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Fusion of multi-spectral and panchromatic images using fuzzy rule

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Abstract

A fusion approach is proposed to refine the resolution of a multi-spectral image using a high-resolution panchromatic image. After the two images are decomposed by wavelet transform, five texture features are extracted from the high-frequency detailed sub-images. Then a nonlinear fusion rule, i.e. fuzzy rule is used to merge wavelet coefficients from the two images according to the extracted features. Experimental results indicate that the method outperforms the traditional approaches in preserving spectral information while improving spatial information.

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Keywords: Multi-spectral; Texture features; Fractal; Fuzzy

0. Introduction

In remote sensing applications, data fusion techniques, originally devised to allow integration of different information sources, may take advantage of the complementary spatial/spectral resolution characteristics of multi-spectral and panchromatic data for producing spatially enhanced multi-spectral observations [1–3]. This specific aspect of data fusion is often referred to as data merge or band-sharpening [4–6]. More specifically, sharpened multi-spectral data is a fusion product in which the multi-spectral bands are sharpened via the higher-resolution panchromatic image. In fact, the higher-resolution panchromatic image is acquired with the maximum resolution allowed by the imaging sensor, as well as by the data link throughput, while the

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multi-spectral bands are acquired with coarser resolutions, typically, two or four times lower. Then the panchromatic image may be merged with the multi-spectral data to enhance their spatial resolution.

In such applications as classification, fusion algorithms are required to maintain the spectral characteristics of the original data to avoid misinterpretation as well as introduction of undesired effects. Data merge methods, based on injecting high frequency components taken from the panchromatic image into re-sampled versions of the multi-spectral data, have demonstrated superior performance. Multi-resolution analysis (MRA) provides effective tools, like wavelets and Laplacian pyramids, to help carry out data fusion/merge tasks [7,8]. The basic idea of MRA was developed in a multi-resolution framework by employing the wavelet transform (WT) [9–12] and the generalized Laplacian pyramid (GLP) as analysis–synthesis tools [13].

Redundant multi-resolution structures, like the generalized Laplacian pyramid (GLP) [12] matching even fractional scale ratios between the images to be merged, the un-decimated discrete wavelet transform (UDWT), and the "a trous" wavelet transform (ATWT) [14,15] have been found to be particularly suitable for image fusion thanks to their translation-invariance property (not strictly possessed by GLP).

In this paper, a fusion algorithm combined with five textural features for the fusion of multi-spectral images is proposed. First, five texture features of images are extracted. Then a nonlinear fusion rule, i.e. fuzzy rule is applied to merge wavelet coefficients from the two images according to the extracted features. The result of merging is assessed by using very high-resolution Quick-Bird data (four 2.8 m multi-spectral bands plus one 0.7 m panchromatic band) of an urban area. Experimental results indicate that the method outperforms the traditional approaches in preserving spectral information and improving spatial resolution.

1. Urban texture features

Urban areas always have many streets, blocks and such man-made objects. So images of urban areas have different texture than images of non-urban areas. Extraction of urban-related features is an important technique to analyze the distribution of different areas in an image and for the fusion of images.

Texture features can be extracted based on the three approaches [16]: (1) statistical approach (2) structural approach and (3) spectral approach. In the statistical approach, moments of different order in a localized window represent smooth, coarse, and grainy texture. In the structural approach, spatial structure descriptors are used to identify geometric primitives and their arrangement in an image. Some techniques using this approach are: local interaction models like auto regressive moving average model, the Gauss–Markov random field model and the fractal model. The spectral approach is the transform domain approach that is used to detect global periodicity in an image by finding high energy, narrow peaks in the spectrum. This approach is not popular due to high computational cost. Recently, a combination of spectral and spatial approaches, such as Gabor filters and wavelet transform, are becoming popular.

Along with the evolution of fusion schemes, the fusion rules are also advanced from the early simple pixelly maximum or minimum selection to area-based fusion rules [17]. Fusion rules should be variable to fit the various needs of different areas of image, that is, the fusion rules should suit the area features of images so that the useful information could be preserved and extruded.

2. Texture features extraction

For an image $f(x,y)$ of size $M \times N$, where $M = 2^m$, $N = 2^n$, according to wavelet decomposition theories, the approximation of image $f(x,y)$ at resolution 2^j can be obtained as follows:

$$f(x,y) = A_j f(x,y) + D_j^1 f + D_j^2 f + D_j^3 f \tag{1}$$

where $A_j f$ is the low-frequency approximation of image $f(x,y)$ at resolution 2^j and $D_j^1 f$, $D_j^2 f$, $D_j^3 f$ represent the vertical, horizontal and diagonal wavelet coefficients at 2^j, respectively. These coefficients describe the high-frequency information of image at vertical, horizontal and diagonal directions, respectively.

Five textural features are used to represent the characteristics of image and calculated as following.