Infrared Physics & Technology 60 (2013) 235–243

Contents lists available at SciVerse ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

Fusion of infrared polarization and intensity images using support value transform and fuzzy combination rules

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HIGHLIGHTS

- Two fuzzy combination rules are developed for fusion of images.
- Fuzzy combination rule for low-frequency components has much higher effectiveness.
- Trapezoidal membership functions are adapted in the fuzzy combination rules.
- Two features, LDF and SDF, are proposed as the variable in the membership functions.

ARTICLE INFO

Article history:
Received 15 January 2013
Available online 25 May 2013

Keywords:
Image fusion
Infrared polarization image
Fuzzy combination rule
Support value transform

ABSTRACT

Infrared polarization and intensity imagery provide complementary and discriminative information in image understanding and interpretation. In this paper, a novel fusion method is proposed by effectively merging the information with various combination rules. It makes use of both low-frequency and high-frequency images components from support value transform (SVT), and applies fuzzy logic in the combination process. Images (both infrared polarization and intensity images) to be fused are firstly decomposed into low-frequency component images and support value image sequences by the SVT. Then the low-frequency component images are combined using a fuzzy combination rule blending three sub-combination methods of (1) region feature maximum, (2) region feature weighting average, and (3) pixel value maximum; and the support value image sequences are merged using a fuzzy combination rule fusing two sub-combination methods of (1) pixel energy maximum and (2) region feature weighting. With the variables of two newly defined features, i.e. the low-frequency difference feature for low-frequency component images and the support-value difference feature for support value image sequences, trapezoidal membership functions are proposed and developed in tuning the fuzzy fusion process. Finally the fused image is obtained by inverse SVT operations. Experimental results of visual inspection and quantitative evaluation both indicate the superiority of the proposed method to its counterparts in image fusion of infrared polarization and intensity images.

1. Introduction

Polarization is a fundamental property of light. The polarization of light can provide unique information which the intensity of light does not. Modern infrared (IR) imaging systems are sensitive to weak targets, but background clutters make the detection difficult. The introduction of an IR polarizer into a thermal imaging system is one of the techniques to improve such low target-to-background contrast. The use of polarized IR helps in detecting man-made objects with complex background, because they produce the contrast where the intensity contrast does not exist [1]. While the spectral and intensity information reveals materials of target, polarization information tells us about target surface features, shape, shading, and roughness. Therefore, polarization trends to provide information that is largely uncorrelated with intensity images [2]. Since infrared polarization and infrared intensity images can provide complementary information for a scene, a better distinction between targets and background is expected by merging the two images. Consequently, how to fuse the infrared polarization and intensity images becomes an important task in the information fusion processing.

Infrared polarization image fusion is popularly used for false color mapping. Wolff [3] proposed a scheme, which maps images obtained from partially polarized light onto an image in the HSI (Hue, Saturation, and Intensity) color space, and establishes a rela-

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http://dx.doi.org/10.1016/j.infrared.2013.05.008

tionship between polarimetric and spectral information. Samia et al. [4] presented an ad hoc color display method as an aid to interpret physical properties of encoded polarization images, and explored potential information for object classification. Using the polarimetric and spectral characteristics of specular and diffuse reflected light, Zhao et al. proposed an HSI color mapping fusion method for object separation [5]. To overcome shortcomings in the false color mapping such as lack of color consistency, and unnatural color appearance, an image fusion approach for near natural color polarization imagery with color transfer and clustering-based segmentation was proposed by Shen and Zhou et al. [6,7]. Lavigne et al. [8] designed a false color fusion algorithm to discriminate man-made objects in shadow areas of visible and mid-wave infrared polarimetric images.

The dominant method of gray-level fusion of infrared polarization and intensity images is multi-resolution transform that fuses multiple images at different spatial resolutions [9]. Many multi-resolution methods have been proposed and used for fusion of infrared intensity images and visible images, such as pyramid decomposition, discrete wavelet (DWT), discrete wavelet frame (DWFT), stationary wavelet (SWT), dual-tree complex wavelet (DTCWT), curvelet (CT), contourlet (CVT), and non-subsampled contourlet transform (NSCT) [10]. The key process in multi-resolution image fusion is to choose an optimal solution to combine coefficients in the transformed domain so that the fused image integrates effectively information contained in all source images. The general fusion rule of combining low frequency coefficients is the average method, and that of combining high frequency coefficients is to choose pixel energy maximum. Based on these general rules, several new fusion rules, such as selection method, entropy method, and linear dependency method, have been developed [10]. These new methods can improve fusion performance in some aspects or to some extent [11]. However under most circumstances, a fusion rule of combining coefficients remains unchanged throughout the entire image fusion process. This seriously limits its effectiveness. To solve this problem, other methods based on fuzzy logic are introduced [12]. Seng et al. [13] developed a fuzzy operator in the form of IF-THEN rule instead of using a standard global operator to fuse multi-view Through-the-Wall Radar images. Based on the dual-tree discrete wavelet transform (DT-DWT) of both infrared and visible images, Saeedi and Faez [14] used a fuzzy triangular membership function to establish a fuzzy fusion rule which includes three general combination rules, but it was only used to combine high frequency wavelet coefficients. An et al. [15] also used a fuzzy triangular membership function to combine high frequency NSCT coefficients of infrared polarization and intensity images, but the fusion effectiveness is under expectation. In fact, the energy and many main characteristics of an image are retained in low-frequency coefficients. Therefore it is crucial to take low-frequency information in studying a new fuzzy combination rule for image fusion to replace the traditional single combination method.

SVT uses a mapped least squares support vector machine (LS-SVM) [16] to efficiently calculate the support values of images. These support values represent the importance related to the visual result of images. It makes avail of the approximation capability of LS-SVM to represent an image, and can effectively present the salient features of original images and merge the salient features into a fused image. It is proved [17,18] that SVT has better outcome in multi-resolution image fusion compared to other approaches such as Laplacian pyramid and DWT. Considering the aliasing, isotropic and shift-invariant properties [17], we use SVT, which also takes less time than DT-DWT and NSCT, in fusion operations of infrared polarization and intensity images.

This paper firstly decomposes both infrared polarization and intensity images into low-frequency component images and support value image sequences by SVT. Then the low-frequency component images are combined using a fuzzy combination rule of region feature maximum, region feature weighting, and pixel value maximum meanwhile the support value image sequences are merged using a fuzzy combination rule between pixel energy maximum and region feature weighting. The rest of this paper is organized as follows. In Section 2, the image fusion framework is presented with a review of SVT. Sections 3.1 and 3.2 describe fuzzy combination rules for low frequency components and support value image sequences, respectively. Section 4 presents experimental results and discussions. Finally, the main conclusions of this paper are drawn in Section 5.

2. Image fusion with support value transform

2.1. Framework for SVT-based image fusion

In this paper, it is assumed that the polarization and intensity images used for the fusion have already been co-registered. The framework of image fusion with SVT is shown in Fig. 1. As a summary of Fig. 1, the SVT-based fusion approach for co-registered infrared polarization and intensity images is listed in the following steps.

(1) To apply the SVT to decompose the infrared polarization and intensity images into a low-frequency component image $\{P_{j+1}\}$ and the support value image sequences $\{S_1, S_2, \ldots, S_j\}$.
(2) To combine low-frequency components from the polarization image and intensity image together at each pixel position using fuzzy combination rule 1 (the rule will be introduced in Section 3.1).
(3) To combine support value images of infrared polarization and intensity images at each decomposition level together at each pixel position using fuzzy combination rule 2 (the rule again will be introduced in Section 3.2).
(4) To use inverse support value transform (ISVT) to recover the fused image from the combined low-frequency components and the combined support value image sequence.

Conventionally, a combination rule of low-frequency component image is simply an average, and that of support value image sequences is pixel energy maximum [18]. Assume r is the last decomposition level and $j = 1, 2, \ldots, r$, P_{1r} and P_{2r} represent the two low-frequency component images of rth decomposition level, respectively, and S_{1j} and S_{2j} represent the two support value images of jth decomposition level, respectively, then,

$$\begin{cases} P_{Cr}(x,y) = \frac{P_{1r}(x,y)+P_{2r}(x,y)}{2} \\ S_{Cj}(x,y) = \begin{cases} S_{1j}(x,y) & S_{1j}^2(x,y) > S_{2j}^2(x,y) \\ S_{2j}(x,y) & \text{otherwise} \end{cases} \end{cases} \tag{1}$$

where (x, y) denotes position of a pixel in the images, $P_{Cr}(x, y)$ and $S_{Cj}(x, y)$ denote corresponding combination results of low-frequency and high-frequency images, respectively.

Since the conventional combination rule remains unchanged in formula (1), it neither facilitates a fine fusion, nor is favorable to increase the quality of fusion. The fuzzy combination rules developed in this paper takes advantage of multiple combination rules to overcome the drawbacks introduced by the conventional single combination rule.

2.2. Support value transform (SVT)

Support value transform is proposed by Zheng et al. in [16]. Its construction is briefly reviewed in this section.