Study on Efficiency of Fusion Techniques for IKONOS Images

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Abstract. Many image fusion techniques have been proposed to achieve optimal resolution in the spatial and spectral domains. Six different merging methods were listed in this paper and the efficiency of fusion techniques was assessed in qualitative and quantitative aspect. Both local and global evaluation parameters were used in the spectral quality and a Laplace filter method was used in spatial quality assessment. By simulation, the spectral quality of the images merged by Brovery was demonstrated to be the worst. In contrast, GS and PCA algorithms, especially the Pansharpening provided higher spectral quality than the standard Brovery, wavelet and CN methods. In spatial quality assessment, the CN method represented best compared with that of others, while the Brovery algorithm was worst. The wavelet parameters that performed best achieved acceptable spectral and spatial quality compared to the others.

1. Introduction

The IKONOS satellite is the first commercial remote sensing satellite in the world to provide high-resolution satellite images, which successfully launched in the United States on September 24, 1999.

Currently the most popular methods in image fusion are divided into several categories, the spectral or color-based transform fusion, such as the HIS transformation, principal component transformation, the integration of algebra-based fusion method and the signal decomposition and reconstruction of the spatial-based domain transformation, such as wavelet transform, high pass filtering, etc.³

These fusion methods achieved good results in medium and low resolution images. Along with the applications of high spatial resolution satellites, such as IKONOS, Quickbird, and other remote sensing images, different fusion algorithms were proposed and their efficiency in high-resolution sensors were studied, but the evaluation system of theory and results have not formed yet. Practicality of the fusion methods in high-resolution images needs further study.⁴

In this paper, some popular fusion methods were listed including Brovery, wavelet, PCA, Pansharpening, Gram-Schmidt and CN algorithm, and assessed both in qualitative and quantitative aspect. Quality assessment for these methods was carried out. The qualitative assessment is achieved by visual observation, and spectral and spatial evaluation methods were used to quantitatively evaluate
the listed fusion methods. The comparison aims at selecting fusion algorithm for IKONOS image of different purpose and providing reference for the follow-up application.

The paper was structured in four sections. In the following section, evaluation methods both in quantitative and qualitative analysis were introduced. Experiments conducted based on IKONOS images were presented in section III with their results and the analysis. Finally, in Section IV, the conclusions of the comparison were given.

2. Quality evaluation of merged images

The quality assessment of the merged images could be divided into two parts: quantitative and qualitative evaluation.

2.1. Qualitative evaluation

Qualitative evaluation is mainly achieved by visual observation. The human eye has a strong perception of color, and the image sizes, resolution, range and the existence of noise could be determined preliminarily. The qualitative evaluation is simple and high efficiency. But uncertainty exists as different experience and expertise of different people\textsuperscript{[10]}.

2.2. Quantitative evaluation

2.2.1. Spectral Quality of the Merged Images

The spectral information of merged images and the original multispectral images are compared to achieve the quantitative evaluation. This comparison is performed using the following indicators\textsuperscript{[11]}:

a. Correlation coefficient between the multispectral and the merged images. The range of the value is 0 to 1. The greater the index is, the better spectral quality of the merged images is.

b. Difference between the means of the multi-spectral and the merged images, relative to the mean of the multi-spectral image, expressed as percentage. The ideal value is 0. The bigger the difference is, the worse the spectral quality of the merged images is.

c. Standard deviation of the difference image, relative to the mean of the original image, expressed as percentage. The higher of this parameter is, the worse spectral quality of the merged images is.

The above parameters could assess the difference in spectral information between each band of the merged image and the original multi-spectral image. To estimate the global spectral quality of the merged images, the following parameters are selected.

a. The relative average spectral error RASE expressed in percentage and demonstrates the average performance of a method in the considered spectral bands\textsuperscript{[12]}:

$$RASE = \frac{100}{M} \left( \frac{1}{N} \sum_{i=1}^{N} \text{RMSE}^2(B_i) \right)^{1/2}$$  \hspace{1cm} (1)

Where $N$ is the total number of multi-spectral bands and $M$ the mean value of the $N$ multi-spectral bands ($B_i$). And RMSE is the root mean square error computed as follows:

$$\text{RMSE}^2(B_i) = \text{bias}^2(B_i) + \text{SDD}^2(B_i)$$  \hspace{1cm} (2)

The lower of the RASE value is, the higher spectral quality of the merged images.

b. relative global dimensional synthesis error\textsuperscript{[13][14]}.

$$\text{ERDAS} = 100 h \left( \frac{1}{N} \sum_{i=1}^{N} \left[ \text{RMSE}^2(B_i) / (M_i^2) \right] \right)^{1/2}$$  \hspace{1cm} (3)
Where $h$ is the resolution of the high spatial resolution image and $l$ the resolution of the low spatial resolution image and $M_i$ the mean of each spectral band involved in the merging. The lower of the ERDAS value is, the higher spectral quality of the fusion images.

2.2.2. Spatial quality of the Merged Images

This comparison was performed quantitatively using the following indicators:

a. The variance reflects discrete level of the gray value of each pixel in the image that relative to the mean. Variance of a single band could be described as follows.

$$Var = \frac{1}{MN-1} \sum_{x=1}^{M} \sum_{y=1}^{N} \left[ f(x, y) - u_f \right]^2$$

(4)

A smaller variance indicates smaller contrast of the image and less information while the larger one means larger dispersed distribution of gray level and more information.

b. A good fusion method should inject more spatial detail of the PAN image to the multispectral image. The additional spatial detail is evident for all the merged images when compared to the initial multispectral image.

To evaluate this spatial detail addition, the correlation coefficients between the high-pass filtered PAN images could be the index of assessing the spatial quality. The method was introduced by Zhou\textsuperscript{[15]}, the PAN and merged images are both filtered by using the Laplacian filter illustrated in the following equation.

$$\begin{bmatrix}
-1 & -1 & -1 \\
-1 & 8 & -1 \\
-1 & -1 & -1 \\
\end{bmatrix}$$

(5)

A higher correlation between the high frequency components of PAN and the high frequency components of the merged images indicates that, more spatial information from PAN image is incorporated during merging\textsuperscript{[16]}.

3. Experiments and results

3.1. Experiment Data

![Figure 1. Original images of IKONOS(The left is the panchromatic image, and right is a multispectral images after geometric correction)](image)

The experimental data was IKONOS data obtained on May 6th, 2011, which contains 4 wave bands of 4m resolution and a panchromatic band of 1m resolution. Buildings, roads, farmland, water...
and other surface features were included as shown in figure 1. The precision of geometric correction was less than half a pixel.

3.2. Results of qualitative evaluation

By visual observation, the merged images were enhanced by different fusion algorithm in details of space and maintained the spectral characteristics of the original image. Roads, the edges of building, farmland were apparent and identifiable. But it was worth mentioning that the Brovery and CN transform method distorted the spectral characteristics of the source image compared with others, as color of the bare land and road and the buildings had been changed. The wavelet transform tended to appear a block effect and blurring as discarding the low frequency components of the high spatial resolution images. The GS, Pansharpening algorithms provided good spectral quality, as well as PCA algorithms from a visual perspective.

3.3. Results of quantitative evaluation

3.3.1. Results of spectral quality of the Merged Images

Table 1 showed the values of the quality indexes resulting from the merged images when different fusion methods were applied.

|                  | PCA       | Pansharpening | GS        | CN        | Brovery   |
|------------------|-----------|---------------|-----------|-----------|-----------|
| Correlation coefficient (CC) |           |               |           |           |           |
| B1                | 0.7143    | 0.8231        | 0.7871    | 1.0000    | 0.8798    |
| B2                | 0.9685    | 0.9119        | 0.9350    | 0.8441    | 0.8492    |
| B3                | 0.7048    | 0.7969        | 0.7677    | 0.8284    |           |
| B4                | 0.7360    | 0.8073        | 0.7868    | 0.7630    | 0.7540    |
| Mean difference relative to original image (%) |           |               |           |           |           |
| B1                | 0.0000    | 0.0000        | 0.0000    | 0.0000    | 0.6737    |
| B2                | 0.0000    | 0.0000        | 0.0000    | 0.0486    | 0.6724    |
| B3                | 0.0000    | 0.0000        | 0.0000    | 0.0491    |           |
| B4                | 0.0000    | 0.0000        | 0.0000    | 0.0509    | 0.6741    |
| SDD relative to the original mean (%) |           |               |           |           |           |
| B1                | 0.0521    | 0.0125        | 0.0434    | 0.0000    | 0.6309    |
| B2                | 0.0972    | 0.0415        | 0.0704    | 0.1834    | 0.5916    |
| B3                | 0.0441    | 0.0301        | 0.0508    | 0.2001    |           |
| B4                | 0.0539    | 0.0552        | 0.0669    | 0.2356    | 0.5895    |
| RASE(%)           | 1.5660    | 0.7811        | 1.3171    | 5.8204    | 69.7600   |
| ERGAS             | 0.3583    | 0.1917        | 0.3180    | 1.4065    | 14.8977   |

One of the disadvantages of Brovery method is that it could only be applied to three-band RGB images. The red, near-infrared and blue band were selected when applying the Brovery method, as the larger information entropy compared to the green band and the least correlation of the combination. The red band of CN-merged images were the directly output band without any change.

To assess the different fusion methods, the values of the spectral correlation coefficient (correlation coefficients of each band with the original MS images and the corresponding average values) and the RASE and ERGAS index of the merged images were displayed by bar diagrams. And the wavelet parameters that performed best were joined to the comparison.
Figure 2. Correlation coefficient and the RASE, ERGAS index of the merged images

It could be observed that the one performed the least correlation and the largest RASE or ERGAS value was the Brovery transformation, which usually performed well in merging SPOT Pan with other MS images. The value of the ERGAS was much higher compared to others, indicating that along the merging process the spectral information has been modified significantly, and the smaller correlation coefficient represented the smaller the degree of similarity between the merged image and the referred multi-spectral image. A major reason for the significant spectral distortion in fusion is the wavelength extension of panchromatic images. Different from the Pan image of the SPOT and other sensors, the wavelength range of IKONOS is extended from the visible to the near-infrared band. Traditional image fusion techniques that were useful for fusing SPOT Pan with other MS images might not achieve acceptable quality as band extension.

The second one that caused larger spectral differences was the CN method, though the average correlation was a little higher than that of PCA, GS and the Pansharpening algorithm. The main reason for the higher correlation was that the red band of the merged images and the multi-spectral images were exactly the same.

The remaining four methods achieved better values in correlation, RASE or ERGAS value. The wavelet method (applying parameters that performed best) showed best correlation, but with a relatively high RASE or ERGAS value. This modification of the spectral information during the fusion process is acceptable when the merged images are applied to extract thematic structure information such as farmland regions.

The Pansharpening, PCA and GS algorithms had been confirmed to be high-fidelity in figure 2. The PCA and GS algorithms are both based on orthogonal linear transformation of the component replacement. The GS algorithms was demonstrated to get better results both in the correlation coefficient and ERGAS index compared to PCA. The ERGAS and RASE index performed well in the GS method. Though the near-infrared band’s correlation coefficient of the merged image referred to GS method was lower than that of PCA’s, the other three bands were higher. A similar situation happens in the Pansharpening method which provided good average correlation coefficient and global index in spite of the correlation of near-infrared band. Globally, the Pansharpening, GS algorithms and PCA provided higher spectral quality.
3.3.2. Results of spatial quality of the Merged Images.

The variance of the merged images, correlation coefficients of the high-pass filtered PAN and merged images were shown in table 3. The other parameters of wavelet method were not mentioned as the large spectral distortion.

| Table 2. Variance of the merged images and correlation coefficients of the high-pass filtered PAN and merged images |
|---------------------------------------------------------------|
|                | Original | PCA      | Pansharpening | GS      | CN      | Brovery | Wavelet-L |
| Variance       | B1       | 13782.930 | 12384.697     | 13440.634 | 12611.429 | 13782.930 | 1877.941 | 14883.774 |
|                | B2       | 13653.965 | 16436.847     | 14809.448 | 15643.024 | 19122.556 | 2277.032 | 14413.407 |
|                | B3       | 9984.853  | 9122.973      | 9393.525  | 8996.644  | 14381.557 | -         | 11139.404 |
|                | B4       | 4990.485  | 4466.728      | 4454.931  | 4344.875  | 7618.781  | 841.109   | 6158.852  |
| Correlation coefficient | B1       | 1.000     | 0.957         | 0.828     | 0.881     | 0.665     | 0.852     | 0.810     |
|                | B2       | 1.000     | 0.580         | 0.634     | 0.607     | 0.787     | 0.743     | 0.728     |
|                | B3       | 1.000     | 0.981         | 0.884     | 0.926     | 0.901     | -         | 0.836     |
|                | B4       | 1.000     | 0.909         | 0.840     | 0.868     | 0.902     | 0.888     | 0.795     |

What can be seen from table 2 was that variation of the two indexes was consistent in general. The Brovery method were proved to retain a minimum of spatial information, as the filtered Brovery images had the lowest correlation with panchromatic band, as well as the variance of Brovery merged images.

The highest average variance was the CN algorithm compared with those of other methods, explaining largest dispersed distribution of gray level and information. What should be noted is that, spectral distortion usually happens when the calculated correlation coefficient between filtered-pan and MS images is low and a higher variance exists. This was consistent with the above results and analysis. And the wavelet method was the same situation. Less pan detail information was injected to the fusion images, but with a larger dispersed distribution of gray level. It is more appropriate for visual interpretation to extraction regions in such circumstances instead of calculating index.

Differences of spatial evaluation were subtle between the high-fidelity methods proven above (the Pansharpening, PCA and GS algorithms). Little difference of dispersed distribution of gray level exists. The correlation coefficient of PCA’s near-infrared bands was only 0.58, though a higher average correlation coefficient was obtained between filtered-pan and MS images than GS algorithms and Pansharpening.

4. Conclusions

Six different merging methods were listed in this paper. Quality assessment was carried out to evaluate the spectral and spatial information in qualitative and quantitative aspect. Both local and global evaluation parameters were used in the spectral quality and the Laplace filtering method was used to assess spatial quality. Wavelet method that performed best were joined to the comparison. The Brovery merged images was demonstrated to own the least spectral quality. In contrast, GS and PCA algorithms, especially the Pansharpening provided higher spectral quality than the standard Brovery, wavelet and CN methods. In spatial quality assessment, the CN method represented best compared with that of others, while the Brovery algorithm was the worst. The wavelet parameters that performed best achieved medium spectral and spatial quality. The ultimate goal of remote sensing image fusion is to application. The emphasis of different fusion methods differs in practice and the paper helps if such confusion is faced.

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