Blind Estimation of Motion Blur Parameters for Image Deconvolution*

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Abstract. This paper describes an approach to estimate the parameters of a motion blur (direction and length) directly form the observed image. The motion blur estimate can then be used in a standard non-blind deconvolution algorithm, thus yielding a blind motion deblurring scheme. The estimation criterion is based on recent results about the general spectral behavior of natural images. Experimental results show that the proposed approach is able to accurately estimate both the length and orientation of motion blur kernels, even for small lengths which are traditionally difficult.

1 Introduction

In image deconvolution/deblurring problems, the goal is to estimate an original image $f = \{f(x,y),\ x = 1,...,N,\ y = 1,...,N\}$ from an observed image $g = \{g(x,y),\ x = 1,...,N,\ y = 1,...,N\}$, assumed to have been produced according to

$$g = f * h + w, \tag{1}$$

where $h = \{h(x,y),\ x = 1,...,N,\ y = 1,...,N\}$ is the blur point spread function (PSF), $w = \{w(x,y),\ x = 1,...,N,\ y = 1,...,N\}$ is a set of independent samples of zero-mean Gaussian noise of variance σ^2, and $*$ denotes the discrete two-dimensional (2D) convolution,

$$(f * h)(x,y) \equiv \sum_u \sum_v h(u,v)\ f(x-u, y-v). \tag{2}$$

After collecting the elements of f, g, and w into vectors $\mathbf{f}, \mathbf{g}, \mathbf{w} \in \mathbb{R}^{N \times N}$, usually in lexicographic order, (1) can be written in vector notation as

$$\mathbf{g} = \mathbf{H}\mathbf{f} + \mathbf{w}, \tag{3}$$

where $\mathbf{H}$ is a matrix representing the blur operator. This makes clear that (1) is a particular case of the general problem of signal/image restoration from linear and

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noisy observations. For most non-trivial blur kernels, the corresponding matrix is severely ill-conditioned, or even singular, making deconvolution an ill-posed inverse problem.

It's well known that the ill-posed nature of image deconvolution demands some kind of regularization to be used. Among the state of the art methods, we find those based on *total variation* (TV) regularization (see [3,4,8] and further references therein) which favors images of bounded variation, without penalizing possible discontinuities, as well as wavelet-based methods [2,9,10], which also provide regularization without overly penalizing image discontinuities.

In standard deconvolution problems, it is assumed that $\mathbf{H}$ (equivalently h) is fully and exactly known. In *blind* deconvolution, the goal is to deblur an image with (total of partial) lack of knowledge about the blurring operator [13,14]. Blind deconvolution is significantly more difficult than its non-blind counterpart [1]. The problem is now ill-posed both with respect to the unknown original image and to the blur operator. Simply put (and because convolution can be expressed as a product in the Fourier domain), blind deconvolution can be seen as the problem of recovering two functions from their product; a clearly hopeless goal, in the absence of some rather strong assumptions or prior knowledge about the underlying image and blur. Assumptions about the blur PSF which have been used are positiveness, known shape (*e.g.*, Gaussian blur) or known support.

There are essentially two alternative approaches to blind deconvolution: **(i)** simultaneously estimate the image and the blur [1,7]; **(ii)** perform a previous step of blur estimation and then feed this blur estimate to a classical non-blind image deblurring algorithm [6]. In this paper, we introduce a blur estimation technique to be used in an approach of type **(ii)**. More specifically, we introduce a method to estimate the parameters of a "motion blur" from the noisy blurred image, with weak assumptions on the underlying original image.

The particular class of blur operators herein considered, known as motion blur, arises when there is relative motion between the acquisition device (*i.e.*, the camera) and the scene being acquired. For simplicity, we assume that the camera is moving with constant speed and direction, with respect to the scene. The resulting blur kernel/filter has a linear support in the spacial domain and a sinc-like (recall that $\text{sinc}(x) = \sin(x)/x$) behavior in the Fourier domain, leading to well pronounced valleys in the logarithm of the magnitude of the spectrum of the observed image. The method proposed in this paper, exploits the identification of the parameters characterizing this sinc-like behavior (namely, the orientation and period, which correspond to the orientation and length of the blur kernel) using the Radon transform [5]. As will be shown in the experimental results, the proposed algorithm is able to accurately estimate the motion blur parameters (orientation and length) for motion blurs with lengths as short as three pixels.

This paper is organized as follows. In Section 2 we define the motion blur and corresponding parameters for the continuous and the discrete cases. We also define the blur kernel structure used in this work. In Section 3.1, we review some of the state of the art methods and present the proposed algorithm. In