A NEW DATA FUSION METHOD FOR IMPROVING CBERS-1 IRMSS IMAGES BASED ON CCD IMAGE

Z.R. Qi

Centre for Aero Geophysics and Remote Sensing, Ministry of Land and Resources, 29, College Road, Beijing, China, qizr@cugb.edu.cn

KEY WORDS: CCD, Fusion, High Resolution, Registration, Pixel, Spectral

ABSTRACT:

A new data fusion method is proposed in this paper to improve CBERS-1 IRMSS images based on CCD image. Each pixel in an IRMSS image with lower spatial resolution is correspondence with a group of sub-pixels in a CCD image with higher spatial resolution after precise co-registration. For each pixel in the IRMSS image, the average value of its co-registered sub-pixel brightness values in the CCD image is computed. The difference between the pixel brightness value in the IRMSS image and its sub-pixels average value was added to every sub-pixel value in the CCD image. This procedure is applied to each pixel to produce a data fusion image. The fusion image had more spatial details than the IRMSS image and had similar spectral information to the IRMSS image. The test indicated that the new data fusion method was a superior fusion technique not only enhancing the spatial details of IRMSS image but also keeping the fidelity to the image spectral properties. Different from the other data fusion methods, which need more than one band low resolution image to be merged with one high resolution image, the new method can perform data fusion for an individual low resolution image and it can be used for enhancement of the thermal infrared band 6 of Landsat with the other higher resolution band image. It is a new, very simple and practical technique. It is potentially useful for enhancing the spatial details and preserving the spectral fidelity of the low spatial resolution images.

1. INTRODUCTION

China-Brazilian earth resources satellite 1(CBERS-1) is equipped with three types of sensors，such as CCD camera，Infrared Multi-spectral Scanner(IRMSS) and Wide Field Imager(WFI), and provides three types of remote sensing image data (see table 1). Because of lower spatial resolution, CBERS-1 IRMSS images have not been widely used in application. Data fusion technique can be used for improving the spatial resolution and enhancing the spatial details for IRMSS images with CCD image, which is potential useful and significant for developing IRMSS image application market.

There are many methods for data fusion at the present, and they can be divided into two methods: spectral component substitution techniques and spatial domain techniques. The former replaces a spectral component of the multi-spectral images by the radio-metrically-adjusted pan-image such as hue-intensity-saturation (HIS) colour spatial transformation and principal component analysis (PCA) (P. S. Chavez et al, 1991; C. Conese et al, 1992). The latter adds high resolution information from the high resolution image to all the low resolution spectral bands by using various deterministic or statistical predictors, such as high pass filter (HPF) (C.Conese et al, 1992; R. A. Schowengerdt, 1998; V.T. Tom et al, 1985), wavelet transform (WT) (H. Li et al, 1995; B. Garguet-Duport et al, 1996). Some researches combine two techniques, such as combination of multi-resolution wavelet decomposition and HIS transform for the fusion of high resolution pan-image and multi-spectral images (Jorge Nunez et al, 1999). Price uses panchromatic gray value to estimate single multi-spectral image values as a result of the highly-correlated statistical analysis of SPOT panchromatic channel (0.51-0.73μm) and TM 1(0.45-0.52μm)，TM 2(0.52-0.60μm), so this algorithm is confined to the images of highly-correlated statistical analysis (John C. Price, 1987 and 1999). Zhukov etc. utilize the class information of high resolution images and PSF (point spreading function) to un-mix the low resolution images, but this algorithm needs multiple high-resolution images so as to classify them (Boris Zhukov et al, 1999). Ryuei Nishii etc. employ a multivariate normal distribution for the seven TM band values to predict the value of band 6 by the conditional expectations (Ryuei Nishii et al, 1996). Jiao etc. present a data fusion algorithm based on scale-transformation at spatial domain (Jiao et al, 2002).

Table 1. Some technique parameters of CBERS-1 sensors

Sensor	Bands/ μm	Resolution /m	Image width in equator/km
CCD camera	B1: 0.45-0.52	20	113
	B2: 0.52-0.59	20	113
	B3: 0.63-0.69	20	113
	B4: 0.77-0.89	20	113
	B5: 0.51-0.73	20	113
IRMSS	B6: 0.50-0.90	78	120
	B7: 1.55-1.75	78	120
	B8: 2.09-2.35	78	120
	B9: 10.4-12.5	156	120
WFI	B10: 0.63-0.69	258	890
	B11: 0.77-0.89	258	890

All these methods described as above can improve the spatial resolution for lower resolution images, but they cannot completely restore the lower resolution images, i.e., they will not preserve the spectral fidelity of lower resolution images to some extent after data fusion processing. For image processing, image spectral analysis and interpretation, preserving spectral fidelity is more important than enhancing the spatial details and improving the spatial resolution for the lower resolution image. In order to integrate and process CCD and IRMSS images, and to mine the multi-spectral properties in CBERS remote sensing data, it is necessary to develop a data fusion method not only for enhancing the spatial details but also keeping the spectral fidelity of the IRMSS image.

2. METHOD PRINCIPLE

Generally, each pixel in a lower resolution image is in correspondence with some given numbers of pixels (called as sub-pixels) in a higher resolution image after precise registration. Data fusion is to decompose each pixel in a lower resolution image into a group of sub-pixels and to predict their values, which can not be observed in the lower resolution image. The ideal situation is that the predicting values for these sub-pixels are the same as their real observation data. In this case, not only the spatial details are enhanced, but also the spectral fidelity is preserved. However, this is only ideal, and it is impossible in application.

Based on remote sensing theory, the average value of these sub-pixels real observation data is equal to their correspondent pixel brightness value in a lower resolution image. Therefore, each pixel brightness value in the lower resolution image should be equal to the average value of its co-registered sub-pixel values in the new fusion image, i.e., the spectral energy is unchanged after data fusion processing. In this case, the fidelity to the image spectral properties will not be destroyed to some extent. In fact, the spectral energy is unchanged at least within a single original pixel of the lower resolution image. According to this kind of signature, a new method, termed as Preserving Spectral Fidelity method (named as PSF for simplicity), can be used for data fusion to enhance the spatial details of a lower spatial resolution image without destroying its spectral fidelity.

3. ALGORITHM

Based on the analysis as above, each pixel in a lower resolution image is in correspondence with some given numbers of pixels in a higher resolution image after precise registration. Firstly, for each pixel in a low resolution image, the average value of its correspondent sub-pixels values in a high resolution image is computed; secondly, calculate the difference between the pixel brightness value in the low resolution image and its average value, generally, Each pixel in the low resolution image will have a correspondent average value in the high resolution image and have a given difference; then, add the difference to every sub-pixel value in the high resolution image. This procedure is applied to every pixel to produce a new image, which will have similar spatial details to the high resolution image, since it is derived from the high resolution image; at the same time, it still keeps its original spectral fidelity of the low resolution image, because the spectral energy is unchanged within one pixel of the low resolution image.

The operation procedures are as the following:

(1). To compute the average value of a group of sub-pixel values in a higher resolution image. Considering the spatial resolution of CCD images(19.5m) and IRMSS images (78m), one pixel in an IRMSS image is in correspondence with 4×4 sub-pixels in a CCD image. Set CCD and IRMSS digital image functions as DN_h and DN_l respectively. For any pixel at (x, y) in an IRMSS image, its correspondent average value $\overline{DN_h(x, y)}$ in a CCD image is computed as the following:

$$\overline{DN_h(x, y)} = \frac{1}{4\times 4}\sum_{i=0,j=0}^{i=3,j=3} DN_h(4x+i, 4y+j) \tag{1}$$

Here: x,y=0,1,2,3,…

Each pixel in the IRMSS image will have a group of co-registered sub-pixels and have a correspondent average value in the CCD image.

(2). To calculate the difference between the pixel brightness value in the IRMSS image and its correspondent average value in the CCD image.

Every pixel in the IRMSS image will have a given difference, so that the difference is a variable of pixel position (x, y), $f(x, y)$:

$$f(x, y) = DN_l(x, y) - \overline{DN_h(x, y)} \tag{2}$$

(3). To add the difference to every sub-pixel value in the CCD image and to produce a new pixel brightness value $DN_n(4x+i, 4y+j)$:

$$DN_n(4x+i, 4y+j) = DN_h(4x+i, 4y+j) + f(x, y) \tag{3}$$

Equation (3) is a mathematic model of preserving spectral fidelity method for data fusion. Each pixel in an IRMSS image will have a group of co-registered sub-pixels in a CCD image, this procedure is applied to each pixel in the IRMSS image and further to every sub-pixels in the CCD image to produce a new image.

Since the new image is derived from the CCD image, obviously it has the similar spatial information to the CCD image. At the same time, the new image keeps the spectral energy unchanged within one pixel of the IRMSS image, so that the new image has the similar spectral information to the IRMSS image and the spectral fidelity is preserved. It is easy to prove the spectral energy unchanged within one pixel of an IRMSS image after data fusion processing.

From Equation (3), compute the average value for a group of 4 ×4 sub-pixels, which are co-registered with one pixel in an IRMSS image.

$$\overline{DN_n(x, y)} = \frac{1}{4\times 4}\sum_{i=0,j=0}^{i=3,j=3} DN_n(4x+i, 4y+j) \tag{4}$$

i.e.,

$$\overline{DN_n(x, y)} = \frac{1}{4\times 4}\sum_{i=0,j=0}^{i=3,j=3} (DN_h(4x+i, 4y+j) + f(x, y)) \tag{5}$$

Combine equations (1) and (2):

$$\overline{DN_n(x,y)} = \overline{DN_h(x,y)} + (DN_l(x,y) - \overline{DN_h(x,y)})$$

Therefore,

$$\overline{DN_n(x,y)} = DN_l(x,y) \qquad (6)$$

From the equation (6), the average value for a group of 4×4 sub-pixels in the new image is equal to their correspondent pixel value in the IRMSS image. Obviously, the new image has the same spectral energy as the IRMSS image within one original pixel of the IRMSS image. So that, the data fusion image produced by this method can keep the spectral energy balance and can preserve the fidelity to the lower resolution image spectral properties. The new method can also be called as Spectral Energy Balance method.

4. APPLICATION

Based on the introduction as above, data fusion methods at the present can be divided into two methods: spectral component substitution techniques and spatial domain techniques. The former replaces a spectral component of the multi-spectral images by an adjusted high resolution image. The latter adds high resolution information from the high resolution image to all the low resolution spectral bands. Obviously, the spatial domain techniques will not keep the spectral energy balance and the spectral fidelity to the lower resolution image will be destroyed because of adding a variable value to every pixel of the low resolution image. According to hue theory, any colour is quantitatively defined in terms of three variables: hue, intensity and saturation, which give a numerical description of the spectral range, brightness and purity of a colour. These three variables are independent of each other (Qi, 1996). HIS method for data fusion is to replace an intensity of the three Band colour composite image with a high resolution image. Based on the hue theory, intensity is independent of hue and saturation to some extent, and the hue and saturation will not be affected by such substitution in HIS data fusion. PCA method is to replace the first principal spectral component in principal component analysis of the multi-spectral images with a high resolution image. Because the first principal component takes the most information in principal component analysis, and it is dependent of the solar incident radiance and the spectral properties of the surface materials, any other band image cannot represent the first principal component either in information content or spectral properties. Therefore, the HIS method is better than the PCA method in preserving the spectral fidelity. Preserving spectral fidelity method also belongs to the spectral component substitution techniques and it replaces a low resolution band with an adjusted high resolution image, i.e., every pixel brightness value in the high resolution image is adjusted by its co-registered pixel in the low resolution image. Therefore, the fusion results produced by HIS and PSF methods will be compared, mainly in preserving the spectral fidelity.

CBERS images in Guizhou Province, China, taken on July 18, 2000 are used for test. Image data is a 2 grade image data, supplied by China Centre for Resources Satellite Data and Application. CCD B4 image was selected as a higher resolution image and IIMSS B6 □ B7 □ B8 were selected as lower resolution images. Original image size is 400×200 pixels for CCD image and 100×50 pixels for IRMSS images.

Three gray scale images based on CBERS CCD B4, IRMSS B7 and their data fusion image are shown if Fig.1: image marked A is CCD B4; image B is IRMSS B7; image C is data fusion image of B4 and B7 by PSF method. Image B and C show clearly that the fusion images have more spatial details than IRMSS B7, and have a similar spectral information to B7; From image A and C, the fusion image contains the similar spatial details in B4 image, but image brightness distribution in image B is definitely different from image C.

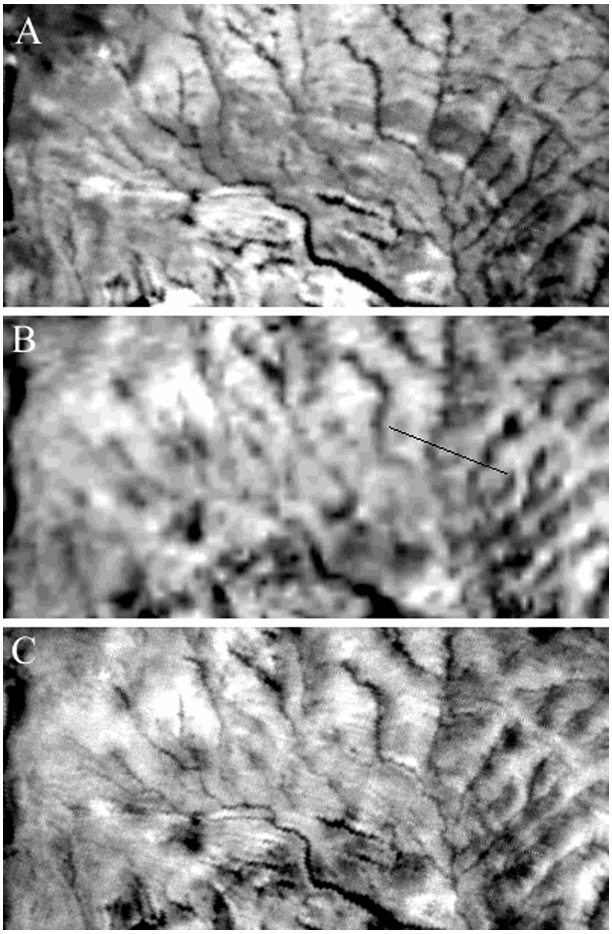

Figure 1. Gray scale images based on CBERS CCD B4, IRMSS B7 and their data fusion image: image A is B4; image B is B7; image C is data fusion image of B4 and B7 by PSF method

Three Band colour composite image can more clearly show the difference between the original image and the data fusion image. Image marked A in Fig. 2 is a three band colour composite image of B7, B8, B6; image B is a data fusion image derived from B7□B8□B6 and B4 by HIS method; image C is a data fusion image by PSF method. Compared with image A, both image B and C had more spatial details, such as some small water system, which indicates that the data fusion method can be used to enhance image spatial details and improve image spatial resolution for lower resolution image; image C had the similar colour to image A, while image B is quite different from image A in colour. Which confirms that PSF method can be used for preserving the spectral fidelity of the lower resolution image in data fusion processing, but HIS method cannot.

Obviously, PSF method is better than HIS method in keeping spectral fidelity.

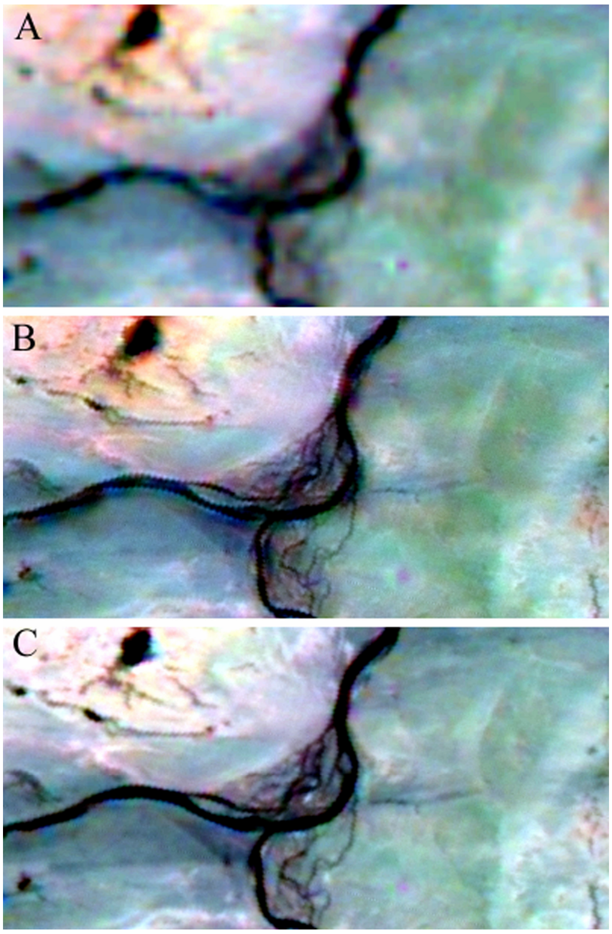

Figure 2. Three Band colour composite image of IRMSS images and their data fusion image based on CCD image: image A is a colour image of B6□B7□B8; image B is a data fusion image by HIS method; image C is a data fusion image by PSF method.

Image spectral profile can also show the effect of data fusion. An image spectral profile located at a black line on image B in Fig. 1, is shown in Fig. 3. Here black curves are the original image spectral profiles: upper curve is B4 image spectral profile, the other black curve is B7 image spectral profile; gray curve is a spectral profile of data fusion image derived from B7 and B4 by PSF method. In Fig. 3 it shows clearly that the spectral curve of B4 image is far away from the spectral curves of B7 image and the data fusion image, while the curve of data fusion image is very close to the curve of B7 image, the difference is only that the spectral curve of data fusion image has more high-frequent change than the curve of B7 image, and the high-frequent change is quite similar to that in the curve of B4 image, which indicates that data fusion image has more spatial details and its spectral properties are close to its original image's.

The image mean and deviation can also show the effect of data fusion. The image mean and deviation of original B6□B7□B8 image, data fusion images derived from B6□B7□B8 and B4 by PSF method and HIS method respectively are listed in Table 2. From table 2, the image deviation of data fusion image is larger than the deviation of original image at correspondence band, while the deviation of data fusion image produced by PSF is similar to the deviation of image by HIS method, which indicates that both methods can be used for improving lower resolution image; the image mean of data fusion image by PSF method is nearly the same as the mean of original IRMSS image, but the image mean of the data fusion image by HIS method is different from the mean of original IRMSS image, which confirms that total spectral energy in data fusion image produced by PSF method is the same as that in the original IRMSS image and the spectral fidelity of the IRMSS image is preserved after data fusion, but the same phenomenon does not exist in HIS method.

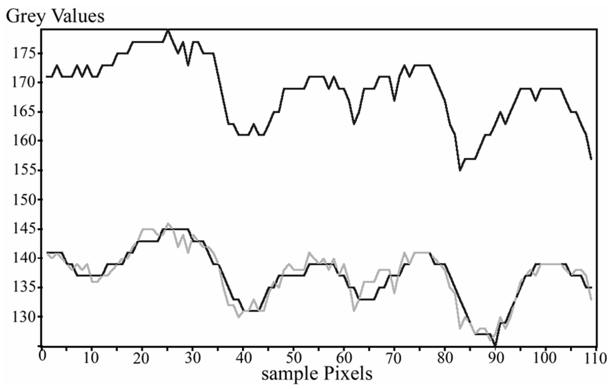

Figure 3. Image spectral profile of samples

Table 2. The statistics of B6□B7□B8 images and their data fusion images

	Mean			Deviation		
	B6	B7	B8	B6	B7	B8
IRMSS	123	111	75	12.8	9.7	7.6
PSF [1]	123	111	75	25.9	20.0	15.7
HIS [2]	177	166	130	35.5	29.8	24.7

Note: PSF [1]: PSF data fusion image;
HIS [2]: HIS data fusion image.

Images, image spectral profiles and statistics indicated that PSF method can be used for improving the lower resolution image and enhancing the spatial details, and at the same time, the data fusion image produced by PSF still preserves the fidelity to the lower resolution image spectral properties. Preserving spectral fidelity is very useful and important for integrating and analysing IRMSS images.

Since the spatial information in data fusion image is derived from the higher resolution image, the image with more spatial information content and more spatial details selected as the higher resolution image in data fusion processing, will make the data fusion image have more spatial details. CCD B5 image has more spatial information content and more spatial details because of its panchromatic spectral properties, therefore, using CCD B5 as a higher resolution image will lead to produce a good quality data fusion image. At absent of CCD B5, CCD B4 image is a good image as the higher resolution image to take part in data fusion processing. The intensity component of three CCD band colour composite image will have more spatial details, it will be better to use the intensity component as the higher resolution image. Here it is not discussed in detail for simplicity.

5. CONCLUSIONS AND DISCUSIONS

(1). The PSF method for data fusion is a new, very simple and practical technique for data fusion. The image produced by the method can improve the spatial details and preserve the fidelity to the lower resolution image spectral properties. The latter is more important for image classification and spectral interpretation.

(2). Different from the other data fusion methods, such as PCA and HIS, the proposed method can perform data fusion for an individual lower resolution band image. So they can be used for enhancement of the thermal infrared band 6 based on one of remaining TM bands.

The PSF method for data fusion is more sensitive to image co-registration accuracy than HIS, PCA and WT techniques. Inaccurate co-registration may lead to spectral distort of an individual multi-spectral band, because the spectral fidelity is preserved under such assumption that each pixel in the low resolution image is completely precisely co-registered with a group of sub-pixels in the high resolution image.

(3). PSF method can be used for improving IRMSS image and enhancing the spatial details without destroying the fidelity to the IRMSS image spectral properties. Preserving Spectral Fidelity is very useful for integrating, analysing CCD and IRMSS images, and is very significant for developing application market of IRMSS data.

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Acknowledgments

This study is a part of a research in Centre for Aero Geophysics and Remote Sensing, Beijing, China, supported by the Ministry of Land and Resources in China. This work has benefited from the comments and assistance from Prof. Feng Z. L. and Prof. Zen Z. M. during the research.