Infrared Physics and Technology 92 (2018) 190–196

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

Regular article

Weight strategy aided infrared and visible image fusion utilizing the center operator from opening and closing based toggle operator

Xiangzhi Bai[a,b,*], Sheng Guo[a]

[a] Image Processing Center, Beijing University of Aeronautics and Astronautics, 100191 Beijing, China
[b] State Key Laboratory of Virtual Reality Technology and Systems, Beihang University, 100191 Beijing, China

ARTICLE INFO

Keywords:
Infrared and visible image fusion
Toggle operator
Center operator
Opening
Closing
Mathematical morphology

ABSTRACT

Fusion of infrared and visible images is an effective way for image analysis. The crucial factor of the fusion is extracting and combing the image features of original images. In this paper, an effective algorithm for infrared and visible image fusion utilizing a center operator is proposed. The center operator constructed from opening and closing based toggle operator is used to extract the multi-scale features of original images. After that, the final fusion features are calculated from these extracted multi-scale features through a weight strategy. The weight strategy is based on the entropy and gradient information of the extracted features, which is an effective way for integrating the information of the original images. Finally, the fusion image is produced by adding the final fusion features with the average image of original images. Experimental results of different types of infrared and visible images indicate that, the proposed algorithm performs effectively for infrared and visible image fusion.

1. Introduction

Infrared and visible image fusion has been an important technique for different applications [1–3], such as target identification, recognition and so on. Infrared image could be used to identify the target information. Visible image provides clear details for understanding the scene. The task of infrared and visible image fusion is combining the information of these images to generate one image, which facilitates the analysis of the scene [1–3].

To fuse the infrared and visible images, different types of algorithms utilizing various mathematical tools have been proposed [4–9]. The independent component analysis or principle component analysis has been tried for extracting the important information of the original images for fusion [4,5]. However, some useful information of the original infrared and visible images may be discarded, which would produce some unclear fusion results. Pyramid decomposition based algorithm [6] could extract the useful information of the original images for the effective fusion. However, some information may be lost in the procedure of decomposition, which causes the loss of details in the fusion result. In addition, the wavelet and curvelet transform based algorithms are proposed to extract the features of the original images [7–9], which have been used well for infrared and visible image fusion. However, some information may be still smoothed and the fusion results are not very clear. Sparse representation based algorithms for infrared and visible image fusion have been tried [29]. These kind of algorithms generally represent infrared and visible images with sparse coefficients, and combine information of original images according to these coefficients. Since the sparse coefficients have no concrete relation with image structure information, the fusion results of these algorithms may lose details of original images.

Based on the theory of mathematical morphology [10–16], the morphological operators have been used for the infrared and visible image fusion. Some basic morphological operators are used for infrared and visible image fusion [11]. As the algorithm may smooth the image details, the fusion result may be not clear. Some improved morphological operators [3,17–19], including the modified top-hat transforms, sequential toggle operator and so on, have been tried for infrared and visible image fusion. However, the details of the original infrared and visible images may not be combined effectively. In order to improve the fusion result, the improved sequential toggle operator is proposed for infrared and visible image fusion [30]. This method uses sequential toggle operator to extract multi-scale features of original images. At each scale, the extracted features of visible and infrared images are fused using the maximum strategy. The generated multi-scale features are aggregated using the maximum strategy and linear addition strategy, separately. These two generated features are added with the average image of the original images. This method has a good fusion result. However, the extracted multi-scale features are not precise

* Corresponding author at: Image Processing Center, Beijing University of Aeronautics and Astronautics, 100191 Beijing, China.
E-mail address: jackybxz@buaa.edu.cn (X. Bai).

https://doi.org/10.1016/j.infrared.2018.05.023
Received 7 September 2017; Received in revised form 24 May 2018; Accepted 25 May 2018
Available online 28 May 2018
1350-4495/

enough, which may cause the loss of details in the fusion result. Further, in the multi-scale features aggregation, the linear addition is weighted by the average intensities of features. Since the average intensity may not well reflect feature information, the fusion result could not effectively combine useful information of infrared and visible images.

In this paper, we propose an effective fusion method for infrared and visible images. We first use a center operator from opening and closing based toggle operator (*MCTO*) to extract multi-scale features of infrared and visible images. At each scale, the extracted features of infrared and visible images are fused according to their entropy information. The generated multi-scale fusion features are aggregated according to their gradient information. Finally, the aggregated features are added with the average image of infrared and visible images. The center operator (*MCTO*) is constructed in [20]. It could precisely extract multi-scale image features, which help decrease the coupling among the extracted features at adjacent scales. The multi-scale features of low coupling will help preserve more details in the fused image. The entropy of an image could reflect the amount of information it contains. The entropy based feature fusion strategy could preserve more information of infrared and visible images. Gradient information based aggregation strategy, could effectively preserve salient scale features. Hence, the proposed algorithm could effectively combine the useful information of original infrared and visible images. Experiment results show that the proposed algorithm provides a good fusion result, both in human visual perception and objective assessment metrics.

2. Related works

2.1. Fundamental operators

After being proposed by Matheron and Serra [21], the mathematical morphology has been an important theory for infrared image analysis [3,10,12,13,17–20]. One of the crucial concepts of mathematical morphology is the structuring element, which is used to process an image based on the set theory [10,21]. The basic morphological operators using a structuring element $B(u, v)$ to process the image $f(x, y)$ are as follows.

$$f \oplus B = \max_{u,v}(f(x-u, y-v) + B(u, v)), \tag{1}$$

$$f \Theta B = \min_{u,v}(f(x+u, y+v) - B(u, v)), \tag{2}$$

$$f \circ B = (f \Theta B) \oplus B, \tag{3}$$

$$f \bullet B = (f \oplus B) \Theta B, \tag{4}$$

where (u, v) and (x, y) represent the pixel coordinates of B and f, respectively. $\oplus$, Θ, $\circ$ and $\bullet$ represent the basic morphological operators of dilation, erosion, opening and closing, respectively.

Based on the morphological opening and closing operators, the classical morphological center operator is defined as follows [10,22].

$$MC(f) = \min\{\max\{f, \min\{AF_1(f), AF_2(f)\}\}, \max\{AF_1(f), AF_2(f)\}\}, \tag{5}$$

where $AF_1(f)$ and $AF_2(f)$ are defined as follows,

$$AF_1(f) = (f \circ B) \bullet B, \tag{6}$$

$$AF_2(f) = (f \bullet B) \circ B. \tag{7}$$

The classical anti-center operator $\overline{MC}(f)$ of $MC(f)$ is defined as the complementary of $MC(\overline{f})$, where $\overline{f}$ is the complementary of f.

2.2. The morphological center operator from opening and closing based toggle operator (MCTO)

The opening and closing operators based toggle operator TO_B is defined as follows [18,19,23],

$$TO_B(f)(x, y) = \begin{cases} f \circ B(x, y), & \text{if } f \bullet B(x, y) - f(x, y) < f(x, y) - f \circ B(x, y) \\ f \bullet B(x, y), & \text{if } f \bullet B(x, y) - f(x, y) > f(x, y) - f \circ B(x, y) \\ f(x, y), & \text{else} \end{cases}. \tag{8}$$

By utilizing this toggle operator, the center operator *MCTO* constructed in paper [20] is defined as follows,

$$MCTO(f) = \min\{\max\{f, \min\{AO^1(f), AO^2(f)\}\}, \max\{AO^1(f), AO^2(f)\}\}, \tag{9}$$

where

$$AO^1(x, y) = IFO_B(IFC_B(x, y)), \tag{10}$$

$$AO^2(x, y) = IFC_B(IFO_B(x, y)), \tag{11}$$

$$IFO_B(f)(x, y) = f(x, y) - \max\{f(x, y) - TO_B(f)(x, y), 0\}, \tag{12}$$

$$IFC_B(f)(x, y) = f(x, y) + \max\{TO_B(f)(x, y) - f(x, y), 0\}. \tag{13}$$

Similarly, the anti-center operator $\overline{MCTO}$ of *MCTO* is defined in a way similarly with $\overline{MC}$.

Operators *MCTO* and $\overline{MCTO}$ could be effectively used for feature extraction [20]. As one key factor of infrared and visible image fusion is effectively extracting the features of the original images, these operators could be used for the fusion of the infrared and visible images.

3. Infrared and visible image fusion

3.1. Fusion feature extraction using entropy based weight strategy

3.1.1. Feature extraction

Both the center operator *MCTO* and anti-center operator $\overline{MCTO}$ could smooth images. The pixel values of image bright features would be decreased, while that of dark features increased. Hence, the image bright and dark features could be extracted as follows [20],

$$BFCO(f) = \max\{f(x, y) - MCTO(f)(x, y), 0\}, \tag{14}$$

$$BFACO(f) = \max\{f(x, y) - \overline{MCTO}(f)(x, y), 0\}, \tag{15}$$

$$DFCO(f) = \max\{MCTO(f)(x, y) - f(x, y), 0\}, \tag{16}$$

$$DFACO(f) = \max\{\overline{MCTO}(f)(x, y) - f(x, y), 0\}, \tag{17}$$

where $BFCO(f)$ and $BFACO(f)$ represent the extracted bright features by the center operator *MCTO* and anti-center operator $\overline{MCTO}$, respectively. $DFCO(f)$ and $DFACO(f)$ represent the extracted dark features by the center operator *MCTO* and anti-center operator $\overline{MCTO}$, respectively.

Let f_I and f_V represent the infrared and visible images, respectively. Then, the extracted bright features of the infrared image f_I by operators *MCTO* and $\overline{MCTO}$ could be expressed as follows,

$$BFCO(f_I) = \max\{f_I(x, y) - MCTO(f_I)(x, y), 0\}, \tag{18}$$

$$BFACO(f_I) = \max\{f_I(x, y) - \overline{MCTO}(f_I)(x, y), 0\}. \tag{19}$$

The extracted dark features of the infrared image f_I by operators *MCTO* and $\overline{MCTO}$ could be expressed as follows,

$$DFCO(f_I) = \max\{MCTO(f_I)(x, y) - f_I(x, y), 0\}, \tag{20}$$

$$DFACO(f_I) = \max\{\overline{MCTO}(f_I)(x, y) - f_I(x, y), 0\}. \tag{21}$$

Similarly, the extracted bright and dark features of the visible image f_V by operators *MCTO* and $\overline{MCTO}$ could be expressed as follows,

$$BFCO(f_V) = \max\{f_V(x, y) - MCTO(f_V)(x, y), 0\}, \tag{22}$$

$$BFACO(f_V) = \max\{f_V(x, y) - \overline{MCTO}(f_V)(x, y), 0\}, \tag{23}$$