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Fusion of Multispectral and Panchromatic Satellite Images in Environmental Issues

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ABSTRACT
Image fusion of multispectral and panchromatic satellite image is used to combine spatial detail of the panchromatic image of high spatial resolution and spectral information of multispectral image of low resolution, in order to create a synthetic multispectral high-resolution image. This process is called pansharpening and the resulting image, has among others, improved visual quality and visual interpretation capabilities. These improvements are particularly useful in studying environmental issues. A large number of fusion techniques have been developed at various levels. This paper includes a critical consideration of certain fusion techniques at pixel level, as well as a relevant example of panchromatic and multispectral satellite image fusion of satellite Landsat 8.

Keywords: digital image processing, image fusion, Landsat 8, pansharpening, remote sensing

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I. INTRODUCTION

Image fusion is the combination of two or more different images to form a new image by using a certain algorithm [1]. Concerning image fusion of satellite images, these can be acquired from the same satellite, from different satellites optical and / or radar at different times.

Most modern optical Earth observation satellites such as SPOT, Landsat 7/8, IKONOS, Quickbird, WorldView receive panchromatic and multispectral imagery simultaneously with different spatial resolutions. Fusion of a multispectral image of relatively low spatial resolution with a high resolution panchromatic image is called pansharpening and it is an important issue for a number of remote sensing applications such as environmental issues. The image resulting from this process contains more information than the original images and is called "pansharpened", but often referred to as "fused image".

The information resulting from the combination of spectral information of the multispectral image with spatial information of the panchromatic image has been exploited in many environmental issues such as the study of urban areas, change detection, land cover study, study of catastrophic phenomena (landslides) etc. [2], [3], [4].

This paper includes a critical consideration of certain fusion techniques that are commonly used as well as a relevant example of panchromatic and multispectral satellite image fusion of satellite Landsat 8.

II. IMAGE FUSION TECHNIQUES

Image fusion techniques can be divided into three levels: pixel level (virtual), feature level (symbolic) and decision level (cognitive) [5], [6]. The algorithms used in pixel level, process the information pixel by pixel to generate a new image (fusion product) with more interpretable features and which can improve digital image processes such as classification. In feature level, features are recognized and exported using the intensity of the pixel, the edges or the texture of the original data sources. In decision level, multiple algorithms are applied which are subsequently combined with decision rules.

Regarding remote sensing applications, pixel level fusion techniques are of great interest because of their linearity and simplicity. Among others, multiplicative method, Brovey transformation, IHS fusion, Principal Component Analysis, multi-resolution methods such as Wavelet transform, high pass filtering fusion and Ehlers fusion are used.

Multiplicative method is a simple fusion method based on the multiplication of each multispectral band with the panchromatic image. Spectral bands of higher correlation are created, modifying the spectral characteristics of the original image [6].

The basic process of Brovey transformation primarily includes a multiplication of each multispectral band with the panchromatic band (high resolution band) and subsequently a division of each product with the sum of multispectral bands [7].

Spectral properties are not well preserved in the fused image [6].

In intensity-hue-saturation (IHS) fusion, three bands of the multispectral image are transformed from the RGB domain (color model of the three primary colors) into the IHS color space (intensity - hue - saturation color model). The panchromatic component is matched to the intensity of the IHS image. Subsequently, the panchromatic image replaces the intensity in the original IHS image and fused image is transformed back into the RGB color space. This is a relatively simple method applied to three spectral bands, which may in some cases produce significant spectral distortion [7].

The principal component Analysis (PCA) is a statistical technique that transforms a multivariate dataset of correlated variables into a dataset of uncorrelated linear combinations of the original variables. In this fusion method, the correlated multispectral bands are converted into a new set of uncorrelated components. The first component (PC_1) is replaced by the high resolution panchromatic image. The panchromatic image is fused with the multispectral image by performing a reverse transform [7]. The fused image due to the statistical process followed, presents spectral degradation and depends on the area to be applied [6].

Wavelet methods belong in the broader category of Multiple Resolution Analysis (MRA) methods. In wavelet fusion, a high resolution panchromatic image is first decomposed into a set of low resolution panchromatic images using corresponding wavelet coefficients (spatial details) for each level. Individual bands of the multispectral image then replace the low resolution panchromatic image at the resolution level of the original multispectral image. The high resolution spatial detail is injected into each multispectral band by performing a reverse wavelet transform on each multispectral band using the corresponding wavelet coefficients [7]. The result of the fusion usually presents minimal spectral distortion but also less spatial improvement [6].

High pass filtering (HPF) pansharpening uses a high pass convolution filter (kernel). Its size is generally equal to the ratio between the spatial resolution of the panchromatic and multispectral images. First, the high pass filter is applied to the panchromatic image and is added to each multispectral band. A linear stretch is applied to the fused products to correlate the mean and standard deviation values of the multispectral images [8]. It is a method that gives generally accepted results, emphasizing however the edges in the fused image [6].

In Ehlers fusion technique, as a first step an IHS transform is applied to the multispectral image to separate the spatial and color information. The Fast Fourier transform (FFT) and a low-pass filter are applied to intensity obtained from the IHS transform. Additionally, the Fast Fourier transform (FFT) and a high-pass filter are applied to the panchromatic image. After filtering, the images are transformed back into the spatial domain with an inverse FFT and added. As a final step, an inverse IHS transformation is applied to produce the fused RGB image. The algorithm of this process is relatively complex, however the fused image preserves well the spectral properties of the original multispectral image [6].

The fused images can be evaluated qualitatively (visual analysis using spatial details, geometric model, object size, etc.) and quantitative. The quantitative evaluation includes spectral and spatial evaluation. It is performed by various techniques such as the correlation of the spectral bands of the original multispectral image with the corresponding bands of fused image, the mean value, the standard deviation, etc. [9].

III. IMPLEMENTING PANSHARPENING TECHNIQUES USING LANDSAT 8 SATELLITE IMAGERY

Satellite Landsat 8 was launched on February 11th, 2013 and carries two instruments: Operational Land Imager-OLI and Thermal Infrared Sensor-TIRS. The Operational Land Imager (OLI) sensor has eleven spectral bands with a spatial resolution of 30 m for bands 1-7 and 9. The spatial resolution for band 8 (panchromatic) is 15 m and for bands 10, 11 is 100 m [10].

The image employed was obtained free of charge and downloaded from the website http://earthexplorer.usgs.gov [11]. Its acquisition date is 2014-03-14 (path: 185, row: 32) and its processing level is 1T-Standard Terrain Correction (systematic radiometric and geometric accuracy) with map projection: UTM, zone 34, spheroid & datum WGS 84. The image is cloud-free and has excellent quality. The processing was done with ERDAS IMAGINE 2011 software.

Three representative fusion methods (Brovey transformation, Principal Component Analysis and Discrete Wavelet Transform) were implemented using a subset of the image, which includes part of Lake Orestiada (NW Greece) and part of the wider region of the city of Kastoria (Figs. 1-3). The results of the applied fusion methods are presented in Figs. 4-6.

Figure 1. Study area

Figure 2. Original multispectral image (color composite 4-3-2)

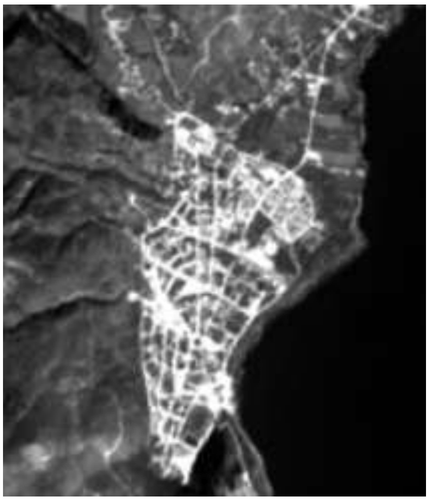

Figure 3. Panchromatic image

Observations and remarks related to visual interpretation of the original images and fused images follow. The fused images (Figs. 4-6) compared to the original multispectral image (Fig. 2), present improved spatial resolution, which approaches visually the resolution of the panchromatic image (Fig. 3).

Figure 4. Fused image (color composite 4-3-2) using Brovey Transformation

Figure 5. Fused image (color composite 4-3-2) using Principal Component Analysis

Figure 6. Fused image (color composite 4-3-2) using Wavelet Transform

The Brovey transformation fused image (Fig. 4) shows small changes in colors (relief area in the left part of the image, coastline, crops). Road network and the residential area are highlighted. The PCA fused image (Fig. 5) shows relative clarity (residential area), but it is spectrally degraded. Areas with crops are less clear, meanwhile road network is distinct and clearly visible. Discrete Wavelet transform (DWT) results in an image with minimal spectral distortion, which however has a reduced spatial detail (urban area, coastline) and different texture (Fig. 6).

IV. CONCLUSIONS-DISCUSSION

Fusion methods for multispectral and panchromatic images (pansharpening) result in a synthetic image, which can be used for visual interpretation and further digital processing (classification). Various fusion techniques have been developed among which, those mentioned in Section II. The knowledge of a wide variety of fusion techniques could be useful to the final user, in order to choose the appropriate technique, depending on the area of implementation and the theme of the application. Visual interpretation and classification of the fused image can contribute significantly to the study of environmental issues such as change detection, land cover, catastrophic events, etc.

In the example given in this paper, concerning fusion of multispectral and panchromatic image of satellite Landsat 8, three representative fusion techniques were applied: a numerical (Brovey transformation), a statistical (Principal Component Analysis) and a multi-resolution analysis technique (Wavelet Transform). All three methods that were applied produce better images visually. Brovey transformation improves the color contrast of the features as well as the texture of the fused image, making it effective for further visual interpretation. The resulting fused image using Discrete Wavelet transform (DWT) seems to preserve better the spectral characteristics of the original multispectral image and can be more effective for further digital processing (e.g. classification of fused image).

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