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A novel modified cepstral based technique for blind estimation of motion blur

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ABSTRACT

In the problem of blind image deconvolution, estimation of blurring kernel is the first and foremost important step. Quality of restored image highly depends upon the accuracy of this estimation. In this paper we propose a modified cepstrum domain approach combined with bit-plane slicing method to estimate uniform motion blur parameters, which improves the accuracy without any manual intervention. A single motion blurred image under spatial invariance condition is considered. It is noted that the fourth bit plane of the modified cepstrum carries an important cue for estimating the blur direction. With the exploration of this bit plane no other post processing is required to estimate blur direction. The experimental evaluation is carried out on both real-blurred photographs and synthetically blurred standard test images such as Berkeley segmentation dataset and USC-SIPI texture image database. The experimental results show that the proposed method is capable of estimating blur parameters more accurately than the existing methods.

1. Introduction

Most commonly encountered image degradation during image capture phenomenon by handheld cameras is motion blur. Motion blur is caused when there is a relative motion between the camera and the object being imaged during an exposure time. A motion blurred image is obtained by convolving the point spread function (PSF) with the original image. If the blur kernel i.e., PSF is known a priori, recovering original image from the blurred one becomes feasible easily. However, in the problem of blind deconvolution both the blur kernel and the original image are unknown and both unknowns are required to be estimated from a single blurred image.

A primary step in blind image deconvolution technique is the estimation of PSF either separately or jointly with the restored image. Numerous techniques for PSF estimation have been proposed over the years; an overview of which is found in [11]. These techniques work in spatial as well as frequency domain. Amongst the existing techniques, spectral and cepstral zeros method is widely popular because of its less computational complexity and minimal prior assumptions on images [7,18,2,3]. In the pioneering work by Cannon [2], estimation of motion blur parameters is based on power cepstrum of the image and inspection of negative twin peaks. Chang et al. [3] extended this work in the context of power bispectrum which is more robust to noise. More robust method by employing filtering techniques has been proposed by Fabian et al. in [5] to improve the identification accuracy of the spectral nulls in presence of noise. Rekleitis [17] proposed the use of steerable filter in cepstral domain, to improve the identification accuracy.

Recently the Radon transform (RT) based approach has been proposed for blur angle estimation in [10,14,4]. Instead of working directly on the spectrum of the blurred image, the method proposed by H. Ji et al. in [9] explores the same cepstrum domain using the image gradients. The Hough transform based PSF estimation for motion blurred images using the log spectrum of the blurred images is also presented in [13,19,21]. An obvious limitation on use of Hough transform is the choice of threshold values during binarization and also error in angle estimation causes erroneous length estimation.

In this paper a new modified-cepstral approach along with a novel bit-plane slicing method is proposed to estimate motion blur parameters accurately from single blurred image. This novel yet easier and powerful PSF estimation scheme is useful for blind estimation of motion blur parameters and is applicable to both synthetic as well as naturally motion blurred single image or photograph without any manual intervention.

The rest of the paper is organized as: in Section 2, a uniform motion blur model is presented along with different mathematical preliminaries. Section 3 presents proposed technique for estimation of PSF parameters of motion blur kernel. This section also introduces modified-cepstrum term and compares conventional

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cepstrum versus modified cepstrum based estimation. Experimental results are discussed in Section 4 and conclusions are provided in Section 5 followed by possible future directions of the work.

2. Mathematical preliminaries

In this section, some useful mathematical preliminaries are discussed.

2.1. Uniform linear motion blur model

A blurred image is modeled by 2-D convolution of original image and motion blur kernel as given in Eq. (1).

$$g(x, y) = f(x, y) \otimes h(x, y) + n(x, y) \tag{1}$$

$$g(x, y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(\alpha, \beta) \cdot h(x - \alpha, y - \beta) d\alpha \cdot d\beta + n(x, y), \tag{2}$$

where $\otimes$ is the convolution operator, $h(x, y)$ is a linear PSF characterizing blurring phenomenon for any α and β; $f(x, y)$ is the original image, $g(x, y)$ is the observed blurry image and $n(x, y)$ represents additive noise. With an introduction to the terms blur angle θ and blur length $L = v_0 \times T$ (where v_0 is the velocity of camera movement and T is the exposure time), the motion blur PSF $h(x, y)$ is given by Eq. (3) [12].

$$h(x, y; L, \theta) = \begin{cases} \dfrac{1}{L} & \text{if} \quad \sqrt{x^2 + y^2} \leq \dfrac{L}{2} \text{ and } \dfrac{x}{y} = -\tan\theta \\ = 0 & \text{elsewhere} \end{cases} \tag{3}$$

The task of blind motion deblurring can be divided into two phases:

1. To estimate a PSF that caused the blur and
2. to restore original image by applying conventional image restoration or deblurring algorithms.

2.2. Spectral analysis of uniform motion blur kernel

In order to recover the original image, the two convolved signals are required to be separated from the convolutive mixture, which is possible by means of deconvolution operation. The deconvolution operation becomes convenient in frequency domain, as it takes a multiplicative form as,

$$G(u, v) = H(u, v) \cdot F(u, v) \tag{4}$$

where $G(u, v)$, $F(u, v)$ and $H(u, v)$ are the Fourier transform of $g(x, y)$,$f(x, y)$ and $h(x, y)$, respectively. Here noise term is not considered. Eq. (4) can be rearranged as,

$$H(u, v) = \frac{G(u, v)}{F(u, v)} \tag{5}$$

Obtaining 2-D Fourier transform of Eq. (3),

$$H(u, v) = \sum_x \sum_y h(x, y) e^{-j\frac{2\pi}{M}ux} e^{-j\frac{2\pi}{N}vy} = \frac{1}{L} \sum_{i=l}^{L+l-1} e^{-j\frac{2\pi}{M}ui\cos\theta} e^{-j\frac{2\pi}{N}vi\sin\theta} \tag{6}$$

where i accounts for the possible displacement of the pixels in the direction θ within a span given by the factor L, i.e, blur length.

$$H(u, v) = \frac{1}{L} \sum_{i=l}^{L+l-1} [e^{-j2\pi(\frac{u\cos\theta}{M} + \frac{v\sin\theta}{N})i}] \tag{7}$$

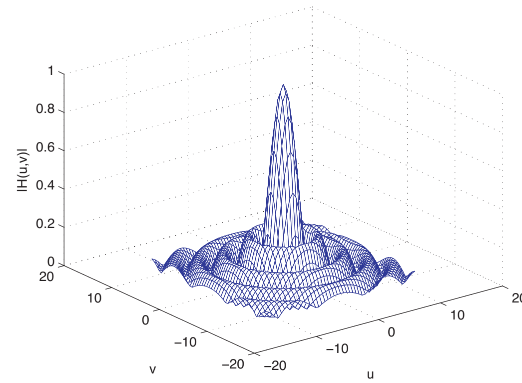

Fig. 1. Magnitude spectrum of motion blur kernel.

Let us assume the factor ω as, $\omega = 2\pi((u\cos\theta/M) + (v\sin\theta/N))$ and using a mathematical identity of finite geometric sum series, Eq. (7) becomes,

$$H(\omega) = \frac{1}{L}.e^{j\omega l}.\frac{1 - e^{j\omega L}}{1 - e^{j\omega}} = \frac{1}{L}.e^{j\omega l}.e^{\frac{j\omega(L-1)}{2}} \frac{\sin(\omega L/2)}{\sin(\omega/2)} \tag{8}$$

Taking magnitude of both sides, magnitude spectrum can be obtained as,

$$|H(\omega)| = \frac{1}{L} \cdot \left| \frac{\sin(\omega L/2)}{\sin(\omega/2)} \right| \tag{9}$$

which is plotted in Fig. 1. Evaluating Eq. (9), for $(\omega L/2) = \pm n\pi$, $|\sin(\omega L/2)|$ becomes 0 and hence $|H(\omega)| = 0$. This corresponds to the zero crossings present in the sidelobes. Also, for $\omega \to 0$, $\lim_{\omega \to 0} |H(\omega)| = 1$. It corresponds to central bright stripe, which is oriented perpendicular to the direction of blur. Thus, the magnitude spectrum characterizes both length and direction of motion blur. This peculiar characteristics is retained in the spectral representation of motion blurred images. Hence the spectral domain analysis of blurred image is found to be useful in the identification of blur parameters. The length of motion, L can also be expressed in terms of D, the distance between two consecutive zeros and the image size $(M \times N)$ as,

$$L = \frac{M \times N}{D} \tag{10}$$

In the conventional techniques, image size is commonly considered to be square-sized for the sake of simplicity. However, in reality, rectangular-sized images such as photographs captured are more popular. As the spectral orders of rectangular-sized images differ from square-sized images, it affects blur length estimation. The proposed technique in this paper performs PSF estimation accurately irrespective of the size of test image, it does not constrain image size to be squared shape only. Therefore it is also suitable for blind deblurring of photographs and natural scenes without any image resize operation.

2.3. Radon transform

Radon transform is an integral transform that consists of the integral of a function along straight lines. Formally, the Radon transform of a real-valued function $\phi(x, y)$ defined over R, at an angle θ and distance ρ from the origin, is given by,

$$R(\phi, \rho, \theta) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \phi(x, y) \cdot \delta(\rho - x\cos\theta - y\sin\theta) dxdy, \tag{11}$$

where δ denotes the dirac delta function. The Radon transform $R(\phi, \rho, \theta)$ is nothing more than the integral of ϕ along a perpendicular direction to a line that forms an angle θ with the x-axis,