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Use of wavelet analysis for improving autofocusing capability

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Abstract

A novel method for improving autofocusing capability by using wavelet-based correlation is proposed. Experimental results show that the proposed wavelet-based analysis could detect slightly out-of-focused images. Therefore, it could improve autofocusing capability.

Keywords: Autofocus; Wavelet analysis; Wavelet correlator

In the ancient days of photography, focusing a camera meant laboriously twisting the lens barrel until an image in the viewfinder was in a sharp focus. An autofocus technology today has made focusing as painless as pressing a shutter button. In order to obtain a sharp image, the autofocus camera bounces an infrared light beam off subjects. From the time difference between the transmitted and reflected beams, the distance between the subject and the camera is calculated. This information is then used for controlling a motor to adjust a focusing lens of the camera into a correct position. However, the disadvantage of this technique is that it is not as precise as a measuring subject contrast which is used widely in most single-lens reflex cameras. For this reason, recently Jutamulia et al. have proposed a new autofocusing technique based on power-spectra analysis which is applicable to telescopic, microscopic, opthalmoscopic, or endoscopic camera as well [1]. In their report, autofocusing is achieved by taking an autocorrelation of the observed image. If the image is focused, then its autocorrelation peak is sharp. This result is due to edges of the image exist. Whereas, if the image is blurred, the resultant peak is broad. Therefore, the adjustment of the lens position could be controlled by the width of the autocorrelation peak. In order to implement the technique, either ring detector or a joint-transform correlator have been suggested. However, on the basis either power spectra or autocorrelation function, it is hard to determine the in-focused from the slightly out-of-focused images, since the width of either their autocorrelation functions or their power spectra are approximately the same.

In this work, we propose a new technique to improve the autofocusing capability of the above mentioned cameras by using a wavelet analysis. The reason for this interest is that a wavelet transform (WT) is useful for an enhancement of edge features in images [2]. We have verified that the edge-enhancement property of the WT is powerful for improving pattern discrimination and association [3–5]. On the basis of the fact that the autocorrelation of the edge-enhanced image produces a sharper peak than of the original image, the wavelet-based correlation could be used to detect slightly out-of-focused images.

The autocorrelation of the wavelet-transformed image is given by

$$C(x,y) = \iint_{-\infty}^{+\infty} W_f(x',y')\, W_f^*(x'-x, y'-y)\, \mathrm{d}x'\, \mathrm{d}y', \quad (1)$$

where $W_f(x,y)$ is the WT of an image $f(x,y)$ defined as [6]

$$W_f(a_x,a_y,b_x,b_y) = \iint_{-\infty}^{+\infty} f(x,y)\, h^*_{a_x a_y b_x b_y}(x,y)\, \mathrm{d}x\, \mathrm{d}y. \quad (2)$$

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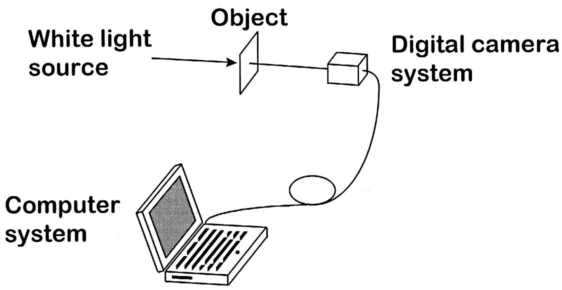

Fig. 1. Schematic diagram of the experimental setup.

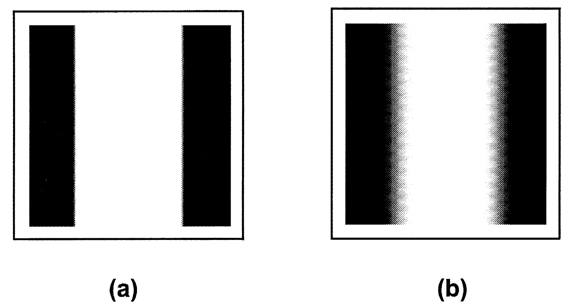

Fig. 2. Images of a bar object that are (a) in focus, and (b) slightly out of focus.

Here, the daughter wavelet $h_{ab}(x,y)$ is defined as

$$h_{a_x a_y b_x b_y}(x,y) = \frac{1}{\sqrt{a_x a_y}}\, h\left(\frac{x-b_x}{a_x}, \frac{y-b_y}{a_y}\right) \tag{3}$$

is generated by shifting and dilating the mother wavelet $h(x,y)$. In the Fourier domain, Eq. (1) can be rewritten as

$$C(x,y) = \iint_{-\infty}^{+\infty} |F(u,v)|^2 \, |H_{a,b}(u,v)|^2 \times \exp[-i2\pi(xu+yv)] \, du \, dv, \tag{4}$$

where $F(u,v)$ and $H_{a,b}(u,v)$ correspond to the Fourier transforms of the image and the daughter wavelet, respectively. Eq. (4) shows that the wavelet-based autocorrelation could give a sharper correlation peak than the conventional autocorrelation method does. Note that a factor of $F^*(u,v)|H(u,v)|^2$ in Eq. (4) is known as the wavelet-matched filter [7].

In order to verify the feasibility of our proposed method, a preliminary experimental investigation has been conducted. Fig. 1 shows a schematic diagram of the experimental setup. Image of an object is captured by the Canon PowerShot 600 digital camera connected to a computer system. For a computational purpose, the captured image is stored in the computer. In order to simplify the computations, autocorrelations of one-dimensional (1-D) cross-sectional scan of the image are computed by using the conventional and the wavelet-based methods, respectively. Finally, the resultant autocorrelation functions are plotted and widths of their peaks are compared in order to verify the feasibility of our proposed method. In the experiment, a binary transparency of a bar object and a Mexican hat wavelet were used as the input object and the analyzing wavelet filter, respectively. The Mexican hat wavelet was chosen because it is localized optimally in a space and spatial-frequency domains [8]. All computations were done by using a Matlab version 4.0. Fig. 2(a) and Fig. 2(b) show the in-focused and the slightly out-of-focused images of the object, respectively. Whereas, their corresponding 1-D cross-sectional scans are illustrated in Fig. 3(a) and Fig. 3(b), respectively. Fig. 4(a) shows the resultant autocorrelation computations of the 1-D cross-sectional scan data based on the conventional method, while the resultant wavelet-based method for a scaling factor $a = 2^{-6}$ is

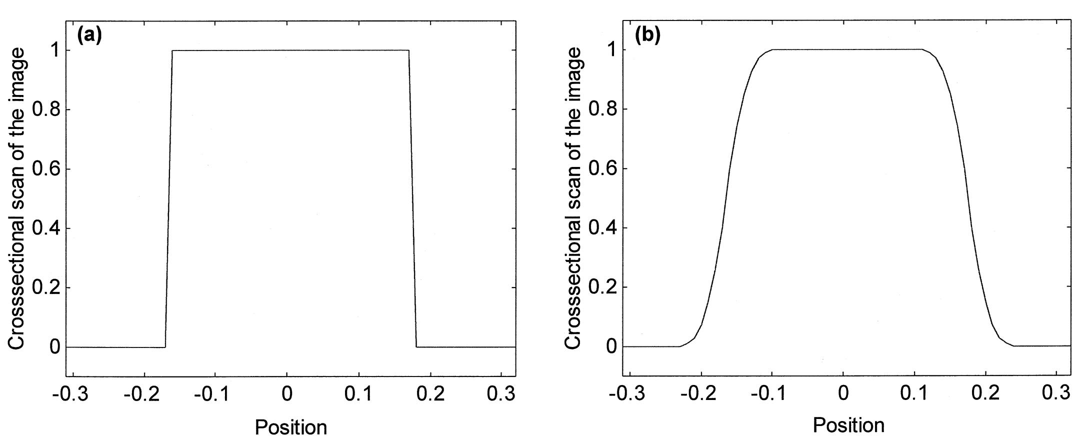

Fig. 3. 1-D cross-sectional scans of (a) the in-focused, and (b) the slightly out-of-focused images.

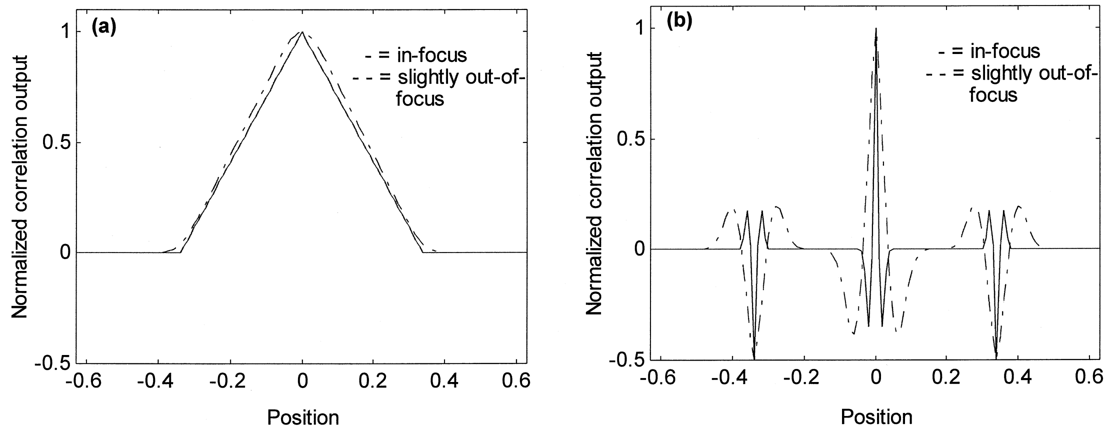

Fig. 4. Autocorrelations of the in-focused and out-of-focused images computed (a) by the conventional method, and (b) by our proposed wavelet analysis.

shown in Fig. 4(b). Here, the solid and the dash lines correspond to the autocorrelation functions of the in-focused and the out-of-focused images, respectively. From Fig. 4(a), it is clear that the widths of the autocorrelation functions of the in-focused and the out-of-focused images are approximately the same. Therefore, it is hard to determine the correct position of the focusing lens. However, our proposed wavelet-based method gives significantly two different widths of autocorrelation function that are illustrated in Fig. 4(b). Fig. 4(b) shows that in comparison with the out-of-focused image, the autocorrelation of the in-focused image is obviously sharper because sharp edges of its image were enhanced strongly by the WT. Therefore, on the basis of the correlation width, our proposed method could determine two slightly different position of the focusing lens. As the result, it could be used for improving the autofocusing capability of camera system. Furthermore, in real applications we may deal with more typical-complicated scenes that are dominated with discontinuities or edge features so that they contain a broader, from low to high, spatial-frequency information than the input image used in the experimental verification. For this kind of scenes, our proposed method still produces a sharper correlation peak. The reason is that first according to pattern recognition theory, although high spatial-frequency information plays an important role in determining a sharpness of the correlation function, the low spatial-frequency information of the scene will broaden the resultant correlation function. Therefore, the conventional autocorrelation of the typical scene does not produce a sharp correlation peak. Second, the wavelet transform provides a set of signal representation in given frequency band by dilating and translating a wavelet kernel. Thus, the use of wavelet transform could enhance certain localized features of input signal. If the enhanced features of the scene are edges, then the autocorrelation of the wavelet-transformed scene gives a sharper correlation peak than the conventional autocorrelation does.

In addition, some comments on the practical implementation of our proposed method may be worth making. Our proposed method can be implemented electronically to the camera mechanism system by using a single-chip wavelet processor [9] in conjunction with a CCD array detector used to capture the input image. The captured image or its 1-D cross-sectional scan is wavelet transformed. The result is then autocorrelated. Finally, the width of the correlation peak is used to find a correct position of the camera focusing lens through an electronic motor.

In summary, we have described a new method for improving autofocusing capability of camera system by using a wavelet analysis. Since the sharpness of the autocorrelation peak is important to control precisely the position of the lens of the camera system, our proposed method significantly improves the autofocusing capability.

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