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Infrared and visual image fusion through feature extraction by morphological sequential toggle operator

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HIGHLIGHTS

- Utilizing the sequential toggle operator to solve the fusion problem.
- Weight strategy based fusion feature construction.
- Performing effectively for combining the information of the original images.

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ABSTRACT

Effectively extracting the features of the original images is crucial for infrared and visual image fusion. To well maintain the information of the original infrared and visual images and make the fusion image clear, a sequential toggle operator based algorithm through feature extraction is proposed in this paper. Firstly, sequential toggle operator based on multi-scale theory is discussed. Secondly, the features in the original infrared and visual images are extracted. Thirdly, the final fusion features are calculated from the extracted multi-scale image features through the weight strategy and considering the image details. Finally, after the base image is calculated from the original images, the final fusion image is obtained through enlarging the contrast between the final fusion features by using the base image. Experimental results on different types of infrared and visual images show that, the fusion result effectively combines the information of the original images and the result is clear. So, the fusion result is effective for different infrared image related applications, such as target detection, recognition, and surveillance.

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1. Introduction

Image fusion is an important technique for combining the superiorities of multi-sensors in optical signal and image processing [1–3]. Especially, infrared image could present the important regions of interest. But, the image details in infrared image may be not rich. Conversely, visual image contains rich image details. But, some regions of interest may be not observed. Then, fusion of the infrared and visual images may produce an effective result which contains both the regions of interest and rich image details [4]. So, the final fusion image would be more useful for different image based applications.

The crucial of infrared and visual image fusion is well combining the image information of the original images, so that the fusion image contains more information and is clear. To achieve this purpose, different types of algorithms have been proposed [5–22]. Independent component analysis (ICA) or principle component analysis (PCA) based algorithms [5–7] effectively extract the important information contained in the original images as the final fusion image. However, some image details may be smoothed. This may affect the performance of these algorithms for infrared and visual image fusion. Pyramid decomposition based algorithms through utilizing the Laplacian, wavelet and curvelet transforms [8–12] could combine the multi-scale features of the original images to achieve an effective fusion result. But, some image details may be not well extracted, which results in an un-clear fusion image and may not perform well for infrared and visual image fusion. A SFCE method, which could simultaneously perform the fusion, compression, and encryption on sequential images, has been proposed [13]. The effectiveness of this method has been verified. However, this method may be not appropriate for infrared and visual image fusion. Discrete wavelet transform has been used

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for fusion the multiple polarimetric SAR images with a panchromatic image [14]. Although the method performs effectively, it is mainly used for fusion the SAR images. Both the integer wavelet transform and PCA have been used for fusion the Landsat TM multispectral images with low-resolution and the SPOT panchromatic image to produce multispectral images with high-resolution [15]. The spectral information would be well preserved by this method. But, for the application of infrared and visual image fusion, the region information of the infrared image might be smoothed. The wavelet transform based color image fusion has been proposed, which was used for asymmetric cryptosystem and hiding [16]. However, the infrared and visual image fusion discussed in this paper is mainly for the gray images. Also, the modified wavelet transform based image fusion has been used for asymmetric watermarking [17], which could suppress the effect of noise like features. And, the fusion method using the discrete wavelet transform has been also extended for the protection of the multiple images [18]. These methods demonstrate the applicable of image fusion for solving the problems of data protection. But, these methods do not focus on the application of infrared and visual image fusion. Digital holography with multi-wavelength has been used for fusion of three-dimensional images based on wavelet decomposition [19]. But, the color information the method needed may be not provided by the gray infrared image in the application of infrared and visual image fusion. Through segmenting the corresponding regions of the original images and combining the useful segmented regions as the final fusion image is effective for images containing different clear regions [20]. But, the useful information in both the original images may be not well maintained in the final fusion image. Artificial tools, such as neural networks, could be used for multi-focus image fusion [21,22], which may be not effective for infrared and visual image fusion.

Mathematical morphology is an effective tool in image processing [23], which has been also used for image fusion. Top-hat transform is one widely used operator for morphological feature extraction [24,25], which could be extended for image fusion through multi-scale feature extraction [4,26,27]. But, the image details in the fusion image may be not clear or the fusion image may contain heavy noises. So, most of the existed algorithms may not perform effectively for infrared and visual image fusion. Morphological toggle operator [28–30] has been tried for feature extraction after being proposed, which is verified as one good tool for the extraction of image details [31–36]. Moreover, by using the multi-scale morphological theory [31–36], the multi-scale image features could be extracted. This would be useful for extracting the important information of the original image, which may be used for infrared and visual image fusion. Therefore, through appropriately utilizing the multi-scale morphological theory and toggle operator, an effective infrared and visual image fusion algorithm may be proposed.

In this paper, an effective infrared and visual image fusion algorithm based on the multi-scale sequential toggle operator is proposed. Firstly, the multi-scale sequential toggle operator is used to extract the bright and dark fusion features at each scale of the original infrared and visual images. Secondly, the final bright and dark fusion features of all the scales are calculated based on the extracted multi-scale features through the weight strategy and considering the image details. Finally, the final fusion features are imported into the base image through contrast adjustment to form the final fusion image. The main contributions of the paper are: (1) Utilizing the sequential toggle operator to solve the fusion problem; (2) weight strategy based fusion feature construction. Because of the final fusion feature extraction by multi-scale sequential toggle operator, the fusion result contains the regions of interest and rich image details of the original images. And, the result image has a good contrast. So, the proposed algorithm could be used for different infrared image related applications, such as target detection, recognition, and surveillance.

2. Mathematical morphology

Mathematical morphology has been widely used in image related applications [23–36]. Suppose $f(x,y)$ and $B(u,v)$ are two sets which represent the original image and structuring element, respectively. (x,y) represents the coordinate of pixels in image f. (u,v) represents the coordinate of pixels in structuring element B. The two basic operations defined using $f(x,y)$ and $B(u,v)$ are dilation and erosion which are defined as follows:

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

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

$\oplus$ and $\ominus$ denote the dilation and erosion operations, respectively.

Through combining the dilation and erosion, the opening and closing of $f(x,y)$ using $B(u,v)$, denoted by $f \circ B$ and $f \bullet B$, are defined as follows:

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

$$f \bullet B = (f \oplus B) \ominus B. \tag{4}$$

Opening and closing are useful operators for smoothing bright and dark image features.

Toggle operator is defined based on the primitives and rules. Using the opening and closing operations as primitives, one toggle operator could be defined as follows [32]:

$$TO(f)(x,y) = \begin{cases} f \circ B(x,y), & \text{if } f \bullet B(x,y) - f(x,y) < f(x,y) - f \circ B(x,y) \\ f \bullet B(x,y), & \text{if } f \bullet B(x,y) - f(x,y) > f(x,y) - f \circ B(x,y) \\ f(x,y), & \text{else} \end{cases}. \tag{5}$$

This definition indicates that, the pixels in TO are the selected pixels from the result of opening and closing which are more different from the pixels of the original image. These pixels represent the important features in the original image [32]. This means, the definition of TO could identify the important image features, which would be useful for the fusion of the information of the original images.

Usually, in infrared and visual images, the regions of the important image features will be different from other regions. Then, after the smoothing by opening or closing, the pixels of these regions in the result of opening or closing would be more different from the original image. Then, TO could be used to extract these important image features. This means, this definition of TO could be well used for infrared and visual image fusion.

3. Infrared and visual image fusion

3.1. Sequential toggle operator

Toggle operator could identify the image features smoothed by opening or closing corresponding to the structuring element. In fact, image features usually existed at the multi-scales of an image. Extracting these multi-scale image features would be crucial for infrared and visual image fusion. To identify the multi-scale image features, multi-scale structuring elements should be used [25–36]. Sequential toggle operator using multi-scale structuring elements is defined as follows [32].

$$STO_i(f) = TO_i(STO_{i-1}(f)), \tag{6}$$

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