Optimal Parameters for Nearest Neighbor Deblurring Algorithm

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***Abstract*— A new method for determining the optimal parameters for Nearest Neighbor Deblurring algorithm is presented. The maximum entropy in image frequency domain is used as the optimization criteria. The proposed method allows finding optimal parameters from three images: the image in focus and two images at adjacent levels. An automatic parameter setup procedure can be built on the basis of proposed method.**

***Index Terms*— Frequency Domain Entropy, optimal parameters, Nearest Neighbor Deblurring.**

I. Introduction

Dr. Castelman and his colleagues proposed a method for deblurring of optical section images [1]. This method is given by

$$f_j \approx g_j - \sum_{i=1}^{M} (g_{j-i} * h_i + g_{j+i} * h_i) * k_0 \qquad (1)$$

where f_j is the actual specimen image at focus level j, g_j is the optical section image obtained at level j, h_i is the blurring point spread function (PSF) due to being out of focus by i steps, k_0 is a heuristically designed high pass filter, * is the convolution operation, and *M* is the number of adjacent images. This approach allows partially remove a defocused structures by subtracting *2M* adjacent images blurred by defocus PSF. If the number of adjacent images equals two, *M=1*, the equation becomes

$$f_j = a g_j - b(g_{j-1} + g_{j+1}) * h_1 \qquad (2)$$

where $a = 2b + 1$, h_1 is a PSF that models blurring due to defocus [2]. This algorithm is called Nearest Neighbor Deblurring (NND). To use the NND algorithm knowledge of h_1, a, b are required. PSF or h_1 can be calculated from the parameters of optical system, but a and b parameters need to be determined empirically. Usually, NND algorithm users determine a and b parameters through multiple tries using personal visual criteria for parameters selection. This is essential inconvenience. Other much more advanced deconvolution methods are available, but they are more computationally expensive. NND provides the essential image improvement at very reasonable computation expense. That is why NDD still remains attractive to users.

The next section of this article presents a method for automatic parameters determining for Nearest Neighbor Deblurring algorithm from three images: from the image in focus and two images at adjacent levels

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II. Maximum Entropy criterion for deblurring parameters estimation

As was mentioned earlier a part of NND parameters have to be determined empirically. It will be shown that NND parameters can be determined directly from images. The idea behind proposed method is based on the premise that blurring decreases image focus and deblurring increases images focus. Then the focus measure can be used as an estimate for the blur level. We look for parameters which produce the image with the best focus. It requires a measure of image focus. This measure of focus shall satisfy the following criteria [3]:

Extremum of the focus measure must correspond to the image with the best focus.

Extremum should be well expressed.

Focus measure should be strictly monotonic, or at least do not have expressed local extremums.

It should be robust with different textures.

It should be robust in different lighting and contrast conditions.

As shown in [3] the entropy of image frequency domain satisfies the criteria formulated above. This focus measure is called Frequency Domain Entropy (FDE) and is defined by following expression

$$FDE = -\sum_{i,j \in D} fr_{norm}(i,j) \log(fr_{norm}(i,j)) \qquad (3)$$

where fr_{norm} is the normalized frequency spectrum

$$fr_{norm}(i,j) = \frac{1}{\sum_{i,j \in D} |fr(i,j)|} |fr(i,j)| \qquad (4)$$

Fig.1 illustrates how FDE measure works. Image blurring removes high frequencies.

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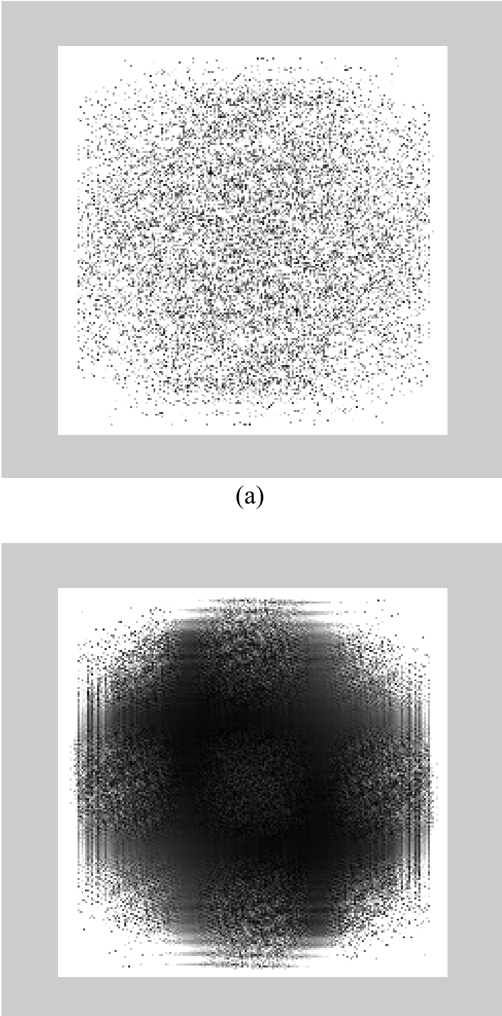


(a)

(b)

Fig.1. (a) Focused image frequency spectrum (amplitude), (b) defocused image frequency spectrum (amplitude). Spectrum (a) has higher entropy than spectrum (b)

The image frequency domain can be viewed as a distribution where the amplitude of each frequency represents the probability that the frequency is expressed. This explains why the entropy of the focused image is higher than the entropy of defocused image.

Let us rewrite expression (2) as

$$f_j = ag_j - bg_{j-1} * h_1 - bg_{j+1} * h_1 \qquad (5)$$

where $bg_{j-1} * h_1$ represents an image of objects from section (*j-1)* projected on image in section *j*. The term $bg_{j+1} * h_1$ represents an image of objects from section *(j+1)* projected on an image in section *j*. Parameter b in both terms is an attenuation value. The influence of the object from adjacent level (*j-1)* on level *j* can not be higher than the intensity of the object itself. So the value of parameter b is always between 0 and 1.

Let us define a new image s produced after both terms are subtracted from g_j as function of parameter b

$$s(b) = g_j - bg_{j-1} * h_1 - bg_{j+1} * h_1 \qquad (6)$$

Note that parameter a is not included in the expression. Excluding parameter a from the expression we fix the entropy of the base image g_j, to get the goal function with the expressed extremum.

Then maximal sharpness or best focus of image $s(b)$ will correspond to such parameter b that removes influence from adjacent images on image g_j. Using FDE as the measure of focus, the previous statement can be written as

$$b_{opt} = b \mid Max(FDE(s(b))) \qquad (7)$$

Or, in other words, the optimal parameter b is such b that maximizes Frequency Domain Entropy of $s(b)$. Behavior of Frequency Domain Entropy of $s(b)$ on interval [0, 1] is shown on Fig. 2

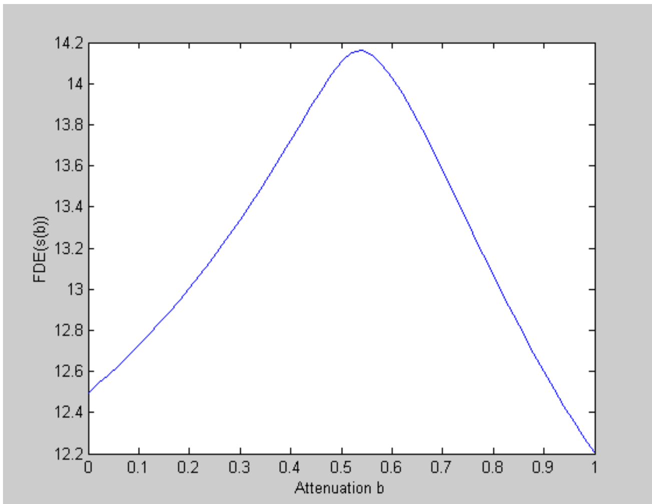


Fig.2. Function $FDE(s(b))$

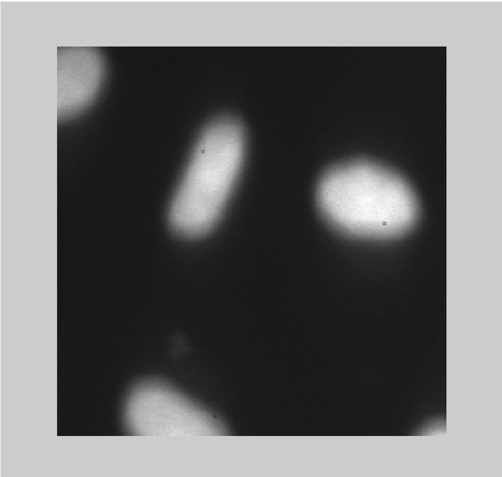
Function $FDE(s(b))$ has a well expressed maximum, then parameter b can be found algorithmically.

III. Results

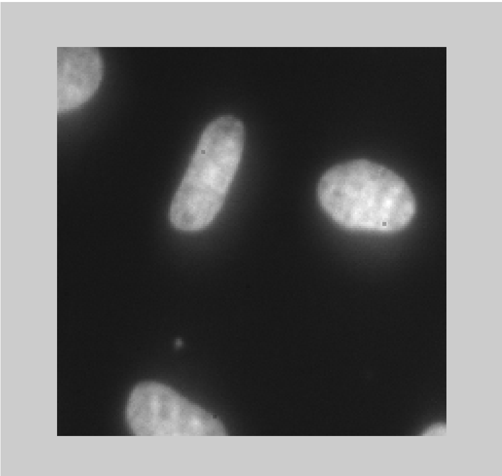
The proposed method was tested on fluorescent images of U2OS cell nuclei shown on Fig. 3. Defocus PSF were modeled by the cylinder function

$$h_1 = cil(\frac{r}{D}) \quad (8)$$

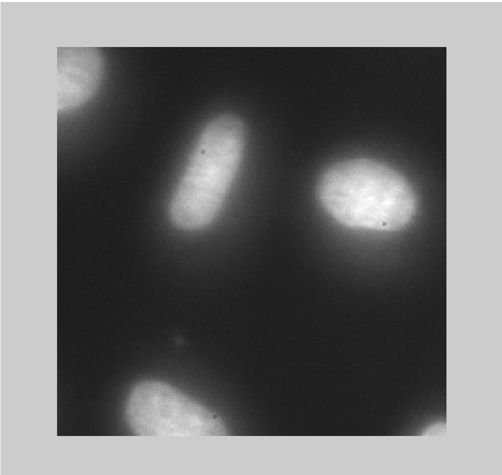
where D is an exit pupil diameter.



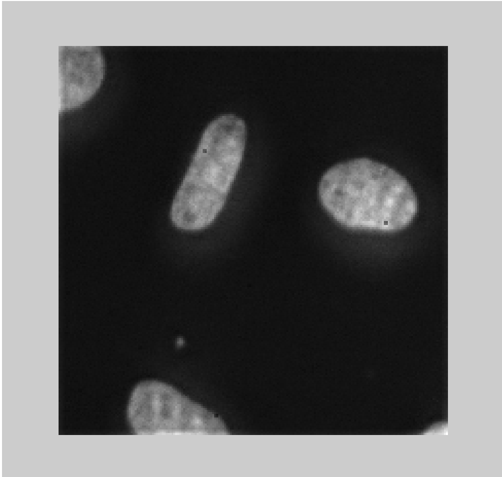
(a)



(b)



(c)



(d)

Fig.3. (a) Image above focus, (b) image in focus, (c) image underneath focus, (d) deblurred image. Deblurring parameters found by algorithm from (7)

Expression (7) was implemented in Matlab. The parameters for deblurring were found from images (a), (b), (c) Fig. 3. The deblurring result is shown on image (d) Fig. 3.

IV. Conclusion

It is shown that Nearest Neighbor Deblurring algorithm parameters can be found from three images: the image in focus and two images at adjacent levels.

Usage of Frequency Domain Entropy of the image as measure of blurring level gives results close to intuitive human perception.

An automatic parameter setup procedure can be built on the basis of proposed method.

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