Fast Motion Deblur with Deringing

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***Abstract*—The paper presents a novel technique to restore motion blurred images. Motion blur generally appears due to shaken camera. The method estimates the motion length and motion angle with less computational time. The image is restored using least squares method with the estimated kernel. The deconvolved image is further segmented for smoothening purpose to remove the ringing artifacts. The image clarity is maintained with improved visual quality.**

***Index Terms*— Blur kernel, PSNR, SSIM, ringing artifacts**

I. INTRODUCTION

Motion blur is the result of the relative motion between the camera and the scene during image exposure time. This includes both camera and scene objects motion. Blur is usually modeled as a linear convolution of an image with a blurring kernel, also known as the point spread function (or PSF). Image deconvolution is the process of recovering the unknown image from its blurred version, given a blurring kernel. In most situations, however, the blurring kernel is unknown as well, and the task also requires the estimation of the underlying blurring kernel. Such a process is usually referred to as blind deconvolution. One of the challenging area in research is the estimation of the unknown PSF.

The manner of the PSF estimation significantly depends on the particular kind of images such as astronomy and astrophysics photograp, computed tomography images, fluorescence micrographs or confocal microscope images. The existing techniques for blur kernel estimation is not only time consuming but also complex. The proposed method aims at fast kernel estimation and deconvolution.

Linear deblurring methods tend to introduce oscillatory artifacts. Ringing artifact manifests itself in the form of spurious oscillations in reconstructed pixel values in the vicinity of edges in a compressed image and causes severe visual degradation. The ringing artifact is analogous to the Gibbs phenomenon and results from the high frequency detail loss due to quantization. Ringing artifact is often described as the noise created during reconstruction.

The method estimates the blur kernel using the power spectrum and radon transform. Least squares method is used for deconvolution. The deconvolved image is segmented and smoothened to remove ringing artifacts.

II. PSF ESTIMATION

A motion blur is generally modeled as $B=K\otimes L+N$, where B is a blurred image, K is a motion blur kernel, L is a latent image, N is unknown noise.

A. Power spectrum estimation

The PSF estimation is a step by step procedure which is followed by deconvolution and smoothening. The first step in PSF estimation is taking the fourier transform of the gradient of the corrupted image and hence the computation is done in frequency domain. The gradient of a continuous image intensity function I (x, y) is defined as a vector of partial derivatives given as

$$\Delta I = \begin{pmatrix} \Delta I_x \\ \Delta I_y \end{pmatrix} = \begin{pmatrix} \frac{\partial I}{\partial x} \\ \frac{\partial I}{\partial y} \end{pmatrix} \tag{1}$$

Approximate the horizontal component of the gradient of I by central differences as

$$\Delta I_x(x,y) = I(x+1,y) - I(x-1,y) \tag{2}$$

where the boundaries are assumed as

$I(:,N+1) = I(:,N)$ and

$I(:,0) = I(:,1)$

Similarly the vertical component of the gradient of I is given by

$$\Delta I_y(x,y) = I(x,y+1) - I(x,y-1) \tag{3}$$

The power spectrum of the image gradient in the frequency domain is taken as

$P(x,y) = 1 + \log(\Delta I)$

The power spectrum consists of parallel stripes whose direction relates to the motion blur angle.

B. Filtering and Smoothening

The spectrum consists of high frequency structures classified as noise. Hence the spectrum needs to be filtered and smoothened. A butterworth bandpass filter is defined which is used to remove noise and unwanted frequencies. The filter function is given as

$$H(u,v) = 1 - \frac{1}{1+ \frac{D(u,v)W}{D^2(u,v) - D_0^2}^{2n}} \tag{4}$$

where

$$D(u,v) = \sqrt{(u-\frac{M}{2})^2 + (v-\frac{N}{2})^2} \tag{5}$$

D_0 is the center pixel, n the order which is set to 2 and W the bandwidth which is set to 30% of the original image size. The mentioned parameters are found to be optimal.

The spectrum is further smoothened using median filter with 3 x 3 search window for easiness in the calculation of the blur parameters.

C. Motion blur parameters estimation

1) Blur angle estimation : The smoothened power spectrum of the gradient contains a regular pattern of parallel stripes. Rotating such a matrix by the angle α and summing the columns of the result produces a vector, for each value of α. In such a vector, the crests and valleys of the original stripe structure usually cancel out, unless the angle α is very close to the angle of the direction of the stripes. The projection at this very angle has the largest span of values — the greatest difference between its largest value (sum of the crest-values) and its smallest value (sum of the valley-values). The angle α is the estimated motion blur angle. The blur angle is estimated using radon transform.

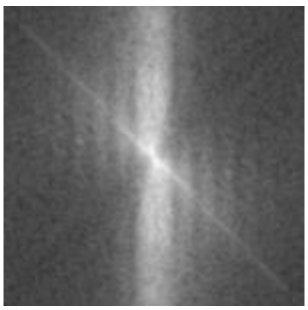


Figure 1. Filtered and smoothened power spectrum of the image gradient in the frequency domain

2) Blur length estimation : The power spectrum is rotated along the estimated angle to get an erected power spectrum as shown in figure 1 for estimating the blur angle. In the above figure 2d is mentioned as the distance between two minima closest to the center of the image which is used to find the blur length L. The blur length L is found as

$$L = \frac{1}{r} \qquad (6)$$

where

$$r = \frac{c}{q} \qquad (7)$$

Here c is the number of coefficients in the power spectrum greater than a threshold T and q is the total number of coefficients in the power spectrum. For optimal computation the threshold value is taken as 0.78 for normalized power spectrum coefficients. The estimated blur parameters are used for deconvolution.

III. Image Deconvolution

The least squares method is used for deconvolution of the image which is an iterative algorithm. The iterative update algorithm is defined as follows

$$I^{t+1} = I^t + K * (I_b - I^t \otimes K) \qquad (8)$$

I^{t+1} is the deblurred estimate, t is the number of iterations, K the estimated PSF, I_b the blurred image, * is the correlation operator and $\otimes$ is the convolution operator. For optimal restoration 600 iterations are carried out.

IV. Smoothening Ringing Artifacts

The areas with less image features (low texture areas) are smoothened to remove the ringing defects. For this purpose the image is segmented into several layers according the intensity inhomogeneity. This distinguishes the high texture areas from its counterparts.

The first step involves the calculation of a smooth version of the image given as

$$I_g = I \otimes G (0,\sigma) \qquad (9)$$

$G(0,\sigma)$ is a Gaussian kernel with mean 0 and standard deviation σ. For each pixel *i* in smoothed image I_g, the standard deviation of pixel colors in kernel range is calculated, which can be seen as the weighted standard deviation of pixel colors, then the maximum r_{max} and minimum r_{min} is obtained. The number of layers is user defined. If the image is divided into P layers, and the first layer is the whole image, then pixel (i, j) belongs to the j^{th} layer if

$$r_{(i,j)} > \frac{P-j+1}{p} r_{min} + \frac{j-1}{p} r_{max} \qquad (10)$$

After the multilayer formation a mask M with the same size of the image for each layer can be obtained which is given as

$$M_p(i,j) = \begin{cases} 1, & pixel\,(i,j) \in \text{layer P} \\ 0, & else \end{cases} \qquad (11)$$

Notice that if pixel (i, j) belongs to the j^{th} layer, it also belongs to the j -1^{th} layer. Here the number of layers is taken as 3. The mask is shown in the figure2.

Figure 2 : Segmented image mask

The black region describes areas with high texture and white region the less image detail area. Only the low texture region is smoothened median filter of 5 x 5 window size whereas the pixels with high details are retained. This technique proves better compared to smoothening only non-edge pixels shown in figure 3(e).

V. Results and Discussion

Different test images were used and were checked with different lengths and angles to prove the efficiency. The performance of the method is measured using PSNR (peak signal-to-noise ratio) and SSIM (structural similarity index. The SSIM value is 1 if both the images compared are same. The blurred image is restored using inverse and least squares technique. The proposed method proves to be better.

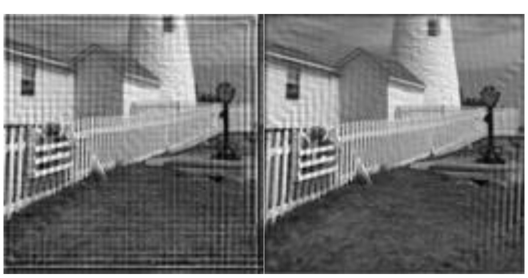
(a) (b)

(c) (d)

(e) (f)

Figure 3 : Restoration results for lena image blurred with angle 45° and length 20 (a) original image (b) blurred image (c) inverse filter result (d) least squares deconvolution (e) smoothening with edge preservation (f) proposed method

(a) (b)



(c) (d)

(e) (f)

Figure 4 : Restoration results for light house image blurred with angle 45° and length 20 (a) original image (b) blurred image (c) inverse filter result (d) least squares deconvolution (e) smoothening with edge preservation (f) proposed method

TABLE 1 COMPARISON OF PSNR VALUES OF PROPOSED TECHNIQUE WITH EXISTING TECHNIQUES FOR 512X512 LENA IMAGE ,FOR ANGLE = 45° AND LENGTH = 20

Method	**PSNR**	**SSIM**
Inverse filter	15.0939	0.4998
Least squares	27.6066	0.8951
Smoothening with edge preservation	27.3312	0.8896
Proposed method	27.5280	0.9016

TABLE 2 COMPARISON OF PSNR VALUES OF PROPOSED TECHNIQUE WITH EXISTING TECHNIQUES FOR 512X512 LENA IMAGE ,FOR ANGLE = 60° AND LENGTH = 15

Method	**PSNR**	**SSIM**
Inverse filter	16.1181	0.5927
Least squares	27.2062	0.8666
Smoothening with edge preservation	27.9914	0.9030
Proposed method	27.4386	0.8886

TABLE 3 COMPARISON OF PSNR VALUES OF PROPOSED TECHNIQUE WITH EXISTING TECHNIQUES FOR 512X512 LIGHT HOUSE IMAGE ,FOR ANGLE = 45° AND LENGTH = 20

Method	**PSNR**	**SSIM**
Inverse filter	13.9671	0.3854
Least squares	22.9900	0.7847
Smoothening with edge preservation	22.1417	0.7333
Proposed method	23.4035	0.8035

The algorithm that finds the size and direction of the linear motion blur proved to be successful. The estimate of the blur parameters is made from a single photograph.

VI. CONCLUSION

Image deblurring is an effective and primitive step in any kind of digital image processing where the image is restored from the blur caused due to camera imperfections and timing. The blur kernel estimation is one of the challenging areas in image processing. The existing works concentrates on deconvolution leaving behind the ringing defects.

The proposed technique not only aims in efficient computation of PSF but also concentrates on deranging. Also the computational time is less. The algorithm works equally well for color images as well.

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