Circle Detection Using a Gabor Annulus

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We present a novel circle detection technique based on the desirable properties of Gabor wavelet filters. Circles are found frequently in nature, as perfect circular structures provide an optimal area-to-perimeter ratio. The ability to accurately detect circles is therefore useful in a range of practical image processing applications.

In the case of circular features identified by strong edges, techniques such as the Circular Hough Transform (CHT) can be used to identify the circle's centre location. However in real applications it is common to encounter circular features where edges are not clear, and some radial pattern may instead identify the feature. Work by Atherton and Kerbyson [1] focussed on assessing the CHT and modifications to the technique. This includes an 'Annulus' version of the CHT which uses a single accumulator space for multiple radii, and a Phase Coded Orientation Annulus (PCOA) which incorporates edge orientation.

Gabor wavelet filters are used in a large number of image processing tasks, for example in texture analysis [3] and face recognition [2, 4]. Gabor wavelet filters are a method of extracting the spatial location of underlying frequencies within an image. It is this useful property which acts as the basis for our new filter design aimed at extracting circular or symmetrical features within an image, where clear edges may be absent or only partially present.

Our proposed filter aims to use the ability of Gabor wavelets to detect image features and patterns at specific scales and orientations in order to detect circular features. The proposed Gabor Annulus technique therefore offsets the traditional Gabor filter by a radius which wraps around the origin, and is defined as follows:

$$G(x,y) = \frac{1}{2\pi\sigma r_0} e^{-\pi\left[\frac{(r-r_0)^2}{\sigma^2}\right]} e^{i[2\pi f_0(r-r_0)]} \tag{1}$$

where

$$r = \sqrt{(x-x_0)^2 + (y-y_0)^2}$$

In this new filter σ specifies the standard deviation of the Gaussian envelope in the waveform direction, which now expands radially outwards from the centre of the filter. r_0 specifies the radius of the 'annulus' shape. The second exponent is the complex plane wave with frequency f_0 in the waveform direction. (x_0, y_0) specify the centre coordinates of the filter in the spatial domain.

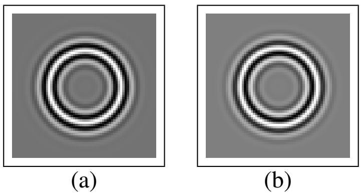
(a) (b)

Figure 1: Example Gabor Annulus filter. (a) Real part of filter (b) Imaginary part of filter. The filters were generated using Equation 1 with $r_0 = 16$, $\sigma = 10$ and $f_0 = 1/5$.

An example of a generated Gabor Annulus filter is provided in Figure 1. The filter is similar to the original Gabor wavelet filter, but the complex plane wave now radiates from the centre of the filter, and the Gaussian envelope is now centred around the radius of the filter. This creates a filter that responds to image features which are circular in form and consist of matching radial frequencies on their boundaries. The filter response will be strongest at the centre of a matching feature, giving a centre location for the circular image feature. Similarly to traditional Gabor filters the new Gabor Annulus technique can use a single 'mother' filter to create a family of filters at various scales. These can then be used to match circular image features at various sizes within the image.

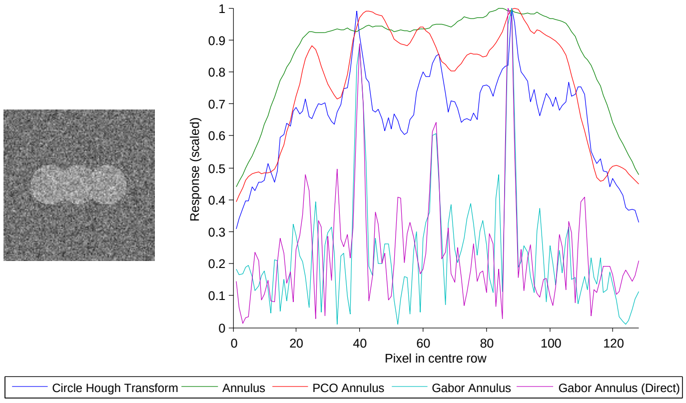

Figure 2: Tests with a multiple circle synthetic image with added Gaussian noise ($\sigma = 0.7$). Graph shows filter responses (scaled by the maximum response in the row) at each pixel for the centre row of the image. We ideally expect three clear peaks indicating circle centre locations against a low background response.

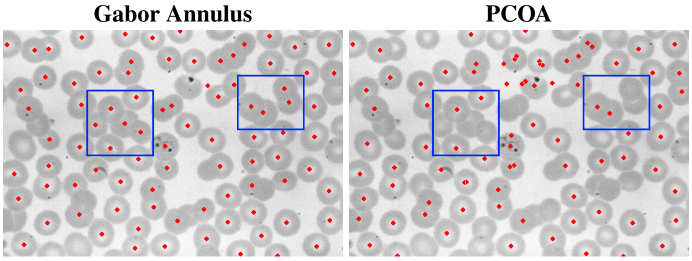

Figure 3: Circle detection applied to microscopic image of red blood cells. Cell centre locations for each technique are marked in red. Example areas containing numerous overlapping cells are highlighted in blue rectangles.

The proposed filter was first tested on synthetic images of single and overlapping circles, both with and without added noise. An example test of multiple overlapping circles with noise is shown in Figure 2. In the synthetic tests the technique demonstrated higher peak to mean response ratios in all cases, clearer responses in high levels of noise, the ability to respond to overlapping circles with a lower background level response, and the ability to run directly on the image (i.e. without first performing edge detection) without affecting accuracy. This latter attribute makes the filter suitable for use in scenarios where clear edges are not present.

This was demonstrated in the real image tests using microscopic red blood cell images obtained from the Centre for Disease Control and Prevention (CDC) Public Health Image Library, where the proposed Gabor Annulus technique demonstrated the best detection rates and the lowest false positive rates. An example showing detected cells is shown in Figure 3. We therefore conclude that the proposed technique is a viable circle detector which offers advantages over traditional CHT and CHT based modifications, and has direct applications to real medical images.

[1] T.J. Atherton and D.J. Kerbyson. Size invariant circle detection. *Image and Vision Computing*, 17(11):795–803, 1999. ISSN 0262-8856.

[2] C. Liu and H. Wechsler. Gabor feature based classification using the enhanced fisher linear discriminant model for face recognition. *Image Processing, IEEE Transactions on*, 11(4):467–476, 2002. ISSN 1057-7149.

[3] B.S. Manjunath and W.Y. Ma. Texture features for browsing and retrieval of image data. *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, 18(8):837–842, 1996. ISSN 0162-8828.

[4] L. Shen and L. Bai. A review on Gabor wavelets for face recognition. *Pattern Analysis & Applications*, 9(2):273–292, 2006. ISSN 1433-7541.