Color fusion of SAR and FLIR images using a natural color transfer technique

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Fusion of synthetic aperture radar (SAR) and forward looking infrared (FLIR) images is an important subject for aerospace and sensor surveillance. This paper presents a scheme to achieve a natural color image based on the contours feature of SAR and the target region feature of FLIR so that the overall scene recognition and situational awareness can be improved. The SAR and FLIR images are first decomposed into steerable pyramids, and the contour maps in the SAR image and the region maps in the FLIR image are calculated. The contour and region features are fused at each level of the steerable pyramids. A color image is then formed by transferring daytime color to the monochromic image by using the natural color transfer technique. Experimental results show that the proposed method is effective in providing a color fusion of SAR and FLIR images.

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Combining multi-sensor images to a single image that is more suitable for visual perception, computerized object detection and target recognition has drawn a lot of attention recently. In particular, many algorithms have been proposed for fusing synthetic aperture radar (SAR) and forward looking infrared (FLIR) images[1−3]. However, most of these algorithms use the same measurement to select features from the SAR and FLIR images for fusion. This is not effective for the SAR and FLIR scenes that have different characteristics. In addition, these algorithms usually do not consider color and produce a monochromic fused image only, which is not favorable for human perception. In this paper, we propose a color fusion scheme for SAR and FLIR images based on the contours feature of SAR and the target region feature of FLIR at different resolution levels. This fusion algorithm does not only combine the useful information of the SAR and FLIR images but also gives the fused image a natural color appearance by using the natural color transfer technique. The overall scene recognition and situational awareness are therefore improved.

In FLIR images, man-made targets always have higher graylevels that are relatively easier to detect, while the important contours are often salient in SAR images. The intensity of a SAR image depends on the characteristics of the illuminated surface scene as well as on the signal which reflects rich contour features. On the other hand, a FLIR imagery relies mainly on multispectral reflectivity of the target illuminated by sunlight and the temperature of the object itself. For SAR/FLIR images, we observe that there are two important regions, one is the temperature contour detected by FLIR and the other is the material contour detected by SAR. Our proposed image fusion scheme is therefore to extract the target regions feature in FLIR images and the contours feature in SAR images.

Target regions can be easily detected in a FLIR image. We employ the intraclass variance minimization technology to segment out all possible targets appearing in a FLIR image. However this kind of targets are often man-made objects having contours that cannot be detected accurately by FLIR only. SAR can overcome this weakness by using steerable filters.

In the proposed method, we develop a novel steerable pyramid image fusion method which can be summarized into the following steps:

1) The SAR and FLIR images are decomposed into steerable pyramids.

2) The edge maps of the SAR image steerable pyramid at all scales are obtained using local orientation and local energy. The region maps of the FLIR image steerable pyramid at all scales are calculated based on minimizing the intraclass variance of the black and white pixels.

3) The SAR and FLIR images are fused by setting the priority of the contours of SAR image and the regions of FLIR image.

A steerable pyramid is a multi-scale, multi-orientation, and self-inverting image decomposition, which has the advantage that the sub-bands are both translation and rotation invariant[4,5]. The image is divided into a collection of sub-bands localized in scale and orientation. Let $X(\omega)$ be the original image, the reconstructed image $\hat{X}(\omega)$ can be expressed as

$$\hat{X}(\omega) = \left\{ |H_0(\omega)|^2 + |L_0(\omega)|^2 \left(|L_1(\omega)|^2 + \sum_{k=0}^{n} |B_k(\omega)|^2 \right) \right\} X(\omega) + \text{a.t.}, \quad (1)$$

where $H_0(\omega)$ is a non-oriented high-pass filter, $L_0(\omega)$ is a low-pass filter, $L_1(\omega)$ is a narrow-band low-pass filter, $B_K(\omega)$ refers to band-pass filterswith, $k = 0, 1, \cdots, K$, and K is the total number of filters. The a.t. stands for the aliasing terms, and n is one less than the orientation number, i.e. $n = K - 1$.

When a SAR image is decomposed into a steerable pyramid, the four directional band-passed images and their quadrature pairs are used for orientation analysis. We use the orientation energy method proposed by Freeman, which measure the orientation strength along a particular direction θ by the squared output of the quadrature pair of bandpass filters steered to the angle θ, to obtain the edge maps of the SAR image steerable pyramid at all scales. The details are given in Ref. [4].

The region map of the FLIR image steerable pyramid is calculated by minimizing the intraclass variance of the black and white pixels[6]. FLIR image is segmented into two regions: the brighter region is treated as target, and the rest is the background. It automatically divides an image's light intensity histogram into two distinct regions. The maximum value of the discriminant criterion is discovered by using

$$\sigma_B^2 = \frac{\left[\mu_{\mathrm{T}}\omega(k) - \mu(k)\right]^2}{\omega(k)\left[1-\omega(k)\right]}, \quad (2)$$

where $\omega(k) = \sum_{i=1}^{k} P_i$ is the zeroth cumulative moment, $\mu(k) = \sum_{i=1}^{k} i{\cdot}P_i$ is the first cumulative moment, and $\mu_{\mathrm{T}} = \sum_{i=1}^{L} i \cdot P_i$ is the total mean level. L denotes the levels of gray, k denotes the threshold, and P_i denotes the probability distribution. The details can be found in Ref. [6].

The fusion strategy is based on the priority of the contours of the SAR image and the regions of the FLIR image. For many tasks, material contours are the most important ones[7]. We set the region of FLIR image having the highest priority, so that it can prevent the influence of SAR image. The edges of SAR image are set to lower priority. If no contours or target region is found at a location of the scene, the pixel in the images will be fused based on the salience and match measure[8].

The last procedure of the proposed color image fusion method is to assign color to the fused image. One simple way is to put the SAR and FLIR images into the RGB channel. But the color will be false in this case. Natural color transfer is a technique which transfers color characteristics of an image to another, and hence gives a natural appearance[9,10]. The transfer is carried out in the color space $l\alpha\beta$, which was derived from a principal component transform by Ruderman *et al.*[11]. The transformation from RGB space to the $l\alpha\beta$ space is as following:

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} 0.3811 & 0.5783 & 0.0402 \\ 0.1967 & 0.7244 & 0.0782 \\ 0.0241 & 0.1288 & 0.8444 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}. \quad (3)$$

The data in this LMS color space shows a great deal of skew, which can be largely eliminated by converting the data to logarithmic space LMS. And then we can use Eq. (4) to get the $l\alpha\beta$ space.

$$\begin{bmatrix} l \\ \alpha \\ \beta \end{bmatrix} = \begin{bmatrix} \frac{1}{\sqrt{3}} & 0 & 0 \\ 0 & \frac{1}{\sqrt{6}} & 0 \\ 0 & 0 & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & -2 \\ 1 & -1 & 0 \end{bmatrix} \begin{bmatrix} L \\ M \\ S \end{bmatrix}. \quad (4)$$

In the $l\alpha\beta$ space, the l axis represents an achromatic or luminance channel which calculates the amount of light falling on the retina, while the α and β channels are chromatic yellow-blue and red-green opponent channels which calculate the hues. Our color transferring method operates in this $l\alpha\beta$ space because it provides a decorrelated achromatic channel for color images. This allows best pixels matching through achromatic luminance channel and selectively transfers the chromatic α and β channels from the color image to the grayscale image conveniently.

In order to find corresponding color characteristics from the source daytime color image, each pixel in the grayscale night vision image must be matched to a pixel in the color image. For the grayscale image is described only by the luminance distribution, so our matching algorithm is based on the luminance value and neighborhood statistics of each pixel. We choose the standard deviation, and the homogeneity based on the co-occurrence matrix as the measure standard.

The pixels matching measure between two images is defined as

$$M = \alpha_1 \mathrm{Std} + \alpha_2 W_{\mathrm{H}}, \quad (5)$$

where Std is the standard deviation, and W_{H} is the homogeneity. The weights associating with the Std and W_{H} are α_1 and α_2, respectively. The definition of standard deviation is given by

$$\mathrm{Std} = \left(\frac{1}{n} \sum_{i=1}^{n} (x_i - \overline{x})^2 \right)^{\frac{1}{2}}, \quad (6)$$

where $\overline{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$, n is the number of pixels in the neighborhood area. The homogeneity is defined by

$$W_H = -\sum_i \sum_j \frac{P[i,j]}{1+|i-j|}, \quad (7)$$

where $P[i,j]$ is the value of element in the co-occurrence matrix and $[i,j]$ is the coordinate.

The luminance is not used as a measure because the luminance features of the SAR and FLIR images are different from the daytime images. For instance, a low luminance object in the daytime image may appear a high luminance in the FLIR image. So we choose the measure that can describe the texture features of images. Once the best matching pixel in the color image is found, the chromaticity values, α and β, are transferred to the corresponding pixels in the grayscale image while the l channel value retains the original luminance value of the grayscale image.

In our experiments, we apply our color fusion algorithm to the SAR and FLIR images in Figs. 1(a) and (b). We can define the roads in the scene as targets that will be detected. Another part of the scene is considered as background. The clearer road can be taken by using our proposed method than the traditional methods such as gradient pyramid or daubechies wavelets, without losing or reducing the background information. Figure 1 shows the results of color fusion for SAR/FLIR images. Image (a) is the SAR image, image (b) is the FLIR image, images (c) and (d) are the fusion results that adopt gradient pyramid and daubechies wavelets, respectively, and images (e), (f)

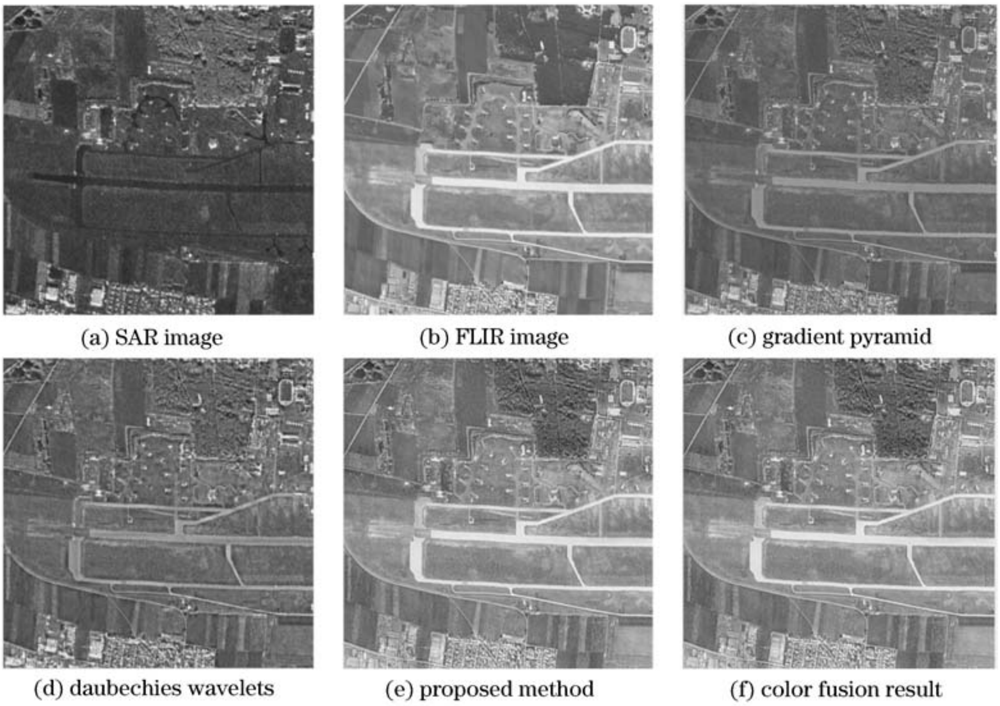

Fig. 1. Results of SAR/FLIR fusion.

Table 1. Evaluation of Fusion Results by Objective Image Fusion Performance Measure (OM)

Method	Gradient	Wavelet	Steerable
OM	0.4542	0.3995	0.4638

are the fused results of SAR and FLIR image that adopt the method proposed in this paper. It can be found that image (e) retains the clearer road and more background information than images (c) and (d). An objective image fusion performance measure is employed for evaluation of the fusion results. Table 1 shows the evaluation results. And we can see that the color image (f) has natural color characteristics and is easier to interpret than the other grayscale images.

A color fusion scheme, which not only combined the information of SAR image and FLIR image but also gave the fused image a natural color appearance, is presented in this paper. In this fusion scheme, the SAR image and FLIR image were fused based on steerable pyramid decomposition firstly, and then a daytime natural color appearance was transferred to the fused image based on the color transfer technique. So we got a natural color image in possession of the contours feature of SAR and the target region feature so that the accuracy of scene recognition and situational awareness can be improved.

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