WAVELET BASED HALFTONE SEGMENTATION AND DESCREENING FILTER DESIGN

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ABSTRACT

The advent of electronic publication creates strong interest in converting existing printed documents into electronic formats. During this process, image reproduction problems can occur due to the formation of Moiré patterns in the screened halftone areas. Therefore, optimal quality of a scanned document is achieved if halftone regions are first identified and processed separately. In this paper, we propose a complete algorithm to achieve this objective. A wavelet based halftone segmentation algorithm is first designed to locate possible halftone regions using a decision function. We then introduce a suboptimal FIR descreening filter to efficiently handle various screening frequencies and angles. Experimental results are offered to illustrate the performance of our algorithm.

1. INTRODUCTION

The advent of electronic publication creates strong interest in converting existing printed documents into electronic formats. A printed document usually consists of text regions and image regions. A variety of halftoning techniques have been developed for the bi-level representations of images. For example, error diffusion, dither matrices, etc [12]. Among them, most commercially printed images are halftoned using a screening process. Hence, we will emphasize screened halftones in this paper. During transformation from a scanned halftoned image to electronic formats, the quality of the image may suffer degradation through the introduction of artifacts such as moiré patterns [9]. Transforming a halftoned image into a continuous-tone image is desirable before subsequent image manipulation such as image compression and scaling. Therefore, optimal quality of a scanned document can be obtained if halftoned regions are handled independently from text regions. As a result, a halftone segmentation algorithm is required to preprocess a scanned document, followed by a descreening algorithm which transforms the detected halftoned regions into continuous tone.

Halftone segmentation techniques can be classified into two categories: frequency-domain approaches [3] and spatial-domain approaches [5]. Because a repeating threshold matrix is used during the screening process, a halftoned image inherits this repetition frequency. Based on this observation, Dunn et. al. proposed a halftone segmentation algorithm based on texture analysis [3]. A predefined Gabor filter is chosen by first identifying the point with maximum energy in an annular region. A printed document is then filtered by the chosen Gabor filter. The halftone region is identified if the magnitude of the filtered image exceeds a predefined threshold. On the other hand, Jaimes et. al. proposed a segmentation algorithm by combining an α-crossing technique and a Union-Find algorithm to attack this problem from the spatial domain [5]. Because the algorithm does not require FFT transforms, its computational complexity is $O(N)$, where N is the number of pixels, hence it is more efficient than FFT-based algorithms.

In this paper, we propose a halftone segmentation algorithm based on wavelet analysis. Because of the nature of an image, most of the energy is concentrated near the DC component. Hence, for example, node $(3,0)$ will contain most of the energy if we adopt a three-level wavelet transform [8]. As a result, if a halftone image resides in a printed document, nodes which contain the repetition frequency and its harmonics will exhibit strong peaks in the spatial frequency domain. Based on this observation, the proposed halftone segmentation algorithm first computes a three-level wavelet transform on an image, and a two dimensional FFT algorithm is applied on selected nodes. If strong peaks appear, instead of choosing from a predefined filter bank as previous approaches [3], an optimal bandpass filter is designed based on the detected frequency components. Note that a printed document is usually scanned at very high resolution to avoid generating moiré patterns, which means that the size of the scanned image is very large. Hence, it poses a computational problem if the whole image is analyzed at once. Moreover, if halftone regions only occupy a small portion of the document, the frequency peaks become less pronounced, causing erroneous classification. Therefore, we first divide an image into 512×512 overlapping blocks, and adopt the halftone segmentation algorithm to each block independently. Hence, frequency peaks, if they exist, are usually more pronounced because they compose a significant portion of the area. We should emphasize that only the central region of each block is used in analysis to avoid the boundary effect introduced via the wavelet transform [8].

This paper then addresses the problem of designing a descreening filter to convert a halftoned image into continuous tone. Three factors need to be considered:

- Eliminate periodic signals corresponding to the screen in the original halftone image.

- Preserve inherent edge information.
- Remain visually appealing.

where the first two factors conflict with each other. Several inverse halftoning techniques has been reported in the literature [4][5][11][13][14]. Some of them concentrate their analysis on the error diffusion halftoning process [4][11][13], and this makes them difficult to be applied in the descreening process. Wavelet based approaches claim to be applicable regardless of the halftoning process used. However, because the algorithm involves downsampling and upsampling operations, moiré patterns might appear which inevitably deteriorate the quality of the reconstructed images. Wavelet methods have not been adequately tested on halftone samples which are generated by screening processes; hence, further investigation is required.

We propose a suboptimal linear FIR filter approach to achieve halftone descreening. Because our objective is to eliminate the harmonics generated by the screening process, adding other constraints would only increase the minimal size of the filter, resulting in more blurred descreened images. Hence, our linear filter design algorithm first locates peaks in the spatial frequency domain of the halftoned image. The constraint of a descreening filter is to have zero frequency response at these peak locations and have a one at the origin (DC component). As a result, the problem can be formulated as a linear system, $Ax = b$, and solved efficiently. By gradually increasing the size of the filter, we can generate a sequence $\{r_n\}$, where $r_n = \|A\hat{x}_n - b\|$. The suboptimal FIR filter corresponds to $\hat{x}_i$ where r_r is the knee point of the sequence $\{r_n\}$.

2. HALFTONE SEGMENTATION

Researchers have adopted filter banks for texture analysis and classification [2][6]. The size of a filter bank should be sufficiently large to be generally useful. Randen and Husoy offered a comprehensive review on this topic [10]. The same technique can be applied to halftone segmentation by treating the halftone repetitive pattern as a texture [3]. Since our objective is restricted to deciding if a halftone pattern exists, the dimension of the feature space used to make this decision can be significantly reduced. In fact, Dunn et. al. used only one feature and successfully detected halftone regions. Our algorithm is similar to their approach. However, the constraint of using one of the predefined Gabor filters is removed. In exchange, an efficient filter design procedure is offered to achieve better separation in the feature domain between halftone and non-halftone regions.

In designing a filter bank for texture classification, the Gabor filter bank and the wavelet packet transform are two widely adopted approaches. Even though Gabor filters possess optimal joint resolution in spatial and frequency domain, Randen et. al. demonstrated that the Gabor filter bank usually has inferior performance than wavelet and QMF filter banks [10]. Hence, we adopt the wavelet transform to divide the spatial frequency domain into each subband filtered image. Because most of the energy of an image resides at low frequencies, the harmonics will compose most of the energy in a corresponding subband image. As a result, the frequency response of the image will be dominated by significant peaks contributed by the halftone periodic signal. It should be noted that the identified harmonics in the subband image are not necessarily the same as the repetition frequency adopted in the screening process. This is because the downsampling process in the wavelet transform might interfere with the existing halftone pattern, and create a different frequency component.

To identify the existence of a halftone pattern, we first take 128 × 128 2D FFT on a subband image, $F(w_x, w_y)$, and find the histogram $H_f(n)$ of $\|F(w_x, w_y)\|$ with 128 bins. When $\|F(w_x, w_y)\|$ is dominated by harmonic peaks, $H_f(n)$ will concentrate near $n = 1$. Otherwise, $H_f(n)$ is distributed over a wider range. Therefore, assuming

$$\begin{aligned} n_0 &= \min\{n | H_f(n) \leq 0.1 \times \max\{H_f(n)\}\} \\ M &= \max\{\|F(w_x, w_y)\|\} \end{aligned}$$

we can design a halftone indicator H_{ind} as follows such that $H_{ind} = 1$ if a halftone pattern is detected and zero otherwise:

$$H_{ind} = \begin{cases} 1 & \frac{M}{n_0} \geq \lambda_h \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where λ_h is a predefined threshold. In our experiment, $\lambda_h = 10$. If an image block is classified as "no halftone pattern exists", the next block is processed at once without performing the following segmentation filter design routine.

2.1. Segmentation Filter Design

The objective of this segmentation filter is to achieve maximal separation between halftone and nonhalftone regions. Similar to [3], we design a function $S_f : \mathbf{R}^3 \rightarrow \mathbf{R}$ such that $dist\{S_1, S_2\}$ is maximal, where $S_1 = \{S_f(x) | x \in R_{halftone}\}$ and $S_2 = \{S_f(x) | x \in R_{nonhalftone}\}$. Note that $S_f(x) \equiv F_g(F_s(x))$, where F_s is the designed segmentation filter and F_g is a gaussian low pass filter. Since most energy of an image is concentrated near the DC component, it is captured at node zero. Hence, for other nodes, we can assume that the average of the magnitude of frequency components is similar to white noise. Under this assumption, the problem can be restated as following:

Objective: Design a 2-D filter efficiently to separate between noise and a periodic 2-D signal with a given spatial frequency and its harmonics at $(w_x(i), w_y(i))$ with $i = 1 \cdots n$.

The optimal filter can be shown to have a spatial frequency response $F_s^1(w_x, w_y)$ as follows:

$$F_s^1(w_x, w_y) = \begin{cases} 1 & (w_x, w_y) = (w_x(i), w_y(i)),\ i = 1 \cdots n \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

Researchers have proposed design routines to solve the above question via frequency sampling methods [1][7]. However, the computational complexity becomes very high to satisfactorily meet the objective, and the size of the filter becomes very large. To solve the problem efficiently, we relax the frequency response requirement to be following:

$$F_s^1(w_x, w_y) = \begin{cases} 1 & (w_x, w_y) = (w_x(i), w_y(i)), i = 1 \cdots n \\ 0 & (w_x, w_y) \in Null_{set}^1 \end{cases} \quad (3)$$

where $Null^1_{set} = \{(0,0), (\pm\pi, 0), (0, \pm\pi), (\pm\pi, \pm\pi)\}$. By reordering the filter into a vector, we can formulate constraint (3) as a linear system $Ax_{seg} = b_{c1}$, where A is a Kronecker product of the vertical and the horizontal 1-D FFT chosen basis vectors, and $b_{c1} = [1 \cdots 1, 0 \cdots 0]^t$ with the first n elements being 1 and nine 0s. It can be shown that singular values associated with A gradually decrease to zero, hence, the range space $R(A)$ composed of vectors with negligible singular values should be excluded to solve the corresponding equation with numerical stability. Hence, we adopt the truncated singular value decomposition to solve the above equation.

3. DESCREENING FILTER DESIGN

The objective of designing a descreening filter is to eliminate periodic signals associated with the screening process while preserving edge information within the original image. Several techniques have been proposed to process an image into piecewise smooth regions while preserving or even enhancing edges. For example techniques such as anisotropic diffusion, total variation minimization, and Markov random fields. Instead of adopting the traditional L^2 norm, the above techniques minimize a predefined energy term with a regularization term under L^1 norm, which does not penalize a function for being piecewise constant. As a result, a processed image becomes near-graphic. For instance, the image may appear to have posterization effects, where there are large areas of uniform gray scale. Although edge information is preserved, even enhanced, people often find its visual quality objectionable and prefer a slightly blurred image instead. Note that simply applying those techniques is insufficient because they do not differentiate real edges from halftone patterns. To accomplish the objective, we propose a suboptimal FIR filter. This algorithm offers a computationally efficient descreening approach.

3.1. Linear FIR Filter Design

Because of the objective noted previously, we can restate it in the frequency domain as the following requirement:

$$F_s^2(w_x, w_y) = \begin{cases} 0 & (w_x, w_y) = (w_x^s(i), w_y^s(i)),\ i = 1 \cdots n \\ 1 & \text{otherwise} \end{cases} \tag{4}$$

where $(w_x^s(i), w_y^s(i))$, $i = 1 \cdots n$, are detected screen repetition frequencies and their harmonics. Following the same argument made in the previous section, it is necessary to relax constraint (4) to achieve efficient implementation. We suggest a reduction in the number of constraints to only $n+1$, where n is the number of detected frequencies. They are shown as follows:

$$F_s^2(w_x, w_y) = \begin{cases} 0 & (w_x, w_y) = (w_x^s(i), w_y^s(i)),\ i = 1 \cdots n \\ 1 & (w_x, w_y) = (0, 0) \end{cases} \tag{5}$$

This simplified constraint only requires the filter to have frequency response one at the DC component and zero at the harmonics. "Don't care" is assigned to the rest of the frequency domain. Like the previous segmentation filter design procedure, constraint (5) can be easily formulated as a linear system, $Ax_{ds} = b_{c2}$ with x_{ds} being the filter coefficients in lexicographic order and $b_{c2} = [0\ 0 \cdots 0\ 1]^t$. As we gradually increase the size of a filter, the error term $r(n) = \| A\bar{x} - b_{c2} \|$ will gradually reduce towards zero. The size of the filter is chosen at the knee point of the obtained sequence $\{r(1), r(2), \cdots, r(n)\}$, and the filter is the corresponding solution vector $\bar{x}_n$. As a result, the designed filter can eliminate frequencies generated by the screening process without excessively blurring the halftoned image.

4. EXPERIMENTAL RESULTS

Figure 1 illustrates the original halftoned image, and the detected halftone regions are shown in Figure 2. The result shows that the proposed halftone detection scheme accurately segments the image into halftone and non-halftone regions. Moreover, this algorithm is applicable to a document which contains halftone regions with irregular boundaries. For example, in the bottom image in Figure 1, the road and the sky do not contain halftone patterns. Hence, they are excluded by the segmentation algorithm. Figure 3 illustrates the 5×5 suboptimal descreening FIR filter associated with this halftone pattern. Unlike traditional low pass filters, e.g. Gaussian low pass filters, coefficients of the filter do not reduce to zero at the boundaries. On the contrary, they exhibit a periodic structure.

Figure 4 and Figure 5 show a segment of the original image and the corresponding descreened image. It demonstrates that the above filter successfully removes the screen without excessive blurring.

Figure 1: Original halftone image

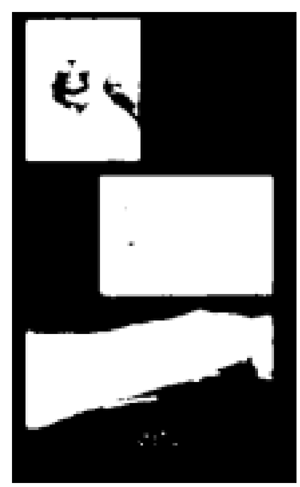

Figure 2: Detected halftone region

5. DISCUSSION AND FUTURE WORK

The proposed algorithm offers efficient and complete gray scale halftone document analysis. It can be applied to documents with complex halftone regions. A complete halftome document analysis should include processing of color halftones.

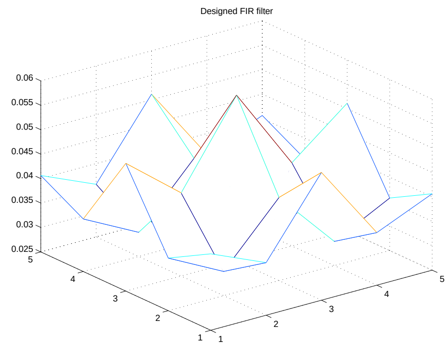

Figure 3: Descreening FIR filter

Figure 4: Halftone image

Figure 5: Descreened image

Hence, we plan to generalize this technique to handle color halftones.

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