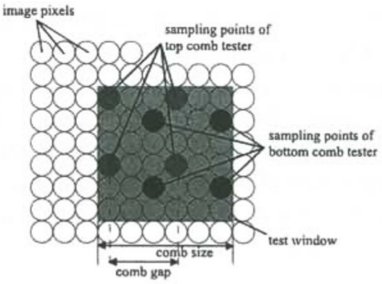


Fig. 15 Organization of a 6-6-3-2-1 comb filter.

(a) Source halftone image. (b) Result of top comb tester.

(c) Result of bottom comb tester. (d) Result of the comb filter.

Fig 16. Operation of 2D comb filter.

4.2 Selection of comb filters

Comb filters should be adjusted for different purposes. Different sized comb filters are used for detecting halftone picture areas and text galleys. The selection of comb gaps is related to the *n* value which is used for the calculation of the CSS. The offset of the bottom comb with respect to the top comb can be determined by the angle of the halftone images. The parameters, *w-h-g-sx-sy*, of the comb filter is variant for different document analysis applications and the character sizes of printed articles.

To detect halftone pictures on printed articles, the CSS is calculated first according to the halftone angle and frequency. For most of gray scale halftone images, when the screen angles are simply 0° or 45°, the moiré signals perfectly match the screen signals in the frequency domain. Since the scanning result has periodical structures which repeat every *n* pixels horizontally and vertically, *w-h-n-sx-sy* is a good selection for the comb filter to detect the halftone areas. According to the property of the halftone, the square area is usually selected as the testing window of the comb filter. The size of the square should be twice of the comb gap. Smaller test windows may cause erroneous detection results but larger test windows may be too conservative. Normally, three times of the comb gap is selected for the test window. For example, for the case of selecting n=2 for the picture detection, the parameter of 6-6-2-0-1 is selected for the comb filter.

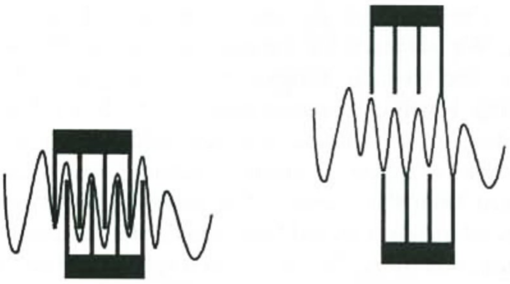
When the angle of the halftone screens is not 0° or 45°, the periodical structures which repeat on the scanning result are not regular squares. For these cases, The displacement of the bottom comb should be adjusted to fit the pattern skew. For this purpose, a larger *n* value is used to calculate the CSS, i. e., larger comb gaps are selected and this makes more choices possible for the *sx* and *sy* values.

The analysis of color halftones are much more complicated than the gray-scale halftones. Even though, the detection of the color halftone by the comb filter is simple. According to the Fourier analysis of the moiré signal of printed color halftones, we know that the black halftone screen will convolve with the other three color halftones. This means that the screen and the moiré signals of the black halftone exist in the color halftone images. By using the comb parameter selection guide for the gray-scale image, the selected comb filters are feasible for the detection of color halftone picture areas.

For the detection of text galleys, 1D comb filters are used. We can simply adjust the dimension of the test window to reduce the comb filter to be one dimensional, such as *w*-1-*g*-*sx*-1 or 1-*h*-*g*-1-*sy* for horizontal or vertical 1D comb filters, respectively. The comb gap is selected as twice of the text line distance.

4.3 Phasing of comb filters

Since the top comb tester is used to gauge the highest valley and the bottom comb test is used to gauge the lowest hill, it is important to ensure correct signal phase, i. e., the tips of the top comb tester should be placed upon valleys and the bottom comb tester should be placed under the hills. If this is not the case, the comb filter could not perform correct operations. The phasing problem is shown in Fig. 17. This problem should be solved before the comb filter is applied.



(a) Correct phase for detection.

(b) Signal phase not matching the comb testers.

Fig. 17 Comb filter may not operate correctly for incorrect positing of comb testers.

If the gap of comb testers are 2 pixels, the phasing problem can be solved by just interchanging the top and bottom comb testers. In Fig. 17(b), obviously, the comb testers are not placed at the right place that is, the top comb tester is placed on the signal hills and the bottom testers is placed on the signal valleys. If we interchange the top and bottom comb testers, the top comb tester is placed on valleys and the result of the comb filter will be correct. So, a feasible solution to the phasing problem is merging two testing results, one generated by the original two comb testers, and the other by the interchanged comb testers. The merge can be accomplished by a logical OR operation.

5. Image Quality Improvement and Moiré Suppression

To detect the areas of periodical halftone pictures, the CSS is first calculated and is used in the scanning process. The scanning process will limit the moiré signals in certain frequency bands in the frequency domain. The scanning process is identical to the moiré pattern suppression work which was proposed by Yang and Tsai [11]. The moiré patterns can be easily suppressed by designing and applied a spatial filter on the scanning result to suppress the controlled moiré patterns. For details, see [11].

6. Summary of Proposed Method

The proposed method can effectively detect the halftone pictures, tinted areas, artworks, and text galleys, and is summarized as a flowchart shown in Fig. 18. It is suitable for segmentation of mass document scanning. For the pages of magazines or newspapers, the printing technology and the composing style are not changed. Identical screen angles and frequencies are used for all the halftone pictures in the pages. The distance of the text lines in text galleys are also invariant to keep similar styles. We measure the screen frequencies, the screen angles, and the line distance in the text galleys before scanning. Firstly, a scanning resolution CSS is calculated according to the halftone characteristics. By using the resolution, a moiré controlled scanning result can be acquired from the scanner. The scanning result is then processed to detect the halftone areas in the document by a selected comb filter. The detection result is an image mask which is then used to segment out the screened parts from the scanning result. The screened part may contain picture and tinted areas. Using the method proposed in [11], a spatial filter is designed to suppress the screen signals on the screened part. A better, moiré suppressed, image can be obtained. On the other hand, artworks and text galleys may remain in the scanning result when the screened areas are erased. By using a 1D comb filter, the text galleys which contains text lines with certains line distances can be extracted. The remaining part of the image is of course the artworks.

7. Experimental Results

A series of experiments has been conducted and some of the experimental results is shown here. For the article in Fig. 19 which is printed by 45° and 159 LPI screen, the CSS was calculated to be $n \times \cos(45^\circ) \times 159$. For different n values, a series of CSS values were calculated and the scanning results and the corresponding Fourier spectrums are shown in Fig. 20. Obviously, all the moiré signals are placed on designed frequency bands. For n=2, the result has moiré signals on the four corners, i.e., within half of the highest frequency. The periodical structure repeats on the scanning result every 2 pixels, as shown in Fig. 20(a). For n=3 and n=4, the periodical structures repeat every 3 and 4 pixels, respectively, as shown in Fig. 20(b) and Fig. 20(c). This result supports the screening analysis described in Section 3. Here, we use the scanning result obtained from the use of the CSS with n=3 to do halftone detection. A *9-9-3-1-0* comb filter was applied to the image. The result of the comb filter is shown in Fig. 21. Using the result of the comb filter as an image mask, the halftone part and the line art can be segmented. The two images are shown in Fig. 22. For the segmented line-art image which is shown in Fig. 22(b), we scaled the resolution down to 24 DPI, because the text lines repeat every 6 pt. (1/12 inch). Then we used a *4-1-2-1-1* comb filter to detect the text lines. The detection result is shown in Fig. 23. Using the result, we can easily segment the text from Fig. 22(b) and yield text galleys in the document. The result is shown in Fig. 24(a). By applying a 3 by 3 averaging operation to the segmented halftone image, a better moiré suppressed image was yielded. The result is shown in Fig. 24(b). The remanding areas are the artworks as shown in Fig. 24(c).

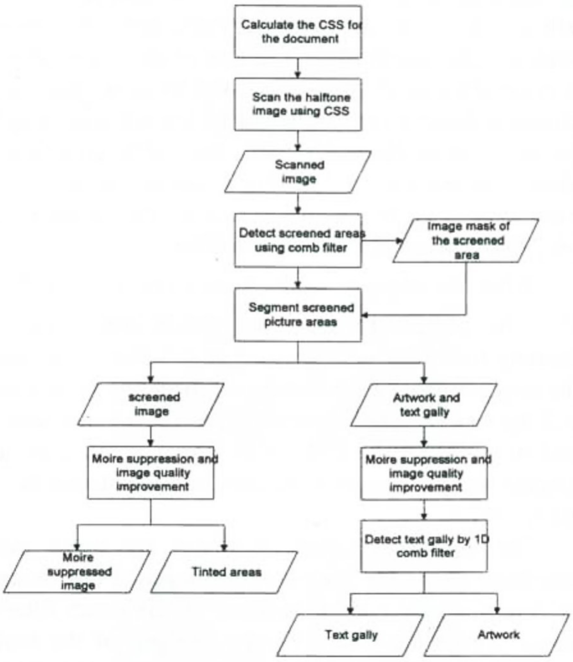


Fig. 18. Flow chart of the proposed method.

8. Conclusions

Periodical structures such as halftone screens, color components, and text galleys which often appear in printed magazines and newspapers yield moiré patterns after they are scanned. The moiré patterns degrade the scanning results and make the document analysis more difficult. A new approach to image segmentation and quality improvement for such scanning results is proposed. A scanning resolution, called the conductor of screen sharing, has been proposed to control the frequencies of moiré signals in the frequency domain. With the resolution, moiré patterns are generated and enhanced in certain designed areas in the frequency domain. Then, a logical filter, called the comb filter, has been proposed to detect the moiré pattern. The new method is performed in the spatial domain. The proposed method can efficiently extract gray or color pictures, artworks, and text paragraphs in printed documents. Moreover, the moiré patterns on the segmented document components can be suppressed.

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Moiré patterns are distortions on the results of scanning printed documents. However, the patterns can be utilized in document image segmentation and quality improvement. The moiré phenomenon causes from sampling periodical structures in images. Some periodical structures such as halftone screens, color components, and text galleys which often appear on printed magazines and newspapers. The generated moiré patterns appear on the scanning results in the form of obvious periodical patterns, color skew, and color noise on the edges of artworks. The moiré pattern degrades the scanning result and makes document analysis more difficult. A new approach to document image segmentation and quality improvement by moiré pattern analysis and suppression is proposed. A scanning resolution, called the conductor of screen sharing, is proposed to control the moiré pattern. With the resolution, moiré patterns are generated and enhanced in certain designed areas in the frequency domain. Then, a logical filter, called the comb filter, is proposed to detect the moiré pattern. The new method which is based on the sampling theory and moiré analysis in the frequency domain is actually performed in the spatial domain as re-sampling and logical filtering. The proposed method can efficiently extract gray or color pictures, artworks, and text paragraphs in printed documents. Moreover, the moiré patterns on the segmented document components can be easily suppressed. The suppression yields better image quality for further analysis and image compression. Experimental results are shown to demonstrate the feasibility of the proposed approach.

Fig. 19. An article which is printed by 45° and 159 LPI screen.

(a) n=2 (CSS=225 DPI).

(b) n=3 (CSS=337 DPI).

(c) n=4 (CSS=450 DPI).

Fig. 20. A series of scanning result and correspondent Fourier spectrums which scanned with different CSS.

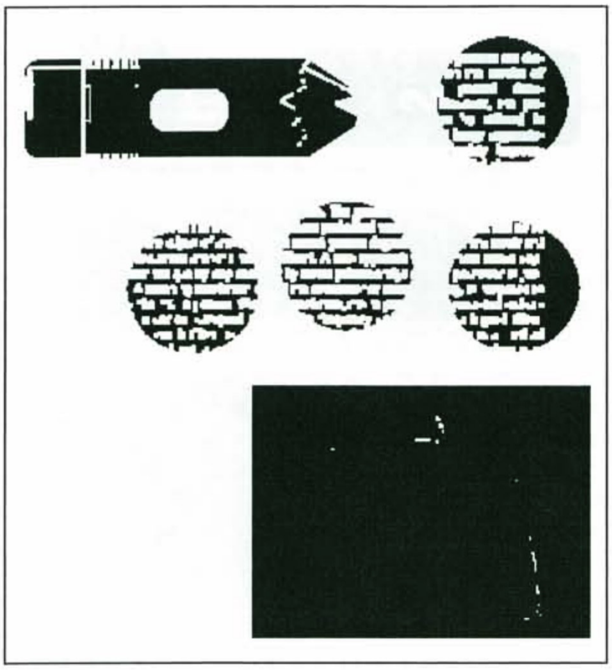

Fig. 21. Result of 9-9-3-0-1 comb filter.

(a) Scaled 24 DPI image. (b) Detection result of *4-1-2-1-1* comb filter.

Fig. 23. Detection of text galleys.

(a) Text galleys in document. (b) Moiré suppressed images in document. (c) Artworks in document.

Fig. 24. Results of the segmentation.

(a) Segmented halftone image. (b) Segmented line-art image.

Fig. 22. Segmented halftone and line-art images.