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Wavelet Transform for Autofocusing Detection Systems

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ABSTRACT Use of wavelet transform for a new autofocusing mechanism is proposed. In comparison with autofocus mechanisms of commercially available camera systems, our proposed method is more accurate. In conjunction with a use of charge-coupled device image sensor, implementation of the method leads to simple and low cost camera systems.

KEYWORDS: wavelet transform, autofocus camera, autocorrelation function.

INTRODUCTION

Autofocus camera technology today uses a principle of measuring a distance of a main object scene to the camera by using an infrared (IR) sensor system. The measurement is done by sending pulse signals from the IR transmitter off the object scene appeared at a center of the viewfinder. The bounced signals are registered by the IR receiver. The time difference between the outgoing and incoming signals is measured and then is used for calculating the sought distance. This information is finally used for controlling an electronic motor which needs to bring a lens into a correct position. However, this technique has several limitations. First, the detector is sensitive to other IR sources such as fire. Second, the autofocusing capability is not as precise as measuring contrast of the object scence which is widely used in most single-lens reflex cameras. In this case, a scene with high contrast contains edge features. For this reason, autofocus mechanism based on contrast measurement has been suggested.[1] In this technique autofocusing is achieved by taking an autocorrelation of the object scence. If the scene is focused, then its autocorrelation peak is sharp because edges of the scene exist. On the contrary, if the scene is blurred, the resultant peak is broad. Here, the resultant correlation width is then used for adjusting the lens. However, this technique still suffers from inaccuracy. Because in case of an in-foused and a slightly out-of-focused scenes, the widths of their autocorrelation are approximately the same.

In this work, a new technique for improving autofocusing capability of camera systems by using a wavelet transform (WT) is proposed. The reason of using the WT is that it is useful for an enhancement of edge feature in images.[2] Therefore, the autocorrelation of the edge-enhanced image gives a sharper correlation peak than of the original image.[3] In our research project, the WT-based correlation could be applied to improve autofocusing capability of camera systems. Our proposed method is suitable for a camera system that uses a charge-coupled device (CCD) as an image sensor. In comparison with the IR systems, this technique does not require any particular transmitter-receiver system. Thus, it is simple and low cost.

MATERIALS AND METHODS

The WT of an image $f(x,y)$ is defined by[4]

$$W_f(a_x, a_y, b_x, b_y,) = \int\int_{-\infty}^{+\infty} f(x,y) \times h^*_{a_x,a_y,b_x,b_y}(x,y)dxdy, \quad (1)$$

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

$$h_{a_x,a_y,b_x,b_y}(x,y) = \frac{1}{\sqrt{a_x a_y}} h\left(\frac{x-b_x}{a_x}, \frac{y-b_y}{a_y}\right) \quad (2)$$

is generated by shifting and dilating the analyzing mother wavelet $h(x,y)$. Throughout this paper, x and y are the coordinates along the horizontal and the vertical directions, respectively. The WT has an interesting property that a set of daughter wavelets gives a multiresolution space spatial-frequency signal representation and it can enhance edge features of images.[2] According to the WT, a signal analysis is done by a frequency filtering where a characteristic of the filter is determined by the analyzing wavelet. It is a fact that frequency information corresponds to a particular feature of the original signal, thus the WT could localize certain feature of the analyzed signals such as edges. Since edge features that indicate a shape and an extension of an object scene are considered as important information for the identification of the object, a correlation between two wavelet-transformed images given by

$$C(x,y)\int\int_{-\infty}^{+\infty} W_f(x', y')W_f^*(x'-x, y'-y)dx'dy', \quad (3)$$

provides a higher discrimination ability than the conventional autocorrelation does.[3,5,6] Here, $W_f(x,y)$ is the WT of the image $f(x,y)$ given by Eq (1).

Results and Discussions

In order to verify the feasibility of our proposed method, a preliminary experimental investigation has been conducted. Figure 1 shows a diagrammatic arrangement for verification of our proposed method. Image of an object is captured by a CCD camera system connected to a computer system via a frame grabber. 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. The width of resultant autocorrelation functions are then compared. In the experiment, where all computations were done by using the Matlab software, a binary transparency of a bar object and a Mexican hat wavelet were used as the input scene and the analyzing wavelet filter, respectively. The bar object was chosen because it is widely used for measuring resolution and contrast in designing lenses,[7] while the Mexican hat defined by

$$h(x,y)=\frac{1}{\sigma^3\sqrt{2\pi}}\left(1-\frac{x^2+y^2}{\sigma^2}\right)\exp\left(-\frac{x^2+y^2}{\sigma^2}\right) \quad (4)$$

was utilized because it is localized optimally in a space and spatial-frequency domains.[8] The parameter s is defined in such away that when the mother wavelet is scaled down its resultant center frequency could cover the wanted high frequency of the bar object, while the dilation factor a is varied by following a dyadic sequence.[2]

Figures 2(a) and (b) show the in-focused and the slightly out-of-focused images of the object scene, respectively. Whereas, their corresponding 1-D cross-sectional scans are illustrated in Figs 3(a) and (b), respectively. The slightly out-of-focused image was obtained by twisting manually the focusing lens of the CCD camera system. Figure 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 dilation factor $a = 2^{-6}$ are 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. These results can be analytically explained as follows: By defining mathematically the 1-D cross-sectional scan of the bar object with the width of D as

$$f(x)=\begin{cases}1 & |x|\le D\\ 0 & \text{otherwise,}\end{cases} \quad (5)$$

the autocorrelation of this 1-D signal gives a triangle function which can be expressed as

$$g(x)=\begin{cases}1-|x| & |x|\le 2D\\ 0 & \text{otherwise,}\end{cases} \quad (6)$$

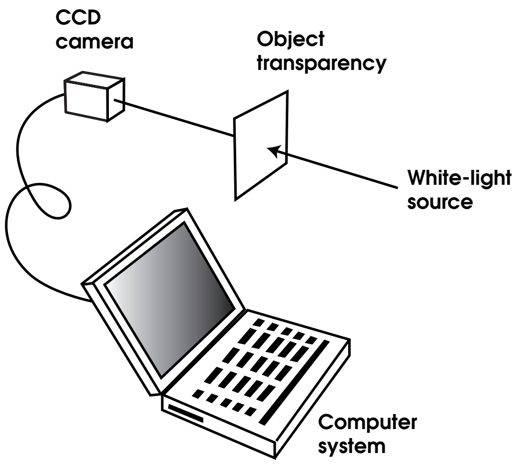

Fig 1. Diagrammatic arrangement for experimental verification of our proposed method.

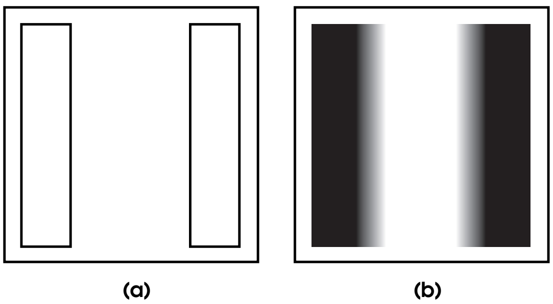

Fig 2. Image of a transparency bar object (a) in focus, and (b) slightly out of focus.

and is shown as the solid line in the Fig. 4(a). Whereas the wavelet-based autocorrelation of $f(x)$ produces

$$C(x)=\frac{1}{2\sigma^3\sqrt{\pi}}\left[\left(a^2\frac{x^2}{\sigma^2}\right)\exp\left\{\frac{-x^2}{4a^2\sigma^2}\right\}\right.$$
$$+\left\{\frac{a^2}{2}-\frac{1}{\sigma^2}\left(\frac{x+D}{2}\right)^2\right\}\exp\left\{\frac{-(x+D)^2}{4a^2\sigma^2}\right\} \quad (7)$$
$$\left.+\left\{\frac{a^2}{2}-\frac{1}{\sigma^2}\left(\frac{x-D}{2}\right)^2\right\}\exp\left\{\frac{-(x-D)^2}{4a^2\sigma^2}\right\}\right].$$

The first term on the right side of Eq (7) corresponds to the central peak of the resultant correlation function shown by the solid line in Fig 4(b), while the second and third terms associate to the left and right peaks, respectively. Equation (7) also shows that the width of the correlation function depends on the dilation factor *a* that is a smaller dilation factor gives sharper correlation peak.

From fig 4(a), it is obvious that the widths of the autocorrelation functions of the in-focused and the out-of-focused images are approximately the same.

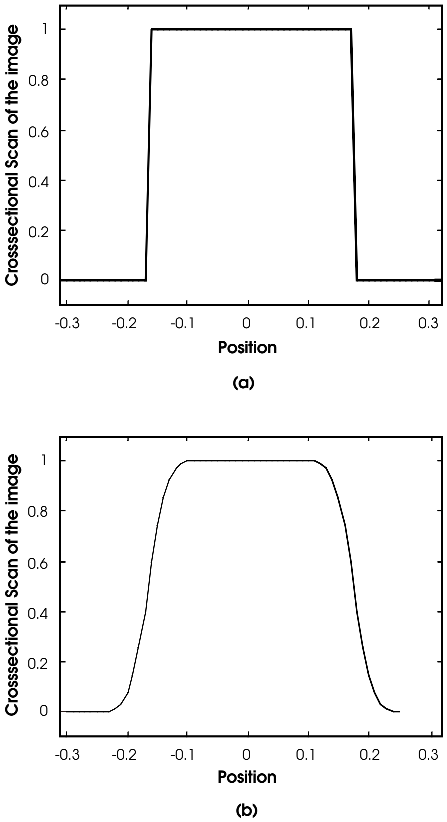

Fig 3. Cross-sectional scan of (a) in-focused, and (b) slightly out-of-focused images of the bar object.

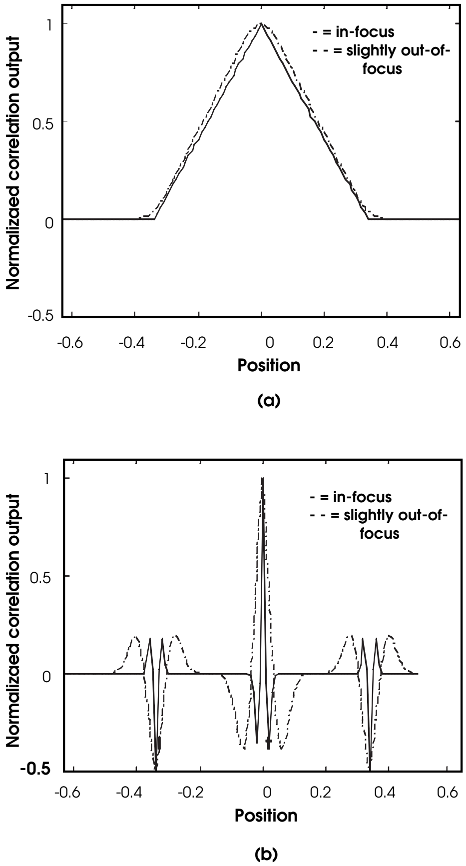

Fig 4. Resultant autocorrelations calculated by using (a) conventional, and (b) our proposed techniques.

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). Figure 4(b) shows that in comparison with the out-of-focused image, the autocorrelation of the in-focused image is significantly 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, our proposed method could be used to improve the autofocusing capability of camera systems.

Possible Implementation

In practice, we may deal with more typical and complicated scenes that are dominated with different scale of discontinuities or edge features so that they contain a broader, from low to high, spatial-frequency information than the bar object used in the experimental verification. In this kind of situation, our proposed method still produces a sharper correlation peak. Because, first 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. Therefore, the conventional autocorrelation of the typical scene does not produce a sharp correlation peak. Second, the WT provides a set of signal representation in given frequency bands by dilating and shifting a wavelet kernel. Thus, the use of the WT could enhance certain local features of the input scene. If the enhanced features are edges, then the autocorrelation of the wavelet-transformed scene gives a sharper peak.

As mentioned above, our proposed method is suitable for a camera system that uses the CCD as the image sensor. The CCD sensor consists of small light-sensitive elements which converts the incoming light to an electrical signal. Figure 5 shows an artistic model for implementing our proposed method. The implementation is done as follows: Selection of the main object of the scene is first done by using a viewfinder of the camera. This preliminary step is taken by the conventional camera systems as well. Although the scene consists of several objects with different distances, only one object of principal interest appeared at the center of the viewfinder will be recorded in focus. The target scene appeared at the center of the viewfinder is captured by the CCD sensor. For reducing computational time, the 1-D cross-sectional scan of the captured image is then wavelet-transformed by using a single-chip wavelet processor.[9] The result is then autocorrelated. The width of the correlation peak is finally used to adjust the electronic motor that controls position of the focusing lens of the camera systems. The sharpest correlation peak is sought by varying the dilation factor of the wavelet. The focusing lens is in correct position provided the sharpest correlation peak is achieved.

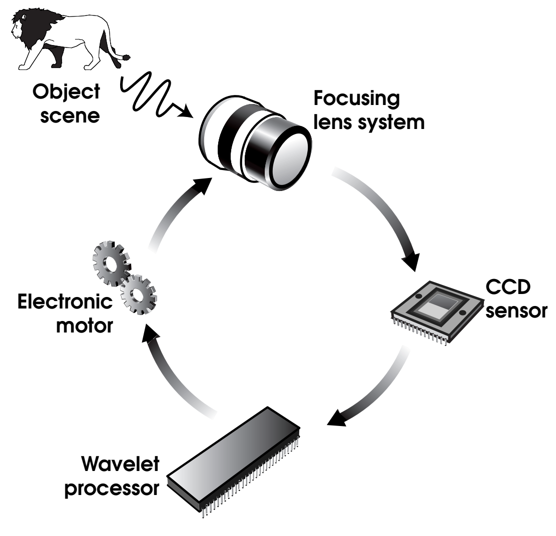

Fig 5. Artistic model for implementation of the proposed method.

Conclusions

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 improves significantly the autofocusing capability compared with the autocorrelation method.[1] Finally, in conjunction with the use of CCD sensor, our proposed method leads to a simple and low cost camera system. In addition, we consider that it is important to verify the reliability of the whole system. However, we would like to leave this matter for our next investigation due to unavailability of infrastructures that could support this research work at the present time.

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