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Fusion of infrared polarization and intensity images based on improved toggle operator

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ABSTRACT

Integration of infrared polarization and intensity images has been a new topic in infrared image understanding and interpretation. The abundant infrared details and target from infrared image and the salient edge and shape information from polarization image should be preserved or even enhanced in the fused result. In this paper, a new fusion method is proposed for infrared polarization and intensity images based on the improved multi-scale toggle operator with spatial scale, which can effectively extract the feature information of source images and heavily reduce redundancy among different scale. Firstly, the multi-scale image features of infrared polarization and intensity images are respectively extracted at different scale levels by the improved multi-scale toggle operator. Secondly, the redundancy of the features among different scales is reduced by using spatial scale. Thirdly, the final image features are combined by simply adding all scales of feature images together, and a base image is calculated by performing mean value weighted method on smoothed source images. Finally, the fusion image is obtained by importing the combined image features into the base image with a suitable strategy. Both objective assessment and subjective vision of the experimental results indicate that the proposed method obtains better performance in preserving the details and edge information as well as improving the image contrast.

1. Introduction

Modern infrared imaging systems that often measure the intensity of optical radiation are sensitive to weak targets, but they often lose efficacy when target information is annihilated in complex background clutters [1,2]. The polarization of optical radiation can provide some unique information which the intensity image does not supply [3–5]. While the intensity information over some wave band of interest reveals infrared target, polarization information tells us target surface features, shape, shading, and roughness with the lack of marked infrared target information [3]. In other words, infrared intensity image and polarization image have preferable complementary information for a scene, but neither of them can comprehensively describe infrared information of the observational scene. Consequently, appropriate fusion methods for infrared intensity and polarization images should be further developed with reliable and accurate description.

In the field of infrared polarization image fusion, false color mapping and gray-level fusion are two important research branches. The false color mapping method maps multiple images obtained from partially polarized light onto an image in color space, while gray-level fusion method combines multi-source images into an image directly on the grayscale [6–9]. In this paper, our work mainly focuses on the gray-level fusion for infrared intensity image and infrared degree of linear polarization (DOLP) image.

In our observation, the popular method of gray-level fusion can be classified into three categories: substitution methods [10–14], neural network methods [15] and Multi-scale transform methods (MST) [16–20]. The substitution methods, including independent component analysis (ICA), principal component analysis (PCA) and sparse representation (SR), can extract main information and have been successfully applied in image fusion [10–14]. However, these algorithms are easy to loss some details in the process of information substitution. Neural network method such as pulse coupled neural network (PCNN) [15] has attracted the attention of many scholars and has been widely developed in image fusion domain. Compared with other methods, PCNN has so many parameters with complex structures, which is the major limitation to practical application in essence. MST based methods are the most popular tools used in various image scenarios owing to their simplicity and effectivity in implementation. Typical MST-based fusion methods include Laplacian Pyramid (LP) [16], Discrete Wavelet Transform (DWT) [17], Curvelet Transform (CVT) [18], Non-Subsampled Contourlet Transform (NSCT) [19], Non-Subsampled

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Shearlet Transform (NSST) [1], Support Transform (SVT) [20] and so on. These MST based methods need to predesign artificial multi-scale decomposition filters which are mainly used to represent the sharpness and edges of image. However, the pre-design multi-scale decomposition filters inevitably have some deficiencies to analyze the frequency or space characteristics of source images, which will influence the performance of these MST-based fusion methods [21].

Mathematical morphology provides another excellent approach to image processing based on shape concept stemmed from set theory [22]. With improved structural elements and sequence operators, multi-scale morphology has good ability to extract the target feature regions and fetch the distinct details from source images, and is widely used in target detection, image segmentation, image enhancement, image fusion and so on [23–33]. Among them, toggle operator with pre-defining primitives is an important morphology operation and is used widely in the processing of image features extraction [34–37]. With different rules and structure elements, toggle operator can selectively extract image details as well as improve image contrast for meeting different purposes.

In this paper, an improved morphology method is proposed to preserve abundant salient edge as well as shape information in polarization image and plenty of details and targets in infrared image based on toggle operator. The new toggle operator uses opening and closing with center-surround dual structure elements as primitives, it is suitable for details extraction and image contrast enhancement. Meanwhile, redundant information among different scales is dropped and more useful image details can be preserved by using spatial scale. The effective fusion result is obtained by performing appropriate merging method on the extracted multi-scale image features.

2. Toggle operator with opening and closing

Mathematical morphology has been widely used in image processing. Most of the morphology operations consist of sequential operations based on dilation and erosion with specific structuring element. Dilation obtains the maximum information value from the neighborhood of a given structuring element. Instead, erosion obtains the minimum information value. Assuming that $f(x, y)$ is a gray scale image with the size of $M \times N$, and $B(u, v)$ is a structuring element, the dilation and erosion of $f(x, y)$ by $B(u, v)$, denoted by $f \oplus B$ and $f \Theta B$ respectively, are defined as

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

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

Based on dilation and erosion, the opening and closing operations of $f(x, y)$ by $B(u, v)$, denoted by $f \circ B$ and $f \bullet B$ respectively, are defined as below

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

The opening operation smooths bright image regions by removing the bright features while the closing operation is responsible for the dim ones by removing the dark features. Sizes of these smoothed regions are smaller than the structuring element.

Setting primitives and defining rules appropriately, toggle operator can't only selectively capture important features, but also achieve the distinction between important features and their surrounding regions [36]. The important information from infrared image is the infrared target which may be dim in infrared DOLP image. And, infrared DOLP image provides useful target edge and contrast information which may not be provided by the corresponding infrared image. And the feature information existing in the infrared intensity and polarization images is significantly different from their surrounding regions. Because opening smooths bright image features while closing smooths dark image features, the two operations can successfully smooth the proprietary feature information in intensity and DOLP images. If the gray value changed after opening operation is larger than that after closing operation, the corresponding image features may be taken as important bright image features. Otherwise, the corresponding image features may be taken as important dark image features [36]. Therefore, when setting opening and closing as primitives, toggle operator can effectively extract image features compared to other rules and primitives. More details about the reason why we choose opening and closing as primitives can be found in Ref. [36]. Toggle operator using opening and closing as primitives could be defined as follows for features extraction.

$$TO(f) = \begin{cases} f \circ B(x,y) & \text{if} \quad f \bullet B(x,y) - f(x,y) < f(x,y) - f \circ B(x,y) \\ f \bullet B(x,y) & \text{if} \quad f \bullet B(x,y) - f(x,y) > f(x,y) - f \circ B(x,y) \\ f(x,y) & \quad\;\; else \end{cases} \tag{4}$$

As shown in formula (4), choosing bigger change through the comparison can selectively achieve the distinctive image bright and dark features, which is conducive to identify underlying salient information from infrared intensity and polarization images.

3. Proposed image fusion algorithm

3.1. Structure element selection

Although traditional opening and closing with sole structure element can effectively smooth image bright and dark regions, some useful image details between the region of interest and its surrounding regions may be lost, which will result in that performance of toggle operator may be not very effective in features extraction [32]. For the purpose of preserving the feature regions and the useful image details between the regions of interest and its surrounding regions well, two different types but correlated structuring elements defined as the inner structuring element (B_i) and outer structuring element (B_o) are used in the proposed toggle operator. As shown in Fig. 1, The first structuring element, called marginal structuring element and denoted by $\Delta B = B_o - B_i$, picks out the discriminating information between the region of interest and its surrounding regions [32]. The second structuring element is denoted by B_b, whose size could change from B_i to B_o according to different applications.

The intuitive parameter annotation of the dual structuring elements is clearly marked in Fig. 1. L and W are the size of B_b and ΔB. And, the margin size of ΔB is set as M. Based on the novel dual structure elements, the new opening and closing operations can be calculated as follows.

$$f \circ B_{oi}(x,y) = (f \Theta \Delta B) \oplus B_b \tag{5}$$

$$f \bullet B_{oi}(x,y) = (f \oplus \Delta B) \Theta B_b \tag{6}$$

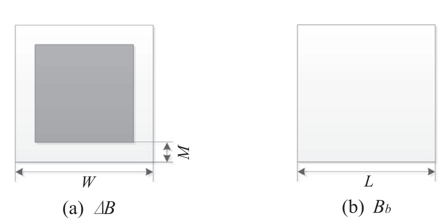

Fig. 1. Used structuring elements in this paper.