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Morphological center operator based infrared and visible image fusion through correlation coefficient

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ABSTRACT

It is important to well maintain the information of infrared (IR) and visible images, including image regions and details, in a fusion image. To be effective for fusion, an algorithm for fusion IR and visible images based on the morphological center operator through feature extraction and correlation coefficient is given. This paper utilizes the contrast enlargement strategy for fusion. Firstly, the morphological center or anti-center operator identifies the bright and dim features of the IR and visible images, and these identified features are used for fusion based on the correlation coefficient. Secondly, the multi-scale morphological theory is employed to extract the multi-scale features through the correlation coefficient based strategy to form the final fusion features. Finally, the extracted final fusion features are combined to form the final fusion image by utilizing the contrast enlargement strategy. Because of the effectively feature identifying by the morphological center and anti-center operators, the proposed algorithm has good performance for IR and visible image fusion. Experiments on different IR and visible images verified that the proposed algorithm performed effectively.

1. Introduction

An infrared (IR) image contains important regions which could not be observed by visible imaging sensor [1]. And, visible image contains rich details which could not be expressed by IR imaging sensor [2]. To obtain the image containing both the important regions and rich details, the strategy of fusion the IR and visible images is an effective way [3,4]. Image fusion has been an important technique in the wide application areas of signal processing, such as target recognition [3,5], segmentation [6] and so on. The principle component analysis or independent component analysis has been used as the tool to extract the important features in the original images to produce the effective fusion image [7,8]. But, some details might be smoothed, which may affect the combination of the details of the visible image into the fusion result. Pyramid based algorithms, such as Laplacian, wavelet and curvelet transforms, form the multi-scale space of the original images and extract the important features of each scale to produce a good fusion image [9–17]. However, some information might be waived in the scale space decomposition, which might abandon some features in the fusion result. Segmenting the important regions and combining them to produce the fusion result have also performed well in some cases [18,19]. But, the details in the visible image could not be well extracted in the procedure of segmentation for IR and visible image fusion. Intelligent tools [20], like neural networks, are well used for fusion multi-focus images, which might be inappropriate for the application of IR and visible image fusion.

Mathematical morphology is the important theory in the area of optics and signal processing applications [21–32], including the IR and visible image fusion. Especially, morphological top-hat transform or toggle operator based algorithms [4,25,26,30–32] could fuse the information of IR and visible images. However, these algorithms may produce noises or smooth the detail information of images, which may affect the performance for fusion. To fuse the information of IR and visible images, image features have to be extracted and fused. Morphological center operator [21,22,27,28] could well extract image features. Moreover, morphological center operator mainly extracts gray value features. Also, the information in the visible and IR images is mainly expressed by the gray values. Therefore, the morphological center operator may be a useful tool for IR and visible image fusion.

In light of this, an algorithm for IR and visible image fusion based on morphological center operator through the feature extraction and correlation coefficient is given in this paper. The

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contrast enlargement strategy is used to fuse the extracted features. Firstly, feature extraction through the morphological center or anti-center operator is discussed following the purpose of IR and visible image fusion. Secondly, through utilizing the multi-scale morphological theory, the image features of multi-scales in IR and visible images are extracted to construct the final fusion features through correlation coefficient. Finally, the final fusion features are combined by using the contrast enlargement strategy to generate the fusion result. Experiments on IR and visible images verify that the performance for IR and visible image fusion is effective.

2. Mathematical morphology

2.1. Fundamental operators

Mathematical morphology is an effective tool in image analysis based applications [21–32]. Two fundamental operators, dilation and erosion, denoted by $\oplus$ and Θ, are defined using the image $f(x,y)$ and structuring element $B(u,v)$.

$$f \oplus B(x,y) = \max_{u,v}(f(x-u,y-v) + B(u,v)),$$
$$f \Theta B(x,y) = \min_{u,v}(f(x+u,y+v) - B(u,v)).$$

By sequentially operating the dilation and erosion operations, the opening and closing, denoted by $\circ$ and $\bullet$, are defined as below.

$$f \circ B = (f \Theta B) \oplus B,$$
$$f \bullet B = (f \oplus B) \Theta B.$$

By using the opening and closing, two types of alternating filters, denoted by AF_1 and AF_2, are defined as below.

$$AF_1(f) = (f \circ B) \bullet B,$$
$$AF_2(f) = (f \bullet B) \circ B.$$

2.2. Morphological center operator

Although AF_1 and AF_2 have been used as the effective filters for processing the bright and dim features in image analysis, the noise or background regions which are not the useful features would be also smoothed. This may affect the application of the alternating filters for feature extraction in image analysis applications.

To well identify the real image features, the center operator is defined based on alternating filters as follows [21,22,27].

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

Because MC is the center of f, AF_1 and AF_2, the image features smoothed by MC should be really different from f. This would be useful for feature extraction in image [27].

Also, morphological anti-center of f is expressed as the complementary of the center of the complementary of f [21,22,27]. Let $\overline{MC}(f)$ be the morphological anti-center of f. Similar to $MC(f)$, the features smoothed by $\overline{MC}$ should be really different from f. So, MC and $\overline{MC}$ could be effectively utilized for feature extraction.

Some features in IR image may be the important regions which could not be expressed by visible image. And, some features in visible image may be the rich details which could not be expressed by IR image. An effective algorithm for IR and visible image fusion should well extract these features in the original images. Morphological center operators could identify the features in image, which should be appropriate for extracting the features for fusion IR and visible images.

3. The proposed algorithm

3.1. Morphological contrast enlargement based strategy for fusion

Utilizing contrast enlargement based on fusion features is the effective way to obtain an effective fusion result [4,30,31]. Therefore, it would be a good way for image fusion by combining the bright and dim features. This way is also adopted in this paper to combining the fusion features.

Let f_{IR} and f_{VI} be the original IR and visible images for fusion. Suppose $FBIF(f_{IR},f_{VI})$ and $FDIF(f_{IR},f_{VI})$ are the final fusion features of the original IR and visible images produced by center and anti-center operators, the final fusion result could be expressed as follows [4,30,31].

$$FI(f_{IR},f_{VI}) = w_1 \times BI(f_{IR},f_{VI}) + w_2 \times FBIF(f_{IR},f_{VI}) - w_3 \times FDIF(f_{IR},f_{VI}).$$

In this expression, FI is the final fusion result. BI is a base image. BI remains the basic information of the original images, which could be easily calculated as the average of the original images [4,30,31].

In fact, because the expression of $FBIF(f_{IR},f_{VI})$ and $FDIF(f_{IR},f_{VI})$ are the bright and dim features produced by the morphological center and anti-center operators, the expression of FI is one special case of the class of morphological contrast operators [31]. Using the class of morphological contrast operators to combine the fusion features for producing the final fusion image has been one effective way for IR and visible image fusion [4,30,31]. Also, the calculation of FI shows, because the bright and dim image features are enhanced, this strategy would enlarge the contrast of the fusion result FI. Therefore, using the expression of FI, which is one special case of the class of morphological contrast operators in this paper, is effective for IR and visible image fusion.

w_1, w_2 and w_3 are parameters for adjusting the contrast of the final fusion image. Usually, w_1 is 1. w_2 and w_3 are equal and positive values, which could be in $(0,5]$. In this paper, $w_2 = w_3 = 4.0$.

In FI, to produce an effective fusion result, extracting the final bright and dim fusion features would be crucial for the IR and visible image fusion. In this paper, the morphological center operators are used to extract the fusion features effectively.

3.2. Fusion feature extraction

Morphological center or anti-center operator smoothes the features of IR and visible images. These smoothed features could be used for the effective image fusion. Actually, morphological center or anti-center operator is not the extension or anti-extension operator [21,22,27]. Thus, the gray values of the results of morphological center or anti-center operator may be larger or smaller than the original image, which could be used for feature extraction [21,22,27].

If the gray values of the results of the morphological center or anti-center operator are larger than the original image, the smoothed features should be with small gray values in original image. These features represent the dim features of the original image. Then, for morphological center operator, these dim features could be identified through gray value comparing between the result of morphological center operator and the original IR or visible image as below [27].

$$DIF_1(f_{IR}) = \max\{MC(f_{IR}) - f_{IR}, 0\},$$
$$DIF_1(f_{VI}) = \max\{MC(f_{VI}) - f_{VI}, 0\}.$$

$DIF_1(f_{IR})$ and $DIF_1(f_{VI})$ are the extracted dim features by morphological center operator, respectively.

In $DIF_1(f_{IR})$ and $DIF_1(f_{VI})$, the gray values of the extracted dim features are large, which represent the features of the correspond-