THE STUDY ON IMAGE FUSION FOR HIGH SPATIAL RESOLUTION REMOTE SENSING IMAGES

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ABSTRACT:

Remote sensing images fusion can not only improve the spatial resolution for the original multispectral image, but also preserve the spectral information to a certain degree. In order to find out the fusion algorithm which is suited for QuickBird images fusion, four simple fusion algorithms, Multiplication (MLT), Modified Brovey (MB), High-Pass Filter (HPF) and the Smoothing Filter-based Intensity Modulation (SFIM) algorithm have been employed for result evaluation. The study is based on a QuickBird sub-scene covering different land use. Numerical statistical methods such as Bias of Mean, Correlation Coefficient, Entropy, Standard Deviation and Average Grads are used to quantitatively assess the fused images produced using the above algorithms. The analysis indicates that the SFIM-fused image has the best definition as well as spectral fidelity, and is the best in high textural information absorption. Therefore it is suited for QuickBird image fusion best.

1. INTRODUCTION

Nowadays, remote sensing is developing to high-spectral resolution, high-spatial resolution, and high-time resolution. But as far as one and the same data is concerned, it is difficult to obtain the image of high-spatial resolution and high-spectral resolution at the same time. The information content of a single image is limited by the spatial and spectral resolution of the imaging system. Since the advent of the high spatial resolution satellite images, the merging of multiresolution images has been an important field of research. The fusion of remote sensing images can integrate the spectral information of single sensor or the information from different kinds of sensors (Couloigner,1998). In order to improve the dependability for extracting remote sensing information, and enhance the efficiency of using data. Literature has shown a large collection of fusion methods developed over the last two decades, such as the Multiplication (MLT) algorithm, Modified Brovey (MB) algorithm, High-Pass Filter (HPF) algorithm, the Smoothing Filter-based Intensity Modulation (SFIM) algorithm (Liu,2000a), the Principal Components Analysis (PCA), the Intensity-Hue-Saturation (IHS) and so on. All of the above-mentioned methods can realize the fusion of multi-spectral and high-resolution images, besides it can improve the spatial resolution and preserve the spectral information to a certain degree. For the moment, every method has its own advantages and disadvantages. Even if we use the same fusion to deal with the different images, we will get the different effect. In this paper, we evaluate the effect and applicability of different methods for high-resolution images through comparing the staple fusion methods. It can offer the reference to the fusion of high-resolution images.

2. FUSION ALGORITHMS

Data fusion provides several advantages (Ranchin,2003): preservation of computer storage space; enhancement of aesthetic and cosmetic qualities; improvement of spatial resolution; and analytical improvements. Each reason for data fusion relies on the following premise--for a data fusion model to be effective, the merged images should retain the high spatial resolution information from the panchromatic (Pan) data set while maintaining the basic spectral record of the original multi-spectral (MS) data (Carper et al, 1990).Many methods have been developed in the last few years producing good quality merged images. This study analyzes four current data fusion techniques to assess their performance. The four data fusion models used include MLT, MB, HPF, SFIM algorithms. The reasons of selecting the above methods is mainly as follows: 1) They are all mathematically similar, for example, they are all statistical-based methods rather than color-related techniques; 2) They are simple and easy to be used; 3) They can be performed with any number of selected input bands, while some others like HIS only allow a limited number of input bands to be fused.

2.1 MLT Algorithm

The Multiplication model combines two data sets by multiplying each pixel in each band of the MS data by the corresponding pixel of the Pan data (Pohl.C,1997). To compensate for the increased Brightness Values (BV), the square root of the mixed data set is taken. The square root of

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the multiplicative data set, reduces the data to a combination reflecting the mixed spectral properties of both data sets:

$$MLT_{i,j,k} = \sqrt{a \times b \times Pan_{i,j} \times MS_{i,j,k}} \quad (1)$$

Where MLT is the output image and i and j are pixels of band k. Pan and MS are the panchromatic data and multi-spectral data respectively. To compensate for this effect, weighting coefficients a and b can be used. As Cliche and Bonn (1985, p. 316) noted, "however arbitrary, the weights used for the panchromatic and infrared channels increase the spatial resolution from 20 to 10 m and preserve much of the infrared information."

2.2 MB Algorithm

Since the original Brovey Transform can only allow three bands to be fused, the transform has to be modified in this study. The Modified Brovey algorithm is a ratio method where the data values of each band of the MS data set are divided by the sum of the MS data set and then multiplied by the Pan data set. The MB algorithm attempts to maintain the spectral integrity of each band by incorporating the proportionate value of each band as related to the MS data set before merging it with the Pan data set. By adjusting for the effects of the Pan data set's spectral properties when combining the data sets, the spectral quality of the MS data set is mainly preserved:

$$MB_{i,j,k} = 2 \times (MS_{i,j,k} / \sum MS_{i,j,l..n}) \times Pan_{i,j} \quad (2)$$

where MB is the output image and i and j are pixels of band k. Pan and MS are the panchromatic data and multi-spectral data respectively. The result is multiplied by 2 to increase the digital numbers (DNs) of the resulting fused image.

2.3 HPF Algorithm

The High-Pass Filter model was first introduced by Schowengerdt (1980) as a method to reduce data quantity and increase spatial resolution potential for Landsat MSS data. Chavez et al. (1991) extended this idea to more diverse multispatial data sets when they merged Thematic Mapper (TM) data with a digitized National High Altitude Program (NHAP) aerial photograph. The HPF method submits the high spatial resolution imagery to a small convolution mask (3 x 3) which acts upon the high-frequency spatial information (Pohl, 1998), effectively reducing the lower frequency spectral information of the high spatial resolution image. The filtered result is then added to the MS data and the result divided by two to offset the increase in brightness values:

$$HPF_{i,j,k} = (MS_{i,j,k} + FP_{i,j}) / 2 \quad (3)$$

Where HPF is the output image and i and j are pixels of band k. FP is the filtered result of High-Pass Filter, This technique preserves the MS data while incorporating the spatial resolution of the PN data.

2.4 SFIM Algorithm

The SFIM algorithm is a ratio method that the high-resolution image is divided by a simulated low-resolution image and the result is then multiplied by the low-resolution image. Liu (2000a, b) defined the algorithm as follows:

$$SFIM_{i,j,k} = (MS_{i,j,k} \times Pan_{i,j}) / Mean_{i,j} \quad (4)$$

Where SFIM is the output image and i and j are pixels of band k. Mean is a simulated low resolution pixel derived from the high-resolution image using an averaging filter for a neighbourhood equivalent in size to the spatial resolution of the low-resolution data. Pan and MS are the panchromatic data and multi-spectral data respectively. For example, suppose the high resolution image consisted of SPOT 10x10 m panchromatic data and the low-resolution image consisted of Landsat ETM+ 30x30 m data. In this case the Mean value would be the average of the nine 10x10 pixels centred on the pixel under investigation in the high-spatial-resolution dataset. Liu (2000a) suggests that the SFIM can produce optimally fused data without altering the spectral properties of the original image if the co-registration error is minimal.

3. QUALITY ASSESSMENT CRITERIA

Quality refers to both the spatial and spectral quality of images (Wald,1997). Image fusion methods aim at increasing the spatial resolution of the MS images while preserving their original spectral content. Spectral content is very important for applications such as photo interpretation and classification that depend on the spectra of objects. The evaluation of the fusion results is based on the quantitative criteria including spectral and spatial properties and definition of images (Xu,2004). Numerical statistical methods such as Bias of Mean(BM), Standard Deviation(SD), Entropy, Average Grads(AG), Correlation Coefficient(CC) are used in this study to quantitatively assess the fused images produced using the above algorithms.

3.1 Spectral Fidelity

The basic principle of spectral fidelity is that the low spatial frequency information in the high-resolution image should not be absorbed to the fusion image, so as to preserve the spectral content of original MS image. The indexes which can inflect the spectral fidelity of fusion image include:

3.1.1 Bias of Mean: BM is the difference between the means of the original MS image and of the fused image (Stanislas de Bethune,1998). The value is given relative to the mean value of the original image. The ideal value is zero. Let F refers to the fused image.

$$BM = \frac{MS_{mean} - F_{mean}}{MS_{mean}} = 1 - \frac{F_{mean}}{MS_{mean}} \quad (5)$$

Where BM is the Bias of Mean, MS is the multi-spectral data.

3.1.2 Correlation Coefficient: CC measures the correlation between the original and the fused images. The higher the correlation between the fused and the original images, the better the estimation of the spectral values. The ideal value of correlation coefficient is 1.

$$CC = \frac{\Sigma\Sigma(MS_{i,j}\ \ MS_{mean})(F_{i,j}\ \ F_{mean})}{\sqrt{\Sigma\Sigma(MS_{i,j}\ \ MS_{mean})^2}\sqrt{\Sigma\Sigma(F_{i,j}\ \ F_{mean})^2}} \quad (6)$$

Where CC is the Correlation Coefficient, F is the fused image and i and j are pixels, MS is the multi-spectral data.

3.2 High Spatial Frequency Information Absorption

The high spatial frequency information absorption is that the enhancement of resolution and increasing of information of the fused image relative to the original MS image. The common assessing index is Entropy. Entropy is a measure of information and its concept has been employed in many scientific fields (Lau,2001). Sun et al. (1997) introduced.

Entropy as a measure to directly conclude the performance of image fusion. The Entropy can show the average information included in the image and reflect the detail information of the fused image. Commonly, the greater the Entropy of the fused image is, the more abundant information included in it, and the greater the quality of the fusion is. According to the information theory of Shannon, The Entropy of image is:

$$E = -\sum_{i=0}^{255} P_i \log_2 P_i \quad (7)$$

Where E is the Entropy of image, and P_i is the probability of i in the image.

3.3 Definition of Image

The definition of image is the contrast of hue between pixels border upon, it can be weighted using the following indexes:

3.3.1 Standard Deviation: SD is an important index to weight the information of image, it reflects the deviation degree of values relative to the mean of the image. The greater SD is, the more dispersible the distributing of the gray grade is. In the statistical theory, the SD is defined as follows**:**

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(MS_{i,j} - MS_{mean})^2} \quad (8)$$

Where σ is the SD, MS is the multi-spectral data. n is the bands of MS.

3.3.2 Average Grads: The AG can reflect the contrast of detail in the image, so it can be used to assess the definition of image. Commonly, the average grads is greater, the image is more legible.

$$G = \frac{1}{n}\sum\sqrt{(\Delta I_x^2 + \Delta I_y^2)/2} \quad (9)$$

Where ΔI_x is the difference of pixel in the direction of x, and ΔI_y is the difference of pixel in the direction of y.

4. EXPERIMENTTEST AND ANALYSIS OF FUSION RESULTS

4.1 Experiment Data

For evaluation, many QuickBird images of different regions have been tested. a small scene of a QuickBird image is used for demonstration of this paper, which has four 2.4-m resolution multi-spectral bands and a 0.6-m resolution Pan band. Band 3, 2, 1 are selected. The land use of the region is complex and it includes farm, vegetation, water, highway and so on. Therefore, if the region is tested, we can compare the fusion result at different DNs with diversified algorithms and assess the algorithms from many aspects. No rectification is needed for the fusion of QuickBird MS and Pan images as they are from same sensor system. As Liu (2000b) recommended (Liu., 2000b), a linear model is employed to resample the 2.4-m resolution multi-spectral bands to a 0.6-m pixel size before fusion can be taken. The resampled multi-spectral and Pan bands are then fused using the above algorithms, respectively. The fusion results are showed in figure1.

4.2 Analysis of Fusion Results

Initial qualitative visual inspections reveal that all the fused images have better qualifications than original non-fused images. The sharpness of the fused images has been significantly enhanced. The further quantitative evaluation can be done with above criteria. The values of the evaluation have been showed in three tables.

Image	BM	SD	AG
MS	0.0000	38.2405	2.8801
MLT	0.0447	45.3288	6.1909
MB	0.0167	39.9507	8.4097
HPF	0.0552	43.4763	8.2676
SFIM	0.0155	45.8497	13.8672

Table 1. Bias of Mean, Standard Deviation, Average Grade of MS and various fused images

Image	Entropy of Band1	Entropy of Band2	Entropy of Band3	Average Entropy
MS	7.5373	7.5710	7.4625	7.5236
MLT	7.3377	7.2514	7.3555	7.3148
MB	7.3292	7.3774	7.3331	7.3466
HPF	7.4572	7.4416	7.4650	7.4546
SFIM	7.5454	7.4225	7.5132	7.4937

Table 2. Entropy of MS and various fused images

Image	CC of Band1	CC of Band1	CC of Band1	Average CC
MLT	0.9051	0.8754	0.9222	0.9009
MB	0.9193	0.9349	0.9345	0.9296
HPF	0.8899	0.8861	0.8956	0.8905
SFIM	0.9358	0.9331	0.9447	0.9379

Table 3. Correlation Coefficient of various fused images with MS image

4.2.1 Spectral Fidelity: Table 1 shows the BM of MS and fused images. It clearly indicates that the BM of SFIM is the minimum, and BM of MB is the second minimum. Table 3 shows that The CC of SFIM-fused image is 0.9379, which is the highest in the four algorithms. HPF is the minimum. According to the BM and CC, we can see that the SFIM-fused image has the maximal relativity with MS image. So SFIM is the best method in retaining spectral property of the original image among the four used methods, and MB takes second place.

4.2.2 High Spatial Frequency Information Absorption: Table 2 shows the Entropy and means of each band MS and fused images. The Average Entropy of SFIM is the highest in the four algorithms, band 1 and band 3 is also the highest of all. The Entropy can reflect the average information included in the fused image, therefore, the SFIM-fused image has absorbed the high spatial frequency information most and thus shows crisper than the others (Figure.1). The other three are not much different but the HPF is a little more in information than MLT and MB.

4.2.3 Definition of Image: Table 1 shows the SD, AG of MS and fused images. SD reflects the change in details of fused image, and AG reveals the change of values between the pixels border upon, namely reflects the definition of image. It evidently indicates that the SFIM is the highest either in the SD, or in AG. SD of MLT is the second highest, and MB takes second place in AG. Therefore， SFIM-fused image is more legible than other three algorithms.

Finally, from the above analysis and comparison, It is summarized that the SFIM-fused image has the best spectral fidelity and definition, and absorbs the high spatial frequency information most. It is a fusion technique based on a simplified solar radiation and land surface reflection model. By using a ratio between a higher resolution image and its low pass filtered (with a smoothing filter) image, spatial details can be modulated to a co-registered lower resolution multi-spectral image without altering its spectral properties and contrast. The technique can be applied to improve spatial resolution for either colour composites or individual bands. So it is superior to the other three methods for QuickBird images. The MB takes second place in BM, AG and CC. So it can also be called a good method for the imagery fusion. The HPF can absorb the spatial information commendably but is bad in spectral fidelity. The MLT is the worst for QuickBird imagery.

5. CONCLUSIONS AND PROSPECT

5.1 Conclusions

(1) The comparison of the SFIM with MLT, HPF and MB shows that the SFIM-fused image has the best definition as well as spectral fidelity, and is the best in high textural information absorption. Therefore it is the best method for QuickBird image fusion in the four algorithms and MB takes second place.

(2) SFIM is a simple but superior fusion algorithm and the time of computing is short, so it is suited for the image fusion which covers a large-scale area.

5.2 Prospect

(1) In order to find out the fusion algorithm which is suited for QuickBird images fusion, this study selected MLT, MB, HPF and SFIM as the tested methods. Through the four algorithms are the representative at pixel level fusion, it is unilateral. In the subsequent research, we should test more fusion algorithms and discovers the best method for QuickBird images.

(2) This study only selects the five common evaluation criteria such as BM, CC, Entropy, SD and AG. Although it covers the most image evaluation field, it has some insufficiency. In the following research, we should adopt more indexes to assess fusion result comprehensively from other aspect, such as image classification.

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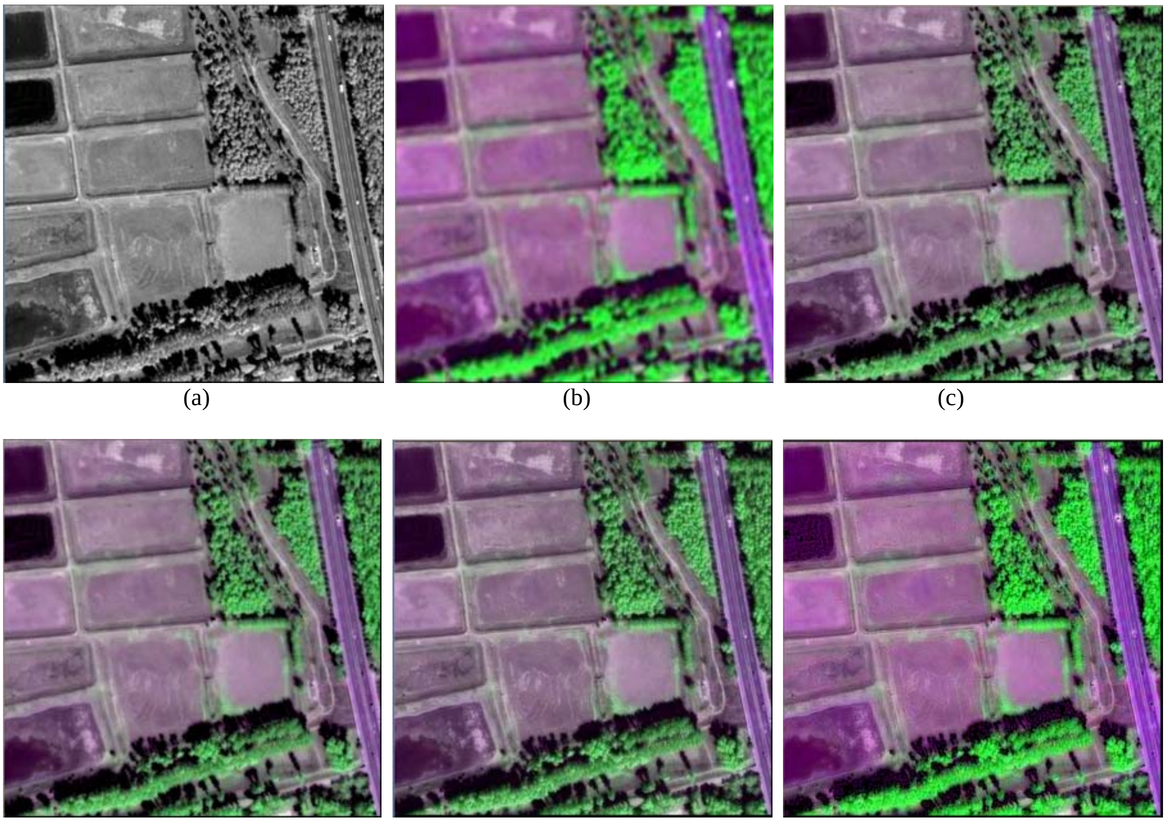

(a) (b) (c)

(d) (e) (f)

Figure1. (a) original Pan image. (b) original MS image.(c) MLT-fused image. (d) MB-fused image. (e) HPF-fused image. (f) SFIM-fused image.