Deep Focus: A Focal Stacking Method Based on Laplacian Filters

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ABSTRACT

Focal stacking is an image processing technique to produce all-focused images with limited depth-of-field and optical constraints. This work involves a detail detection method based on the Laplacian operator and blur-filter workarounds for the image merging process.

INTRODUCTION

Lack of depth-of-field is a common concern in microscopy. Even with a proper light condition, the optical limitation prevents scientists and photographers from obtaining focused images of relatively big objects. The depth-of-field (DOF) d can be represented as

$$d = \frac{\lambda}{NA},$$

and

$$NA = n\sin^2(\alpha),$$

where λ is the wavelength of the light, NA is the numerical aperture, n is the refractive index of the medium, and α is the half-angle of the maximum cone of light entering or exiting the lens. [1] To increase the DOF, a larger λ is required; however, at the same time, the optical resolution becomes much lower, suffering from the long wavelength.

Software methods can be quite good workarounds for those physical restraints. Focal stacking is one of the methods utilizing computers rather than new optical arrangements.

In this method, every in-focused part of a set of images shot at different focal planes is extracted and then merged into one single image. The produced image is in focus everywhere.

The quality of this focal stacking method depends on a good selection rule. The method discussed uses Laplacian filters to detect detailed regions along with blur algorithms to reduce artifacts.

DETAIL DETECTION

The spatial frequency of an image is regarded as a common quantitative criterion of visual information content. A higher value implies the region contains more details.

There are several measurements for spatial frequencies, including Fourier analysis, wavelet decomposition analysis and Laplace transform and so on. Detecting high definition regions can be achieved by applying high-pass filters. In the case shown, a second derivative filter, the Laplacian filter, is used.

The chosen parts of the image stacks will be marked on a map, M, locating which pictures contain the "focused" areas.

THE LAPLACIAN FILTER

The Laplacian filter $L(x, y)$ in a 2-D plane can be described as

$$L(x,y) = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}.$$

And the corresponding 3-by-3 convolution filter matrix h obtained by the `fspecial('laplacian', α )` function of the MATLAB software package [2] is

$$h = \frac{4}{(\alpha+1)}\begin{bmatrix} \frac{\alpha}{4} & \frac{1-\alpha}{4} & \frac{\alpha}{4} \\ \frac{1-\alpha}{4} & -1 & \frac{1-\alpha}{4} \\ \frac{\alpha}{4} & \frac{1-\alpha}{4} & \frac{\alpha}{4} \end{bmatrix}$$

where α is a parameter of `fspecial`. Substituting α by the default value 0.2 yields

$$h_{0.2} = \begin{bmatrix} 0.1667 & 0.6667 & 0.1667 \\ 0.6667 & -3.3333 & 0.6667 \\ 0.1667 & 0.6667 & 0.1667 \end{bmatrix}.$$

The subscript of h indicates the value of the corresponding α.

THE AVERAGE BLUR FILTER

The results, which are shown later, produced solely by the Laplacian filter are often sparse or too noisy depending on the threshold. Thus before merging the images back to a single one, it's necessary to apply the average blur filter to the map M. The average blur filter can be obtained by the MATLAB function `fspecial('average', σ)`, where σ is the average filter size. With the value of $\sigma = 5$, the average filter g matrix is

$$g_5 = \begin{bmatrix} 0.04 & 0.04 & 0.04 & 0.04 & 0.04 \\ 0.04 & 0.04 & 0.04 & 0.04 & 0.04 \\ 0.04 & 0.04 & 0.04 & 0.04 & 0.04 \\ 0.04 & 0.04 & 0.04 & 0.04 & 0.04 \\ 0.04 & 0.04 & 0.04 & 0.04 & 0.04 \end{bmatrix}.$$

The subscript of g indicates the value of the corresponding σ.

RESULTS

Fig. 1 is one of the original photos untouched with a thin DOF.

Fig. 1: a center-focused image

The map M is shown in Fig. 2, consisting of the 17 images filtered by the Laplacian filter. The result is noisy and sparse, not forming an area for selection.

Fig. 2: $\alpha = 0.2$

After the blur filter is applied, each image processed reveals a band of focused area as shown in Fig. 3 and Fig. 4.

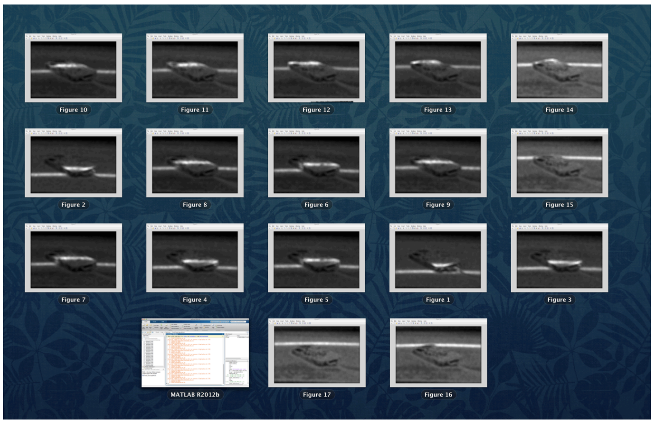

Fig. 3: Thumbnail of the blurred images.

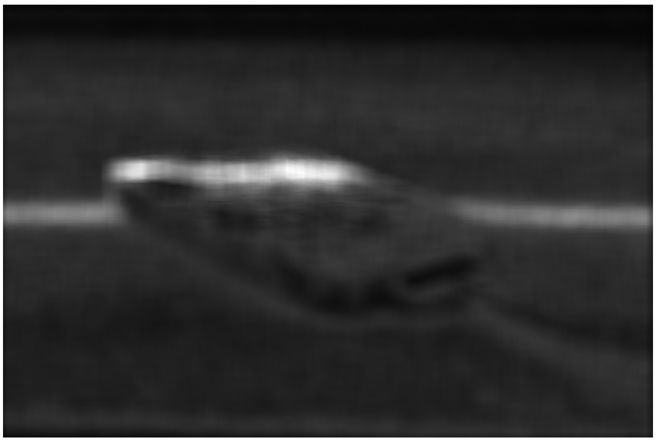

Fig. 4: The lighted band shows the focused area.

The experimental results suggest there are differences between various values of the parameter σ of the average blur filter. Fig.5 through Fig. 9 (cropped images) show the larger σ produces a smoother image.

Fig. 5: $\sigma = 10$

Fig. 6: $\sigma = 25$

Fig. 7: $\sigma = 30$

Fig. 8: $\sigma = 60$

Fig. 9: $\sigma = 90$

As Fig. 9 shows, the image is getting blur when σ is reaching 90, so in this case the values between 60 and 90 will yield best result with the least artifacts.

THE DISCUSSION

In this method, the size of the average filter is still the key point of the result image quality; however, so far appropriate sizes are found in a trial-and-error fashion.

Also, the darker areas of the images, which contain essentially much less information, are still hard to produce decent results for selection.

The future work will emphasize on these topics.

REFERENCE

[1] Born M, Wolf E. 1987. *Principles of Optics*. New York: Pergamon Press.

[2] Rafael C. Gonzalez, Richard E. Woods, Steven L. Eddins. 2009. *Digital Image Processing Using MATLAB, 2e*. Knoxville, TN, USA: Gatesmark Publishing.