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Improved scheme of estimating motion blur parameters for image restoration

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ABSTRACT

A motion deblurring algorithm is proposed to enhance the quality of restoration based on the point spread function (PSF) identification in frequency spectrum. An improved blur angle identification algorithm characterized by bilateral-piecewise estimation strategy and the membership function method is presented by formulating the edges of the central bright stripe. Subsequently, the subpixel level image generated with bilinear interpolation is employed in the blur length estimation by calculating the distance between two adjacent dark strips. Through comparison with the existing algorithms, experimental results demonstrate that the proposed PSF estimation scheme could not only achieve higher accuracy for the blur angle and the blur length, but also produce more impressive restoration results. Furthermore, the robustness of our method is also validated in different noisy situations.

1. Introduction

Motion blur is generated inevitably when relative motion exists between the object and the camera during exposure time [1]. As one of the major causes of image deterioration, it seriously impacts on the performance of vision system in many fields, such as medical imaging, traffic control, aerospace and astronautics [2–5]. Efficient motion deblurring techniques are necessary to enable vision systems function more reliably.

Mathematically, the motion blurred image can be modeled as a convolution of the latent image with the point spread function (PSF), which is also called the blur kernel. In general, the task of motion blurred image restoration is to remove the effect of PSF from the captured blurred one [6]. Early research on motion deblurring mostly focused on pursuing effective solutions to inverse the process, i.e., deconvolution of the degraded image. A lot of well-known deconvolution algorithms have been put forward to solve the problem, such as Wiener filter [7], iterative Richardson–Lucy algorithm [8], Bayesian deconvolution [9], etc. [10,11]. These kinds of approaches are also called non-blind deblurring because of using a predetermined PSF. Most of them could achieve restoration result and thus are widely utilized in inverse filtering. As a matter of fact, PSF is decided by two motion parameters: the direction and angle of motion, whose values are often unavailable due to the unknown motion information under real world circumstances.

An improved solution is the blind image deblurring techniques [12,13], which extracts motion parameters from the blurred image and then restores the true appearance with the estimated PSF. In this kind of method, it is of much significant to determine the PSF, and therefore attracts much attention in the researchers [14–20]. Aizenberg et al. [15] proposed a method to identify both type and parameters of the PSF with multilayer neural network based on multivariate neurons. In order to obtain a good accuracy, an expectation maximization algorithm is presented for recovering blurred images based on a penalized likelihood formulated in the wavelet domain [16]. Cho et al. [17] incorporated the Radon transform within the maximum a priori formulation estimation framework to solve the same problem, which performs well on a broader variety of scenes. Besides, a type of non-stationary Gaussian prior on the gradient fields of sharp images was applied in Ref. [18] without any pre-processing procedures. Hong et al. [19] introduced an adaptive PSF estimation algorithm based on nisotropic regularization, which can effectively remove motion blur of synthetic, indoor, and outdoor real scene images. In most cases, these algorithms have been proved to recover very complex blur kernels and yield impressive results. However, they often need to solve a large system of equations and thus are time-consuming for practical application.

Apart from that, several researchers have proposed some other PSF determination methods by intuitively estimating the blur parameters for blind image deblurring [1,6,21–26]. Lee et al. [1] recovered a simple solution for removing motion blur by discriminat-

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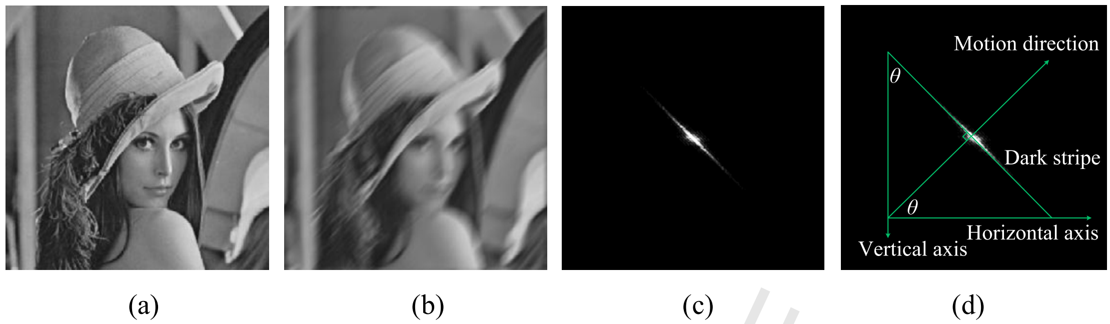

Fig. 1. (a) Original image, (b) motion blurred image, (c) frequency spectrum image of (b), (d) the relationship between the blur angle θ and motion direction in (c).

ing automatically the periodicity of the frequency spectrum based on the gradient variations, but the estimation accuracy of the blur parameters are limited because only one stripe was used directly. Deshpande et al. [23] explored a modified cepstrum domain approach combined with bit-plane slicing method to estimate uniform motion blur parameters without any manual intervention. Aiming to improving the robustness for noisy images, Moghaddam et al. [24,25] combined Radon transform with bi-spectrum modeling and fuzzy set respectively to quantify the motion parameters. However, both algorithms failed to yield good precision especially for large blur length. In addition, Gabor filter and a trained radial basis function neural network are respectively utilized to estimate the blur angle and the blur length in frequency spectrum [6]. Even though this scheme performs comparatively accurate for estimating PSF parameters, it requires sufficient Gabor filter masks in various orientations to ensure its accuracy. The Hough transform based PSF parameters estimation by means of the log spectrum of the blurred images is also presented in Ref. [26]. An obvious limitation of this method is the choice of threshold values during binarization, and therefore the error in angle estimation causes erroneous length estimation. In fact, the estimation precision of the PSF parameters in these methods is limited to a large extent because only the central bright stripe in spectrum was used. Generally speaking, existing approaches for motion deblurring are still not able to achieve a satisfactory balance among precision, robustness and time complexity.

In this paper, a novel motion blur parameters estimation scheme for single blind image restoration is proposed inspired by the regular strips in frequency domain. Differently from the traditional single bright stripe based estimation method, a bilateral-piecewise estimation strategy based on Least Squares combined with the membership function method is presented to obtain a more accurate blur angle. Besides, the subpixel level is also introduced for the blur length estimation in the frequency spectrum image. This method is applicable to both synthetic as well as naturally motion blurred single image, and is also very effective in noisy situations.

The rest of the paper is organized as follows: section 2 introduces the background of image formation in the presence of relative motion and gives the frequently-used motion blur model. Section 3 introduces the two algorithms for estimating the blur angle and the blur length in detail, respectively. A series of comparative experiments are implemented in section 4 to verify the performance of the proposed methods, and conclusions are summarized in section 5.

2. Motion blur model

The image degradation caused by motion can be modeled as a linear shift invariant process [6,27], which is expressed by:

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

where $g(x, y)$, $f(x, y)$, $h(x, y)$ and $n(x, y)$ represent the blurred image, the latent image, the PSF and the additive noise, respectively. The symbol "$*$" indicates the convolution operator.

Assuming the scene object moves uniformly relative to the camera under an angle θ to the horizontal axis during the exposure time, the PSF for motion blurring can be described as [15]:

$$h(x, y) = \begin{cases} 1/L, & \sqrt{x^2 + y^2} \le L/2,\ y = x\tan\theta \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

where L is the blur length and θ is the blur angle.

Figs. 1(a) and (b) show respectively a sharp image and its degraded result caused by a linear motion. When the gradient of such a blurred image is transformed into the frequency domain, a series of bright-dark parallel stripes are contained, as shown in Fig. 1(c). Moreover, Fig. 1(d) illustrates the clues for PSF identification from the periodical distribution of dark stripes. It is clear that the blur angle θ is equivalent to the angle between the parallel dark stripes and the image vertical axis, while the blur length corresponds to the distance between neighboring dark stripes [28]. Therefore, the blur parameters can be determined by calculating the numeric characteristics of these dark stripes.

3. Proposed blur parameters estimation algorithms

3.1. Blur angle estimation

As mentioned previously, the blur angle can be obtained by measuring the direction of the approximately linear dark stripes in frequency spectrum. In order to heighten the estimation accuracy, a bilateral-piecewise estimation strategy is proposed based on the principle of error suppress. First of all, two approximately linear edges on both sides of the central bright stripe, which called upper and lower edges herein after, are extracted by means of edge detection algorithm. Then the identified edges are divided into several overlapping small segments, and the angle between each segment and vertical axis is individually estimated, constituting a series of estimation values of motion direction (i.e., a population of true value). With these angles, the most appropriate representative of the true blur angle can be finally calculated through an effective information fusion method. Compared with traditional approach that just utilizes two points on the central bright strip, the proposed strategy takes the single computation error into account and inherits the conception of reduce the estimation error via multi-measurement average. The detailed processes of the estimation principle are expressed as follows.

3.1.1. Edge detection and piecewise linear fitting

As illustrated in Fig. 1(c), the upper and lower edges determine the range of central bright stripe. Hence, it is very significant to detect them for blur angle estimation. Due to the small margin between the central and secondary bright strips, the result

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