An Auto-Focusing Method for Different Object Distance Situation

Quan Feng, Ke Han, Xiu-chang Zhu

College of Communication and Information Engineering, Nanjing University of Posts and Telecommunications, Nanjing, 210003 China

Summary
The auto-focusing system is an important factor to determine the imaging quality of digital camera. Currently, many auto focusing methods have been proposed, most of which are suitable for the long-object-distance situation, but ignore the long-short-object-distance situation. So this paper analyses the imaging relation and the properties of image clarity evaluation function under long-short-object-distance situation, and finds that the curve of the image clarity evaluation function always has multiple peaks, not the single peak. And according to this property, image clarity evaluation function based on Sobel operator is proposed in this paper. Experimental results indicate that the proposed method can effectively focus the images both under the long-short-object-distance situation and under the long-object-distance situation.
Key words:
Auto-focusing, Image processing, Evaluation function, Gray gradient

1. Introduction

The performance of the auto-focusing system lies on the property of image clarity evaluation function. When we take photos, there are usually many objects in the view scope of lens. According to the difference of many object distances, there are two situations: one is that object distances of all the objects are far longer than the focal length of the lens, which we call long-object-distance situation; the other is that not all the different object distances are far longer than the focal length of the lens, which we call long-short-object-distance situation. Currently, most of papers have proposed methods which are only fit to auto-focus under the long-object-distance situation and have poor performance under the long-short-object-distance situation. And in this paper, we discuss the property of image clarity evaluation function under the long-short-object-distance situation in detail. We find that the curve of the image clarity evaluation function always has multiple peaks. From this viewpoint, the image clarity evaluation function based on Sobel operator is proposed. Experimental results indicate that the proposed method can effectively focus the images both under the long-short-object-distance situation and under the long-object-distance situation

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2. The Imaging in Different Object Distances

Under the long-object-distance situation, the object distances of all the objects are far longer than the focal length of the lens. So the beams of the objects can be considered as parallel beams. As long as the observation plane is located in the place of the focal plane, a focused image where all the objects are simultaneously focused will be obtained on the observation plane. And, if the clarity evaluation function is applied to the focusing criterion, the curve of image clarity evaluation function will have single peak.

Under the long-short-object-distance situation where not all the different object distances are far longer than the focal length of the lens, the light refracted by the lens can not simultaneously converge, as shown in Fig. 1.

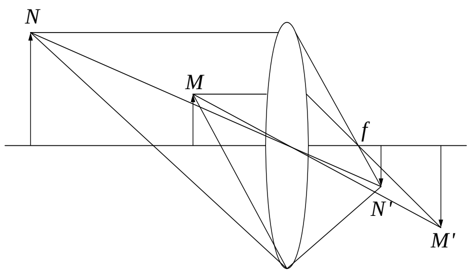


Figure 1. The imaging relation in different (object) distances

In Fig. 1, there are two objects, *M* and *N*, which have different object distances. The two light sources produce two images, *M'* and *N'*. Let *M* and *N* denote the object and the background, respectively. There will be two focused images: the one is obtained when *M* is focused but *N* is defocused; the other is obtained when *M* is defocused but *N* is focused. However we move the observation plane, the focused image where the two objects simultaneously focus can not be obtained.

According to the analysis in theory, in the long-short-object-distance situation, different focused images corresponding to different objects can be obtained. Here, if the clarity evaluation function is applied to the focusing criterion, the curve of image clarity evaluation function will have multiple peaks.

3. The Image Clarity Evaluation Function Based on Sobel Operator

The traditional view is that the curve of image clarity evaluation function always has single peak [1], [2], [3], [4], [5], [6]. But from the analysis above, under the long-short-object-distance situation, the curve of image clarity evaluation function has multiple peaks. According to the analysis of image clarity evaluation function under this situation, the image clarity evaluation function based on Sobel operator is presented in this paper. A focused image contains more edge information in spatial domain and high frequency components in frequency domain than the defocused image [7]. And we can extract edge information by gray gradient method. Whether an image is focused can be reflected by judging whether the edge parts and the detail parts of images are clear in spatial domain or judging whether the high frequency components are rich in frequency domain. The former can obtain the information of edge and detail parts of images by the difference operation of images. The latter can obtain the frequency spectrum information by the fast Fourier transform of images. In this paper, edge information is used as a criterion of image clarity evaluation.

Gray gradient method is usually used for evaluating the image clarity. Sobel operator, Roberts operator, and Laplacian of Gaussian operator have been widely used in the image clarity evaluation function, and these functions present good unbaisedness, the property of single peak, sensitivity under the long-object-distance situation[8]. But under the long-short-object-distance situation, the image clarity evaluation function based on Sobel operator has better performance than the functions based on other operators. In this paper, we compare the performance of the proposed method with the performance of the method based on Roberts operator and Laplacian of Gaussian operator.

Sobel operator is a second differential operator and has good antinoise property. When it is employed to extract the edge information, the edge width is two pixels at the least. And the operator is independent on detection direction. Sobel operator is composed of two convolution kernels. For a gray image f, each pixel $f(i,j)$ is convolved by the two convolution kernels. One convolution kernel has great effect on the horizontal edge, and the result of convolution is defined in Eq. (1) ; the other convolution kernel has great effect on vertical edge, and the result of convolving is defined in Eq. (2). $G[f(i,j)]$ denotes the sum of square of absolute value of Eq. (1) and Eq. (2), as shown in Eq. (3).

$$\begin{aligned}\Delta G_i = {} & f(i-1, j+1) + 2f(i, j+1) + f(i+1, j+1) \\ & - f(i-1, j-1) - 2f(i, j-1) - f(i-1, j-1)\end{aligned} \tag{1}$$

$$\begin{aligned}\Delta G_j = {} & f(i-1, j-1) + 2f(i-1, j) + f(i-1, j+1) \\ & - f(i+1, j-1) - 2f(i+1, j) - f(i+1, j+1)\end{aligned} \tag{2}$$

$$G[f(i,j)] = |\Delta G_i|^2 + |\Delta G_j|^2 \tag{3}$$

According to this method, the image clarity evaluation function based on Sobel operator can be defined as:

$$G_k = \sum_i \sum_j G[f(i,j)]$$
$$N = \max(G_k), \quad k = 1,\ 2,\ \cdots,\ M \tag{4}$$

In Eq. (4), G_k denotes the gray variation rates of the kth image. When the images become clearer, G_k will become larger, which means the image contains more edge information. And the image corresponding to the maximum G_k is the clearest.

4. Experimental Results

This section presents experimental results of the proposed method. We took some photos by the digital camera, the resolution of which is 2496×1664. The center rectangle window is used for saving computational time in the paper, the area of which is 1/9 of the whole image area. And in the experiments, we only use the image in the center rectangle window. We take two situations into consideration: the long-short-object-distance situation, as shown in Fig. 2, and the long-object-distance situation, as shown in Fig. 3.

(a) Both object and background defocused

(b) Object defocused and background focused

(c) Object focused and background defocused

Figure 2. The first group of test images

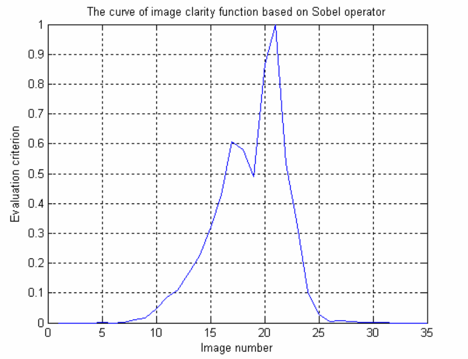
(a) Both object and background defocused

(b) Both object and background focused

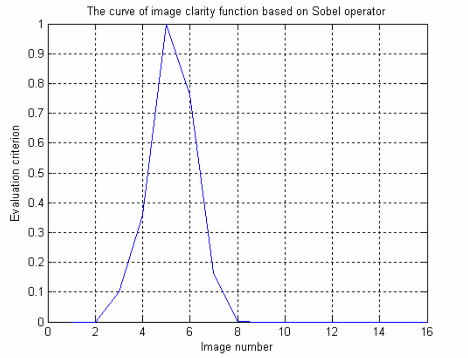
Figure 3. The second group of test images

Fig. 2 expresses that the images where the object and background are simultaneously focused can not be obtained under the long-short-object-distance situation. Fig. 2(a) is the image where both the object and background are defocused. Fig. 2(b) is the image where the object is defocused while background is focused. Fig. 2(c) is the image where the object is focused while background is defocused. Fig. 3 expresses that the images where the object and background are simultaneously focused can be obtained under the long-object-distance situation. Fig. 3(a) is the image where both the object and background are defocused, and Fig. 3(b) is the image where both the object and background are focused.

In the experiments, we compute the image clarity evaluation function by using Eq. (4). In Fig. 4, we plot the curves of the image clarity evaluation function of the two groups of test images, respectively. To effectively evaluate the performance of the proposed method, we compare the performance of the proposed method with the performance of the method based on Roberts operator and Laplacian of Gaussian operator, respectively, as shown in Fig. 5 and Fig. 6.

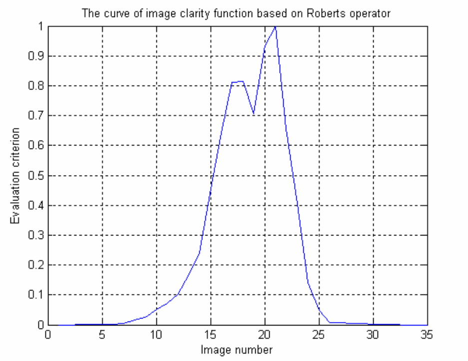


(a) The first group of test images

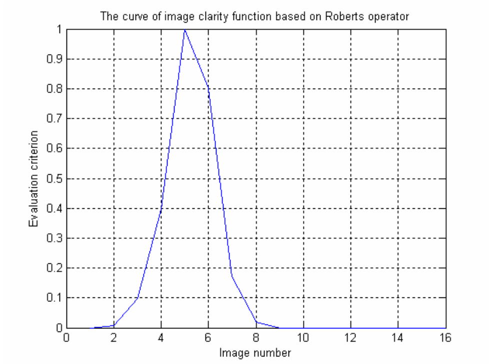


(b) The second group of test images

Fig. 4 The curve of the image clarity function based on Sobel operator

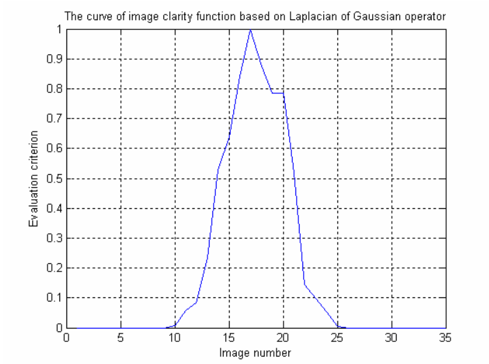


(a) The first group of test images

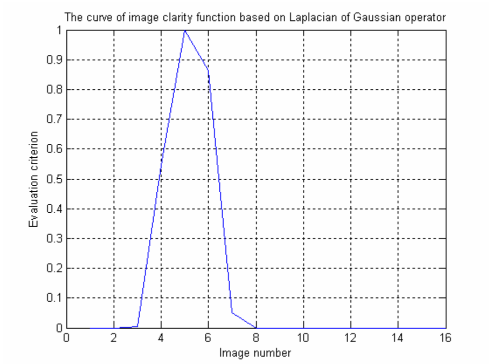


(b)The second group of test images

Fig. 5 The curve of the image clarity function based on Roberts operator



(a)The first group of test images



(b)The second group of test images

Fig. 6 The curve of the image clarity function based on Laplacian of Gaussian operator

In Fig. 4(a), the curve of the image clarity evaluation function based on Sobel operator has obvious two peaks under the long-short-object-distance situation. The image corresponding to the highest peak is the one where the object is focused, while the image corresponding to the hypo-highest peak is the one where background is focused. The two sides of peaks are both smooth, and have no obvious burrs. So the sort of this curve is in favor of searching the clearest image by mountain-climb algorithm.

Fig. 5(a) plots the curve of the image clarity function based on Roberts operator. Although the image clarity function based on Roberts operator has good performance under the long-object-distance situation [4], the performance of the method is worse than the performance of Sobel operator method under the long-short-object-distance situation. In Fig. 5(a), we can find that there is an obvious burr beside the peak which is focused on the background. By using the mountain-climb algorithm, the local clearest image may be regarded as the global clearest image, which leads to appear bias.

Fig. 6(a) shows the curve of the image clarity function based on Laplacian of Gaussian operator. We can easily find that the performance of this method is worse than the performance of the method based on Sobel operator or Roberts operator. In Fig. 6(a), the highest peak and the hypo-highest peak are not corresponding to the image where the object is focused and the image where the background is focused, respectively.

Fig. 4(b), Fig. 5(b) and Fig. 6(b) plot the curves of the image clarity evaluation function based on Sobel operator, Roberts operator and Laplacian of Gaussian under the long-object-distance situation, respectively. We can easily find out that all of the curves vary with the clarity of the images. And the curves have only single peak which is corresponding to the clearest image. So it is proper to conclude that the proposed method is also fit to the image clarity evaluation function under the long-object-distance situation.

5. Conclusions

This paper analyses the imaging relations of the lens system and the properties of image clarity evaluation function under the condition where the object distances of many objects are different. We find that the curve of the image clarity evaluation function always has multiple peaks under the long-short-object-distance situation. The image clarity evaluation function based on Sobel operator is presented in this paper. And the proposed method is compared with the method based on Roberts operator and Laplacian of Gaussian operator, respectively. The experimental results show that the proposed method is suitable for the image clarity evaluation function under the different object distance conditions.

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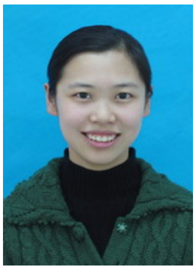

Quan Feng received the B.E. degree in Nanjing University of Posts and Telecommunications. Currently, she is a Master candidate of Nanjing University of Posts and Telecommunications. She is interested in the research on image processing and image telecommunications.

Ke Han received the B.E. and M.E. degrees in Shandong University in 2001 and 2004, respectively. Currently, he is a Ph.D. candidate of Nanjing University of Posts and Telecommunications. He is interested in the research on image processing, pattern recognition, and image telecommunications.

Xiu-chang Zhu received the B.E. degree in radio engineering and the M.E. degree in communication and electronics system from Nanjing University of Posts and Telecommunications, Nanjing, China, in 1982 and 1987, respectively. Currently he is a Professor with the College of Communication and Information Engineering, Nanjing University of Posts and Telecommunications. His research interests include image communication and image processing.