INSPECTION SYSTEM OF FABRIC BASED ON TEXTURE SEGMENTATION UTILIZING GABOR FILTERS

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Abstract

An implementation of Gabor filters for description of texture and subsequent texture segmentation has been described. The filters are applied in a new method for the defect detection of dissimilarities of fabric during it's quality inspection process. Design of Gabor filter is presented in frequency domain. Filtering was realized in software and it has been used together with dedicated inspection.

1 Introduction

There are many approaches in the development of automated system for quality evaluation of surface properties. In textile industry, one can most often see manual methods of inspection of quality of fabrics. This process involves a human operator to watch the surface of material and mark the faulty areas by hand. Advanced loom machines are able to detect some faults by themselves, however, there is still significant amount of defects, that need to be inspected later, after the weaving stage. Those defects, that can not be detected on the loom, are particularly certain variations in the appearance of the product. Defects like broken pick or coarse yarn are sorts of defects that can be detected directly on the loom. In contrast, those defects like appearance fault, a stain, a hole or a weft kinks, belong to class of defects that remain unnoticed by any other systems than the visual.

2 Gabor Filter

Gabor filter is a finite impulse response filter proposed by Gabor [1]. Generalized 2D filters are widely used in image processing for line and edge enhancement. Filters impulse response in spatial domain is defined as Gaussian envelope modulated by periodic function. Gabor kernel in frequency domain is a bandpass filter defined by equation

$$G(\Omega, \Theta) = e^{-(\frac{\theta-\Theta}{2\sigma_r})^2-(\frac{\omega-\Omega}{2\sigma_a})^2}. \qquad (1)$$

The principle of using filters in frequency domain consists of multiplying the spectrum of input image by a set of (non overlapping) kernels that together cover the entire area of the spectrum. The frequency representation of spatial input image is obtained by Fourier transformation with DC component shifted to the center of frequency space. It is appropriate to carry out the design of kernels in polar coordinates, which is consistent with the previous definition of the filter in equation (1). Here the symbols ω, Ω denote frequency - while describing spectrum in polar coordinates - Ω denotes the distance from center of the frequency space ω; Θ refers to angular distance of the origin of the kernel measured relatively to the horizontal axis; σ_a and σ_r denotes axial (frequency) and radial (orientation) bandwidths of the kernel. Construction of Gabor filter in frequency domain is illustrated in Figure 1(a). Note that this illustration shows only the 1^{st} quadrant of the frequency space.

Filters, like the one shown in Figure 1, are constructed to cover the whole frequency space in such a way that they meet certain criteria. There is considerable redundancy when adjacent filters overlap [2], which can be reduced by means of following filter design. Radial (angular) bandwidth σ_r is a constant value for the entire set of filters. Axial bandwidths of the filters are set one octave wide depending on the distance Ω of the filter from the origin O. Let's consider

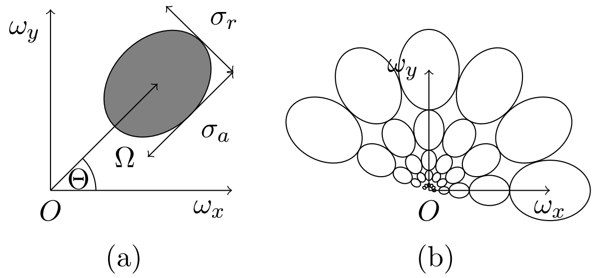

Figure 1: The design of Gabor filter in polar coordinates; (a) only the first quadrant of frequency space is visible, so that O is placed at the center of frequency space; (b) the frequency space is distributed into multiple channels by the set of Gabor filters.

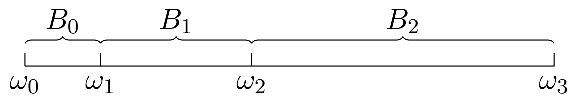

Figure 2: Explanation of octave; w_i denotes increasing frequency, B_i values denote band width of respective octave. The width B_i or width of i-th octave equals to w_{i-1}.

two different frequencies ω_0, ω_1 such that $2\omega_0 = \omega_1$. Then, the distance between these two frequencies is one octave wide. Let's take the third frequency ω_2, which is twice as high as the second frequency: $\omega_2 = 2\omega_1 = 2 \times 2\omega_0 = 2^2\omega_0$. The distance between frequencies ω_0 and ω_2 is in the range of two octaves. It follows that the number of octaves k, that spread between two different frequencies ω_{min}, ω_{max}, is given by equation

$$k = log_2 \frac{\omega_{max}}{\omega_{min}} . \tag{2}$$

The value of i-th bandwidth $B_{a,i}$, in axial direction, equals to its lower frequency limit ω_i, as shown in Figure 2. The center of each filter is placed in the middle of i-th octave. In order to avoid redundancy produced by overlapping adjacent filter, their extents are designed so that the neighbouring filters touch at half of the filters peak value. Filters take values between $< 0, 1 >$; the peak stands in the center of Gaussian and decreases outwards. The size of standard deviation in axial direction σ_a can be derived from Figure 2, where the width of the i-th band is denoted B_i. In accordance to equation (1) we get $e^{(-\frac{B_{a,i}/2}{2\sigma_a})^2} = 0.5$, thus, the i-th standard deviation in axial direction is given by $\sigma_a^i = \frac{B_{a,i}}{2\sqrt{2\,ln(2)}}$. The number n of filters is a constant value for all bands and it defines the bandwidth of the filter in radial direction $B_r = \frac{2\pi}{n}$. The size of the standard deviation in the angular direction is therefore also a constant, $\sigma_r = \frac{B_r}{2\sqrt{2\,ln(2)}}$.

Thanks to the symmetry of the Fourier spectrum around the origin, it is sufficient to process only one half of the domain. At the moment of preparing bank of filters, it is therefore sufficient to include only the filters at angles between $\langle 0, \frac{\pi}{2} - B_r \rangle$. Resulting filter bank for $B_r = 30°$ and octave count $k = 7$ is shown in Figure 3.

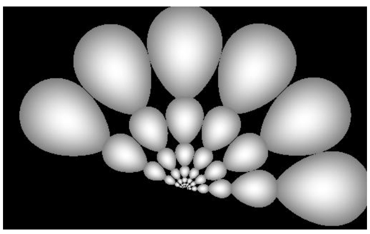

Figure 3: A bank of Gabor filters.

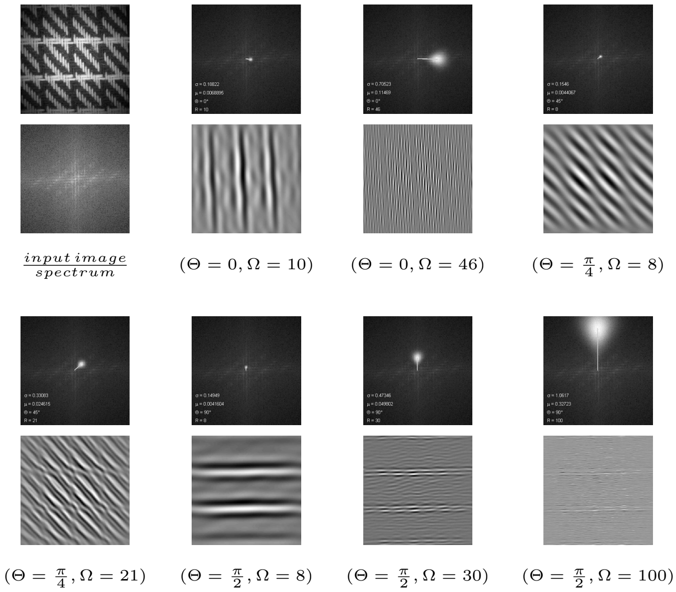

Figure 4: Output of filtering the spectrum of an input image (see left hand upper corner) by various Gabor filters. Superimposed spectrum with the filter is show in the 1^{st} and the 3^{rd} row. There is also a radius vector printed on each image that connects the center of the spectrum plane with the origin of the filter. Pictures below show the inverse Fourier transform of filtered spectrum.

It is worth to mention how the filter bank is used during the process of texture description and segmentation. In textile industry, the inspection system has to deal with large images. In order to analyse them, the approach of local analysis is used instead of capturing global information about the input image that is acquired from the surface of fabric. Local analysis is carried out by means of dividing the area of input image into two dimensional rectangular sub ranges. The later analysis is performed within each range independently. This process is also called a tessellation of spatial domain. Within each range, the Fourier transform is carried out and then shifted so that the DC component appears in the center of spectrum domain. After that, each filter from the bank is used as a mask of given spectrum, in order to perform band pass filtering. In frequency domain, filtering is carried out by multiplying corresponding pixels of the spectrum and the filter. There are certain examples of filtering the input image by Gabor filters of various settings shown in Figure 4. There are both the spectrum and the filter superimposed in odd rows and the result of filtering on even rows. The result is presented here as the inverse Fourier transform of filtered spectrum. The special feature of Gabor filter, which lies in the fact that it gives information about certain frequency at specified orientation, is perfectly usable in conjunction with patterned textiles.

3 Conclusion

Application of filters in frequency domain was used for calculation of similarity between a set of different textures. The principle of similarity estimation was also used for inspection of woven textiles in terms of defect detection and localization. In order to evaluate the possibility of deploying Gabor filters for surface inspection under real conditions, dedicated laboratory device had been built. The device acquires digital image of moving fabric with an array of line scan cameras. The application provides a robust platform for high performance software components, that implement specific tasks and that allows connection of these components into complex processing pipeline. Gabor filters, implemented in such environment, proved themselves to be suitable method of inspection in real-time with sufficient accuracy on certain types of visible defects.

Acknowledgment

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