DEFOCUS BLUR PARAMETER ESTIMATION TECHNIQUE

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ABSTRACT

De-blurring through blind image deconvolution requires deriving the blur kernel or point spread function (PSF) as it cannot be assumed. In case of defocus blur, the PSF or the degradation function can be represented through parametric expressions. Identification of the parameters is sufficient in these situations to formulate the PSF. In this paper, a technique to estimate defocus blur parameter is proposed. The approach is based on the relationship between the blur radius and the spectral features of defocus blurred image. The method proposed is aimed at finding the radius of the innermost circle among the concentric circles in the frequency spectrum of defocus blurred images. The proposed technique is tested on Berkeley and Pascal VOC datasets which displays around 98% defocus blur radius estimation accuracy for blur radius between 3 and 50.

Key words: Defocus Blur, Image De-Blurring, Parameter Estimation, Point Spread Function.


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1. INTRODUCTION

In real vision based applications or in any application involving image processing, the image quality cannot be compromised with. An image blur filters the high frequencies in an image and hence the information in an image is lost on blurring it. Therefore blurring has always led to difficulties in interpreting scenes and in image analysis.

A blurred image is obtained by convolving the point spread function (PSF) and the original image. A lot of research work has already been carried out in the field of image blur restoration. But still it poses a lot of challenges in the field of digital image processing. General image restoration algorithms assume the PSF of imaging system, imaging environment, and the noise information as a priori known knowledge [1]. But in practical applications nothing is known. So, there exist a number of techniques of blind image deconvolution in literature. In blind deconvolution, both the PSF and the original image are unknown and these unknowns are required to be estimated from the blurred image, in order to restore the original image.

In case of defocus blur, the degradation function can be formulated as parametric expression. Thus, the identification of the PSF of imaging system can be converted to the identification of the parameters of the
PSF. So a primary step in blind image deconvolution technique is the extraction of required parameters by processing the blurred image to estimate the PSF.

For defocus lens system blur, many methods based on power spectrum analysis, power cepstrum analysis and the bispectrum analysis in frequency domain have been proposed [2, 3, 4 and 5]. The basic principle of these algorithms is searching for zero crossings in the frequency domain of the degraded images. Analysis of the frequency spectrum of defocus blurred images in [6] resulted in the derivation of a formula relating the radius of blur with the radius of concentric ring observed in the blurred image’s spectrum. In [4], polar transformation on blurred image’s spectrum in frequency domain is used to find the blur parameters.

In this paper, a technique to estimate the blur radius by finding the radius of the innermost circle in the spectrum of the blurred images is proposed. The proposed technique is tested on Berkeley and Pascal VOC datasets with images blurred with 12 different defocus blur parameter values. The proposed method gives accurate estimate of the blur radius. The results obtained are compared with existing defocus blur parameter estimation techniques [4 and 5].

The paper is organized as follows: Section 2 gives the mathematical modelling of the degradation process and the defocus blur. Section 3 describes the proposed technique for defocus blur radius estimation. The experimental results are discussed in section 4. It also gives comparison of the obtained estimation results with other techniques and section 5 presents conclusion.

2. MATHEMATICAL MODEL OF BLUR

In the image degradation model, blurring an image is equivalent to convolving the original image with the Point Spread Function (PSF) or the blur kernel. Any noise is modelled as additive. The following equation mathematically formulates the blur model.

\[ g(x, y) = f(x, y) * h(x, y) + n(x, y) \]  

Here, \( f(x, y) \) is the original image, \( h(x, y) \) represents the PSF, \( n(x, y) \) is the additive noise and \( g(x, y) \) is the blurred image.

Applying Fourier transform on both sides of the equation,

\[ G(u, v) = F(u, v).H(x, y) + N(u, v) \]  

\( G(u, v) \), \( F(u, v) \), \( H(u, v) \) and \( N(u, v) \) represent the Fourier transform of the spatial domain functions \( g(x, y) \), \( f(x, y) \), \( h(x, y) \) and \( n(x, y) \) respectively. From (2) one sees that in cases where the additive noise can be neglected due to low magnitude, the regions of zero crossings in \( F(u, v) \) and \( H(u, v) \), form the zeros of \( G(u, v) \). Hence the parametric expressions representing the degradation functions can be obtained by exploring the spectral zero crossings of degraded image. So, the frequency spectrum of the blurred image needs to be analyzed.

A defocused image capturing mechanism introduces defocus blur in an image. The image is said to be out of focus. The defocus blur kernel causes the image pixel intensities to spread out equally in every direction. This PSF or blur kernel \( h(x, y) \) for defocus blur is modeled to be the following cylinder for the defocused lens system having circular aperture,

\[ h(x, y) = \begin{cases} 
\frac{1}{\pi R^2}, & x^2 + y^2 \leq R^2 \\
0, & \text{otherwise}
\end{cases} \]  

where, \( R \) is the defocus blur radius, and is proportional to defocusing extent. The Fourier transform of (3) is:

\[ H(u, v) = \frac{J_1(\pi Rr)}{\pi Rr} \]  

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Here, \( J_1(.) \) is the Bessel function of first order belonging to the first class, \( R \) is the radius of blur and \( r = \sqrt{u^2 + v^2} \). As \( H(u, v) \) has circular symmetry, the frequency spectrum of every defocus blurred image can be characterized by periodic occurrence of concentric circular rings, as shown in Fig. 1 (b). As the blur radius increases, the size of the concentric circles in the frequency spectrum of the blurred image decreases. This is also evident from Fig. 1.

![Fourier spectrum of defocus blurred images](http://www.iaeme.com/IJECET/index.asp)

**Figure 1** Fourier spectrum of defocus blurred images. (a) Original Image, (b) Defocus Blurred Image with radius 8, (c) Amplitude Spectrum of the Fourier Transform of (b), (d) Defocus Blurred Image with radius 15, (e) Amplitude Spectrum of the Fourier Transform of (d).

Considering \( r_0 \) as the radius of the first zero crossing or as radius of the innermost circular ring in the frequency spectrum \( G(u, v) \) of the defocus blurred image, the following relationship [6] has been derived between \( r_0 \) and \( R \) (defocus blur radius):

\[
R = \frac{3.83 L_0}{2\pi r_0}
\]  

where \( L_0 \times L_0 \) is the size of the DFT of the blurred image. Hence, if \( r_0 \) can be determined from the Fourier spectrum of the defocus blurred image, radius of the blur \( R \) can be estimated using (5).

**3. PROPOSED TECHNIQUE TO FIND THE BLUR RADIUS**

The radius of defocus blur can be calculated from (5) only if the radius of the innermost ring in the frequency spectrum of the blurred image is known. A technique to find this radius from the spectrum of the blurred image is proposed in this paper.

This technique works by considering the frequency spectrum of the defocused blurred image as an image. Edge detection is applied on this spectrum such that the resultant image must consist of the proper edges of the concentric circles of the Fourier spectrum of the blurred image. To meet these requirements, the logarithmic frequency spectrum of the blurred image is converted to binary using the canny edge detector. Here, the threshold values should be such that only the edges of the concentric circles (especially of the innermost circle) are visible without any other noise. This process is image specific. The threshold values for edge detection may differ for different images.
This algorithm works on finding the distance of the first white pixel from the center in the edge detected image of spectrum of the blurred image. To guarantee accuracy in radius determination, the distance is measured in four directions from the center, i.e. left, right, top and bottom. The distance values measured from these four directions is stored in a matrix and the maximum of all the four distances is taken as the radius. Once the maximum value of radius is determined, that value is considered as \( r_0 \) and placed in (5) for estimation of the blur radius. This whole procedure has been depicted in Fig. 2. Fig. 2(a) shows the input blurred whose defocus blur radius is to be estimated. Its frequency spectrum is depicted in fig. 2(b). For determining the radius, canny edge detection on the spectrum is applied as shown in fig. 2(c) and the radius is estimated by finding the first white pixel in all the four directions from the center as shown in fig. 2(d).

![Figure 2. The stages of proposed radius estimation method. (a) Input blurred image; (b) Frequency spectrum of (a); (c) Result of edge detection on (b); (d) Arrows showing the directions along which the first white pixel is to be detected in enlarged version of (c).](image)

### 4. EXPERIMENTAL RESULTS

The proposed technique was tested on the images of the standard datasets: the Pascal dataset [8] and the Berkeley dataset [9] both with 200 original images. All the images were resized to 512 x 512 and converted to grayscale. Each image in both the dataset was blurred with 12 different values of radius ranging from 3 till 50 making a database of 2400 defocused images of Pascal and Berkeley database each, giving total 4800 defocused images. The obtained results were then compared with the results of two other techniques of defocus blur parameter estimation also working in the spectral domain: Polar Transformation technique of [4] and Mathematical Model approach of [5]. Tables 1 shows the results of defocus blur radius estimation by the proposed technique and its comparison with radius estimation by [4] and [5].

It can be observed that the estimates values obtained from the proposed technique are close to the original radius and accurate as compared to the other techniques. This holds true in case of both the datasets. As the blur radius increases, the results become poor for all the techniques, but the proposed technique comparatively performs better than the other two even for higher blur radius. The best estimation of the proposed technique was 3.00 for blur radius, \( R=3 \) pixels and worst estimation was 52.05 for \( R=50 \) pixels. However, the estimation results are comparatively better for all radius values, while method of [4] and [5] exhibit degradation in estimation for radius greater than 20.
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Table 1 Estimated values of blur radius for the bikes image of fig. 2, blurred separately with 12 different values of blur radius

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>3</td>
<td>2.97</td>
<td>2.98</td>
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<td>5</td>
<td>4.96</td>
<td>5.1</td>
<td>5.03</td>
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<td>44.62</td>
<td>-48.08</td>
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<td>50</td>
<td>52.05</td>
<td>-48.08</td>
<td>52.05</td>
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Table 2 Accuracy of all techniques of Defocus Blur Parameter Estimation for test datasets

<table>
<thead>
<tr>
<th>Method</th>
<th>Berkeley Dataset</th>
<th>Pascal Dataset</th>
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<tbody>
<tr>
<td>Liang [4]</td>
<td>90.54%</td>
<td>90.54%</td>
</tr>
<tr>
<td>Moghaddam [5]</td>
<td>87.00%</td>
<td>86.00%</td>
</tr>
<tr>
<td>Proposed Technique</td>
<td>98.25%</td>
<td>98.00%</td>
</tr>
</tbody>
</table>

Table 2 shows the overall accuracy of radius estimation for all the test images generated from the Berkeley and Pascal dataset. The estimation accuracy of the proposed technique is 98.25% and 98.00% for Berkeley and Pascal dataset, outperforming the accuracy of techniques of [4] and [5].

Table 3 PSNR values of image restored with the radius estimated by the proposed technique

<table>
<thead>
<tr>
<th>Original radius of blur</th>
<th>Estimated radius by proposed method</th>
<th>PSNR values (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3.00</td>
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<tr>
<td>4</td>
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<td>24.23</td>
</tr>
<tr>
<td>10</td>
<td>10.07</td>
<td>23.16</td>
</tr>
</tbody>
</table>

Figure 3 Blurred image restored using LR algorithm for defocus blur parameter estimation by proposed technique. (a) Original Image; (b) Image blurred with defocus blur of radius 5; (c) Restored image by estimated blur radius 5.03 from the proposed method.
5. CONCLUSION

In this paper, an approach to measure the features in the spectrum of defocus blurred image and hence obtain the defocus blur radius is proposed. The radius was estimated by using edge detection on the spectrum of blurred image in the proposed technique. The proposed method was tested on Pascal and Berkeley datasets with large number of blurred images having blur radius ranging from 3 to 50. The experimental results show accuracy of around 98% for blur radius. The proposed technique effectively estimated the blur radius and resulted in better quality image restoration. The performance does degrade for large values of blur radius but is comparable with the existing techniques.

REFERENCES


