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Robust multi-scale orientation estimation: Directional filter bank based approach

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ABSTRACT

Orientation estimation is considered as an important task in many subsequent pattern recognition and image enhancement systems. In a noisy environment, the gradient-based estimator provides poor results. A pre-smoothing Gaussian function with an appropriate scale is conventionally used to get improved gradients. Later on, a family of pre-smoothing Gaussian functions with a range of scales is employed for estimation, this is referred to as multi-scale orientation estimator. To provide groundwork for comparison, a more formal framework of multi-scale orientation estimation, based on scale-space axioms, in spatial domain is presented. Then for improvement purposes a Fourier domain approach, where directional filter bank (DFB) structure is embedded in multi-scale orientation estimation framework, is proposed. This is referred to as multi-scale DFB approach. The paper presents the comparison work for estimation of local orientations using multi-scale approaches both in spatial and Fourier domain. In the Fourier-domain approach, two linear combinations are deployed, one across the directional image, and the other across the scales. This is opposed to only one linear combination across the scales, used in simple spatial domain techniques. Further more, the DFB-based Fourier domain approach extracts the best local orientation by comparing and contrasting all possible orientations with their respective strength measures. The strength measure used in Fourier method is based on local variance, free from inaccurate gradient calculation. Simulations are conducted over noisy test images as well as real fingerprints. Our objective results indicate that multi-scale Fourier domain approach always yields better estimates at variable level of noise as compared to stand alone multi-scale spatial domain approaches. The improvements made by Fourier domain estimate can largely be attributed to the use of double linear combination both across the directional bands and across the scales.

1. Introduction

The flow directions, also called orientation field (OF) estimation, can quickly become challenging in the presence of noise and variable background illumination. Once reliably extracted the orientation field can be utilized in a number of ways to enhance the quality of the elongated features present in a given image. The motivation for extracting a reliable

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orientation field came from our previous work on angiogram images [4], where a two-dimensional anisotropic diffusion process put forth in [1] for enhancement was found to be conveniently decomposed as a product of two independent one-dimensional diffusion processes, where one process goes along the features, and the other across it. Seeing their greater role in simplifying the enhancement process, we focus here on robust estimation of the orientation fields for noisy images in general.

The simplest and most natural approach for extracting local directions is based on computation of gradients. Invariably, the camera sensors contribute their electronic noise to the image formation process. This makes the job of extracting local orientation hard. One effective way to reduce noise is to smooth the image before taking derivatives. For this purpose, a 2-D Gaussian function $G(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$ is employed with a specified scale σ. The scale used with Gaussian function has to be linked with width of the elongated features present. This invokes scale-space theory [12–14], which advocates the usefulness of shape-adaptive smoothing in the form of choosing an appropriate scale matched to feature width. In the work presented here, we look towards scale-space theory for guidance in providing a unified framework for selecting appropriate scales for extracting effective and reliable local orientations.

Earlier in literature, a simple but elegant regularization step was proposed by Kass and Witkin in [2], which allows local gradient estimates to be properly averaged. They introduced the idea of doubling the orientation angles, and then averaging the angles in a local window with x- and y-component treated separately. In the mean time, the idea of orientation diffusion was also floated [15] as a gradual iterated smoothing process. The orientation diffusion on average is found to take a large number of iterations to converge, and lacks a proper stopping rule. Later on, the authors in [5] shown an effective averaging concept for computing the orientation field. Their derived method is found to be mathematically equivalent to taking the Principal Component Analysis (PCA) of autocorrelation matrix of a group of gradient vectors within a local neighborhood. Inspired by this development, a PCA-based method in a multi-scale framework was put forth in [3], which effectively enforced smoothness across scales, but needs no iterations. The multi-scale PCA provides a compromise between native resolution of the orientation field and its relative accuracy. Though the multi-scale PCA technique is shown to produce robustness against noise, its performance degrades quickly as the intensity of noise increases. For noisy environment, reliable orientation estimates can be obtained in the Fourier domain [8]. Another recent article [7] proposes the use of parallel neighboring cells to improve the local estimate. However, the neighborhood size is fixed for all the pixels under consideration. In the same vein, a reliable orientation estimate is also put forth in [9]. However, all these methods deal in one way or the other with the spatial domain enhancements.

There are a few fixed-scale transform domain orientation estimation techniques reported in literature. A Curvelet-based method for local orientation is introduced in [10], where a *mother curvelet* is scaled and rotated to find the optimal local orientation. However, the method is strictly fixed-scale with assumption of knowing the object size. Another Fourier-based technique is demonstrated with finding the fiber orientation of a paper surface [11]. Here Fourier transform of the whole image region is taken and then converted to polar co-ordinates. The power spectrum is radially accumulated along various orientation. The orientation of the paper is announced with maximum accumulation along a given orientation. This method provided global orientation of a given paper image, while ignoring the local perturbations. Considering a texture image as a combination of piecewise linear components, a directional filter bank (DFB) based approach has been successfully used in the past for enhancing weak elongated features [4]. The method was used for enhancement of narrow width and weaker contrast vessels. The directional decomposition has one main advantage. The directional images, as output of DFB, contain only features in a narrow directional range and are found to contain significantly less noise as compared to the original image. Thus provides a natural domain of quantized directions. This results in directional images to have strong energies in particular directions, which provides a stronger clue towards their local orientations.

Capitalizing on the gains associated with the use of directional decomposition, we suggest to incorporate the DFB structure with multi-scale framework. We employ directional energy computations as a mean to extract local orientations. Directional energy parameter is computed through local variance in each directional image, which release us from the worry of computing inaccurate gradients, which remains to a larger part the weak point of almost all spatial domain techniques. The strength parameter can later be used to compare directional images to come up with a final orientation image. The directional energy strength measure can be computed as a function scale to make it flexible enough to obtain an optimal orientation estimate with the characteristics of low noise power and feature localization.

The paper is organized in eight sections as follows. Section 1 provides the introduction of the orientation estimation issue and previous attempts to solve it. Section 2 explains the gradient based approach, which is extended to include Principal Component Analysis (PCA) in Section 3. In Section 4, the multi-scale PCA approach is formulated. For implementing DFB based orientation estimation, the DFB construction rules are discussed in Section 5. The Section 6 is describing our multi-scale DFB approach for orientation estimation. The last two Sections (7 and 8) are about simulation results and concluding remarks.

2. Gradient based method

The most natural tool for finding orientations at location (i,j) of an image f, is the use of the gradient, denoted by ∇f, and defined as the vector