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Accurate optical flow in noisy image sequences using flow adapted anisotropic diffusion

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Abstract

In this paper, we combine 3D anisotropic diffusion and motion estimation for image denoising and improvement of motion estimation. We compare different continuous isotropic nonlinear and anisotropic diffusion processes, which can be found in literature, with a process especially designed for image sequence denoising for motion estimation. All of these processes initially improve motion estimation due to reduction of noise and high frequencies. But while all the well known processes rapidly destroy or hallucinate motion information, the process brought forward here shows considerably less information loss or violation even at motion boundaries. We show the superior behavior of this process. Further we compare the performance of a standard finite difference diffusion scheme with several schemes using derivative filters optimized for rotation invariance. Using the discrete scheme with least smoothing artifacts we demonstrate the denoising capabilities of this approach. We exploit the motion estimation to derive an automatic stopping criterion.

Keywords: Motion estimation; Noise removal; High accuracy

1. Introduction

Scientific, medical or industrial imaging often operates at the sensor sensitivity limit and thus the acquired data suffers from noise. In this article we focus on anisotropic diffusion techniques specially designed for the enhancement of image sequences with dense temporal sampling and motion estimation in these sequences. Combining motion estimation and smoothing is crucial in order to temporally average over the same area of a moving object.

Motion estimation by conventional optical flow uses a brightness constancy assumption via the brightness constancy constraint equation (BCCE). This means that motion can be estimated consistently if the local temporal evolution of the image can be explained by pure translation of the initial

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image patch. In spatio-temporal image regions where this constraint is not fulfilled, e.g. motion boundaries due to occlusion or sharp accelerations, motion cannot be estimated with this simple model.

Densely sampled image sequences are 3D data with special properties: in areas where the BCCE is fulfilled they contain projections of object trajectories and thus line-like structures with slowly or not changing gray values. Therefore in these areas it is appropriate to smooth data along these lines and avoid smoothing across them.

In addition a suitable denoising scheme has to avoid to smooth across motion boundaries. The accuracy gain in motion estimation achieved by applying a denoising scheme is maximal, if the smoothing scheme adapts to the spatio-temporal image structure as much as possible. Consequently the smoothing process (orientation-enhancing diffusion) suggested here exploits all the information that is used for motion estimation. In contrast to other schemes (like e.g. edge-enhancing diffusion) it does not enforce the brightness constancy assumption avoiding hallucinated motion estimates at motion boundaries. They are not handled by the motion model and must be suppressed.

In the presented approach we construct an anisotropic diffusion process adapted to the image sequence content via the structure tensor [6,7,18,17]. As the denoising is based on the structure tensor and the full motion information it provides, we also use this method for the final motion estimation. A superior estimation scheme or motion model could be applied there, but still denoising would be done via the structure tensor.

In addition to the diffusion process we carefully design a discrete scheme which allows directed smoothing with especially low directional error and still good smoothing properties. We compare different novel and well known explicit update schemes and select the best scheme for subsequent experiments.

1.1. Previous work and scientific impact

The presented 3d diffusion schemes have been investigated for different applications in [33,32,46,37]. This approach could be shown to be a major contribution to the quantitative analysis of fluorescence microscopic image sequences [32,40]. It promises the use of low light level microscopic data, as e.g. in single molecule experiments in new applications in the entire field of life science. Here we summarize the results of these publications and extend them by

- an analysis of the noise propagation from the data into the structure tensor,
- a derivation of the best suited explicit anisotropic diffusion scheme,
- a more detailed performance comparison of the different diffusion processes,
- more example results on well known test sequences.

Wherever possible we give statistical motivations for parameter settings.

1.2. Related work

Anisotropic diffusion in general has become a widely used technique with a well understood computational theory. It was introduced in [25,9], see e.g. [5,8,38,23,43] for recent overviews. It has been applied to medical [2] and microscopy images [15], and was used for the enhancement of corners [28], ridges and valleys [35] and can be extended to color images [42,22].

There are many different implementation approaches to numerically solve (or simulate) anisotropic diffusion. For isotropic nonlinear diffusion the most simple and common choice is two-level explicit finite-difference schemes. But besides this, there are for instance three-level methods [16], semi-implicit approaches [9] and their additive operator splitting variants [47], multigrid methods [1], adaptive finite element techniques [3], numerical schemes with wavelets as trial functions [16], spectral methods [16], and stochastic simulations [27]. Numerical techniques for anisotropic diffusion filters with a diffusion tensor include finite elements with grid adaptation [26] or multigrid acceleration [12], as well as lattice Boltzmann techniques [21]. Explicit finite difference schemes have been applied before [10,11,45].