

# BLOCK-REGRESSION-BASED FUSION OF OPTICAL AND SAR IMAGERY FOR FEATURES ENHANCEMENT

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## ABSTRACT:

This paper focuses on fusion of optical and Synthetic Aperture Radar (SAR) images to combine these two types of remotely sensed imagery for features enhancement. We have proposed a new fusion technique, namely Block-based Synthetic Variable Ratio (Block-SVR), which is based on block multiple linear regression to fuse optical and SAR imagery. In order to investigate the effectiveness, the fusion results of higher resolution airborne SAR image and lower resolution multispectral image have been given. According to the fusion results, the fused images have enhanced certain features, namely spatial and textural contents as well as features not visible in multispectral while preserving the color characteristics. Also the spectral, spatial and textural effects of the presented algorithm were evaluated mainly by visual and quantitative methods comparing to those of IHS, PCA and Wavelet-based methods. During the implementation of the block-regression-based techniques there are at least two advantages. One is that the block-regression-based technique drastically decreases amount of computation, however regression of the whole scene image is almost impossible. The other advantage, also the most important, is that adjustment of regressed-block size can result in different emphases between preservation of spectral characteristic and enhancement of spatial and textural contents. The larger is the block of regression, the more are the spatial and textural details enhanced. In contrast, the smaller is the block of regression, the more are spectral features preserved.

## 1. INTRODUCTION

Data fusion is capable of integrating different imagery data to produce more information than can be derived from a single sensor (Pohl and Genderen, 1998). Optical and SAR imagery are two important types of remotely sensed data. The optical imagery presents characteristics depending on the multispectral reflectance of the target illuminated by sunlight, whereas the SAR imagery presents different characteristics from optical imagery due to the imaging mechanism of actively transmitting microwave pulses and receiving the backscattered echoes. Thus, in order to enhance some features like spatial and textural features as well as features that are not visible in optical images, data fusion of optical and SAR imagery is effective measure. Another case where people need fusion of optical and SAR imagery is that in difficult areas high-resolution optical imagery is difficult to acquire, whereas the SAR imagery is easy to obtain because of independence of daylight and cloud cover.

However, fusion of optical and SAR imagery is more difficult than the ordinary pan-sharpening because the grey values of SAR imagery do not correlate with those of multispectral imagery. In table 1, correlation coefficients between multispectral bands and SAR band are almost zero. In contrast, the correlation between panchromatic and multispectral bands of the same sensor is high, for instance, SPOT panchromatic and XS1, XS2 bands (Shettigara, 1992, Pellemans, 1993). So the classical methods assuming the high-resolution band has a high correlation with the low-resolution bands such as IHS, PCA methods (Chavez, 1991, Carper, 1990, Shettigara, 1992) are not suitable to fuse optical and SAR imagery. Recently Landsat ETM+ and SAR image fusion based on generalized intensity modulation (Alparone, et al, 2004) was illustrated where the pan-sharpened multispectral image (15m resolution) was modulated by textures of ERS image (12.5m pixel size). The distinction of resolution is so small that the enhancement of spatial features is negligible.

Table 1. Correlation between multispectral bands and SAR band

	Band 1	Band 2	Band 3	Average
SAR	-0.0732	-0.0801	-0.0728	-0.0753

We propose the block-regression-based technique for fusion of the optical and SAR imagery, i.e. Block-SVR. The Block-SVR derives a synthetic block, as a linear function of blocks of multispectral images, which has maximum correlation with the relevant block of SAR image for every block of images. The maximum correlation with the block of SAR image results in strong ability of spectral preservation while spatial and texture features of SAR image are imported into the fused image. The Block-SVR has two advantages that will be discussed in section 4.3.

## 2. SVR FUSION METHOD

Before presenting the Block-SVR, we concisely review the SVR technique. The SVR method is a type of arithmetic combinations fusion methods. The results of the SVR method of Munechika et al. (1993) show improvements over those from the methods of Pradines (1986) and Price (1987).

However, determination of the parameters  $\varphi_i$  is very complicated and only specified classes are used in the calculation. Y. Zhang (1999) had developed a new SVR

method that can directly calculate parameters  $\varphi_i$ . In order to merge SPOT panchromatic image (10m resolution) with Landsat TM image (30m resolution), the paper gave a set of equations:

$$XSP_i = Pan_H \frac{XS_{Hi}}{Pan_{HSyn}}$$

(1)

$$Pan_{HSyn} = \sum \varphi_i XH_{Hi}$$

(2)

$$Pan_H = \sum \varphi_i XH_{Hi}$$

(3)

Where  $XSP_i$  is the grey value of the  $i$ th band of the merged high-resolution TM-SPOT image,  $Pan_H$  is the grey value of the original SPOT PAN image, and  $XS_{Hi}$  is the grey value of the  $i$ th band of the TM image modified to have the same pixel size as the original SPOT panchromatic  $Pan_H$  image.  $Pan_{HSyn}$  is the grey value of the high-resolution synthetic panchromatic image simulated through equation 2 where these parameters  $\varphi_i$  are calculated directly through multiple regression analysis of the original panchromatic image  $Pan_H$  and the original multispectral bands  $XS_{Hi}$  formulated in equation 3. According to the results of small test area (600 x 380, 10m), the spectral effect of the new SVR is good in comparison to those of IHS and PCA methods (Carper et al. 1990, Chavez et al. 1991, and Shettigara 1992).

### 3. BLOCK-SVR FUSION METHOD

The main idea of Block-SVR is multiple linear regression of block region between SAR and optical images instead of multiple regression of whole image in the SVR method. The block-based tactics at least have two merits. Firstly, the multiple linear regression of block drastically decreases the requirements of computation. Secondly, the adjustment of block size of regression can result in different emphases between preservation of spectral characteristics and enhancement of spatial and textural contents. In other words, the larger is the block of regression, the more are the spatial and textural contents enhanced. In contrast, the smaller is the block of regression, the more are the spectral features preserved. The algorithm procedure of the Block-SVR is shown in fig. 1 and the explanations of steps are as follows:

- 1) The bands of multispectral image are re-sampled to have the same size of airborne SAR image. Before the resample processing, the multispectral image and airborne SAR image must be co-registered.
- 2) A block and its neighbor are fetched from SAR image and re-sampled multispectral bands in sequence.
- 3) Linear multiple parameters are calculated according equation 3 directly through multiple linear regression between the 3 x 3 blocks fetched from SAR image and these 3 x 3 blocks fetched from multispectral bands.
- 4) The central block of 3 x 3 blocks is selected for the SAR image as well as these multispectral bands.
- 5) According to the coefficients of multiple linear regression, the synthetic block is produced by equation 2.
- 6) The SAR block, three multispectral blocks and synthetic block are used to do ratio-calculation by equation 1. After these steps the fused blocks are produced.
- 7) The result blocks after step 6 are added to the fused bands.
- 8) Repeating steps (2) ~ (7) until the last block.

After above steps, three fused bands are generated. From these steps we can regard SVR algorithm as a special case of Block-SVR in which the block size of regression is the size of

whole image to be merged. In Section 4 the spectral and spatial effects will be assessed through experiment results and comparison to those of IHS, PCA and wavelet-based methods. Also, the traits and flexibility of the method will be analyzed in section 4.

## 4. TEST RESULTS AND DISCUSSIONS

The above technique was tested on an AeS-1 airborne SAR image of area around the new fair in Munich, German and its relevant airborne multispectral image. The wavelength of the airborne SAR image is X-Band and the resolution of the image is 1.5m. The multispectral image was degraded to about 3.0m resolution. Thus, the visual and quantitative assessments will be used to validate the effectiveness of features enhancement compared to those of IHS (Chavez, 1991 and Carper, 1990), PCA (Chavez, 1991, Shettigara, 1992) and Wavelet-based method (Yocky, 1996). Because of the purpose of features enhancement, our attentions will concentrate on the spatial, textural characteristics and features not visible in multispectral images.

### 4.1 Visual Comparison

The apparent resolution of Plate 1e and Plate 1f (Block-SVR fused results) is improved which is close to those of Plate 1c and Plate 1d (the airborne SAR image). Note that the textural characteristics available in the SAR image are imported into the fused image and the color characteristics of the multispectral image are preserved basically. An especial attention should be paid is that the features, which are not visible in the original multispectral image, are enhanced by SAR image. In a word, through the fusion of SAR image and multispectral image, some features like spatial and textural features can be enhanced in multispectral image, and some features that are not available in multispectral image can be imported to the fused images.

In Plate 1 the enhancement results of the multispectral true color image are shown. The slices of the fused image of Block-SVR in Plate 1e and Plate 1f are much closer to the original multispectral in Plate 1a and Plate 1b than those of PCA in Plate 1g and Plate 1h and IHS in Plate 1i and Plate 1j in color characteristics. The color characteristics of wavelet-based method in Plate 1k and Plate 1l are a little better than those of Block-SVR. However, the spatial and textural information imported from SAR image in Plate 1k and Plate 1l is far lesser than those of Block-SVR, especially the features in plate 1k which not available in original multispectral image in plate 1a is obscure whereas that of Block-SVR in Plate 1e is relatively clear. The spatial and textural features of Block-SVR and PCA which are imported from SAR image are almost the same, and are much better than those obtained from IHS and Wavelet-based methods. Considering these above fusion methods we find that the Block-SVR can achieve a satisfying tradeoff between preservation of spectral characteristics and enhancement of spatial and textural contents.

### 4.2 Quantitative Assessments

In order to evaluate the effectiveness of the proposed technique quantitatively, correlation coefficients are calculated. The correlation coefficient denotes the similarity between structures (Wald and Ranchin, 1997). Hence, the correlation coefficients between the multispectral and the relevant fused image can indicate the ability of spectral preservation to some extent; the higher are the correlation coefficients, the more are the spectral characteristic preserved. In table 2 it can clearly be seen that

those of the Block-SVR are more higher than PCA, IHS and SVR, which are slightly lower than wavelet-based method, so the color characteristics in the fused image using Block-SVR are much closer to the original multispectral than those of PCA, IHS and SVR method. The results are also validated by visual comparison. For the case of wavelet-based method, the strong ability of spectral preservation has been gotten on the condition that the fused image largely lacks the spatial and textural information from SAR image. The correlation coefficients between SAR image and fused image indicated in table 3 are also calculated for Block-SVR, PCA, IHS, Wavelet-based and SVR method. The correlation values of Block-SVR can be accepted basically whose average value is 0.5257. The values in table 3 explicitly reveal the fact that spectral preservation and enhancement of spatial and textural information is a pair of contradictions and the best fusion technique is to achieve a satisfying tradeoff between spectral preservation and enhancement of spatial and textural information with respect to a specific application.

Table 2. Correlation between the multispectral and the relevant fused images using Block-SVR, PCA, IHS, Wavelet-based and SVR fusion algorithms

	B-SVR	PCA	IHS	Wavelet	SVR
Band 1	0.4794	-0.0425	0.0353	0.6074	0.1582
Band 2	0.4235	-0.0701	-0.0783	0.5467	0.0294
Band 3	0.4212	-0.0198	-0.056	0.5655	0.1361
Average	0.4414	-0.0441	-0.033	0.5732	0.1079

Table 3. Correlation between SAR and fused images using Block-SVR, PCA, IHS, Wavelet-based and SVR fusion algorithms

	B-SVR	PCA	IHS	Wavelet	SVR
Band 1	0.5061	0.9433	0.8533	0.4265	0.8198
Band 2	0.5277	0.9524	0.8648	0.4587	0.8853
Band 3	0.5433	0.9336	0.8712	0.4574	0.8166
Average	0.5257	0.9431	0.8631	0.4475	0.8406

### 4.3 Algorithm Discussions

During the implementation of the block-regression-based techniques there are at least two advantages.

One advantage, also the most important, is that adjustment of regression block size can results in different emphases between spectral preservation and enhancement of spatial and textural information. The correlation coefficients given in table 4 show that the smaller the block size, the higher correlation between the multispectral and the fused images. Thus, the conclusion can be easily drawn that the smaller is the block of regression, the closer to those of the original multispectral image are the color characteristics of the fused image. This is due to the fact that the regression result (Synthetic Variable in Munechika, 1993 and Y. Zhang, 1999) of small block of multispectral bands is much closer to the SAR image block than those of large block. In contrast, the larger is the block of regression, the more are spatial and textural features imported into the fused image from the SAR image, which can basically be illustrated by the correlation between SAR and fused images indicated in table 5.

The other advantage is efficiency of implementation of the technique. The block-regression-based technique drastically decreases requirements of computation, whereas regression of the whole scene image is almost impossible. The progress of this technique makes possible in real applications because of its efficiency of implementation.

## 5. CONCLUSIONS

Block-regression-based fusion technique has proven itself available and flexible for fusion of optical and SAR imagery. The fusion results show that the fused images have enhanced certain features, namely spatial and textural contents, as well as features not visible in multispectral image while preserving the color characteristics. Also, the spectral, spatial and textural effects of the presented algorithm were evaluated mainly by visual and quantitative methods comparing to those of IHS, PCA and Wavelet-based methods. The assessments indicate that the block-regression-based method is the best technique among these methods, because it can achieve a satisfying tradeoff between preservation of spectral characteristics and enhancement of spatial and textural contents with respect to a specific application.

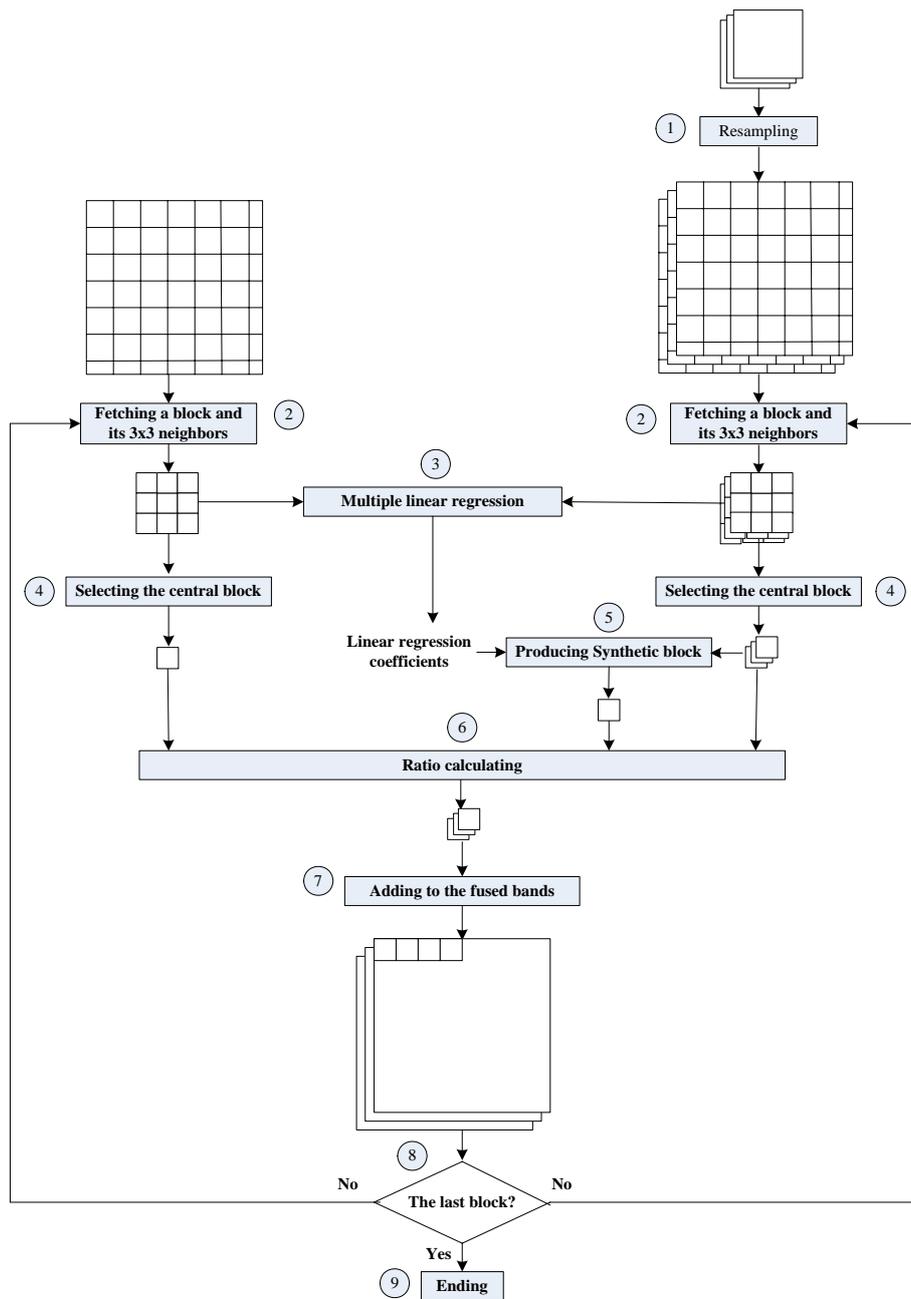
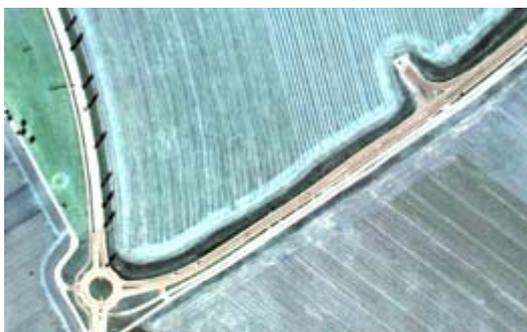


Fig. 1 The procedure of Block-SVR

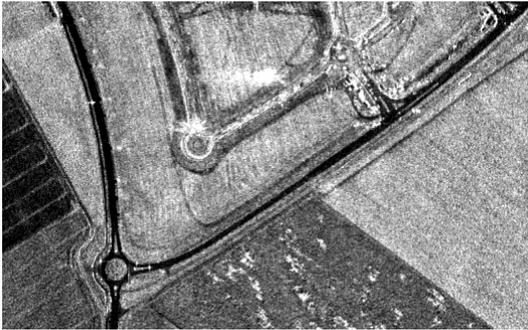


(a)



(b)

Plate 1. Visual comparison of different fusion results (a), (b) two slices of the original multispectral image. (c), (d) two slices of the AeS-1 airborne SAR image (e), (f) fusion results of Block-SVR method. (g), (h) fusion results of PCA method. (i), (j) fusion results of IHS method. (k), (l) fusion results of wavelet-based method. (continued on next page)



(c)



(d)



(e)



(f)



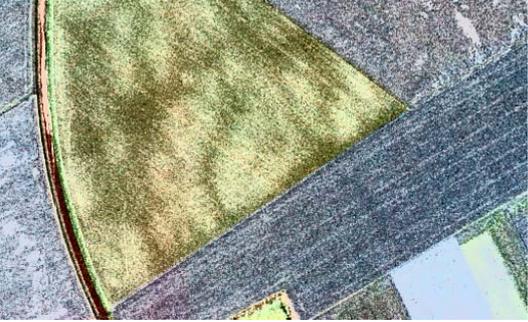
(g)



(h)



(i)



(j)



(k)



(l)

Table 4. Correlation between the multispectral and the relevant fused images using Block-SVR fusion algorithms of different block size

	8 x 8	16 x 16	32 x 32	64 x 64	128 x 128	256 x 256	512 x 512
Band 1	0.5707	0.4794	0.4075	0.34	0.2841	0.222	0.1854
Band 2	0.52	0.4235	0.3478	0.2769	0.2169	0.1532	0.1071
Band 3	0.52	0.4212	0.3453	0.2776	0.2232	0.1715	0.1555
Average	0.5369	0.4414	0.3669	0.2982	0.2414	0.1822	0.1493

Table 5. Correlation between SAR and fused images using Block-SVR fusion algorithms of different block size

	8 x 8	16 x 16	32 x 32	64 x 64	128 x 128	256 x 256	512 x 512
Band 1	0.4337	0.5061	0.5652	0.627	0.6997	0.7787	0.8131
Band 2	0.4553	0.5277	0.5865	0.6502	0.726	0.8087	0.8543
Band 3	0.4692	0.5433	0.6013	0.6606	0.7297	0.7955	0.815
Average	0.4527	0.5257	0.5843	0.6459	0.7185	0.7943	0.8275

## References

A.H.J.M. Pellemans, R.W.L. Jordans, and R. Allewijn, 1993. Merge Multispectral and Panchromatic SPOT Images with respect to the Radiometric Properties of Sensor. *Photogramm. Eng. Remote Sens.*, vol. 59, No.1 pp. 81 – 87.

B. Garguet-Duport, J. Girel, J. M. Chasseny, and G. Pautou, 1996. The use of multiresolution analysis and wavelet transform for merging SPOT panchromatic and multispectral image data. *Photogramm. Eng. Remote Sens.*, vol. 62, pp. 1057–1066.

C. Pohl, J.L. Van Genderen, 1998. Multisensor image fusion in remote sensing: concepts, methods, and applications. *International Journal of Remote Sensing*, vol.19, pp.823 ~ 854.

C.A. Yocky, 1996. Multiresolution wavelet decomposition image merger of Landsat Thematic Mapper and SPOT Panchromatic data. *Photogramm. Eng. Remote Sens.*, vol. 62, pp. 1067–1074.

J. W. Carper, T. M. Lillesand, and R. W. Kiefer, 1990. The use of intensity–hue–saturation transformations for merging SPOT panchromatic and multispectral image data. *Photogramm. Eng. Remote Sens.*, vol.56, pp. 459–467.

Luciano Alparone, Stefano Baronti, Andrea Garzelli and Filippo Nencini, 2004. Landsat ETM+ and SAR Image Fusion Based on Generalized Intensity Modulation. *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 42, No. 12, pp.2832-2839.

L. Wald, T. Ranchin, and M. Mangolini, 1997. Fusion of satellite images of different spatial resolutions: Assessing the quality of resulting images. *Photogramm. Eng. Remote Sens.*, vol. 63, no. 6, pp. 691–699.

Munehika, C. K., Warnick, J. S., Salvaggio, C., and Schott, J. R., 1993. Resolution enhancement of multispectral image data to improve classification accuracy. *Photogrammetric Engineering and Remote Sensing*, vol. 59, pp.67 ~ 72.

Pradines, D., 1986. Improving SPOT images size and multispectral resolution. Proceedings of the SPIE Earth Remote Sensing using the Landsat Thematic Mapper and SPOT Systems, 660, pp.98 ~ 102.

Price, J. C., 1987. Combining panchromatic and multispectral

imagery from dual resolution satellite instruments. *Remote Sensing of Environment*, vol. 21, pp.119 ~ 128.

V. K. Shettigara, 1992. A generalized component substitution technique for spatial enhancement of multispectral images using a higher resolution data set. *Photogramm. Eng. Remote Sens.*, vol. 58, pp. 561–567.

Y. Zhang, 1999. A new merging method and its spectral and spatial effects. *International Journal of Remote Sensing*, vol. 20, pp.2003 ~ 2014.

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