IOP Conf. Series: Materials Science and Engineering **439** (2018) 032011 doi:10.1088/1757-899X/439/3/032011

Image Fusion Method of Infrared and Optical Images Based on Target Extraction

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Abstract. The fusion of infrared and optical images is difficult because images of the intended infrared targets are weakened by the background of optical images when guided by traditional pixel-based fusing rules. In this study, an improved fusion method based on infrared target extraction is proposed. First, to highlight infrared targets in the fused image, this method obtains the target's contour binary image by Canny edge detection and obtains the segmented binary image by using Otsu threshold segmentation method. The proposed method then fuses the two binary images using their complementary information to generate a more complete infrared target image which guides the fusion of low-frequency coefficients of the source images. Second, the extracted infrared target image, the source infrared image, and the V component of the source optical image are all decomposed by Laplacian pyramid transform. High-frequency coefficient fusion is performed using the rules of region mutual information, region match measure, and region energy, meanwhile low-frequency coefficient fusion is performed using the infrared target image and region information rules. Experimental results indicate that the proposed fusion method outperforms traditional fusion methods in preserving infrared target information in the fused image.

1. Introduction

Image fusion is a computer vision technique that integrates all relevant and complementary image information from different sensors into a single composite image without introducing any artifact or noise. Infrared sensors and optical sensors have become essential tools in many application areas like automatic surveillance systems, target tracking, concealed weapon detection, and military reconnaissance. Infrared sensors are sensitive to thermal objects: capable of capturing images of hidden targets. Optical sensors of higher spatial resolution can reflect details of target scenes: better correlate with human vision characteristics[1-3]. Fusion technology for infrared and optical images focuses on how to extract and integrate features from source images and on how to make significant targets from infrared images conspicuous in fused result images.

In order to improve fusing quality of infrared and optical images, various fusing solutions have been proposed. Some examples are: multi-scale image fusion common frame to make the image fusion process more consistent with human vision[4,5], fusion methods based on edge detection to enrich the edge featuresofobjects[6-8]. In the fusion results, and fusion rules based on threshold segmentation to strengthen the target's region features in the fused images[9-11]. However, depending solely on one of

IOP Conf. Series: Materials Science and Engineering **439** (2018) 032011 doi:10.1088/1757-899X/439/3/032011

these methods will not produce distinct and complete target information, especially intended infrared thermal targets, in the fused images.

To overcome this limitation, the authors propose a new fusion method for infrared and optical images, which is based on target extraction. To obtain a fused image with more distinct, complete infrared thermal target information that may be hidden in the optical image, a better extraction method is critical. Canny edge detection operates by extracting edges of objects in the infrared image to form a binary image with edges. After that fills the outlined regions in the binary image by a dilatation operation. The proposed method then employs the Otsu inter-class threshold segmentation method with the infrared image to obtain the segmented binary image. Finally, as complementary information of two extracted binary images are used, the dilated edge image is fused with the segmented image to clearly depict the infrared target's features. The low-frequency coefficients of the extracted infrared target image which is generated by multi-scale transformations are used to guide the fusing rules of the infrared and optical images. Region energy, region matching measure, and region mutual information are employed in fusing rules at each resolution level.

The paper is organized as follow: Section 2 describes the infrared target extraction method. In Section 3, the proposed fusion method is explained. Experimental results are discussed in Section 4. Finally, conclusions of the work are presented in Section 5.

2. Infrared Target Extraction Method

Edge detecting methods can obtain contours of targets in images, but cannot highlight the entireties of these targets, which complicates creation of related fusing rules. Threshold segmentation methods can extract the integrity of objects in images, but may contain unintended targets, which subsequently complicates the identification of demanded targets. In order to efficiently obtain the planned information of infrared thermal targets, the proposed method uses complementary information of both, fuses the edge detected image of the infrared image and the threshold segmented image of the infrared image to obtain a more complete infrared target image.

2.1 Canny Edge Detection

Edges are important features in an image. The Canny edge detection outperforms other edge detection methods in three aspects[12-16]. First, the amplitude signal-to-noise ratio of the gradient is maximized to obtain a low probability of the failure to mark real edge points. Second, the edge points are identified as close as possible to the center of the edge. Third, the detected edges are of one pixel width. After edge detection, dilate the achieved binary edge image to fill small regions that are outlined by these edges (as shown in Figure 1(b) and Figure 1(c)).

2.2 Otsu Threshold Segmentation

The Otsu algorithm is the maximum inter-class variance method, which is based on a one-dimensional histogram[9-11]. The criterion function optimizes inter-class similarity to prove every cluster is well separated and intra-class similarity to achieve the most similarity in each class. This evaluation uses both the heterogeneity between two classes and the homogeneity within each class. By maximizing the criterion function, the variance between two classes can be separated as far as possible, and the variance within each class will be as minimal as possible. The principle of the Otsu method is described as follows:According to the gray value t , divide the pixels into two classes, $C_0 = (0,1,2,...,t)$ and $C_1 = (t+1, t+2,..., L-1)$, then the gray level probability distributions of the two classes are obtained.

2.3 The Proposed Target Extraction Method

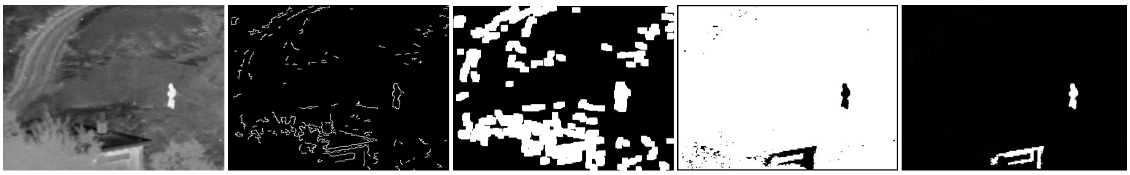
Hidden thermal targets, which are not visible in the optical image but are highlighted in infrared images, are intended and valuable information, such as three thermal objects covered by smoke in Figure 1(a) and one thermal object hidden in a bush in Figure 2(a). Figure 1(b) and Figure 2(b) are the Canny edge detecting binary images. The regions which are contoured by these edges are filled by morphological dilation, such as Figure 1(c) and Figure 2(c), but the size of regions suffers from distortion and unintended small regions become greater when the contrast ratio of a source image is low. Figure 1(d) and Figure 2(d) are the Otsu inter-class variance threshold segmentation images, which contain many unintended objects as well as demanded targets. In order to extract thermal targets in the infrared image as precisely as possible, the proposed method fuses the Canny edge image with the Otsu segmentation image. The extraction results are obviously better than either of the two, which are shown as Figure 1(e) and Figure 2(e). Fusing rules are described as formula (1):

$$F_{TE}=\begin{cases} F_{TE}(i,j)=255 & if\ C(i,j)==255\ and\ T(i,j)==0 \\ F_{TE}(i,j)=0 & if\ C(i,j)==0\ or\ T(i,j)==255 \end{cases} \tag{1}$$

The advanced infrared target image is achieved after fusing rules are applied. As can be seen in the target images (Figure 1(e) or Figure 2(e)), neither the size nor the shape of the infrared targets are distorted; the contours of targets are clear; and fewer insignificant objects are extracted. Just a few highlight objects are contained in the fused images as well as intended targets, which does not significantly affect the final fusion (fusing the infrared image with the optical image) result. This results in better guidelines for fusing the infrared image's low-frequency coefficients with the optical image's low-frequency coefficients.

(a) (b) (c) (d) (e)

Figure 1 Infrared target extraction image-1(a~e)
(a)Infrared image; (b) Edge extraction image by Canny; (c) Canny edge after morphological dilation; (d)Otsu threshold segmentation; (e) Fusion image of (c) and (d)



(a) (b) (c) (d) (e)

Figure 2 Infrared target extraction image-2(a~e)
(a)Infrared image; (b) Edge extraction image by Canny; (c) Canny edge after morphological dilation; (d)Otsu threshold segmentation; (e) Fusion image of (c) and (d)

3. The Proposed Fusion Method

3.1 Fusion Idea

The proposed fusion method in the paper expands the multi-scale image fusion common frame. The infrared target extraction image is added in the fusion frame as well as source images. First, obtain the infrared target extraction image, according to the method in Section 2. Second, transfer RGB color space of the optical image into HSV color space[17-18], and select V component as input image, which takes part in multi-scale decomposition. The infrared image, V component, and the infrared target extraction image are all decomposed by Laplacian pyramid transform. Third, apply different fusion rules to fuse coefficients in different levels. Finally, reconstruct the fused Laplacian coefficients and use it as the new V component of the optical image. The resulting fusion image is generated after color space transform. Diagram of the proposed fusion method is shown in Figure 3.

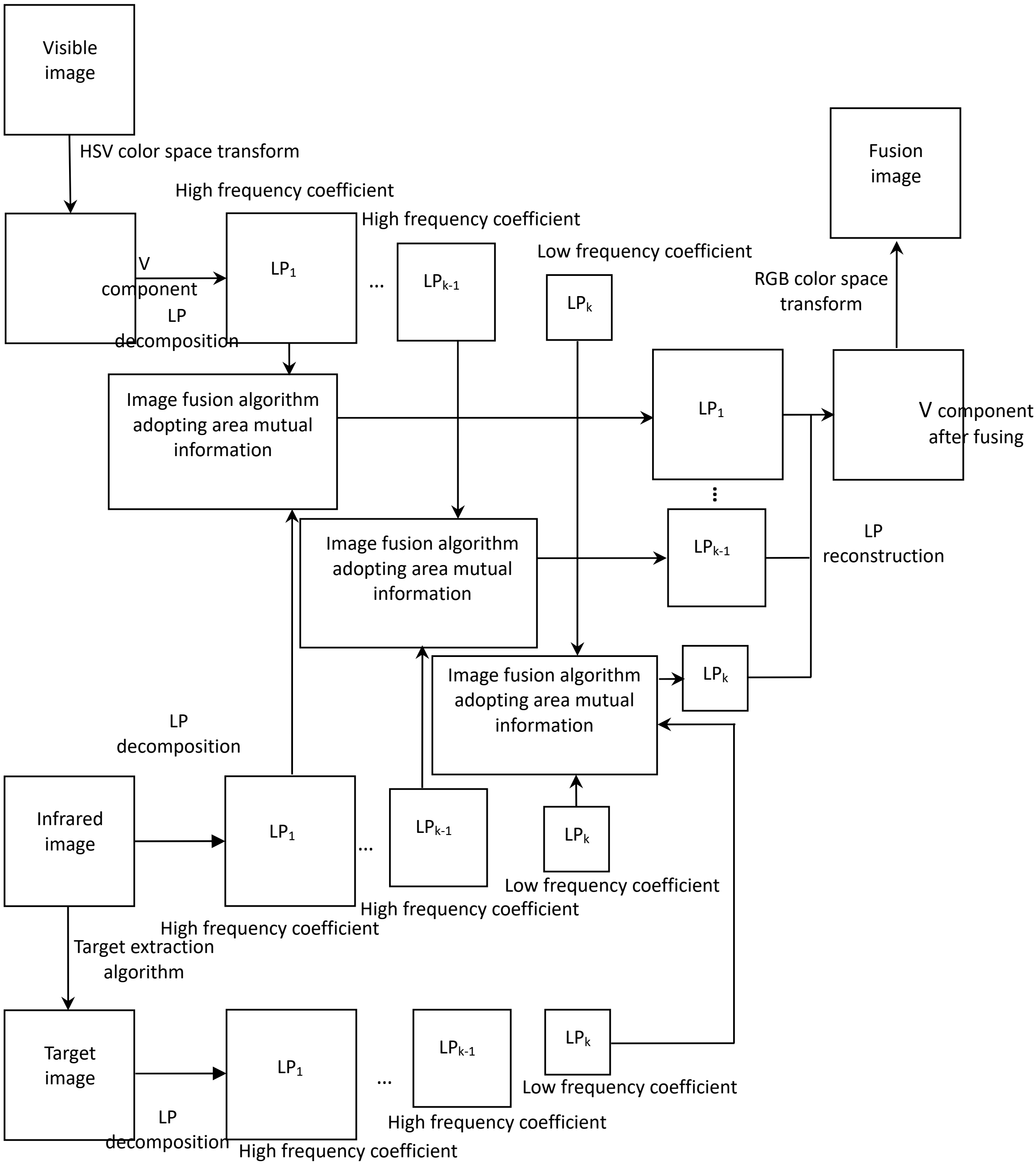


Figure 3 Fusion method diagram of this paper

3.2 Laplacian Pyramid

The Laplacian pyramid is based on the Gaussian pyramid[19-20]. Given an image I, its Gaussian pyramid is a set of images $\{G_k\}$ called levels, representing progressively lower resolution versions of the image, in which high-frequency details progressively disappear. In the Gaussian pyramid, the bottom-most level is the original image $G_0=I$. Image features are intensified in each level of the Laplacian pyramid. Different features in different level can be fused with different fusion methods. Then the final fused image contains characteristics of source images as much as possible.

3.3 High-Frequency Coefficients Fusion Method

High-frequency coefficients represent the spatial details and edge features in source images. Rules based on region-level consider that an image feature is typically represented by several pixels in a local region, which can decrease the probability of selecting error coefficients or pixels, refine fusion quality in aspect of rich details and good visual effects[21-24].

The infrared target extraction image, infrared and optical images are all decomposed by Laplacian pyramid to get high-frequency coefficients in different levels and low frequency coefficients respectively. The high-frequency coefficients of the infrared target extraction image are not considered a lot in the aspect of making high-frequency fusion rules for it containing small information about details of infrared image. The mutual information, energy, and matching measure based on region are the guides of high-frequency fusion rules.In summary, the fusion rules of high-frequency coefficients are described as formula (2).

$$LP_{l,F}(n,m)=\begin{cases} LP_{l,VI}(n,m) & if\ RMI(LP_{l,VI}(R), LP_{l,IR}(R)) \geq T_{RMI} \\ LP_{l,VI}(n,m) & if\ RMI(LP_{l,VI}(R), LP_{l,IR}(R)) < T_{RMI}\ and \\ & M_l \geq T_M\ and\ E_{l,VI}(n,m) > E_{l,IR}(n,m) \\ LP_{l,IR}(n,m) & if\ RMI(LP_{l,VI}(R), LP_{l,IR}(R)) < T_{RMI}\ and \\ & M_l \geq T_M\ and\ E_{l,VI}(n,m) < E_{l,IR}(n,m) \\ w_{\max} LP_{l,VI}(n,m) + w_{\min} LP_{l,IR}(n,m) & \\ & if\ RMI(LP_{l,VI}(R), LP_{l,IR}(R)) < T_{RMI}\ and \\ & M_l < T_M\ and \\ & E_{l,VI}(n,m) > E_{l,IR}(n,m) \\ w_{\min} LP_{l,VI}(n,m) + w_{\max} LP_{l,IR}(n,m) & \\ & if\ RMI(LP_{l,VI}(R), LP_{l,IR}R)) < T_{RMI}\ and \\ & M_l < T_M\ and \\ & E_{l,VI}(n,m) \leq E_{l,IR}(n,m) \end{cases} \tag{2}$$

3.4 Low-Frequency Coefficients Fusion Method

After the infrared image and V component of the optical image are transformed by Laplacian pyramid; their low-frequency coefficients contain the major energies of the source images. Making proper low-frequency fusion rules are crucial to the quality of result fusion image. In this paper, the infrared target extraction image fused by the method elaborated in Section.2 is taken as the guide of the low-frequency fusion rules and simultaneously combined with the region rules. When the value of low-frequency coefficient of the infrared target extraction image (binary image) is equal to 255, select the low-frequency coefficient of the infrared image as the fusion coefficient for outstanding the thermal targets. When the value is not equal to 255, compare the region mutual information with the given threshold. If higher, take the average of the two as the final value. Otherwise, select the coefficient which region energy is larger. The detailed low-frequency fusion rules are described as formula (3).

$$LP_F(n,m)=\begin{cases} LP_{IR}(n,m) \quad if\ LP_{OB}(n,m)==255 \\ 0.5\times(LP_{VI}(n,m)+LP_{IR}(n,m)) \\ \qquad if\ LP_{OB}(n,m)!=255\ and\ RMI(LP_{VI}(R),LP_{IR}(R))\geq T_{RMI} \\ LP_{VI}(n,m) \\ \qquad if\ LP_{OB}(n,m)!=255\ and\ RMI(LP_{VI}(R),LP_{IR}(R))<T_{RMI} \\ \qquad\ and\ E_{VI}(r)\geq E_{IR}(r) \\ LP_{IR}(n,m) \\ \qquad if\ LP_{OB}(n,m)!=255\ and\ RMI(LP_{VI}(R),LP_{IR}(R))<T_{RMI} \\ \qquad\ and\ E_{VI}(r)<E_{IR}(r) \end{cases} \tag{3}$$

4. Experimental Results

In order to evaluate the fusion quality of the proposed fusion method of the infrared and optical images based on target extraction (LPT_OB), we developed an image fusion system and conducted a large amount of related experiments. In the paper, the method based on region mutual information is compared by matching measure and region energy (LPT_Region), and the method based on basic pixel fusion (LPT_Pixel) with the proposed method LPT_OB. Average gradient (G), spatial frequency (SF), standard deviation (SD), correlation coefficient (CC), and universal image quality index (UIQI) are selected as the object evaluation criteria to evaluate qualities of fusion images under three fusion methods. The higher the values of average gradient and spatial frequency, the richer the details of the fusion image. The larger standard deviation is more propitious for identifying small targets. The correlation coefficient and universal image quality index are used to evaluate similarity degree between fusion image and source image. The higher the values are, the more similar they are both in the aspect of the structure and the spectrum.

(a) (b) (c) (d) (e) (f)

Figure 4. The first image fusion experiment of infrared and optical images(a~f)
(a) Original optical image; (b) Original infrared image; (c) Infrared target image; (d) Fusion image of LPT_OB; (e) Fusion image of LPT_Region; (f) Fusion image of LPT_Pixel

Table 1. The first objective evaluation index of image fusion experiment

	LPT_OB	LPT_Region	LPT_Pixel
G	11.0178	10.9644	10.5551
SF	19.4794	19.3160	16.9216
SD	55.3567	50.8499	35.8990
CC	0.9326	0.8706	0.8867
UIQI	0.9080	0.3887	0.7244

The sets of experiments about three methods on the infrared and optical images are shown in Figure 4. The objective evaluation indexes of three methods are listed in Table 1. Comparing the infrared targets in fusion images (d), (e), and (f) respectively in the experimental images, it is obviously to find that the method based on infrared target extraction (LPT_OB) has the advantage of outstanding infrared thermal targets from the visual angle. The values of LPT_OB method are higher than the other two fusion methods in term of spatial frequency, standard deviation, correlation coefficient, and universal image quality index. The experimental results indicate that proposed fusion method is better for enhancing infrared targets as well as retaining details of edges and increasing similarity with source images.

5. Conclusions

In the paper we have proposed a new fusion method which is based on infrared targets extraction. The extraction method can more completely extract infrared targets than traditional methods, which takes advantage of the complementary information of the Canny edge extracted image and the Otsu threshold segmented image. The proposed new fusion rules guided by the infrared targets extraction image can effectively enhance intended thermal targets in fused image of infrared and optical images, which will benefit target locating and tracking in the fusion image. The experimental results indicate that the new fusion method that combines the infrared target extraction image with region mutual information, matching measure, and region energy is better than traditional fusion methods, which are only based on pixel or region, either in the aspect of strengthening infrared targets or enriching details of background in the final fusion image.

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