Improved SMD Image Evaluation Function Based on Pixel Difference

Wenming Yin, Wansheng Liu

ABSTRACT

In order to improve the noise immunity and sensitivity of the definition evaluation function in the remote sensing automatic imaging system, this paper proposes an improved SMD evaluation function. This function increases the difference between images by accumulating pixel differences in multiple directions, and achieves the ability to distinguish finely defocused images. In order to verify its performance, this article compares the performance of this function with other common spatial domain functions in the same set of image sequences with different definitions. It is found that compared with the common evaluation function, this function has better sensitivity, stronger robustness and moderate image processing speed. This function has certain reference value for imaging systems with high accuracy requirements.

KEYWORDS

Image Processing, Clarity Evaluation Function, Spatial Domain, Automatic Imaging.

INTRODUCTION

With the rapid development of aerospace industry, remote sensing imaging technology gradually entered the public vision. For example: satellite maps, resource surveys, environmental monitoring, etc. Because remote sensing imaging is a long-distance, non-contact target detection technology, its operating environment often undergoes drastic changes, causing the deviation of the quasi-focus position and resulting in poor imaging quality, especially due to factors such as mechanical vibration, external shock, and temperature changes. Therefore, it is necessary to correct the focus position in time to ensure the clarity of the output image, so the automatic focus technology becomes particularly important. Among them, the automatic focusing technology based on image processing is a research hotspot[2]. This method uses the image information collected by the imaging system, and then uses the evaluation function to calculate the evaluation value of the collected image, and finally combines the focus search algorithm to complete the automatic focus[1]. How to construct the image definition evaluation function in the automatic focusing system is the core of the research. For this reason, sensitivity and noise resistance have become important indicators for designing the evaluation function. The high sensitivity can ensure that the imaging system outputs high-
quality images, and the strong noise resistance makes the system run more stable. Common image clarity evaluation functions are mainly divided into four categories: spatial domain evaluation functions, transform domain evaluation functions, statistical evaluation functions and information entropy evaluation functions. Because the spatial domain evaluation function has clear physical meaning and fast calculation speed, it is widely used in practical engineering.

The principle of the spatial domain image definition evaluation function is mainly based on the image edge gradient. This type of method is to calculate the image edge and evaluate whether the image is clear or not according to the magnitude of the gradient value. The clear image has sharper edges, higher contrast, and more higher gray scale changes than the blurred image to judge the in-focus and out-of-focus images. Commonly used spatial image definition evaluation functions include SMD function, Sobel function[8], Variance function, Tenengrad function, Brenner function[3][5], Lean function and Roberts function.

Among them, the SMD evaluation function has become one of the classic functions in the space domain due to its simple formula and fast calculation speed, but its evaluation accuracy is relatively low. This paper proposes a new spatial domain image definition evaluation function based on the original SMD evaluation function[4]. The improved SMD function meets the requirements of high sensitivity and strong noise resistance, and can process multiple image data in real time.

**IMAGE EVALUATION FUNCTION IN SPATIAL DOMAIN**

**Traditional SMD Function**

The sum of absolute value of gray difference function (SMD) makes the difference between the gray value of the pixel in the horizontal direction and the vertical direction of the pixel in the image, and then uses the absolute value of the difference between the pixels of the whole image to accumulate and sum, and use the gradient to change The absolute value of is a measure of the image. According to the definition of the function, the function curve reaches its maximum value at the clearest part of the image. The function expression is as follows:

\[
F_{\text{SMD}} = \sum_{x} \sum_{y} |I(x+1, y) - I(x, y)| + |I(x, y+1) - I(x, y)|
\]  

**Improve SMD Evaluation Function**

Since the gray difference between adjacent pixels of the focused image is relatively large and the edges of the image are obvious, the original SMD function only compares two adjacent pixels in the horizontal direction and the vertical direction of the target pixel to distinguish them. But in real life, many images are irregular, and the edge direction of the image is also uncertain. Sometimes the calculated result has a large error, causing mis-adjustment. The subjective evaluation habit of the human eye is to compare the center pixel with the adjacent four or eight pixels[9].

The improved SMD function is to calculate the difference between the target pixel and the adjacent pixels from multiple directions, and take the absolute
value of the multi-directional grayscale difference to accumulate and sum. The specific function formula definition is shown in the formula:

\[
F_{\text{our}} = \sum_{x} \sum_{y} |I(x+1, y) - 2I(x, y) + I(x-1, y)| + |I(x, y+1) - 2I(x, y) + I(x, y-1)| \\
+ |I(x+1, y+1) - 2I(x, y) + I(x-1, y+1)| + |I(x+1, y-1) - 2I(x, y) + I(x-1, y-1)|
\]

(2)

So in order to make the evaluation function applicable to images with more complex content. The improved evaluation function supplements the comparison of two additional pixels in the horizontal and vertical directions on the original basis. In addition, it adds the contrast difference between the 45° and 135° diagonal pixels of the target pixel, which improves the sensitivity and noise resistance of the improved function. This is more in line with scientific judgment, and can better extract edges and filter noise. Figure 1 shows a part of the pixels in an image, and each square represents a pixel. First, use the original SMD function to calculate the Figure (a), because the function is only for the two adjacent pixels in the horizontal and vertical directions. The difference is calculated for each pixel, and the difference between the pixel and the adjacent pixel is 0 according to the formula. Next, using the improved SMD function for the picture (b), it is obvious that there is a difference between this point and the adjacent eight pixels in the vertical direction. The image blur is a continuous gradual process, and the two pictures with slight defocus only rely on the difference in two directions. It may not be enough to distinguish, but the difference between a single pixel of the entire image and the surrounding eight pixels is accumulated and summed, and the accumulated difference value of the improved SMD function is still very different. This explains why the improved SMD function is more sensitive than before.

Figure 1. Image pixel gradient model.

From the analysis of the formula principle and calculation amount, since the Sobel, Tenengrad, and Lean evaluation functions require each pixel to be convolved with different templates Kx and Ky, the improved SMD function only has simple addition and subtraction calculations, so in image processing In terms of speed, the improved SMD function is better than the Sobel, Tenengrad, and Lean functions, and may be worse than the original SMD function, because the improved SMD function adds six additions and six subtractions, but the
analysis of time complexity is the same order of magnitude. So the two are almost the same in efficiency.

SIMULATION ANALYSIS AND VERIFICATION

Image Simulation

According to the schematic diagram of the geometric optical model, as shown in Figure 2, the imaging system images P, in which U is the object distance and V is the distance. When the system is in a quasi-focal state, the points on the image surface are the images generated by the imaging system on the object. Then, using gaussian imaging formula, the object distance and distance meet the following relation:

\[ \frac{1}{U} + \frac{1}{V} = \frac{1}{f} \]  

(3)

Figure 2. Schematic diagram of geometric optics model.

If the imaging system is out of focus, for example, the object distance or distance has changed. As shown in Figure 2, the point will move to the left or right in the defocused state, then the image formed on the detector is not a point, but a diffuse spot. The size of the diffuse spot is directly proportional to the blur degree of the image. The larger the radius of the circle of confusion, the greater the degree of defocus of the imaging system, and the more blurred the image; the smaller the radius of the circle of confusion, the smaller the degree of defocus of the imaging system.

For the generation of blurred images, a two-dimensional Gaussian model can be used to simulate a diffuse spot, and a two-dimensional Gaussian function can be used to approximate the point spread function (PSF). The formula is as follows:

\[ h(x, y) = \frac{1}{2\pi\sigma} \exp\left(-\frac{x^2 + y^2}{2\sigma^2}\right) \]  

(4)
Among them, \( \sigma \) is the standard deviation of the Gaussian function, and the size of the speckle of the imaging system can also be expressed here:

\[
\sigma = kd = kD_s \left( \frac{1}{f} - \frac{1}{U} - \frac{1}{s} \right)
\]

(5)

In the above formula, \( k \) is approximately \( \frac{1}{\sqrt{s}} \), in many cases, and \( s \) is the actual image distance. According to optical principles, the generation of blurred images is the convolution of object intensity and PSF:

\[
g(x, y) = f(x, y) \otimes h(x, y)
\]

(6)

According to the above formula, combined with the Gaussian blur algorithm, by changing the value of \( \sigma \) in the two-dimensional Gaussian function, images with different definitions are generated. In order to verify the sensitivity of various evaluation functions, this paper uses the same target image sequence with different defocus degrees to test. The image sequence is from blur to clear to blur in order, a total of 18 frames, of which the first and 18th frames are the most blurry, and the 10th frame is the clearest. The image sequence generated by the simulation can better control the blur degree of the image, which is convenient for the subsequent result analysis. The image size of each frame is, and the image sequence generated by the simulation is shown in Figure 3.

Figure 3. Different defocus image sequences.

First use the image sequence to analyse the improved SMD evaluation function, verify whether the designed function meets the two basic characteristics of the ideal evaluation function model, and compare it with the SMD function: (1) Unbiased, that is at the focal position of the optical system, the image clarity evaluation value is the maximum value of the focusing curve; (2) Unimodality, that is the evaluation curve has only one global maximum value, and the function increases and decreases monotonously on both sides of the maximum value. It can be clearly seen from Figure 4 that the improved SMD evaluation function conforms to the design principle[6], and
compared with the original SMD function curve, it is found that the curve slope of the improved SMD function is greater near the focus image, indicating that the function is more sensitive. It is helpful to improve the accuracy of the image generated by the imaging system.

Then use the above-mentioned different definition evaluation functions to perform data processing and analysis on the image sequence respectively, and the processing results of various evaluation functions in the spatial domain are shown in Figure 4. It shows the focus characteristic curve of mainstream image evaluation functions of images with different degrees of blur in the airspace, where the abscissa represents the position of the imaging surface, and the ordinate represents the evaluation value of image clarity. It can be seen from the figure that there are multiple local extreme points in the ups and downs of the focus curve of the Variance function, which shows that the function cannot effectively distinguish the sharpness of the image in the complex content image, and it is easy to cause misfocusing. SMD function, Sobel function, Tenengrad function, Brenner function, Lean function, Roberts function and the function curve proposed in this paper are all smooth, which meets the basic requirements of ideal image definition evaluation function.

However, the design of the evaluation function in this paper requires high sensitivity, that is, when the imaging system is close to the in-focus state, the degree of blurring of adjacent images is small, but the evaluation function can also effectively distinguish between two images. It can be seen from Figure 5 that the evaluation function curve designed in this paper is narrower than other evaluation functions at the peak, indicating that the evaluation function is suitable for systems that require high imaging accuracy.
The above-mentioned definition evaluation functions are all performed under the same hardware and software platform (Intel Core i5-9400@3.3GHz+Matlab 2017b). Table I shows the operational efficiency of various functions on image sequences. It can be seen that the evaluation functions of Tenengrad, Sobel, and Lean need to perform convolution processing on the image, so their calculation speed is slightly longer. The evaluation functions of SMD, Variance, Brenner, and Roberts are basically at the millisecond level. Among them, the Brenner evaluation function runs the fastest. The evaluation function designed in this paper and the SMD function have little difference in running speed, which fully conforms to the previous theoretical analysis.

| Type            | Function name | Time/ms |
|-----------------|---------------|---------|
| Spatial domain  | SMD           | 5.73    |
|                 | Sobel         | 16.27   |
|                 | Variance      | 4.29    |
|                 | Tenengrad     | 16.86   |
|                 | Brenner       | 2.84    |
|                 | Lean          | 16.81   |
|                 | Roberts       | 5.71    |
|                 | Our           | 6.44    |

Analysis of Noise Immunity

The focusing system is mainly composed of the three major disciplines of optoelectronics. The mechanical system will produce noise during operation and image transmission, which will have a certain impact on the output image. Therefore, the anti-noise[7] performance of the image definition evaluation function is also one of the focuses of the research. In the experiment, gaussian random noise with mean value of 2 and variance of 4 and pepper and salt noise with probability of 0.1 were added to the sequence images in Figure 3 respectively to generate Gaussian noise image sequences and pepper and salt.
noise image sequences. Then use the evaluation functions listed above to compare, and the results obtained are shown in Figure 7 and Figure 6. Tables II and III are the absolute error analysis of the evaluation values of the image sequence with and without noise. Judge the anti-noise performance of the function.

![Figure 6. Comparison of evaluation functions of salt and pepper noise images.](image)

![Figure 7. Comparison of image evaluation functions with Gaussian noise.](image)

**TABLE II. ERROR ANALYSIS OF NOISE RESISTANCE (SALT AND PEPPER).**

| Name    | Error  | Name    | Error  |
|---------|--------|---------|--------|
| Our     | 0.488  | Brenner | 0.8031 |
| SMD     | 1.057  | Lean    | 1.052  |
| Sobel   | 1.234  | Roberts | 0.639  |
| Variance| 0.5784 | Tenengrad| 2.262  |
As can be seen from Figure 7, after comparison of each function through image sequences polluted by Gaussian noise, it is found that the unimodality and monotonicity of other functions remain basically unchanged except that Variance function has local extreme points, among which the sensitivity of the function proposed in this paper is still better than other functions. However, after adding salt and pepper noise to the original image, the Sobel function, Variance function, Brenner function and Roberts function appear local extreme points where the degree of ambiguity is high, and the results are shown in Figure 6. The improved SMD function curve does not change much, and still maintains unimodality, monotonicity and high sensitivity. For the convenience of calculation, the error values in this paper are all enlarged by 100 times. From Table II and Table III, it can be seen that the improved SMD function can effectively resist the influence of salt and pepper noise, but the influence of Gaussian noise is greater than other functions. As the Gaussian noise has relatively little influence on all functions, combining the two results found that the comprehensive performance of the improved SMD function against noise has been improved. Therefore, compared with other commonly used evaluation functions in the spatial domain, the evaluation function proposed in this paper has the characteristics of strong anti-noise ability and high sensitivity.

SUMMARY

This paper mainly studies the image sharpness evaluation function in the spatial domain, and proposes a new evaluation function according to the design requirements of the ideal image sharpness evaluation function. The performance of this function is compared with several common spatial evaluation functions of SMD function, Sobel, Variance, Tenengrad, Brenner, Lean, and Roberts function. The data set is the image sequence of the same target under different definitions and add image sequences with different noises. After comparing the results of each evaluation function curve, it is found that the function proposed in this paper has the following advantages. (1) The sensitivity of the improved SMD function is better than that of other functions in comparison, whether it is an ideal image quality or when noise is added. (2) The improved SMD function has good single-facetness and no local extreme points. (3) In terms of image processing speed, the function proposed in this paper is at an intermediate level compared to other functions, and can also meet real-time requirements. This function is suitable for imaging systems that require high focusing accuracy.

ACKNOWLEDGEMENTS

Corresponding author: Wansheng Liu
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