ШИНЖЛЭХ УХААНЫ АКАДЕМИ
ИНФОРМАТИКИЙН ХҮРЭЭЛЭН

ЭРДЭМ ШИНЖИЛГЭЭНИЙ БҮТЭЭЛ №10

УЛААНБААТАР
2010 он

Investigation of Fusion Methods using Multispectral Optical and Polarimetric SAR Images

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Abstract: The aim of this study is to explore the performances of different data fusion techniques for the enhancement of urban features. For the data fusion, multiplicative method, Brovey transform, principal component analysis (PCA), Gram-Schmidt fusion, wavelet-based fusion and Elhers fusion are used and the results are compared.

1. Introduction

Image fusion is used for many purposes. Very often it is used to produce improved spatial resolution. The most common situation is represented by a pair of images where the first acquired by a multispectral sensor has a pixel size greater than the pixel size of the second image acquired by a panchromatic sensor. Combining these images, fusion produces a new multispectral image with a spatial resolution equal to the panchromatic one. In addition, image fusion introduces important distortions on the pixel spectra which in turn improve the information content of RS images [3,11].

Over the years, the fusion of optical and SAR data sets has been widely used for different applications. It has been found that the images acquired at optical and microwave ranges of electro-magnetic spectrum provide unique information when they are integrated. As it is known, optical data contains information on the reflective and emissive characteristics of the Earth surface features, while the SAR data contains information on the surface roughness, texture and dielectric properties of natural and man-made objects. It is evident that a combined use of the optical and SAR images will have a number of advantages because a specific feature which is not seen on the passive sensor image might be seen on the microwave image and vice versa because of the complementary information provided by the two sources [1,2].

The aim of this study is to investigate different data fusion techniques for the enhancement of spectral variations of urban features. For the data fusion, fusion of optical data with SAR data has been used. For the actual analysis, ASTER data of 2008, ALOS PALSAR data of 2006 and ERS-2 SAR data of 1997 of the urban area in Mongolia have been used. The analysis was carried out using PC-based ERDAS Imagine 9.1 and ENVI 4.3.

2. Test site and data sources

As a test site, Ulaanbaatar, the capital city of Mongolia has been selected. Ulaanbaatar is situated in the central part of Mongolia, on the Tuul River, at an average height of 1350m above sea level and currently has about 1.25 million inhabitants.

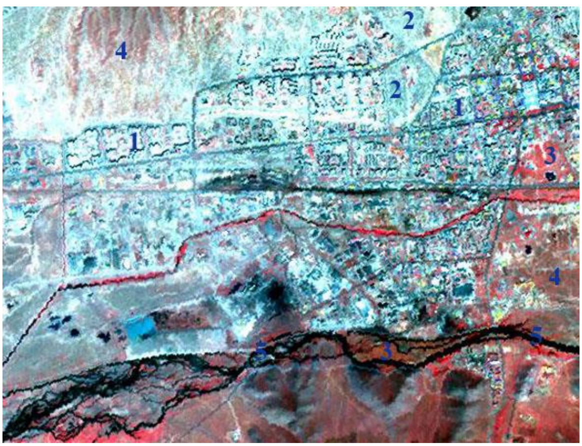

Figure 1. 2008 ASTER image of Ulaanbaatar.

In the present study, for the enhancement of urban features, green (band 1), red (band 2) and near infrared (band 3) bands of ASTER data of 23 September 2008, VV polarized C-band ERS-2 SAR data of 25 September 1997 and polarimetric L-band ALOS PALSAR data of 25 August 2006 have been used.

3. Review of image fusion methods

The concept of image fusion refers to a process, which integrates different images from different sources to obtain more information from a single and more complete image, considering a minimum loss or distortion of the original data. In other words, the image fusion is the integration of different digital images in order to create a new image and obtain more information than can be separately derived from any of them [7,8]. In the case of the present study, for the urban areas, the radar images provide structural information about buildings and street alignment due to the double bounce effect, while the optical images provide the information about the spectral variations and multitemporal changes of different urban features. Moreover, the SAR images provide some additional information about soil moisture condition due to dielectric properties of the soil.

Over the years, different data fusion techniques have been developed and applied, individually and in combination, providing users and decision-makers with various levels of information. Generally, image fusion can be performed at pixel, feature and decision levels [7]. In this study, data fusion has been performed at a pixel level and the following rather common and more complex techniques were compared: (a) multiplicative method, (b) Brovey transform, (c) principal component analysis (PCA), (d) Gram-Schmidt fusion, (e) Wavelet-based fusion, (f) Elhers fusion. Each of these techniques is briefly discussed below.

Multiplicative Method: This is the most simple image fusion technique. It takes two digital images, for example, high resolution panchromatic and low resolution multispectral data, and multiplies them pixel by pixel to get a new image [10].

Brovey transform: This is a simple numerical method used to merge different digital data sets. The algorithm based on a Brovey transform uses a formula that normalises multispectral bands used for a red, green, blue colour display and multiplies the result by high resolution data to add the intensity or brightness component of the image [12]. For the Brovey transform, the bands of Quickbird data were considered as the multispectral bands, while the HH-polarization of TerraSAR image was considered as the multiplying panchromatic band.

PCA: The most common understanding of the PCA is that it is a data compression technique used to reduce the dimensionality of the multidimensional datasets [9]. It is also helpful for image encoding, enhancement, change detection and multitemporal dimensionality [7]. PCA is a statistical technique that transforms a multivariate data set of intercorrelated variables into a set of new uncorrelated linear combinations of the original variables, thus generating a new set of orthogonal axes.

Gram-Schmidt fusion method: Gram-Schmidt process is a procedure which takes a non-orthogonal set of linearly independent functions and constructs an orthogonal basis over an arbitrary interval with respect to an arbitrary weighting function. In other words, this method creates from the correlated components non- or less correlated components by applying orthogonalization process. Generally, orthogonalization is important in diverse applications in mathematics and other applied sciences because it can often simplifiy calculations or computations by making it possible, for instance, to do the calculation in a recursive manner [5].

Wavelet-based fusion: The wavelet transform decomposes the signal based on elementary functions, that is the wavelets. By using this, an image is decomposed into a set of multi-resolution images with wavelet coefficients. For each level, the coefficients contain spatial differences between two successive resolution levels. In general, a wavelet-based image fusion can be performed by either replacing some wavelet coefficients of the low-resolution image by the corresponding coefficients of the high-resolution image or by adding high resolution coefficients to the low-resolution data [6]. In this study, the first approach which is based on bi-orthogonal transforms has been applied.

Elhers fusion: This is a fusion technique used for the spectral characteristics preservation of multitemporal and multi-sensor data sets. The fusion is based on an IHS transformation combined with filtering in the Fourier domain and the IHS transform is used for optimal colour separation. As the spectral characteristics of the multispectral bands are preserved during the fusion process, there is no dependency on the selection or order of bands for the IHS transform [4].

4. Comparison of the fusion methods

After georeferencing and speckle suppression, the above mentioned fusion methods have been applied to such combinations as ASTER and HH polarization of PALSAR, ASTER and HV polarization of PALSAR, ASTER and VV polarization of PALSAR, and ASTER and ERS-2 SAR. Then, in order to obtain good colour images that can illustrate spectral and spatial variations of the classes on the selected optical and SAR images, all the fused images have been visually inspected and compared. In the case of the multiplicative method, the fused image of ASTER and HH polarization of PALSAR demonstrated a better result compared to other combinations, while in the case of Brovey transform the combination of ASTER and ERS-2 SAR created a good image. On the image obtained by the multiplicative method, the built-up and ger areas have similar appearances, however, the green area, soil and water classes have total separations. Likewise, on the image obtained by the Brovey transform, the built-up and ger areas have similar appearances, whereas the green area and soil classes have total separations. Moreover, on this image, a part of the water class is mixed with other classes.

Unlike the SAR/SAR approach, in this approach, PCA has been applied to such combinations as ASTER and ERS-2 SAR, ASTER and PALSAR, and ASTER, PALSAR and ERS-2 SAR. When the results of the PCA have been compared, the combination of ASTER, PALSAR and ERS-2 SAR demonstrated a better result than the other two combinations. The result of the final PCA is shown in table 1. As can be seen from table 1, HH polarisation of PALSAR and ERS-2 SAR have very high negative loadings in PC1 and PC2. In these PCs, visible bands of ASTER also have moderate to high loadings. This means that PC1 and PC2 contain the characteristics of both optical and SAR images. Although, PC3 contained 7.0% of the overall variance and had moderate to high loadings of ASTER band1, HH polarisation of PALSAR and ERS-2 SAR, visual inspection revealed that it contained less information related to the selected classes.

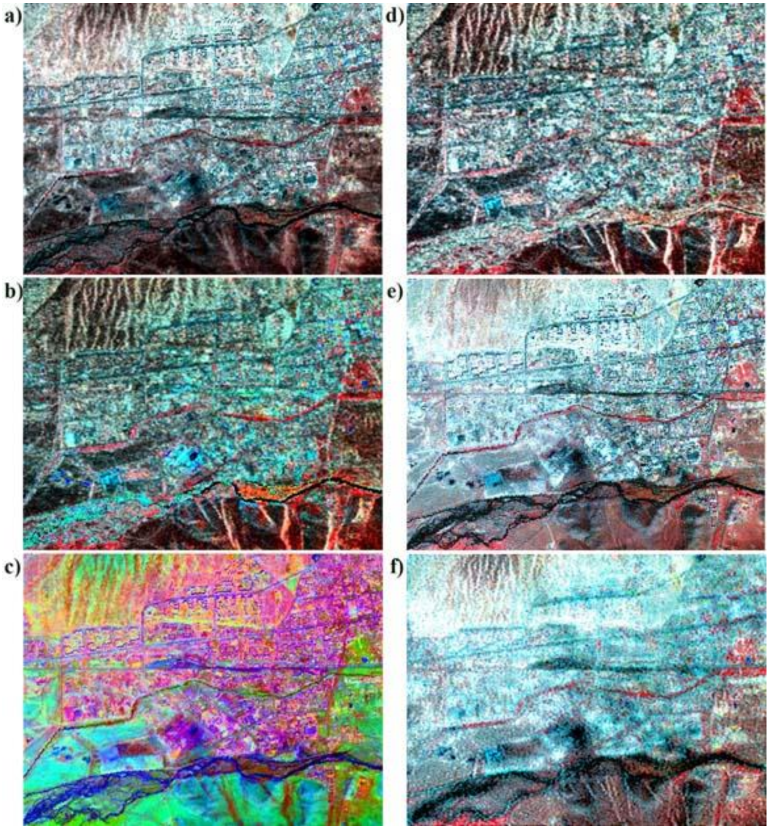

Figure 2. Comparison of the fused optical and SAR images: (a) the image obtained by multiplicative method; (b) Brovey transformed image; (c) PC image (red=PC1, green=PC2; blue=PC4); (d) the image obtained by Gram-Schmidt fusion; (e) the image obtained by wavelet-based fusion; (f) the image obtained by Elhers fusion.

However, visual inspection of PC4 that contained 5.6% of the overall variance, in which VV polarisation of PALSAR has a high loading, revealed that this feature contained very useful information related to the textural difference between the built-up and ger areas. The inspection of the last PCs indicated that they contained noise from the total data set. As can be seen from figure 3c, although the PC image could separate the two urban classes, in some parts of the image, it created a mixed class of green area and soil.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
ASTER-b1	0.33	0.44	0.42	0.35	0.44	0.39	0.17
ASTER-b2	0.50	0.37	0.34	-0.34	-0.38	-0.33	-0.32
ASTER-b3	0.02	0.07	0.11	-0.09	-0.32	-0.19	0.91
PALSAR HH	-0.77	0.34	0.47	-0.14	0.06	-0.15	-0.08
PALSAR HV	0.14	-0.07	-0.06	-0.49	0.73	-0.40	0.13
PALSAR VV	0.02	-0.01	0.01	0.69	0.08	-0.71	-0.04
ERS-2 SAR	0.07	-0.73	0.67	0.01	-0.01	0.02	-0.01
Eigenvalues	8873.3	4896.7	1159.7	934.6	459.2	147.7	81.7
Variance(%)	53.6	29.6	7.0	5.6	2.8	0.89	0.51

Table 1. Principal component coefficients from ASTER, PALSAR and ERS-2 SAR images.

In the case of the Gram-Schmidt fusion, the combined image of ASTER and ERS-2 SAR demonstrated a better result compared to other combinations. Although, the image contained some layover effects available on the ERS-2 image, looked very similar to the image obtained by the multiplicative method. In the case of the wavelet-based fusion, the fused image of ASTER and ERS-2 SAR demonstrated a better result compared to other combinations, too. Also, this image looked better than any other images obtained by other fusion methods. On this image, all available five classes could be distinguished by their spectral properties. Moreover, it could be seen that some textural information has been added for differentiation between the classes: built-up area and ger area. In the case of the Elhers fusion, the combined image of ASTER and VV polarization of PALSAR demonstrated a better result compared to other combinations. Although, this image had a blurred appearance due to speckle noise, still could very well separate green area, soil and water classes. Figure 2 shows the comparison of the images obtained by different fusion methods.

5. Conclusions

The main aim of the research was to compare the performances of different data fusion techniques for the enhancement of different surface features. For the data fusion, multiplicative method, Brovey transform, PCA, Gram-Schmidt fusion, wavelet-based fusion and Elhers fusion were used. Although, fusion methods demonstrated different results, detailed analysis of each image revealed that the image obtained by the wavelet-based fusion gave a superior image in terms of the spatial and spectral separations among different urban features.

6. References

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