Enhancing Oriented Pattern Using Adaptive Directional FFT Filter

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Abstract

It is well known that the output of Fourier Transform in general is orientation dependent. As such, by applying a two-dimensional (2D) discrete Fast Fourier Transform (FFT) onto an image with oriented pattern, the output image will show a clustering around a specific orientation. By strengthening the points located in the cluster and suppressing the points outside of this cluster, the oriented pattern in the image can be enhanced. This paper describes a new method in which a bandpass filter is coupled with an adaptive ‘angular filter’ to achieve directional filtering. This filter is then applied onto the two-dimensional FFT output to enhance the image. The bandwidth of the angular filter is changed adaptively in proportion to the confidence level of the computed orientation of the desired pattern. Such adaptive changes in the angular bandwidth prevent excessive filtering where consistency of the orientation is low. The proposed approach is used to enhance fingerprint images. Experimental results show the desirable features of the proposed approach.

1. Introduction

Two-dimensional discrete Fourier Transform has been a very useful technique in image processing. It is used for enhancement, convolution, filtering and analysis [1]. It is also well known that the output of the 2D Fourier Transform is orientation dependent. As such, by applying a two-dimensional (2D) discrete Fast Fourier Transform (FFT) onto an image with oriented pattern, the output image will show a clustering around a specific orientation. By strengthening the points located in the cluster and suppressing the points outside of this cluster, the oriented pattern in the image can be enhanced. Since fingerprint images is an oriented texture pattern with ridges separated by valleys, such an approach has been applied to enhance fingerprint images [2]. An excellent comparison of the available approaches can be found in [3]. Spatial approaches are proposed in [4,5,6]. Recently, L. Hong, Y. Wan and A. K. Jain in [7] introduced a fingerprint image enhancement method that employed a Gabor filter.

The above proposed approaches basically perform low pass filtering along the dominant orientation which is along the ridge and band-pass filtering along the orientation orthogonal to the dominant orientation. Such filtering, which is a form of oriented bandpass filter, is able to increase the clarity of fingerprint structure or the contrast between the ridges and valleys. Therefore it is able to separate some linked ridges in cases where the ridge frequency is similar to the value estimated before the design of the band pass filter. However, the filtering algorithm will be effective only if the estimated frequency of the textured pattern (ridge frequency) is correct. Otherwise, the filtering could combine two ridges into one if the bandwidth is larger than the actual frequency or a wide ridge is separated into two ridges if the bandwidth is too narrow. Unfortunately, exact and robust estimation of the ridge frequency is not an easy task. Natural variation in the ridge frequency needs to be taken into account in practical fingerprint images as usually, most practical images cannot be considered as statistically stationary. Therefore, some adaptive capability will be useful for practical applications. This paper introduces a method to enhance images with oriented patterns, particularly the fingerprint images, using an adaptive directional bandpass filter, implemented using 2D discrete FFT.

2. Adaptive directional bandpass filter

A gray level fingerprint consists of oriented narrow ridges separated by narrow valleys. Both the ridges and valleys are usually locally parallel, except at the minutia. The local ridge orientation and local ridge frequency are two important intrinsic characteristics of the fingerprint image. When the
Fourier transform of the fingerprint is taken, the local ridge frequency determines its distance from the origin of the transformed output while the local ridge orientation determines its angular position [2]. To perform an effective filtering, the filter parameters should be adaptive to these two intrinsic features of the fingerprint image.

\[ H_m(r) = \frac{1}{\sqrt{1 + p^2}} \]  
\[ \text{where } p = (r^2 - r_o^2)/r*r_{bw}; \]
\( r_o \) is the centre frequency and \( r_{bw} \) the desired bandwidth.

Each local region would normally have only one dominant local orientation (see Fig. 2 and Fig. 3), \( \phi_c \), except for regions where there exist significant changes in the orientation such as the singular regions and at the minutiae. As such, the filter should have a narrow “angular bandwidth” \( \alpha_1 + \alpha_2 \) for local region with strong dominant orientation, but a wider angular bandwidth for region which exhibit substantial orientation changes. In other words, the angular bandwidth in each local region should be adaptive to the level of the orientation dominance. The existence of the angular bandwidth provides the filter with the capability to enhance oriented patterns and as such can be considered as the angular filter, \( H_a(\phi) \) [9]. This can be realized using:

\[ H_a(\phi) = \begin{cases} \cos^2 \frac{\pi f}{2\phi_{bw}} & \text{if } |\phi - \phi_{bw}|, |\pi - \phi| < \phi_{bw} \\ 0 & \text{otherwise} \end{cases} \]  
\[ \phi_{bw} \] is the angular bandwidth of the filter
\( \phi_c \) is the dominant orientation

In order to have an effective bandpass filtering, the filter must be able to reduce noise, smooth the small holes and link the small breaks in a ridge but does not link up two or more not well separated ridges. In the direction parallel to the dominant orientation of the local ridge, the frequency will consist of the dominant frequency, its harmonics and the associated spectral composition adjacent to the dominant frequency. As such, the filter should have a sufficiently large bandwidth \( (R_2-R_1) \) in this orientation (see Fig. 1). This is a magnitude filter, \( H_m(r) \), and a general bandpass filter such as the second order Butterworth bandpass filter is used [8]:

**Fig. 1** The shaded region represents the Bandpass filter zone of the centered Discrete Fourier Transform image.

**Fig. 2** A region selected from a fingerprint image.

**Fig. 3** The magnitude plot of the FFT of Fig. 2. Notice that the FFT image shows a dominant orientation.

The angular filter, \( H_a(\phi) \), can be made adaptive by manipulating the angular bandwidth, \( \phi_{bw} \), such that the value of the angular bandwidth is dependent on the level of the local orientation dominance. This can be done as follows:

1. Threshold the FFT image with a specified magnitude threshold. The pixel with magnitude greater than the threshold value is the foreground pixel.
2. With the centre of the FFT image, divide the image into discrete angular sections (see Fig. 4).
3. Count the number of foreground pixel in each angular section.
4. From the angular section with the largest count, include the count of the two angular sections...
nearest to it (in the clockwise and anti clockwise direction) until a required percentage of the total available foreground pixels have been accumulated. The angle span by these angular sections is the required angular bandwidth, $\phi_{bw}$.

5. The midpoint of the angular bandwidth can be considered as the normal to the desired dominant local orientation, $\phi_c$.

Using the above approach, the desired adaptive directional bandpass filter, $H_f(r,\phi)$, can be obtained from:

$$H_f(r,\phi) = H_m(r) * H_a(\phi) \quad (3)$$

3. **Implementation**

The adaptive directional bandpass filter as suggested above will require that there exist a local dominant orientation. Therefore, applying the filter to the whole fingerprint image will not be possible. A scheme to implement the filter is suggested below:

1. Divide the image into small blocks. The size of each block should cover sufficiently several instances of the oriented pattern so that accurate dominant frequency can be established.

2. For each block, apply 2D discrete FFT to the image and shift it to obtain the FFT spectrum with the zero frequency component located at the centre of the spectrum.

3. From the FFT spectrum, compute the dominant local orientation, $\phi_c$, of each block and its angular bandwidth $\phi_{bw}$ using the method described above.

4. Compute the desired adaptive directional bandpass filter, $H_f(r,\phi)$, using Equation (3).

5. Multiply the FFT spectrum of the block with the respective filter, $H_f(r,\phi)$, computed.

6. Apply the inverse FFT transform to recover the filtered image.

7. Stretch and normalize the contrast if necessary.

8. Repeat the above procedures until all the blocks are processed.

4. **Sample results**

The proposed image enhancement approach is used to enhance the fingerprint images. Fig. 5 and 6 show two sample fingerprint images and Fig. 7 and 8 show the respective enhanced images. Notice that in the regions where the curvature is large, the filter does not excessively erode the curve ridges. This is the feature of the adaptive bandwidth. There are some regions where the enhancement degrades the quality of the fingerprint. This is due to the incorrect estimation of the dominant local orientation, $\phi_c$, which causes the filter to perform erroneously.

5. **Conclusions**

This paper proposed a method to realize an adaptive directional bandpass filter in the frequency domain. Such a filter is useful for enhancing oriented patterns which have dominant local orientations, such as the fingerprint images. The filter is able to reduce noise and link the broken pattern while avoiding excessive filtering in regions with high curvature. Experimental results show the desirable features of the proposed approach.

References


Fig. 5. Sample fingerprint image 1.

Fig. 6. Sample fingerprint image 2.

Fig. 7. Sample enhanced fingerprint image 1.

Fig. 8. Sample enhanced fingerprint image 2.