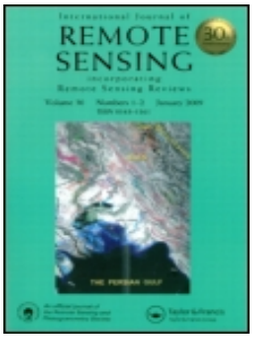

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A new merging method and its spectral and spatial effects

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Abstract. A new SVR (Synthetic Variable Ratio) merging method is described which reproduces the spectral characteristics of an original multispectral image and spatial information of a panchromatic image with higher resolution very well. Different TM bands and SPOT pan images in two different large urban areas were used as test data to assess the new SVR method. The spectral and spatial effects of the new SVR method were assessed by using visual and graphical methods and the results were compared with those of the IHS (Intensity, Hue, Saturation) and PCS (Principal Component Substitution) methods. The results show that the spectral effect of the SVR method is the best of the three merging methods. The spatial effect of the SVR method is the same as that of the other two methods.

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1. Introduction

Landsat Thematic Mapper (TM) images, with their seven spectral bands, deliver a tremendous amount of spectral information of the Earth's surface. However, their spatial resolution is only 30 m (apart from Band 6, 120 m). SPOT multispectral images have a spatial resolution of 20 m and panchromatic images have a resolution of 10 m. The spatial resolution of MOMS-02 multispectral images is 13.5 m and that of its panchromatic images is 4.5 m.

It is expected that multispectral and panchromatic satellite images with higher spatial resolutions will be receivable in the next few years. The planned American system Early-Bird will offer multispectral and panchromatic images with 15 m and 3 m resolution. The planned French SPOT-5 will have a 10 m resolution for multispectral images and 5 m for panchromatic images. The American system Space-Imaging is intended to use five multispectral bands with a resolution of 4 m and to deliver panchromatic imagery with 1 m resolution (Mussio and Light 1995, Fritz 1996, Stoney 1996).

Most satellite images are (or will be) receivable either with higher spectral resolution or with higher spatial resolution. However, many applications of satellite images require both spectral and spatial resolution to be high. This is particularly important in urban areas because the characteristics of urban objects are formed not only by their spectra but also through their structure. It is therefore necessary and very useful to be able to merge images with higher spectral information and higher spatial information.

Many merging methods have been developed, applied and assessed over the past

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ten or so years (e.g. Cliche *et al.* 1985, Göpfert 1987, Price 1987, Welch and Ehlers 1987, Albertz *et al.* 1988, Albertz and Tauch 1991, Chavez *et al.* 1991, Ehlers 1991, Shettigara 1992, Yésou *et al.* 1993, Van der Meer 1997, Wald *et al.* 1997, Zhang 1997). The two most effective methods are the IHS (Intensity, Hue, Saturation) method and the PCS (Principal Component Substitution) method and these are also the most frequently used (e.g. Göpfert 1987, Albertz *et al.* 1988, Albertz and Tauch 1991, Chavez *et al.* 1991, Ehlers 1991, Shettigara 1992, Kaufmann and Buchroithner 1994, Zhang 1997). However, these two methods usually distort the spectral characteristics of the original multispectral images to different extents (Chavez *et al.* 1991, Shettigara 1992).

This paper reports a new SVR (Synthetic Variable Ratio) merging method which reproduces the spectral characteristics of the original multispectral image and the spatial information of the panchromatic image very well. The basis of the new SVR method is Munechika's method (Munechika *et al.* 1993). The spectral and spatial effects of the merged images are usually regarded as two of the most important criteria in an assessment of the merging method. The closer the colour of the merged image is to that of the original multispectral image, the better the spectral effect of the merging method and the more details the merged image shows, the better the spatial effect of the merging method. In Munechika's study merged results were classified and the classification results were compared with those of the original TM image. However, the spectral and spatial effects of the merged image were not assessed; in particular they were not compared with the merged results of the most effective merging methods to date—the IHS and PCS methods.

In order to assess the spectral and spatial effects of the new SVR merging method effectively, different TM bands and SPOT pan images of two different large urban areas were used as test data. Different rectification methods were used in the pre-processing. The spectral and spatial effects of the new SVR method were assessed with the use of visual and graphical methods and the results were compared with those of the IHS and PCS methods.

2. Test areas, satellite images and pre-processing

One of the test areas was the entire urban area of Shanghai, China, which covers over 30 km × 30 km. Land use in Shanghai is very fragmentary and irregular. Most houses in the centre of the area are small and form closely packed rows of terraces. The separation between recently built houses, which are generally larger and relatively regular, increases from the inner city to outside of the city. The streets in the city are narrow. Most green areas are very small, apart from some parks (Shanghai's Remote Sensing Office 1993).

The other test area was the major part of the urban area of Berlin, Germany, covering approximately 20 km × 16 km. Land use in Berlin is more ordered and extensive than in Shanghai. The houses in the central part of the city are predominantly large, with semi-detached or detached houses being dominant in the surrounding parts of the city. There are many extensive green areas in the city and the streets are wider than those of Shanghai.

For the test area of Shanghai TM Bands 3, 4 and 7 were used in the merging, using images taken on 18 May 1987. The used SPOT pan image of Shanghai was taken on 25 October 1989. The images of Berlin were TM Bands 1, 2 and 3, taken on 29 August 1984, and the SPOT pan image, taken on 4 August 1986.

In the pre-processing, TM Band 3, 4 and 7 images of Shanghai were rectified

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using the Nearest Neighbour Method to the co-ordinate system of the SPOT pan image. Spatial information on the SPOT pan image was improved with high-pass filtering and the result was added to the stretched SPOT pan image. TM Band 1, 2 and 3 images of Berlin were magnified three times with the Nearest Neighbour Method. The SPOT pan image of Berlin was also improved with high-pass filtering and added to the stretched SPOT pan image. It was then rectified to the co-ordinate system of the magnified TM image using the Nearest Neighbour Method.

3. SVR (Synthetic Variable Ratio) merging method

3.1. *Background*

On the basis of the methods reported by Pradines (1986) and Price (1987), Munechika *et al.* (1993) proposed the SVR method in which the merged multispectral image is calculated through the equation:

$$XSP_i = Pan_{\mathrm{H}} \frac{XS_{\mathrm{L}i}}{Pan_{\mathrm{LSyn}}} \tag{1}$$

where XSP_i is the grey value of the ith band of the merged high-resolution TM–SPOT image, Pan_{H} is the grey value of the original SPOT pan image, $XS_{\mathrm{L}i}$ is the grey value of the ith band of the original TM image, and Pan_{LSyn} is the grey value of the low-resolution synthetic panchromatic image simulated through the low-resolution TM Bands 1, 2, 3 and 4.

In the study of Munechika *et al.* (1993), the synthetic panchromatic image Pan_{LSyn} was created using a modification of the approach described by Suits *et al.* (1988) to substitute signals from one sensor for those produced by another. The synthetic panchromatic image is formed as:

$$Pan_{\mathrm{LSyn}} = \sum_{i=1}^{4} \varphi_i XS_{\mathrm{L}i} \tag{2}$$

In order to obtain the parameters φ_i Munechika *et al.* (1993) used a modified atmospheric model that accepts target reflectance and relative spectral response (Munechika 1990) and measured the representative reflection spectra of the five land-cover classes of urban, soil, water, trees and grass. The parameters φ_i were then obtained through regression analysis of the values simulated using the atmospheric model and the five classes. After construction of the Pan_{LSyn} a linear histogram adjustment had to be performed to force the SPOT pan image to match the Pan_{LSyn} image in order to eliminate atmospheric and illumination differences.

3.2. *New SVR method*

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 φ_i is very complicated and only specified classes are used in the calculation. On the one hand, the method is not suitable for the merging of a large area and for a routine operation. On the other, there are surely more than the five specified land-cover classes in a large urban area, so it is questionable whether the spectral characteristics of other classes can be clearly retained after merging. In addition, the SPOT pan image has to be forced to match the synthetic Pan_{LSyn} image because the parameters φ_i used in equation (2) are obtained by using a specified atmospheric model and specified classes.

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In this study Munechika's method was modified to simplify the merging operation. The new SVR method can be formulated as:

$$XSP_i = Pan_{\mathrm{H}} \frac{XS_{\mathrm{H}i}}{Pan_{\mathrm{HSyn}}} \tag{3}$$

where XSP_i and Pan_{H} are the same as in equation (1), $XS_{\mathrm{H}i}$ is the grey value of the ith band of the TM image modified to have the same pixel size as the original SPOT pan image, and Pan_{HSyn} is the grey value of the high-resolution synthetic panchromatic image simulated through:

$$Pan_{\mathrm{HSyn}} = \sum \varphi_i XS_{\mathrm{H}i} \tag{4}$$

To calculate the parameters φ_i equation (5) was used and the parameters φ_i were calculated directly through multiple regression analysis of the original panchromatic image Pan_{H} and the original multispectral bands $XS_{\mathrm{H}i}$ which are used in the merging and have the same pixel size as Pan_{H}.

$$Pan_{\mathrm{H}} = \sum \varphi_i XS_{\mathrm{H}i} \tag{5}$$

The first modification developed in this study is that the parameters φ_i are calculated directly from the TM image $XS_{\mathrm{H}i}$ (10 m resolution) and the original SPOT pan image Pan_{H}, instead of from the measured classes. So the simulated panchromatic image Pan_{HSyn} has a high resolution (10 m) and is highly correlated with the original SPOT pan image. Through this modification considerable time and calculation can be saved. In addition, the results φ_i are more stable because the measurements of the representative reflection spectra of different land-cover classes, which are dependent on the user, are renounced. Finally, the need to adjust the SPOT pan image to the Pan_{HSyn} image is obviated.

The second modification is that the synthetic panchromatic image Pan_{HSyn} is calculated from those TM bands which are used in the merging instead of from the TM Bands 1, 2, 3 and 4 constantly. All the TM bands used in the merging can be considered during simulation of the Pan_{HSyn} image. In this way colour distortion of all the used TM bands should be avoided, particularly when TM Bands 5 or 7, which are only weakly correlated with the SPOT pan image, are used.

The pre-processed TM band images and SPOT pan images of the two test areas were merged using the new SVR method. The merged results for Shanghai and Berlin are shown in figures 1 (*b*) and 2 (*b*) respectively.

4. Comparison of the spectral and spatial effects of the merged TM–SPOT images

4.1. *Visual comparison*

For comparison the same pre-processed TM and SPOT pan images of the two test areas were also merged using the IHS and PCS methods. Because the SVR method proposed by Munechika *et al.* (1993) is work intensive and is dependent on the user to a certain extent (to measure the classes), it was not used for comparison in this study. A small section was cut out from each of the original TM images and the merged TM–SPOT images and these are shown in figures 1 and 2 for Shanghai and Berlin respectively (these cut outs are parts of the test areas with rich spatial information). The colour of the sections represents the spectral information of the complete test areas well.

Figures 1 and 2 show that the new SVR method (figures 1 (*b*), 2 (*b*)) reproduces the colour information of the original TM image (figures 1 (*a*), 2 (*a*)) better than the

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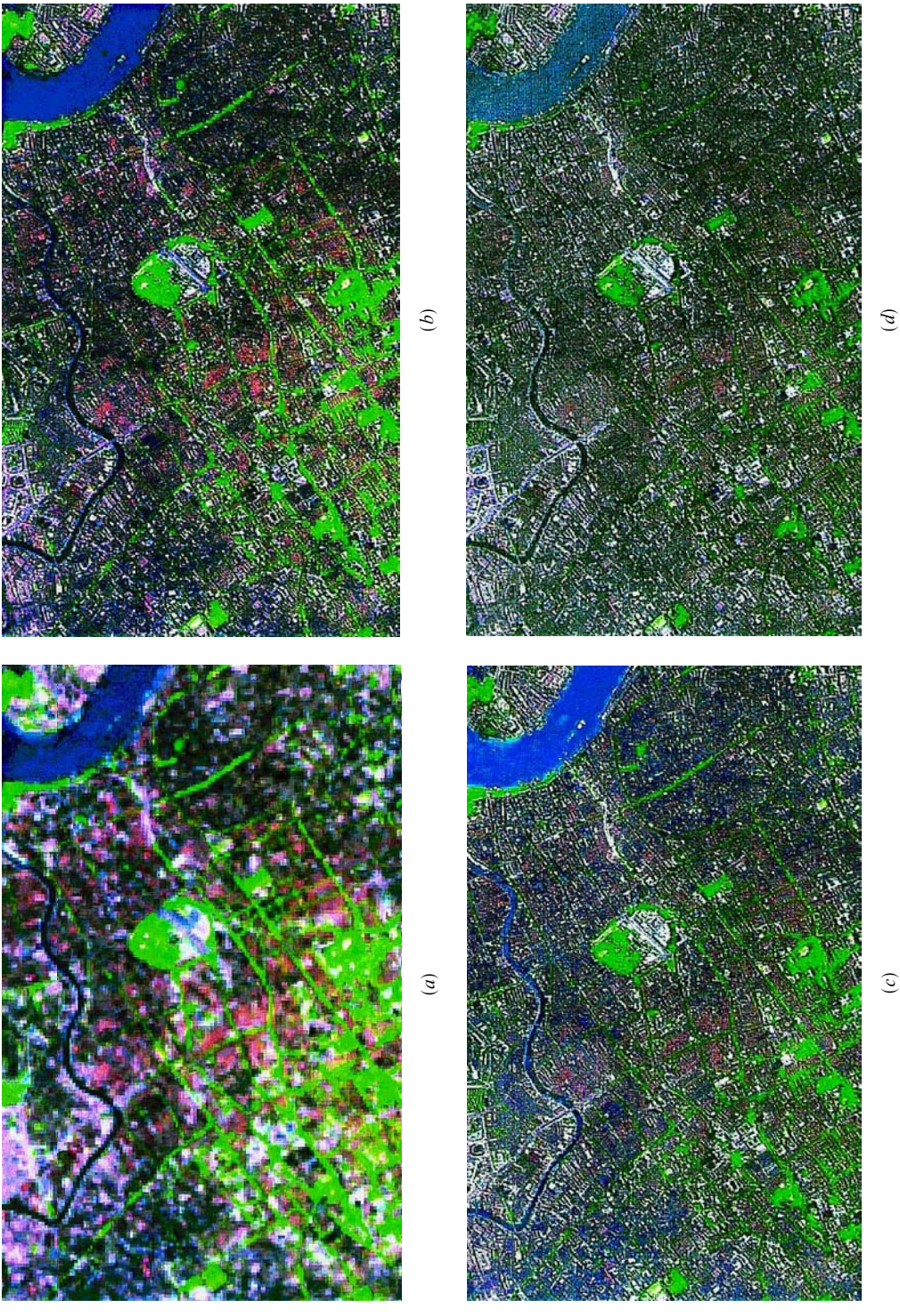

Figure 1. Comparison of the spectral and spatial effects of the merged TM–SPOT images for the test area of Shanghai (600 × 380 pixels, 10 m resolution). (*a*) Original TM image with Bands 3, 4, 7 in colours blue, green, red. (*b*) Image merged using the new SVR method. (*c*) Image merged using the IHS method. (*d*) Image merged using the PCS method.

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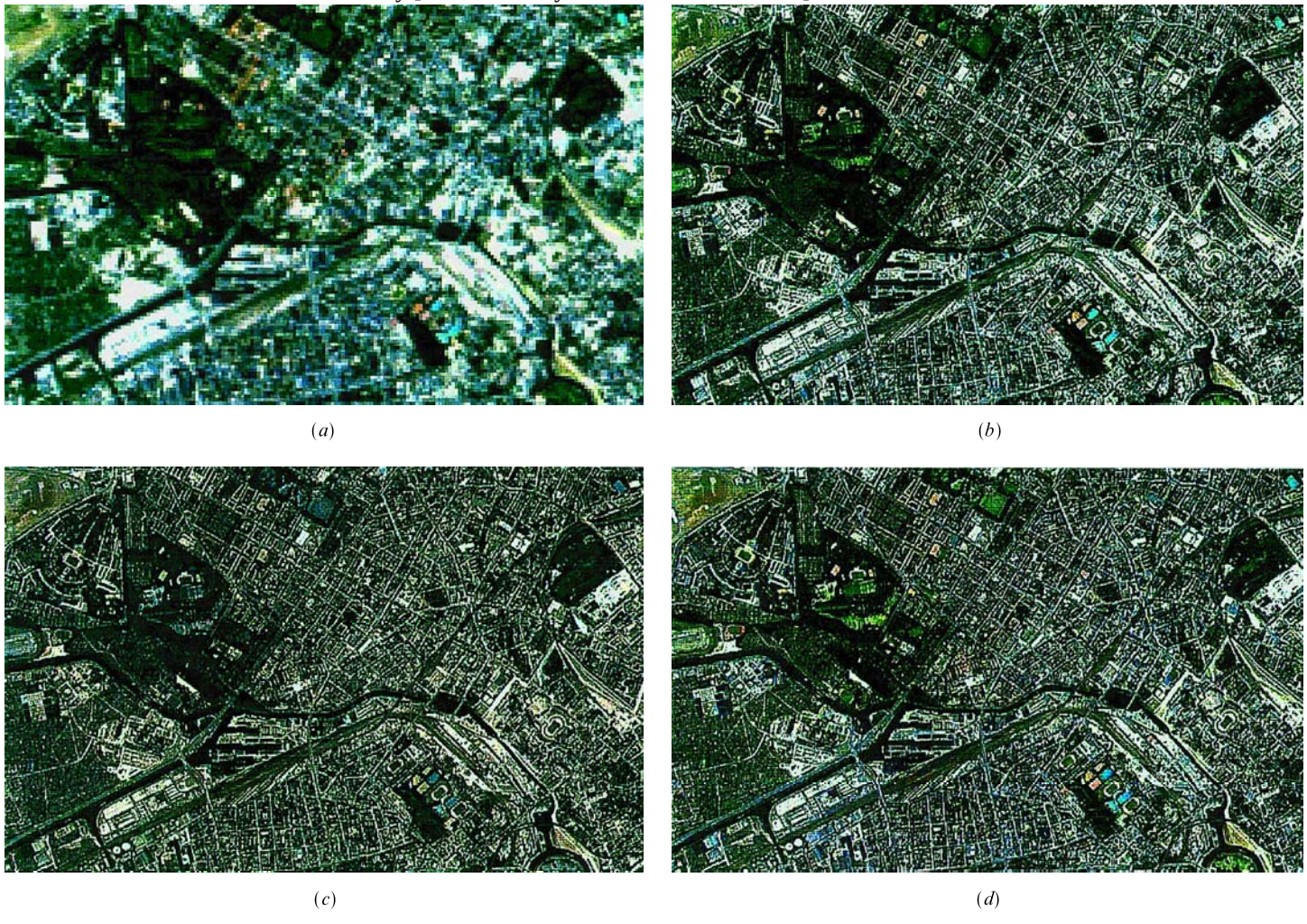

Figure 2. Comparison of the spectral and spatial effects of the merged TM–SPOT images for the test area of Berlin. (*a*) Original TM image with Bands 3, 4, 7 in colours blue, green, red. (*b*) Image merged using the new SVR method. (*c*) Image merged using the IHS method. (*d*) Image merged using the PCS method.

As figure 1, but for Berlin test area.

other two methods tested. The green areas in the SVR images are almost the same colour and brightness as those in the original TM images. The colour of the water areas and residential areas is also almost identical in the SVR images and the TM images. The colour effects of the IHS method (figures 1 (*c*), 2 (*c*)) and the PCS method (figures 1 (*d*), 2 (*d*)) are different and more distorted than those of the SVR method for both test areas. The colour contrast of the PCS method is weaker than that of the IHS method for Shanghai but it is the exact reverse for Berlin.

In a comparison of spatial effects, it can be seen that the results of the three methods display the same details. Houses, streets, sports fields and so on can be clearly recognized in the merged images using all three methods.

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4.2. *Graphical comparison*

Grey level values of six typical land-cover classes were measured in each of the images for a graphical comparison of the spectral effects of the merging methods. These values are the average values of 3×3 pixels in relatively homogeneous areas. The measured grey values in the corresponding bands are displayed in figures 3 and 4.

The graphical comparison of the spectral curves shows a similar result to that of the visual comparison. It can be clearly seen that the spectral curves of the measured classes in the SVR images are most similar to the curves of the original TM images for both test areas.

Comparison of the spectral curves of the IHS images and the PCS images shows that the IHS curves are more similar to the TM curves for the Shanghai test area. However, the PCS curves are closer to the original TM curves for Berlin. The reason for this is that TM Bands 1, 2 and 3 were used for the Berlin images and TM Bands 3, 4 and 7 for Shanghai. The first principal component generated from TM Bands 1, 2 and 3 is more closely correlated with the SPOT pan image than the first

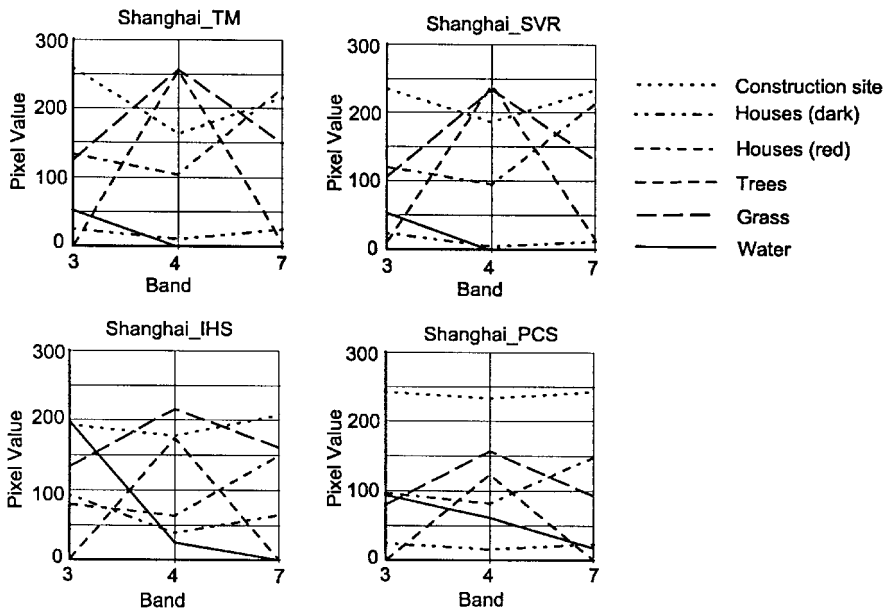

Figure 3. Spectral curves of the original TM image and the merged TM–SPOT images in the test area of Shanghai.

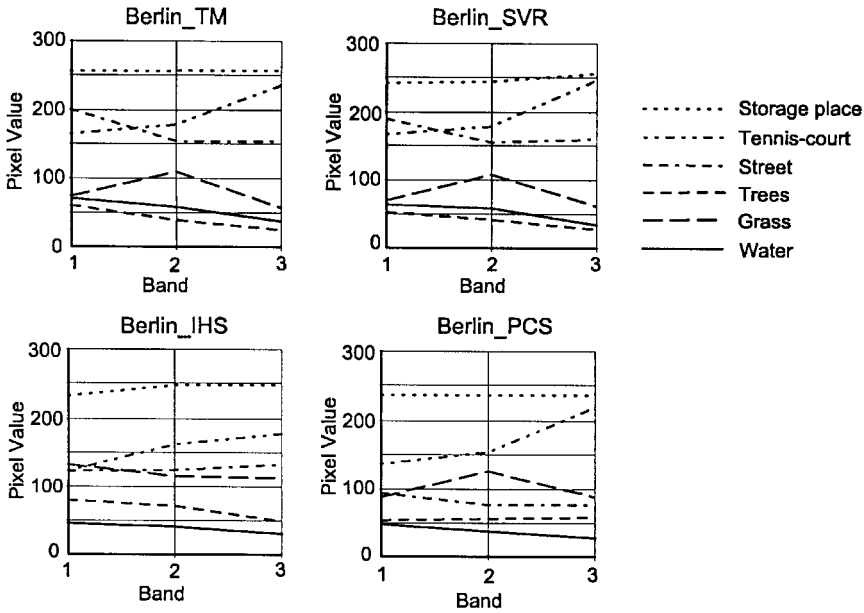

Figure 4. Spectral curves of the original TM image and the merged TM–SPOT images in the test area of Berlin.

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component from TM Bands 3, 4 and 7. Hence colour information on the merged PCS images is richer for the area of Berlin than for Shanghai.

To compare the spatial effects of the merged TM–SPOT images, grey values along a profile line were measured in all the images of the test areas. Line profiles in areas of rich spatial information were selected. In the Shanghai image the profile line was 150 pixels long, running through a small river, a small green area and a residential area. The profile line in the Berlin image was also 150 pixels long, covering a crowded residential area. The profiles of the pre-processed SPOT pan images and that of the first band of the merged TM–SPOT images for Shanghai and Berlin are shown in figures 5 and 6 respectively. The profiles of the other two bands of the TM–SPOT images are similar to that of the first band.

Figures 5 and 6 show that the spatial profiles of the three merged images are almost the same in the two test areas. There are almost no differences between the frequencies of the SPOT pan images and those of the merged images. Only when the profile curves are closely compared it can be seen that the curves of the IHS and PCS images are in slightly better agreement with that of the SPOT pan image (figure 6), which, however, does not affect the spatial details of the merged images. This means that the spatial details of the SPOT pan images were merged into multispectral images using the three merging methods very well and the level of spatial detail in the three merged images is about the same. The merged IHS and PCS images, however, show a stronger correlation with the SPOT pan image.

5. Conclusion

Visual and graphical comparisons of merged TM–SPOT images have shown that the spectral effect of the new SVR method presented here is the best of the methods studied. The colours of the merged SVR images are almost the same as

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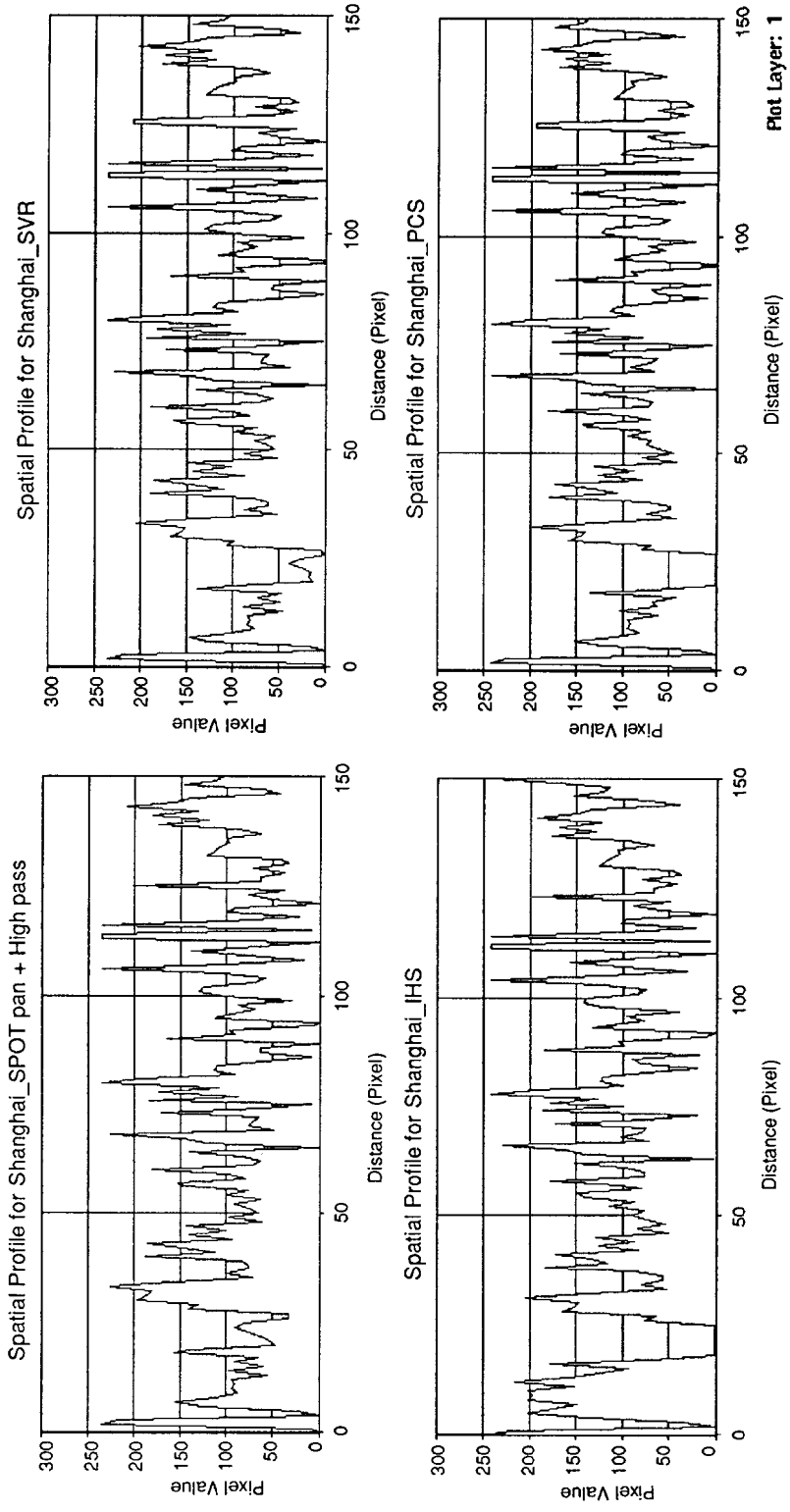

Figure 5. Spatial profiles of the SPOT pan image and the merged TM–SPOT images for the area of Shanghai.

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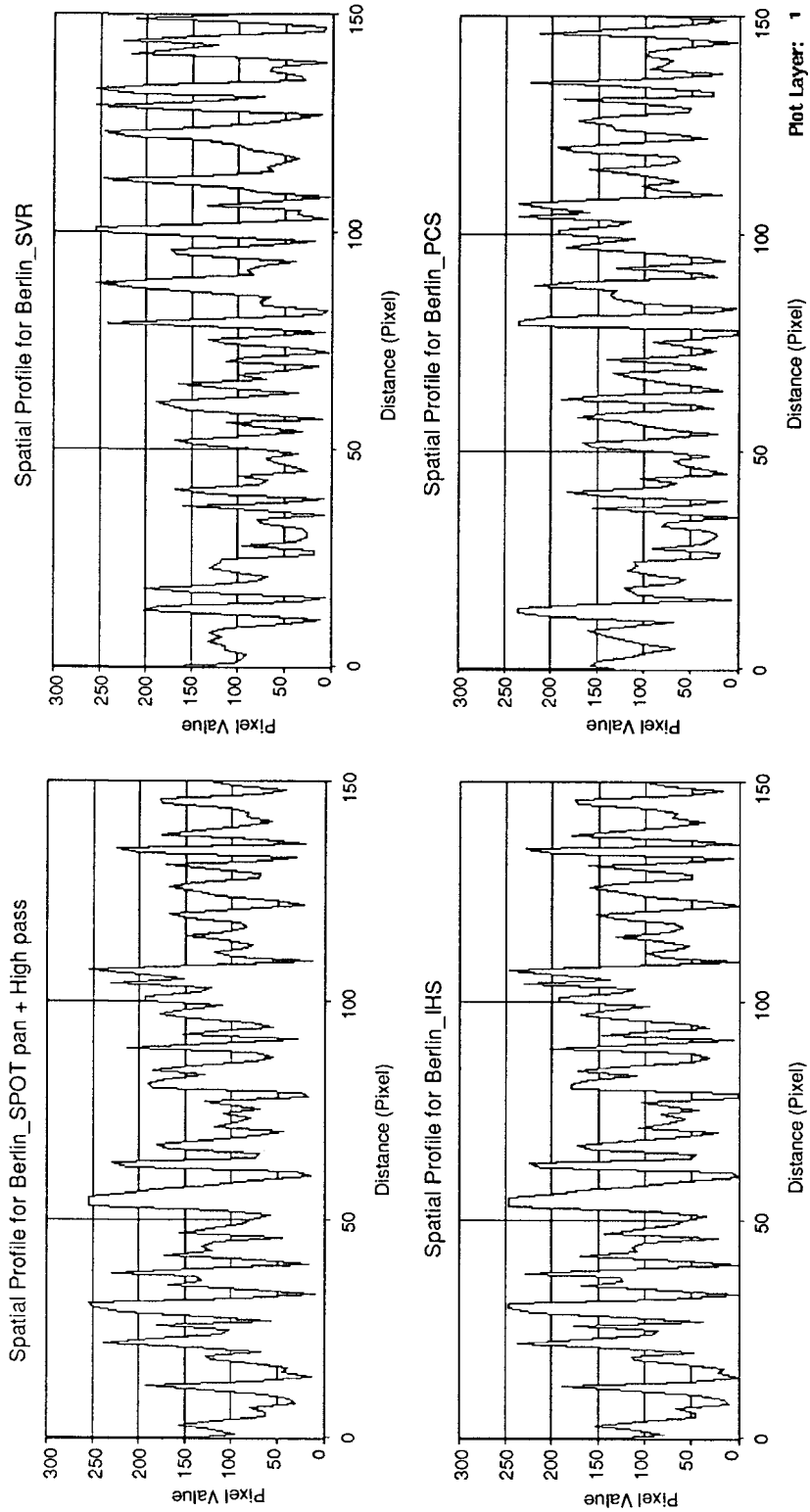

Figure 6. Spatial profiles of the SPOT pan image and the merged TM–SPOT images for the area of Berlin.

those of the original TM images for all the land-cover classes considered. Furthermore, the colour effects are not influenced by the use of different TM spectral bands.

This is not the case for merged IHS and PCS images. The colours of the merged IHS and PCS images are more distorted than those of the merged SVR images and colour distortions are affected by the use of different TM bands. Visual and graphical comparisons of the spatial effects show that the spatial resolutions of the merged IHS, PCS and SVR images are almost the same. The only difference is that the spatial profiles of the merged IHS and PCS images are partly in stronger agreement with that of the SPOT pan (figure 6).

The new SVR method has also been used to merge satellite images of non-urban areas and the results obtained were similar to the findings of this study (Zhang and Albertz 1997). Use of the SVR method could therefore be strongly recommended if the goal of the merging is to achieve the best representation of the spectral information of a multispectral image and the spatial details of a high-resolution panchromatic image. Because the merged results of the new SVR method are independent of the spectral bands used, this method should also be efficient in the merging of other multisensor data.

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