Multiresolution Wavelet Decomposition Image Merger of Landsat Thematic Mapper and SPOT Panchromatic Data

David A. Yocky

Abstract

Spatially registered Landsat Thematic Mapper (TM) and SPOT (Systeme Pour l'Observation de la Terre) panchromatic images were merged by combining multiresolution wavelet decomposition components from each, and then reconstructing a merged image using the inverse wavelet transform. Three wavelet merging techniques were compared to the intensity-hue-saturation merging technique. The comparison results show the wavelet merger providing greater flexibility and the potential for higher accuracy for combining and preserving spectral-spatial information for remotely sensed data and their applications.

Introduction

The number of commercially available satellite and airborne sensors and the data they provide are continually increasing. Each sensor has its mission and applications. For many applications, the combined information from multiple sensors provides more comprehensive information by collecting a wide diversity of sensed wavelengths, spatial resolutions, and look-angles. Multiple-sensor exploitation also means manipulation of multiple data sets, some being quite large. This potentially massive data set demands exploration of some means to integrate the relevant information into a more concise, manageable data set. In this paper, we address "fusing" information by exploring a new technique of combining sensor information by using image merging.

Image merging refers to image processing techniques that combine two image sets from two or more sensors, forming an enhanced final image. Past merger research mainly explored combining spectral information from a low spatial resolution radiometer with the high spatial resolution information from a wide-band optical sensor. The data combination was performed using simple overlaying, the intensity-hue-saturation (IHS) transform merger (Hayden *et al.*, 1982; Carper *et al.*, 1990), component substitution (Shettigara, 1992), and numerous other approaches (Schowengerdt, 1980; Cliche *et al.*, 1985; Tom *et al.*, 1985; Chavez, 1986; Pradines, 1986; Price, 1987; Moran, 1990). These image merging approaches combine the spatial/spectral information from two sensors into one data set, an image. This type of image can be useful in enhancing image mensuration as well as localizing phenomena. If the image merging technique preserves the spectral information, it can be used in spectral classification.

Recently, Yocky (1995) tested a novel approach to image merging using multiresolution wavelet decomposition which employs the discrete two-dimensional wavelet transform. He presented the structure and proposed numerous possibilities in using wavelet decomposition pyramids in image merging. From that research, the "standard" wavelet merger technique was found to outperform the IHS merger in preserving the original spectral content while providing comparable spatial resolution.

In this paper, we apply discrete two-dimensional wavelet transform image merging techniques to combine Landsat TM data and SPOT panchromatic data. First, we present a brief review of multiresolution wavelet decomposition and wavelet image merging. The "standard" TM/SPOT wavelet merge is then presented and compared to the IHS merging technique. We also introduce new algorithms called "additive" and "selective resolution" wavelet mergers. These new wavelet techniques are also compared to the IHS merging algorithm.

Review of Multiresolution Wavelet Decomposition

Multiresolution decomposition (Levine, 1985; Burt, 1989; Wechsler, 1990) provides a simple hierarchical framework for integrating image information. In a pyramidal fashion, image manipulation and analysis can be performed at coarse resolutions proceeding to fine resolutions or *vice versa*. Mallat (1989) showed how the wavelet transform provides this type of decomposition. The multiresolution wavelet decomposition (MWD) transform is an intermediate representation between Fourier and spatial representations, and it can provide good localization properties in both the spatial and Fourier domains (Daubechies, 1988; Mallat, 1989; Daubechies, 1990). The MWD is computed with a pyramidal algorithm and decomposes a given signal or image into a set of frequency channels of constant bandwidth on a logarithmic scale. The MWD process is presented below starting with the one-dimensional wavelet transform. Daubechies (1988), Mallat (1989), and Chui (1992) provide further mathematical details on wavelets.

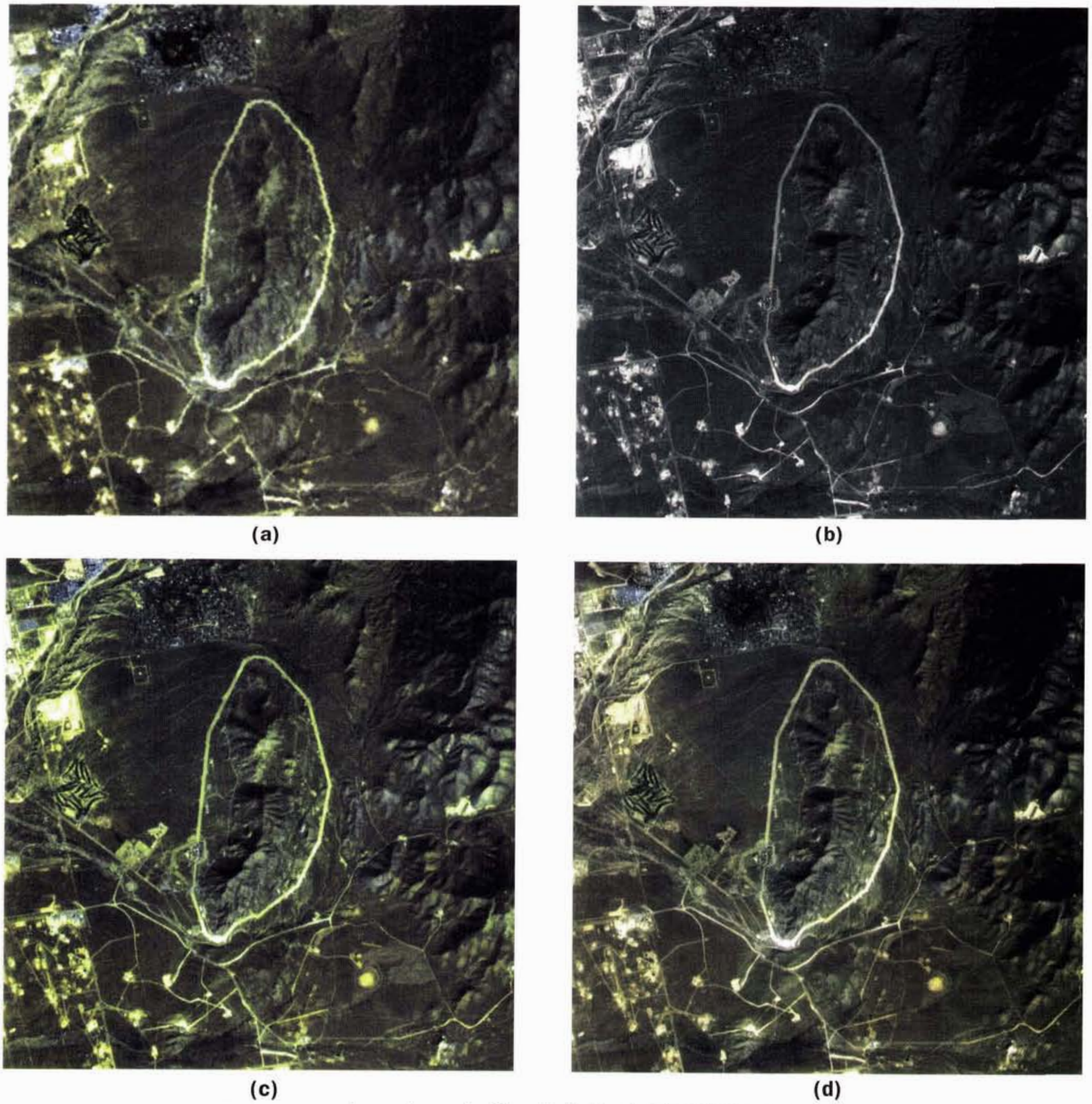
One-Dimensional Wavelet Transform

In the following, $\boldsymbol{Z}$ and $\boldsymbol{R}$ denote the set of integers and real numbers, respectively. $\boldsymbol{L}^2(\boldsymbol{R})$ denotes the vector space of measurable, square-integrable one-dimensional functions $f(x)$. The multiresolution wavelet decomposition is an increasing sequence of closed subspaces $\{V_j\}$ $j \in \boldsymbol{Z}$ which approximate $\boldsymbol{L}^2(\boldsymbol{R})$. In decomposing the signal $f(x)$, the resolutions are reduced by a factor of 2 for each level by using a scaling function $\phi(x)$. The difference in signal at resolutions 2^{j+1} and 2^j

Photogrammetric Engineering & Remote Sensing,
Vol. 62, No. 9, September 1996, pp. 1067–1074.

0099-1112/96/6209-1067$3.00/0

Systems Analysis Department III, Sandia National Laboratories, P.O. Box 5800, Albuquerque, NM 87185-0573.



(a) (b) (c) (d)

Plate 1. Image data set for image merging using part of Sandia National Laboratories, Kirtland Air Force Base, and Southeast Albuquerque, New Mexico. (a) Landsat TM. (b) SPOT panchromatic (copyright, © 1993 CNES). (c) IHS merged image. (d) MWD merged image.

can be extracted on a wavelet orthonormal basis of $\boldsymbol{L}^2(\boldsymbol{R})$. The wavelet function is given by $\psi(x)$, and the wavelet representation is the orthogonal complement of the original signal space, V_{2^j}, denoted as O_{2^j}. The decomposition is a new signal approximation and a detail signal. The signal approximation is given by

$$\hat{f}_{2^j}(x) = \sum_k (\langle \phi_{2^{-1}}(x), \phi(x - (k - 2n))\rangle \langle f(x), \phi_{2^{j+1}}(x - 2^{-j-1}k)\rangle) \quad (1)$$

where $k \in \boldsymbol{Z}$ and $\langle \mathrm{a, b} \rangle$ is the inner product of a and b. The resolution change is obtained by the first inner product which acts as a low pass filter: i.e.,

$$h(n) = \langle \phi_{2^{-1}}(x), \phi(x - n)\rangle \quad (2)$$

and by subsampling by two. Using Equation 2, Equation 1 becomes

$$\hat{f}_{2^j}(x) = \sum_k \tilde{h}(2x - k)\, \hat{f}_{2^{j+1}}(k) \quad (3)$$

where $\tilde{h}(n) = h(-n)$.

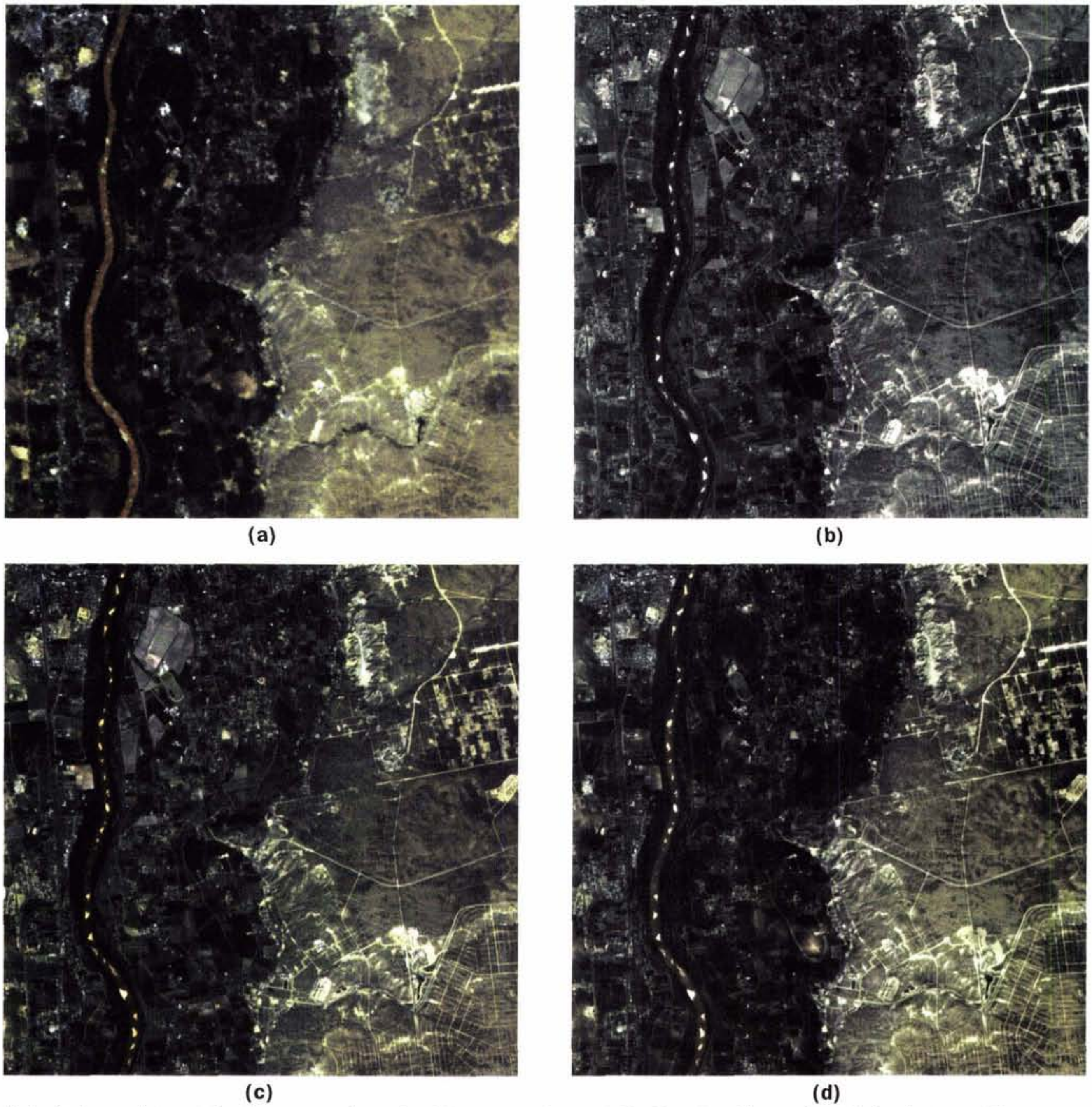


Plate 2. Image data set for image merging using Albuquerque's south Rio Grande valley region. (a) Landsat TM. (b) SPOT panchromatic (copyright, © 1993 CNES). (c) IHS merged image. (d) MWD merged image.

Similarly, the detail signal from the orthogonal projection of $f(x)$ onto O_{2^j} is given by

$$d_{f2j}(x) = \sum_k (\langle \Psi_{2^{-1}}(x), \phi(x - (k - 2n))\rangle\langle f(x), \phi_{2^{j+1}}(x - 2^{-j-1}k)\rangle). \quad (4)$$

The detail difference between resolutions is obtained by the first inner product which acts as a high pass filter

$$g(n) = \langle \Psi_{2^{-1}}(x), \phi(x - n)\rangle \quad (5)$$

where $g(n)$ is the quadrature mirror filter of $h(n)$. Using Equation 5, Equation 4 becomes

$$d_{f_{2^j}}(x) = \sum_k \tilde{g}(2x - k)\hat{f}_{2^{j+1}}(k) \quad (6)$$

where $\tilde{g}(n) = g(-n)$. Thus, the signal approximation at the next lower resolution ($j + 1 \rightarrow j$) is decomposed into a low pass approximation and a high pass detail signal (wavelet coefficients).

Perfect reconstruction of the original signal $f_{2^{j+1}}(x)$, requires that the filters $h(n)$ and $g(n)$ have regularity constraints (Daubechies, 1988). The reconstruction is the inverse wavelet transform that takes the form of

$$\hat{f}_{2^{j+1}}(x) = \sum_k \tilde{h}(2k - x)\hat{f}_{2^j}(k) + \tilde{g}(2k - x)d_{f_{2^j}}(k) \quad (7)$$

TABLE 1. MWD AND IHS MERGER COMPARISON USING THE AVERAGE ABSOLUTE GRAY LEVEL ERROR IN NINE SEPARATE AREAS.

	Absolute Gray Level Error			
Image	Red	Green	Blue	Average
MWD	7.24	5.25	5.29	5.93
IHS	8.46	7.75	9.22	8.48

Two-Dimensional Wavelet Transform

The discrete two dimensional wavelet transform (2DWT) is just an extension of the one-dimensional case. As in the one-dimensional case, the original image is reduced in resolution by a low-pass filter and subsampling, but the detail images are three-fold. The three detail images are a set of independent, spatially oriented frequency channels that detail vertical high frequencies, horizontal high frequencies, and cross-directional high frequencies (Mallat, 1989).

MWD Image Merger

The concept of image merger using MWD arose from the use of the wavelet transform in data compression applications (Antonini *et al.*, 1990; Froment and Mallat, 1992; Lewis and Knowles, 1992; Rosiene and Greenshields, 1994). Because wavelets are used in data compression and reconstruction algorithms, it follows that they may be useful in sensor-compressed information problems. The "sensor-compressed" information problem and how this problem is addressed by wavelet image merging is presented next.

In remote sensing, due to optical diffraction or signal-to-noise design limits, one sensor may provide high spatial resolution at the expense of a wide spectral bandwidth and another sensor may have higher spectral fidelity at the expense of spatial resolution. This is the case with the SPOT panchromatic (10.0-m resolution) and the Landsat TM (28.5- to 120.0-m resolution). The information from both sensors is compressed information because the real world covers all resolutions and a wide energy spectrum. The information is compressed at the sensor, due to the sensor's imaging characteristics. The information gathered by SPOT has retained spatial information, but the spectral information has been compressed in a lossy manner. The information gathered by Landsat TM has retained spectral information, but the spatial information has been compressed; again, a lossy compression. Yet the information compression for the sensor pair is in different information bands; spatial and spectral. Because of the lossy compression of these information bands, the individual decompression of each sensor's information to a higher resolution level is not possible. However, using the differing high resolution information bands (i.e., spatial, spectral), a mutual (merged) decompression may be possible, because information compressed in one sensor is preserved at a higher resolution in the other sensor.

The "standard" MWD merging (Yocky, 1995) of two data sets can be accomplished by the following steps:

(1) The two original images must be spatially registered. Originally, they may not be the same array size, so make them the same size (dimensionally square, each side being a power of two) by interpolation or replication of pixel values.
(2) Choose the wavelet basis for the transform and choose the final resolution for the MWD. The final resolution should be the same for each MWD pyramid.
(3) Perform the MWD on both images.
(4) Extract the desired sensor image approximation from its decomposition pyramid and totally replace the approximation image in the other sensor's decomposition pyramid.
(5) Perform the inverse MWD on the image combination.

Although two spatially different images can be transformed to two separate resolution levels in their respective pyramids (Step 3, i.e., $^1/_2$ for one and $^1/_8$ for the other), to merge them (Step 4), the image approximation must be the correct size to insert into the other sensor's decomposition pyramid. This will not be the case in general; thus, the reason for Step 1. Another approach would be to decompose the two images to equivalent spatial resolution levels and then resize the image approximation to fit correctly into the other decomposition pyramid.

Landsat-SPOT Merging

For our data set, we used a Landsat TM image of Albuquerque, New Mexico, acquired on 15 August 1992. The SPOT panchromatic data were acquired over the same area on 7 November 1993. The two data sets were registered to within 0.25 pixels RMS using control points and a first-order polynomial fit, the Landsat data being resampled. The satellite data were roughly corrected for the Earth's atmosphere by using known low reflecting materials or shadows in the scene. A linear stretch was then applied to each channel separately to fill the full data range. 1024 by 1024 sections of the data were used in the merging procedures described below.

We have shown that the final merged image is dependent on the wavelet basis selected (Yocky, 1995). For the purpose of this paper, we use the family of compact and well localized wavelets presented by Daubechies (1988). These wavelets can be described by the weighting coefficients given to $h(n)$. As the number of coefficients used for $h(n)$ increases, the wavelet becomes smoother. We designate the wavelet by the number of coefficients, i.e., DAUB4 wavelet is the Daubechies wavelet basis with four weights for $h(n)$.

Standard MWD Image Merger

The "standard" MWD image mergers are generated using the steps presented above. TM Bands 3, 2, and 1, and the registered SPOT image were merged using the DAUB4 wavelet basis. The panchromatic and multispectral images were decomposed to five different resolution levels, ending with the image approximations of 32 by 32 pixels. The multispectral MWD is performed for each TM spectral band. At the end of the forward transform, each 1/32-resolution TM spectral approximation was inserted into the 1/32-resolution SPOT panchromatic MWD pyramid and the inverse transform was performed, giving three separate merged bands: red, green, and blue (RGB). A linear stretch was then applied to the images.

The MWD merger is compared with the IHS merger (Haydn *et al.*, 1982). In the IHS merger, the TM bands are transformed from RGB into intensity, hue, and saturation components (Smith, 1978). In the IHS space, the high resolution, panchromatic image is substituted as the intensity component. The image is then transformed back into the RGB space, thus providing a merger between the multispectral and the panchromatic images.

Plate 1 shows the outcome of both the IHS merger and the MWD merger. Plate 1a is the original TM image, Plate 1b

TABLE 2. CORRELATION COMPARISON BETWEEN THE ORIGINAL TM, SPOT, MWD MERGED, AND IHS MERGED IMAGES.

	Correlation		
Image	Red	Green	Blue
TM/PAN	0.806	0.805	0.778
MWD/PAN	0.951	0.949	0.939
IHS/PAN	0.981	0.988	0.974
MWD/TM	0.864	0.869	0.848
IHS/TM	0.809	0.827	0.797

Table 3. Correlation Comparison between Original TM, SPOT, MWD Merged, IHS Merged, AMWD Merged, and Selective Resolution MWD Mergers.

Image 1	Image 2	Correlation		
		Red	Green	Blue
Pan	TM	0.642	0.676	0.666
	MWD	0.855	0.881	0.855
	IHS	0.985	0.950	0.975
	AMWD	0.814	0.838	0.844
	MWD64	0.831	0.853	0.867
	MWD128	0.821	0.840	0.855
	MWD256	0.815	0.833	0.847
	MWD512	0.813	0.831	0.844
TM	MWD	0.838	0.841	0.819
	IHS	0.701	0.685	0.629
	AMWD	0.900	0.869	0.850
	MWD64	0.864	0.859	0.837
	MWD128	0.875	0.867	0.846
	MWD256	0.876	0.868	0.829
	MWD512	0.877	0.868	0.850

is the SPOT image, Plate 1c is the IHS merger, and Plate 1d is the MWD merger. In this case, the IHS merged image has spectral distributions that make the final image look more green and purple than the original. This spectral change most likely will cause misclassification and is not desirable. The MWD merger, on the other hand, visually provides a better spectral representation compared to the IHS. To show this quantitatively, we selected nine portions of the scene to compare color to the original TM. These areas are 9 by 9 pixels centered at every 256-pixel interval, both in rows and columns. The results are shown in Table 1. They further support findings in previous research with laboratory-generated test images (Yocky, 1995).

As suggested by Carper *et al.* (1990), another method of quantifying the spectral changes resulting from the data merger is to determine the change in correlation between the pre- and post-merger multispectral and panchromatic data. A good merger technique should alter the correlation less when preserving spectral data. Still another method examines the correlation between original multispectral data and the merged products. This correlation should be high so that objects that were bright in the original multispectral bands are also bright on the merged image.

Table 2 shows the correlation results where PAN is the SPOT panchromatic. Note that the IHS correlation with the SPOT is very high compared to its correlation with the original TM. Although the IHS has the high spatial details of the SPOT, it also has many of the intensity characteristics of the SPOT at the expense of intensity (color) characteristics of the TM. On the other hand, the MWD has the high spatial details of the SPOT and yet has higher correlation with the original TM, meaning the merged intensities retain more of the TM spectral information.

Problems for the IHS and Standard Wavelet Mergers

The shortcoming of the IHS merger is that it assumes that the intensity is formed by even contributions from the RGB channels. In general, this is not true. The MWD merger is not dependent on this assumption. If the combination of spatial and spectral fidelity is important, the MWD merger provides another alternative. On the other hand, the IHS merger produces very clear spatial detail due to the substitutional nature of the merger. These images exhibit very good resolution transfer to the merged image. Thus, for non-classification problems and for image analysts, they could be appropriate data.

Also, the IHS transform cannot realize all colors in the RGB (chromaticity) space due to the color gamut being a finite triangle (Smith, 1978). Such an error is contrary to the desire of the data merger which should provide more information, or less error, than the original multispectral image. For classification, the degradation of the spectrum would not be acceptable because the individual bands are used to determine spectral signatures.

The IHS merger also changes the intensities of merged colors. This is shown in Plate 2, an image of the Rio Grande valley south of Albuquerque. Plate 2a is the original TM, Plate 2b is the SPOT, Plate 2c is the IHS merger, and Plate 2d is the MWD merger. In Plate 2c, the colors of fields by the river change due the difference in the reflectivity between the TM and SPOT. If the spectral information from the TM is important, it will be lost.

The MWD standard merger also has problems. The spectral content of small objects — one or two pixels — is lost with the multispectral image approximation substitution into the panchromatic pyramid. Also, because the MWD acts as high- and low-pass filters, the final reconstructed image may suffer from ringing. However, because the MWD merger has the pyramidal reconstruction, it may be possible to develop algorithms to minimize or eliminate these artifacts. The standard MWD may also have problems distributing pixel intensities in large, featureless areas like the fields in Plate 2d. Although the original TM colors (Plate 2a) are low reflectance and fairly uniform, the high reflectance SPOT (Plate 2b) and its wavelet coefficients cause ringing.

In response to the MWD's ringing effect in large, featureless objects and using the flexibility of the MWD pyramid structure, we propose two new merge techniques called the additive and selective resolution wavelet merger techniques.

Additive MWD Image Merging

In the standard MWD image merging technique, the wavelet coefficients from the multispectral are discarded and only the original low resolution energy distribution (approximation image) is used. This procedure limits the amount of information that can be combined. Another approach is to add the wavelet coefficients (detail images) for each resolution level and then perform the reconstruction. Thus, the detail information from both sensors is used.

For the additive MWD, the apparent spatial resolution of the final merge will be less than the standard MWD merger due to the blockiness of the larger TM pixels preserved as "detail" in the TM's wavelet coefficients. At the same time, the spectral fidelity of the additive MWD merger should increase (as measured by the correlation with the original TM).

An example of this technique is shown in Plate 3. In addressing MWD ringing and the IHS color change presented above, the additive MWD merger preserved the spectral information to a greater extent while increasing the spatial resolution. In fact, when there is little detail in a large area, the reconstruction of the merged TM spectrum is very close, if not identical, to the original TM. This result is due to the exact reconstruction ability of the two-dimensional wavelet transform and the minute values of the SPOT wavelet coefficients in those areas. The correlation of the additive MWD (AMWD) with the original TM and SPOT are shown in Table 3.

Selective Resolution MWD Merging

Because the MWD merger takes place in the context of a pyramidal structure, we are able to apply techniques at different resolutions. One application of this selective resolution ability is to allow the user to select the acceptable level of SPOT correlation trade-off with the TM correlation in the final product. Using *a priori* knowledge of spectral and spatial characteristics, the merged product can be "tuned" to selectively provide the user with the best MWD merger for the

Plate 3. The additive MWD (AMWD) merger of Plates 2a and 2b data.

task. This may be useful in developing merged data automatic target recognition (ATR) algorithms.

To demonstrate this flexibility, the south valley of Albuquerque data in Plate 2 is used again. A variation on the additive method is performed by adding in TM wavelet coefficients only up to selected pyramid levels (resolutions). Four separate selective resolution images were created. Starting with the 32 by 32 TM approximation image placed in the SPOT wavelet pyramid, TM and SPOT wavelet coefficients were added, ending at pyramid levels 64 by 64, 128 by 128, 256 by 256, and 512 by 512. In each case, the remaining resolution levels use only the SPOT wavelet coefficients in the final reconstruction to the 1024 by 1024 merged image. These merged images — called MWD64, MWD128, MWD256, and MWD512 — are shown in Plates 4a, 4b, 4c, and 4d, respectively. Their correlations with the original TM and SPOT images are also given in Table 3. From Table 3, the additional correlation with the TM data and decorrelation with the SPOT data is evident as more TM wavelet levels are used. The decorrelation with the SPOT data causes a slight degradation in the apparent spatial resolution as is seen in Plate 4.

The results in Table 3 suggest that arithmetic addition of TM and SPOT wavelet coefficients is channel-dependent, as can be expected. For example, the highest TM/merged correlation in the red channel for the Albuquerque south valley data occurs with the AMWD technique — addition at all resolutions. On the other hand, the green channel does not gain appreciable correlation after the 128 by 128 resolution (MWD128). Similarly, the blue channel reaches maximum correlation using MWD512. In addition, we are not constrained in how we combine the final RGB channels. We can choose AMWD for red, MWD128 for green, and MWD512 for blue. This type of selection is not possible with the IHS merger.

Discussion

The MWD merger has been compared to a RGB-type merger because the IHS is a three-space transform. On the other hand, the MWD merger was performed on independent channels, merging the information separately and then combining them using the display. This characteristic demonstrates the larger flexibility of the MWD merger. It can be used on two independent (black and white) channels or sets of data. This is something the IHS merger cannot do.

For both the IHS and MWD, perfect reconstruction is not possible. Most of the errors originate from the smoothing and sub-sampling of the original RGB. Sharp spectral edges are not reconstructed well due to the spatial quantization of the spectral image. Redistribution of the original energy is better accomplished by the MWD versus the IHS, as reflected in the correlation measures.

The pyramidal structure of the wavelet decomposition approach to image merger opens many possibilities for future algorithms. Yocky (1995) also found that some Daubechies wavelets gave better results than others in the merging results, which suggests a optimal wavelet for each merger. Weighted combinations of the panchromatic and multispectral (Carper *et al.*, 1990) is another option for the high resolution image used in the MWD merger.

The MWD merger's link to compression-type algorithms can be exploited in other ways. If sensors are coexistent on a platform, collection, compression, and merging of the data before transmission is a distinct and desirable possibility. Such on-board merging will reduce the transmission from two sensors to that of one and, because the data will be in a wavelet pyramid format, the merged data can be readily encoded with wavelet encoding algorithms. This could be extended to a multisensor data fusion approach which is not limited to images such as a signal compression and fusion process.

Conclusion

We have presented the utility of MWD image merger techniques in enhancing remotely sensed data. We discussed and presented standard, additive, and selective resolution MWD mergers using Landsat TM and SPOT panchromatic data. The MWD mergers were compared to the IHS image merger technique and were shown to possess the capability of preserving spectral qualities as well as enhancing spatial quality when combining low spatial resolution multispectral and high spatial resolution panchromatic images into a merged high spatial resolution multispectral image. The MWD can be used as a viable enhancement process.

Acknowledgments

This work was supported by Sandia Lab Directed Research and Development funding and by the United States Department of Energy under Contract DE-AC04-94AL85000.

References

Antonini, M., M. Barlaud, P. Mathieu, and I. Daubechies, 1990. Image coding using vector quantization in the wavelet transform domain, *Proceedings of the IEEE International Conference on Acoustics, Speech, and Signal Processing*, pp. 2297–2300.

Burt, P.J., 1989. Multiresolution techniques for image representation, analysis, and "smart" transmission, *Proceedings of the SPIE on Visual Communication and Image Processing IV*, 1199:2–15.

Carper, W.J., T.M. Lillesand, and R.W. Kiefer, 1990. The use of the intensity-hue-saturation transformations for merging SPOT panchromatic and multispectral image data, *Photogrammetric Engineering & Remote Sensing*, 56(4):459–467.

Chavez, P.S., Jr., 1986. Digital merging of Landsat-TM and digitized NHAP data for 1:24,000-scale image mapping, *Photogrammetric Engineering & Remote Sensing*, 52(10):140–146.

Chui, C.K., 1992. *An Introduction to Wavelets*, Academic Press, San Diego, California.

Cliche, G., F. Bonn, and P. Teillet, 1985. Integration of the SPOT panchromatic channel into its multispectral mode for image

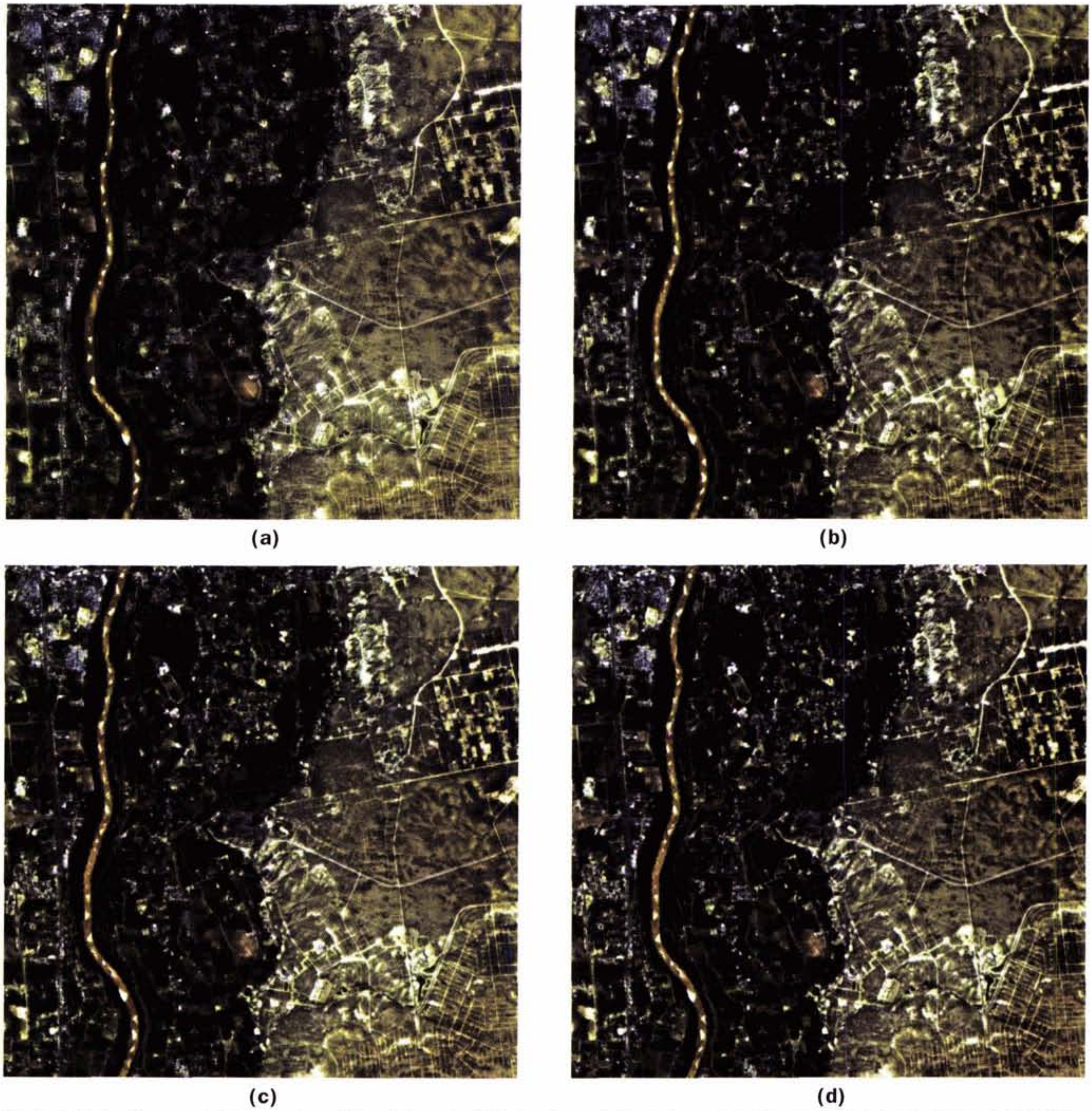

(a) (b) (c) (d)

Plate 4. Selective resolution merger of the data set of Plates 2a and 2b. (a) MWD64. (b) MWD128. (c) MWD256. (d) MWD512.

sharpness enhancement, *Photogrammetric Engineering & Remote Sensing*, 51(3):311–316.

Daubechies, I., 1988. Orthonormal bases of compactly supported wavelets, *Commun. Pure Appl. Math.*, 91:909–996.

———, 1990. The wavelet transform, time-frequency localization and signal analysis, *IEEE Trans. Inform. Theory*, 36(5):961–1005.

Froment, J., and S. Mallat, 1992. Second generation compact image coding with wavelets, *Wavelets: A Tutorial in Theory and Applications* (C.K. Chui, editor), Academic Press, San Diego, California, pp. 655–678.

Haydn, R., G.W. Dalke, J. Henkel, and J.E. Bare, 1982. Application of the IHS color transform to the processing of multisensor data and image enhancement, *Proceedings of the International Symposium on Remote Sensing of Arid and Semi-Arid Lands*, Cairo, Egypt, pp. 599–616.

Levine, M.D., 1985. *Vision in Man and Machine*, McGraw Hill, San Francisco.

Lewis, A.S., and G. Knowles, 1992. Image compression using the 2-D wavelet transform, *IEEE Trans. Image Proc.*, 1(2):244–250.

Mallat, S.G., 1989. A theory for multiresolution signal decomposition: the wavelet representation, *IEEE Trans. Pattern Anal. Mach. Intell.*, 2:674–693.

Moran, S.M., 1990. A window-based technique for combining Landsat Thematic Mapper thermal data with higher-resolution multispectral data over agricultural lands, *Photogrammetric Engineering & Remote Sensing*, 56(3):337–342.

Pradines, D., 1986. Improving SPOT images size and multispectral resolution, *Proceedings of the SPIE on Earth Remote Sensing Using the Landsat Thematic Mapper and SPOT Systems*, 660:98–102.

Price, J.C., 1987. Combining panchromatic and multispectral imagery from dual resolution satellite instruments, *Remote Sensing Environment*, 21(2):119–128.

Rosiene, J., and I. Greenshields, 1994. Standard wavelet basis compression of images, *Opt. Eng.*, 33(8):2572–2578.

Schowengerdt, R.A., 1980. Reconstruction of multispatial, multispectral image data using spatial frequency content, *Photogrammetric Engineering & Remote Sensing*, 46(10):1325–1334.

Shettigara, V.K., 1992. A generalized component substitution technique for spatial enhancement of multispectral images using a higher resolution data set, *Photogrammetric Engineering & Remote Sensing*, 58(5):561–567.

Smith, A.R., 1978. Color gamut transform pairs, *Computer Graphics*, 12(3):12–19.

Tom, V.T., M.J. Carlotto, and D.K. Scholten, 1985. Spatial sharpening of thematic mapper data using a multiband approach, *Opt. Eng.*, 24(6):1026–1029.

Wechsler, H., 1990. *Computational Vision*, Academic Press, San Diego, California.

Yocky, D.A., 1995. Image merging and data fusion using the discrete two-dimensional wavelet transform, *J. Opt. Soc. Am. A.*, 12(9): 1834–1841.

(Received 10 March 1995; accepted 17 July 1995; revised 25 August 1995)

Call for Technical Articles

The Editor of *Photogrammetric Engineering and Remote Sensing* invites high quality manuscripts for peer review and publication on the topics listed below. While materials are sought especially in these areas, contributors from all of the Society's core technologies are encouraged to submit material for review.

Technical

(All aspects of these topics are being sought.)

- Machine Vision and Close Range Photogrammetry
- New Airborne or Spaceborne Sensors
- Applications in Meteorology/Climatology, especially those integrating spectral and geospatial data (all scales of reference are being solicited from local to global)
- Scientific Visualization
- Integrated Global Observing Systems
- Feature-Based Identification Algorithms and Performance Evaluation
- Hyperspectral Data Processing
- Evaluations and Applications of RADARSAT, ERS, and Aerial Microwave Systems

For Theme Issues Scheduled for Sept.-Dec., 1997

(All aspects of these topics are being sought, but the intent is to achieve wide membership and general public interest)

- Machine Vision and Close Range Photography
- Biodiversity Models, Biostereometrics, Complex Emergent Systems
- Data Preservation and Archiving
- *Mapping and Monitoring Cold Places* (high latitude and high altitude)

Anniversary Issue of Landsat Scheduled for July, 1997

All aspects of this topic are solicited, especially those addressing the history of technical improvements in image processing and applications for geology, agriculture, soils and water, habitat mapping, urban places, and similar topics. Temporal comparisons, change detection, and multisensor data integrations are of interest. While this issue is intended to be a 25-year review, contributions should follow the general instructions to authors regarding length and format, (see p. 1048 this issue).