

Current progress on multi-sensor image fusion in remote sensing

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ABSTRACT

This paper describes and explains why image fusion, what is image fusion, and the current research status mainly on wavelet based pixel-based image fusion. Pixel-based image fusion defines the fusion process of original images or the images after pre-processing. Preliminary results of many researches show that the advantages of high-resolution panchromatic image and low-resolution multi-spectral image can be combined by image fusion and the information extraction capability can be improved. The fusion methods evolves from traditional fusion methods, pyramid based fusion methods to nowadays wavelet based fusion methods. The popular wavelet theory based Mallat algorithm and “ \acute{a} Trous” algorithm are explained. In order to overcome some shortcomings of Mallat algorithm and “ \acute{a} Trous” algorithm, MRAIM algorithm is designed, which is based on the image formation principle and multi-resolution analysis theory. It formulates the Mallat algorithm and “ \acute{a} Trous” algorithm from the theoretical point of view. It can improve the spatial resolution while preserve the hue and saturation unchanged.

Keywords: Wavelet theory, Image Fusion, Mallat algorithm, \acute{a} Trous algorithm, MRAIM algorithm

1. BACKGROUND

Information fusion in the context of its use by the society and the journal, encompasses the theory, techniques and tools conceived and employed for exploiting the synergy in the information acquired from multiple sources (sensors, database, information gathered by human etc.) such that resulting decision or action is in some sense better than (qualitatively or quantitatively, in terms of accuracy, robustness etc.) than would be possible if any of those sources were used individually without such synergy exploitation [http:// Belur V. Dasarathy]. Image fusion is one kind of information fusion, it produces a single image from a set of input images, the fused image should have more complete information which is more useful for human or machine perception [http:// LEHIGH University]. Many works have recognized the benefit of merging high spectral resolution (or spectral diversity) and high spatial resolution images, particularly in land mapping applications [Luclen Wald, 1997]. The integration of spectrally and spatially complementary remote multi-sensor data can facilitate visual and automatic image interpretation [X. Li etc. 1998].

From another point of view, if it is possible to fuse high-resolution panchromatic image with low-resolution multi-spectral image to get high-resolution multi-spectral image which preserves the original multi-spectral characteristics, it can direct to remote sensing platform designing. Sensor must collect enough energy in the respective spectrum band before image formation; it is more difficult to improve the multi-spectral image resolution than panchromatic image. In order to get high-resolution multi-spectral images, it is a good idea to equip with a high-resolution panchromatic sensor and low-resolution multi-spectral sensors, and latter to get high-resolution multi-spectral images by image fusion. The new generation remote sensing platforms have applied this research outcomes. For example, Landsat 7 has 15m panchromatic image and 30m multi-spectral images, SPOT has 10m panchromatic image and 20m XS band images, and IKONOS has 1m panchromatic image and 4m multi-spectral images.

Image fusion can be performed at three different processing levels according to the stage at which the fusion takes place: pixel, feature, and decision level [C. Phol, 1998]. Pixel level image fusion defines the fusion processing of original image or the image after the pre-processing. Several methods exist to modulate lower resolution multi-spectral images using a higher resolution panchromatic image, particular for color composites such as IHS(Intensity-Hue-Saturation), PCA(Principal Component Analysis), PBIM, the Brovey transform, HPF etc. [F. Sunar, 1998; E. M. Schetselaar, 1998; J. Zhou, 1998; Deren Li, 1996; Jiabin, Sun, 1998]. However, those methods normally improve the spatial resolution while distort the color composite, It is still necessary to investigate how to improve the spatial resolution of fused images while preserve the color appearance of the images for interpretation purpose. Some papers introduce the wavelet transform methods, which can achieve best spectral and spatial quality [J. Zhou, 1998; Deren Li, 1996; Jiabin, Sun,

2. WAVELET BASED IMAGE FUSION METHODS

More recently, with the development of the wavelet theory, people began to apply wavelet multi-scale decomposition to take the place of pyramid decomposition for image fusion. Actually, wavelet transform can be taken as one special type of pyramid decompositions. It retains most of the advantages for image fusion but has much more complete theoretical support. The wavelet representation is an intermediate representation between the Fourier and the spatial representation, and it can provide good localization in both frequency and space domain. Assuming the two images have already been co-registered, the most often-used wavelet based image fusion methods are Mallat algorithm and á trous algorithm.

2.1 Mallat algorithms

Wavelet transform is first performed on each source images, then a fusion decision map is generated based on a set of fusion rules. The fused wavelet coefficient map can be constructed from the wavelet coefficients of the source images according to the fusion decision map. Finally the fused image is obtained by performing the inverse wavelet transform. When constructing each wavelet coefficient for the fused image. We will have to determine which source image describes this coefficient better. This information will be kept in the fusion decision map. The fusion decision map has the same size as the original image. Each value is the index of the source image which may be more informative on the corresponding wavelet coefficient. Thus we will actually make decision on each coefficient[<http://LEHIGH University>]. Figure 1 describes an often used fusion scheme, it takes the approximation XSi_{20} of multi-spectral image XSi -HR, the wavelet components H_{10-20} , V_{10-20} , D_{10-20} of panchromatic image as the approximation and wavelet component of the fused image. Then inverse wavelet transform is used to get the fused image XSi -P. In order to restore the original data, Mallat used the properties of orthogonal wavelets, but the transform is not shift-invariant, which can be a problem in data fusion[Jorge Núñez, 1999]. The typical Mallat algorithm based image fusion method is ARSIS [L Wald, 1998], in which orthogonal wavelet filter is used.

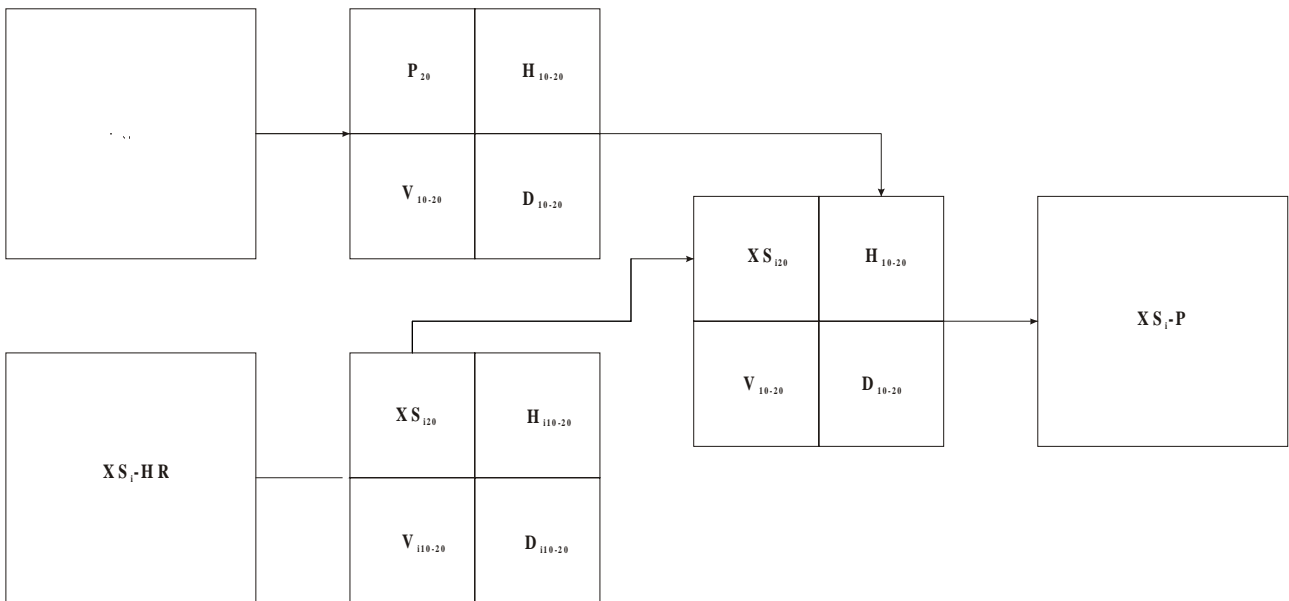


Figure 1: Fusion processing of Mallat algorithm

2.2 á trous algorithms

To obtain a shift-invariant discrete wavelet decomposition for images, “á Trous” algorithm was introduced to decompose the image into wavelet planes[Jorge Núñez, 1999]. Given an image p , we can construct the sequence of approximations: $F_1(p) = p1$, $F_2(p) = p2$, The wavelet planes are computed as the differences between two consecutive approximations:

$$w_l = p_{l-1} - p_l (l = 1, \dots, n), p_0 = p \quad (1)$$

we can write the reconstruction formula as:

$$p = p_r + \sum_{l=1}^r w_l \quad (2)$$

r refers to the decomposition level. Jorge Nunez, etc. (1999) have investigated several image fusion methods based on this algorithm which is called substitution method and additive method. In the substitution method, the wavelet planes corresponding to the multi-spectral image are discarded and substituted by the corresponding planes of the panchromatic image. However, in the additive methods all the spatial information in the multi-spectral image is preserved. Thus the main advantage of the additive method is that the detail information from both sensors is used. But it uses a fixed wavelet filter and does not work well when the resolution ratio between two images is not equal (1/2)^r. For example, when SPOT-P is fused with TM images.

3. MULTI-ANALYSIS RESOLUTION BASED INTENSITY MODULATION(MRAIM)

MRAIM image fusion algorithm has developed to overcome the shortcoming of Mallat algorithm and á Trou s algorithm. It takes image formation theory, wavelet multi-resolution analysis theory and á Trou s algorithm into consideration[Wang Zhijun, 2000]. It has some difference from á Trou s algorithm. Firstly, it uses M-band wavelet theory to design K-regality wavelet filter, the original image can be decomposed into its approximation and wavelet component at any integer ration resolution. Secondly, the fused image is modulated by the ration between the wavelet plane and approximation. It can be reflected by comparison the following equation (3), (4), (5) with á Trou s algorithm equation (2). MRAIM algorithm uses similar method to decompose original image into its approximation and wavelet component at the same scale but 1/M resolution. And then it is not to plus wavelet component with Multi-spectral image band, but use formulation (3), (4), (5) to fuse the image. It is evident that the ration $R_{new}:G_{new}:B_{new}=R_{old}:G_{old}:B_{old}$, its' hue is not changed. The key problem towards to use MRAIM is to design a 1/M band low-pass wavelet filter with K-regularity. It has more theoretical support than other two methods.

$$R_{new} = R_{old} + \frac{w}{a} R_{old} \quad (3)$$

$$G_{new} = G_{old} + \frac{w}{a} G_{old} \quad (4)$$

$$B_{new} = B_{old} + \frac{w}{a} B_{old} \quad (5)$$

4. RESULT AND CONCLUSION

In order to compare MRAIM algorithm with Mallat algorithm and á Trou s algorithm, this paper takes Landsat 7 satellite image as an example. Landsat-7 has been successfully launched at April 15, 1999. It includes panchromatic image (band 8) with 15m resolution and 6 multi-spectral images (band 1,2,3,4,5,7) with 30m resolutions. 15m multi-spectral images can be obtained by using above three wavelet based fusion methods. We use band 7,4,3 as a color composite and call RGB743-30, band 8 is used as panchromatic image and called PAN-15. In order to get 15m resolution multi-spectral data-set RGB743-15, we use the three wavelet based image fusion method Mallat, á Trou s algorithm and MRAIM algorithm to merge RGB743R30 with PAN-10 image data. The test data-set is from the Beijing scene of Landsat-7 data-set of Nov. 7, 1998, the sub-scene size is 512*512 for Band 8, and 256*256 for RGB743R30. Both original image is showed as figure 2 and figure 3. Figure 4,5,6 illustrate the fused results by Mallat algorithm, á Trou s algorithm and MRAIM algorithm. Table 1 describes the statistics comparison result of the original multi-spectral images and the fused results. By interpretation, the objects are sharpened and it is more easy to recognize, the resolution of fused images is improved, and the color appearance is not changed. From table1, mean and median of R,G, B channel of the original image are not changed very much, standard deviation of the image are slightly amplified. The similar degree of the fused image with original image is described by its correlation coefficient; the results of three methods are all kept at a very high degree. The spatial detail information can be described by wavelet energy [Wang Zhijun, 2000], more detail

information relates to an high wavelet energy. Wavelet energy of three results is all improved. Figure 4 and figure 6 give higher wavelet energy,

By analyzing the fused result from interpretation and statistics reports, MRAIM method makes better result than the other two methods. Mallat algorithm uses orthogonal wavelet filter which is not shift-invariant, and it uses pyramid algorithm which includes sampling and interpolation which makes phase changed, so the fused includes the phase distortion, the edge of the objects has ring by interpretation. And $\acute{\alpha}$ Trous algorithm adds same component to each fused image channel, this reduces the saturation of the fused image and also has no theoretical support to do so. MRAIM algorithm uses linear time-invariant wavelet filter and keeps the ration between R, G, and B unchanged from theoretical point of view, so it makes better results.

Table 1:The statistics comparison of the fusion processing of TM8 with multi-spectral image TM743.

		Original TM743	Zoomed TM743	Original TM8	Fused result		
					Mallat	$\acute{\alpha}$ Trous	MRAGM
Mean	R	147.34	147.35	142.02	147.60	147.44	147.43
	G	155.05	155.03		155.29	155.12	155.11
	B	118.53	118.52		118.82	118.64	118.62
Std	R	53.51	53.46	34.46	54.65	54.30	54.41
	G	38.82	38.79		40.14	39.63	40.05
	B	52.28	52.29		53.33	52.97	52.99
Median	R	152	152	143	153	153	152
	G	157	157		158	158	157
	B	119	119		119	119	119
Coefficient			R		0. 98	0. 99	0. 99
			G		0. 98	0. 99	0. 97
			B		0. 98	0. 99	0. 99
Wavelet energy	R	0. 7116	0. 0574	0. 2672	0. 3195	0. 2865	0. 3037
	G	0. 3448	0. 0422		0. 2848	0. 2503	0. 3126
	B	0. 5758	0. 0407		0. 2833	0. 2543	0. 2347



Figure 2: original TM8 (512*512)



Figure 3: linear stretched Landsat TM743 at pixel size 15m



Figure 4: Fused image after Mallat algorithm



Figure 5: Fused image after à Trous algorithm



Figure 6: Fused image after MRAIM algorithm

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