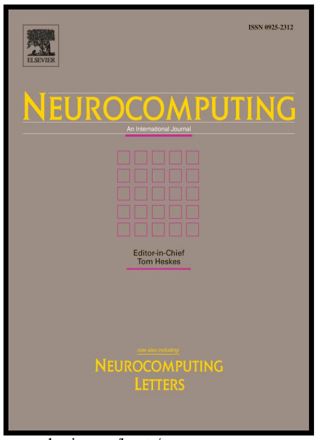

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Abstract

It is hard to estimate optical flow given a realworld video sequence with camera shake and other motion blur. In this paper, we first investigate the blur parameterization for video footage using near linear motion elements. We then combine a commercial 3D pose sensor with an RGB camera, in order to film video footage of interest together with the camera motion. We illustrates that this additional camera motion/trajectory channel can be embedded into a hybrid framework by interleaving an iterative blind deconvolution and warping based optical flow scheme. Our method yields improved accuracy within three other state-of-the-art baselines given our proposed ground truth blurry sequences; and several other realworld sequences filmed by our imaging system.

Keywords: Optical Flow, Computer Vision, Image Deblurring, Directional Filtering, RGB-Motion Imaging

1. Introduction

Optical flow estimation has been widely applied to computer vision applications, e.g. segmentation, image deblurring and stabilization, etc. In many cases, optical flow is often estimated on the videos captured by a shaking camera. Those footages may contain a significant amount of camera blur that bring additional difficulties into the traditional variational optical flow framework. It is because such blur scenes often lead to a fact that a pixel may match multiple pixels between image pair. It further violates the basic assumption – intensity constancy – of the optical flow framework.

In this paper, we investigate the issue of how to precisely estimate optical flow from a blurry video footage. We observe that the blur kernel between neighboring frames may be near linear, which can be parameterized using linear elements of the camera motion. In this case, the camera trajectory can be informatic to enhance the image deblurring within a variational optical flow framework. Based on this observation, our major contribution in this paper is to utilise an *RGB-Motion Imaging System* – an RGB sensor combined with a 3D pose&position tracker – in order to propose: **(A)** an iterative enhancement process for camera shake blur estimation which encompasses the tracked camera motion (Sec. 3) and a *Directional High-pass Filter* (Sec. 4 and Sec. 7.2); **(B)** a *Blur-Robust Optical Flow Energy* formulation (Sec. 6); and **(C)** a hybrid coarse-to-fine framework (Sec. 7) for computing optical flow in blur scenes by interleaving an iterative blind deconvolution process and a warping based minimisation scheme. In the evaluation section, we compare our method to three existing state-of-the-art optical flow approaches on our proposed ground truth sequences and also illustrate the practical benefit of our algorithm given realworld cases.

2. Related Work

Camera shake blur often occurs during fast camera movement in low-light conditions due to the requirement of adopting a longer exposure. Recovering both the blur kernel and the latent image from a single blurred image is known as *Blind Deconvolution* which is an inherently ill-posed problem. Cho and Lee [1] propose a fast deblurring process within a coarse-to-fine framework (Cho&Lee) using a predicted edge map as a prior. To reduce the noise effect in this framework, Zhong *et al.* [2] introduce a pre-filtering process which reduces the noise along a specific direction and preserves the image information in other directions. Their improved framework provides high quality kernel estimation with a low run-time but shows difficulties given combined object and camera shake blur.

To obtain higher performance, a handful of combined hardware and software-based approaches have also been proposed for image deblurring. Tai *et al.* [3] introduce a hybrid imaging system that is able to capture both video at high frame rate and a blurry image. The optical flow fields between the video frames are utilised to guide blur kernel estimation. Levin *et al.* [4] propose to capture a uniformly blurred image by controlling the camera motion along a parabolic arc. Such uniform blur can then be removed based on the speed or direction of the known arc motion. As a complement to Levin *el al.*'s [4] hardware-based deblurring algorithm, Joshi *et al.* [5] apply inertial sensors to capture the acceleration and angular velocity of a camera over the course of a single exposure. This extra information is introduced as a constraint in their energy optimisation scheme for recovering the blur kernel. All the hardware-assisted solutions described provide extra information in addition to the blurry image, which significantly improves overall performance. However, the methods require complex electronic