

Photon Counting Image Fusion Algorithm Based on Adaptive Threshold of Regional Energy

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Abstract. In order to get photon counting fusion images with better effect, it is proposed a fusion algorithm based on adaptive threshold of regional energy fusion rule. The photon counting image is obtained by the MPPC (Multi-pixel Photon Counter) single detector in different illumination conditions, the high-frequency part and the low-frequency part are obtained after redundant wavelet transform of photon counting image. In high-frequency part of the two source images, the energy of the corresponding region, neighborhood mean square, matching degree and adaptive threshold deviation are calculated. And the adaptive threshold is determined by pixel values and mean values of regional image. If the matching degree is greater than adaptive threshold value, weighted regional energy fusion method is used to solve it. Otherwise, the enhanced pixel value of source image with larger energy in local region is selected as pixel value in corresponding fusion image. Using adaptive threshold of regional energy fusion rule for image fusion, it is proved that details of photon counting fusion image are clearer and target is easier to recognize in this paper, the values of information entropy, average gradient and spatial frequency are about 20%, 25%, and 30% higher than that of regional energy fusion rules.

Introduction

Photon counting image is obtained in the low-light environment. With the development of night vision technology, the demand for image fusion is also increasing in the low-light-level image processing system. Image fusion is a process of synthesizing significant features of multiple acquired source images by using mathematical methods^[1]. Since multiple source images can complement each other, image fusion can reduce the fusion image uncertainty and ambiguity, and improve the accuracy and reliability of the fusion image information, forming a more complete description of the target^[2].

In recent years, image fusion has been widely used in visible light images and infrared images^[3], low-light-level images and infrared images^[4]. The effect of fusion image was improved, but there were still noises and unclear phenomena in the fusion image in reference[5]. The image fusion based on the region energy method and the region gradient method fusion rule was used to obtain a high brightness of the fusion image, but the fringe noise appeared and the image outline was not clear^[6].

The above are all the fusion techniques of low-light-level images and infrared images, visible light images and infrared images, but the fusion technology between photon counting images is quite immature, and the corresponding fusion algorithms are rarely studied. Image fusion algorithm bases on regional energy, the fusion image has unclear outline and serious noise. In this paper, the photon counting image is obtained by MPPC detector under different illumination conditions. In image fusion based on redundant wavelet transform, image fusion based on adaptive threshold of regional energy fusion rule can obtain higher image quality, and outline of the target is clearer and target is easier to distinguish.

Regional Energy Fusion Rules

The detail features of an image are often not represented by a single pixel, it is collectively represented and embodied by multiple pixels of local area. And there is a strong correlation between pixels in certain local area of image. The basic idea of regional energy fusion rule is that redundant wavelet transform of source image to obtain different high-frequency and low-frequency parts.

The high-frequency part image uses region energy fusion rule. $E_j^\varepsilon f_A(m,n)$ and $E_j^\varepsilon f_B(m,n)$ represent local region energy of the two source images A and B, which are at the j resolution, and local region energy centered on (m,n) in the ε direction. $E_j^\varepsilon f_{(A \times B)}(m,n)$ indicates local region energy centered (m,n) that image $A \times B$ is in j resolution and ε direction. Thereby, the matching degree M of corresponding local regions of two source images is defined [17]:

$$M = \frac{2 \times E_j^\varepsilon f_{(A \times B)}(m,n)}{E_j^\varepsilon f_A(m,n) + E_j^\varepsilon f_B(m,n)} \quad \varepsilon = 1, 2, 3 \quad (1)$$

The threshold T in regional energy fusion rule is set $T=0.7$ according to the effect of multiple experiments. The weight coefficient can be determined based on matching degree M and threshold T :

$$\begin{cases} \omega_{\min} = \frac{1}{2} \left(1 - \frac{1-M}{1-T} \right) \\ \omega_{\max} = 1 - \omega_{\min} \end{cases} \quad (2)$$

The matching degree is compared with threshold to fuse the image. Where, $f_F(m,n)$ represents photon counting fusion image.

If $M < T$

$$f_F(m,n) = \begin{cases} f_A(m,n), E_j^\varepsilon f_A(m,n) \geq E_j^\varepsilon f_B(m,n) \\ f_B(m,n), E_j^\varepsilon f_A(m,n) < E_j^\varepsilon f_B(m,n) \end{cases} \quad (3)$$

If $M \geq T$

$$f_F(m,n) = \begin{cases} \omega_{\max} \times f_A(m,n) + \omega_{\min} \times f_B(m,n), E_j^\varepsilon f_A(m,n) \geq E_j^\varepsilon f_B(m,n) \\ \omega_{\min} \times f_A(m,n) + \omega_{\max} \times f_B(m,n), E_j^\varepsilon f_A(m,n) < E_j^\varepsilon f_B(m,n) \end{cases} \quad (4)$$

Adaptive Threshold of Regional Energy Fusion Rules

In this paper, the image fusion method based on adaptive threshold of regional energy fusion rule can highlight characteristics of photon counting image. The fusion rule is to calculate energy and mean square error of all pixels in a certain region of source image. The photon counting image is decided by region energy and mean square error. The enhancement factor in adaptive threshold of regional energy is determined by corresponding neighborhood mean square error of two source images, and adaptive threshold is determined by the part image information of two source images. Figure 1 is a block diagram of basic principle of image fusion for adaptive threshold of regional energy fusion rule.

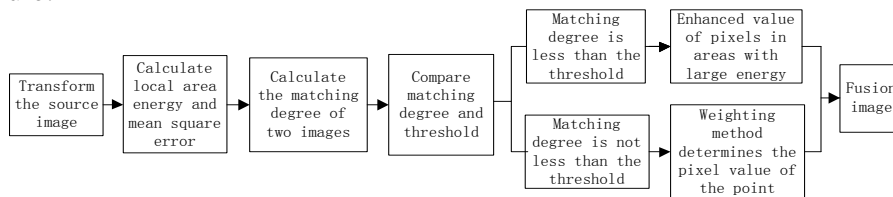


Figure 1. Basic principle block diagram of image fusion for adaptive threshold regional energy.

The neighborhood characteristics of image are affected by many factors, where regional energy and variance are significant. The mean squared error of local area is related to richness of image details. The enhancement value of pixel at a certain point is determined by product of pixel value and enhancement factor at that point, and the pixel enhancement value of high-frequency part image can better reflect the details of the image.

$$\begin{cases} \mu_A = \frac{1}{K \times L} \sum_{m=1}^K \sum_{n=1}^L f_A(m, n) \\ \mu_B = \frac{1}{K \times L} \sum_{m=1}^K \sum_{n=1}^L f_B(m, n) \end{cases} \quad (5)$$

$$\begin{cases} \sigma_A = \sqrt{\frac{1}{K \times L} \sum_{m=1}^K \sum_{n=1}^L (f_A(m, n) - \mu_A)^2} \\ \sigma_B = \sqrt{\frac{1}{K \times L} \sum_{m=1}^K \sum_{n=1}^L (f_B(m, n) - \mu_B)^2} \end{cases} \quad (6)$$

$$\begin{cases} \psi_A = \frac{2\sigma_A}{\sigma_A + \sigma_B} \\ \psi_B = \frac{2\sigma_B}{\sigma_A + \sigma_B} \end{cases} \quad (7)$$

In the above formulas, K and L represent the size of the local region, $m=1, 2, 3, \dots, K$, $n=1, 2, 3, \dots, L$. μ_A and μ_B respectively represent the mean values of the photon counting source images A and B, σ_A and σ_B respectively represent the mean square error of the photon counting source images A and B, ψ_A and ψ_B represent the enhancement factors of the photon counting source images A and B, respectively.

If threshold T is same in different source images fusion, it will influence fusion effect of image. In this paper, it is compared with adaptive threshold T and matching degree of two source images in local regions. The adaptive threshold corresponding to matching degree needs to be calculated. According to formula (5), the adaptive threshold T can be calculated, and calculation formula is:

$$T = \frac{\sum_{m=1}^K \sum_{n=1}^L [f_A(m, n) - \mu_A][f_B(m, n) - \mu_B]}{\sqrt{\sum_{m=1}^K \sum_{n=1}^L [f_A(m, n) - \mu_A]^2 [f_B(m, n) - \mu_B]^2}} \quad (8)$$

It can be seen from equation (8) that adaptive threshold varies with image information of different local regions in this paper. It is compared with adaptive threshold T and matching degree M . It can be known from the formula (2) that weight coefficient is jointly determined by the threshold and the matching degree, and the weight coefficient of the fusion image changes with adaptive threshold T .

If $M < T$

$$f_F(m, n) = \begin{cases} \psi_A f_A(m, n), E_j^e f_A(m, n) \geq E_j^e f_B(m, n) \\ \psi_B f_B(m, n), E_j^e f_A(m, n) < E_j^e f_B(m, n) \end{cases} \quad (9)$$

If $M \geq T$, the formula is same as formula (4).

Experimental Analysis

The experiment selected leaf image and classic Lena image. The only different value of the micro illuminometer is set in two experiments. The value of micro illuminometer is $6.31 \times 10^{-5} lx$ in Figure 2(a) and Figure 4(a), and value of the micro illuminometer is $4.02 \times 10^{-4} lx$ in Figure 2(b) and Figure 4(b).

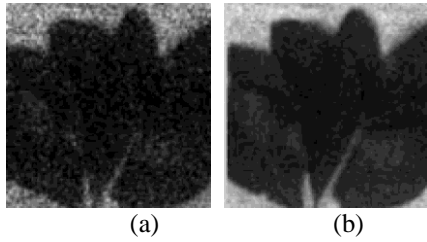


Figure 2. Source images.

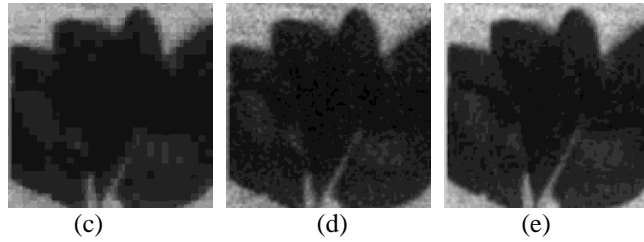


Figure 3. Different fusion images.

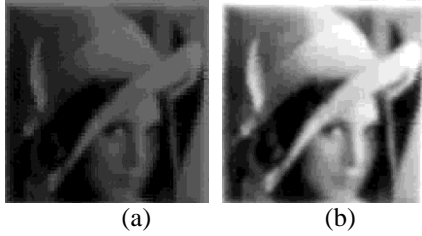


Figure 4. Source images.

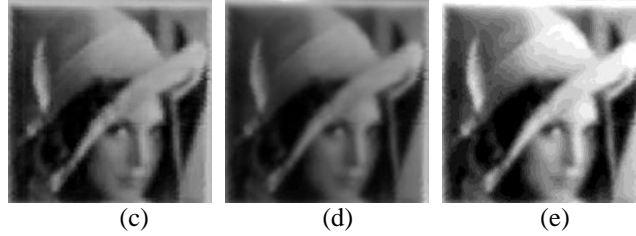


Figure 5. Different fusion images.

In figure 3 and figure 5, figure(c) in high-frequency part of image uses wavelet coefficient larger absolute value method, figure(d) fusion rule is high-frequency part of image fusion method for regional energy, figure(e) high-frequency part image with adaptive threshold of regional energy fusion rule.

Table 1. Evaluation indexes of fusion images.

	Mean	Standard deviation	Average gradient	Information entropy	Spatial frequency
Figure 3(c)	53.6250	45.3152	4.1379	6.2752	11.6165
Figure 3(d)	54.5689	45.9686	6.8036	6.4008	12.8527
Figure 3(e)	54.3907	45.6737	7.8071	7.9605	14.8957
Figure 5(c)	93.7220	54.9280	6.6113	7.1970	10.5665
Figure 5(d)	95.4256	55.7129	6.9220	7.7568	13.3652
Figure 5(e)	95.1087	55.1099	8.1051	9.9660	15.9561

It has massive fuzzy phenomenon of leaf image in figure 3(c), figure(d) and figure(e) are no big difference in subjective visual, but the figure(e) fusion image level more clearly than figure(d). Figure 5 Lena fusion image, figure(e) effect of fusion image and image quality are better than other fusion images. Figure(e) fusion images are distinct, clearer image texture and detail, as you can see adaptive threshold of regional energy fusion rule get fusion images work best. In order to more accurately evaluate the quality of the fusion image, objective evaluation is used. Table 1 objectively evaluates image effect of the fusion images, Figure 3(e) and Figure 5(e) have larger values of information entropy, average gradient, and spatial frequency than values of Figure(c) and Figure(d) of the same group. It explains that the more information the image contains, the richer the edge information and details, the better the image effect. Through the above data analysis, the values of information entropy, average gradient and spatial frequency are about 20%, 25%, and 30% higher than that of regional energy fusion rules, and image quality and performance are best, edge information and texture details are also obvious.

Summary

In this paper, it is compared that fusion images under different fusion rules, and it is verified advantages of adaptive threshold of regional energy fusion rules. The fusion image is obtained by using adaptive threshold of regional energy fusion rule, and experimental results show that details of photon counting fusion image are more obvious, and target is easier to identify. As can be seen from the objective evaluation indexes, information entropy, average gradient and spatial frequency values of the fusion image obtained by using the fusion rules in this paper have been improved, and fusion image has better effect.

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