Geoinformation for European-wide Integration, Benes (ed.)

Radiometric and textural fusion of multiresolution Landsat 7 ETM channels for the improvement of visual image interpretation and land cover classification

M. Mroz
Department of Photogrammetry and Remote Sensing, University of Warmia and Mazury, Olsztyn, Poland

Keywords: ETM, coregistration, fusion

ABSTRACT: This paper presents a comparison of the most frequently used method RGB-IHS for fusion of Landsat 7 ETM+ multi-resolution bands with an approach based on introducing some textural coefficients issued from panchromatic band. The commonly used transformation RGB-IHS with the substitution of Intensity component by Panchro band leads to color alteration and changes of statistics of the input RGB components. This may have an influence on image interpretation and results of image classification. An approach based on texture coefficient application on the Intensity component is proposed in order to avoid color changes during process of spatial resolution enhancement. The results of this methodology can be seen on many figures presented in the paper. The images processed in this work were generated by ESA station using ACS processing chain. This algorithm make the coregistration of the pixels of different resolution (15m Panchromatic and 30m multispectral) in "center-to-center" geometry. Such a geometry of coregistration have an impact on texture formulation. An imperfection of bands coregistration was also stated during image processing.

1 INTRODUCTION

The main aim of the remote sensing data fusion is to extract more information about the imaged objects via improved image interpretation or automatic image classification. Different sensors give the complementary spectral information but often at different spatial (geometric) and temporal resolutions. All data fusion techniques and algorithms require a very high precision of geometric coregistration of the images to fuse. Some algorithms are also based on an assumption of their high temporal and/or spectral coherence. In the case of Landsat 7 ETM+ system the initial conditions for merging of multispectral channels with panchromatic channel, aimed at increasing their spatial resolution, are as follows:

- the panchromatic (PAN) and multispectral (MS) channels are registered simultaneously,
- both (PAN and MS) have the same external orientation of the scanner i.e. are *a priori* perfectly coregistered in the same geometry,
- three MS channels (2,3,4) are spectrally correlated with PAN channel because the PAN sensor maximum sensitivity is shifted towards near infrared wavelengths,
- accuracy of radiometric calibration is estimated and until now achieved at the 5 % level.

The spectral sensibilities of the bands processed in this work are shown in the fig.1. It is noticeable that in the case of ETM+ the term "panchromatic" describing the channel of higher spatial resolution is "no longer valid" compared with the well-known meaning of word "panchromatic". These properties of the system seem to be quite opportune to carry out the task of data fusion. The task consists in fusion of high spatial resolution (15m) information with lower (30m) but multispectral information.

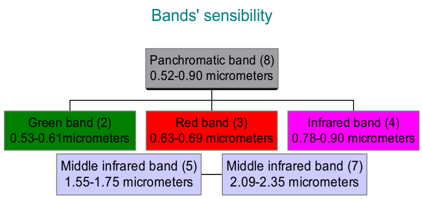


Figure 1. Spectral sensibility of ETM+ bands processed in this work.

The expected results are the color compositions conserving initial spectral characteristics of the origin channels and a good quality derivative layer in the form of classified image.

If the initial multispectral color composition is made using channels 4, 3 and 2 substituted for RGB plans (30m), the fusion with PAN (15m) can be done assuming that there is some luminance equivalent (balance) between PAN and a sum of luminances in MS 234 channels, coming from the same unit area (15x15m). Alternatively the fusion can be made applying the texture of the PAN image on luminance in MS channels (30m). The texture can be expressed as a spatial pattern of PAN luminance changes (15x15 m) within the same MS pixel area (30x30m).

If the initial multispectral composition is made using other subset of ETM+ channels (e.g. 4,7,5) only fusion based on texture is recommended because the radiometric comparison between these channels and PAN band is not justified.

2 SATELLITE DATA

2.1 *ETM+ data types*

Before performing the task of data fusion using the texture and/or radiometric balance it is important to know what algorithm of image formation was used by Processing and Archiving Facility (signal stream processing algorithm) during image production for the customer. Following the Landsat 7 Science Data Users Handbook there are two main systems of pixel coregistration for PAN and MS channels: LPGS and NLAPS. The two systems use slightly different output projection pixel placement schemes. LPGS products have map coordinates that are pixel center based. NLAPS coordinates assign coordinates to the upper left corner of the pixel. The processing chain used by ESA's PAFs, called ACS system, is pixel center based and this system was used for production of images by Neustrelitz station.

Briefly speaking the scene center defined by Latitude/Longitude ellipsoidal coordinates is placed in the pixel center both for PAN and MS channels. It means that PAN channel pixels are geometrically shifted by one half pixel (7.5m) in relation to MS channel pixels when PAN grid is overlaid on MS grid. The pixels in MS channels must be duplicated (image resized) for the same dimensioning of the plans displayed in the form of color composition. These differences in pixel placement must be taken into account for proper calculation of the texture pattern and luminance values in data fusion process. The relative placement of both pixel grids is illustrated in Fig.2. The color squares represent 30-m, MS pixels and black lines represent the grid of PAN pixels. The bottom of the fig.2 shows the example how the pixels originating from 15-m PAN band cover partially the areas represented by adjacent pixel values in 30-m MS bands. Another important parameter is signal resampling method used in image production. It seems that a simple nearest neighbor (NN) algorithm should be used rather than any signal interpolation for future texture analysis.

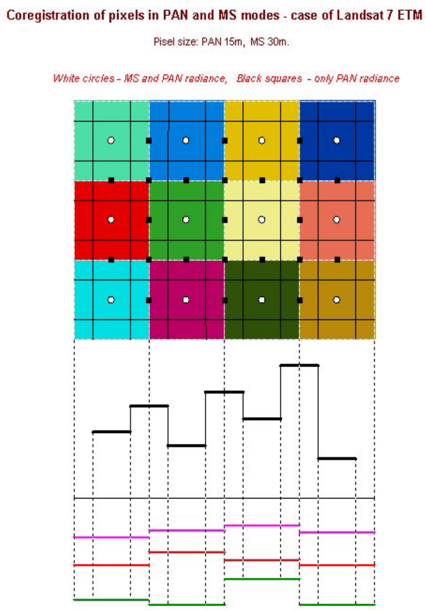


Fig 2. Pixel placement scheme for LPGS/ACS processing chains.

ETM+ images generated at ESA stations can be prepared either using NN or Cubic Convolution resampling and geometrically transformed into two projections: Path Oriented ("in satellite geometry") or Map Oriented (standard UTM zones). The image used in this work is "System Corrected" (level 4 defined by ESA, equivalent to level 1G of NASA).

2.2 *Geometric performance of ETM+ bands (Irish 2001)*

The geometric performance of the ETM+ is judged against three key requirements placed on the Landsat 7 system. They are:

- Absolute Geodetic Accuracy (AGA): Geometrically corrected products shall be accurate to 250 meters (1 sigma), excluding terrain effects, without ground control. Limited by spacecraft instrument geometric model accuracy (e.g., ephemeris, attitude, alignment knowledge),

- Band-to-Band Registration (BtBR): Geometrically corrected products shall have the multispectral bands registered to 0.17 pixels (1 sigma): Limited by focal plane alignment and stability. I.e. 5.1m for bands 1-5 and 7 or 2.55m for band 8 (PAN).
- Image-to-Image Registration (ItIR): Geometrically corrected images from multiple dates shall be capable of being registered to an accuracy of 7.3 meters (1 sigma). Limited by high frequency distortions within images (e.g., uncompensated attitude jitter, scan mirror instability).

Band-to-band registration assessment is performed periodically throughout the mission's life. The purpose of this assessment is to measure the relative alignment of the eight ETM+ spectral bands after processing to Level 1G for verification that the 0.17 pixel band-to-band registration requirement is being met.

Band registration is monitored using desert scenes as they provide the best cross-band correlation performance. The band center locations measured pre-launch were evaluated using on-orbit data updated using calibration scenes during the in-orbit checkout period (first 90 days). The measured band registration accuracy was 0.06-0.08 pixels. However, the registration accuracy degraded after July, 1999. Measurements revealed that registration between the primary and cold focal planes in the line direction increased to 0.08-0.10 pixels (about 1.5 m for PAN and 3m for MS channels).

2.3 *Data processed*

The processed image was registered 10 Sept. 1999 and a floating scene was generated by Neustrelitz station using software release TMFR-VR1.4.0. Processing level 4 was chosen with “Path Oriented” geometry and NN signal resampling method. After deep inspection and careful examination of data quality it was stated that there exist a visible and clear shift of details in PAN band compared with MS channels. Further precise analysis of this shift on many sharp, linear objects permitted to state that the shift is about 3 pixels and 1 row in PAN space.

Two color compositions were done using bands 4,7,5 as RGB plans and merged with PAN via commonly used RGB-IHS-RGB transform, substituting Intensity component with PAN image. The first composition was done on the basis of ESA’s specifications concerning the coregistration geometry. The other one was prepared taking into account the noticeable shift.

The differences between these two compositions are shown in Fig.3a,b,c,d. The influence of PAN band mis-registration is clearly visible.

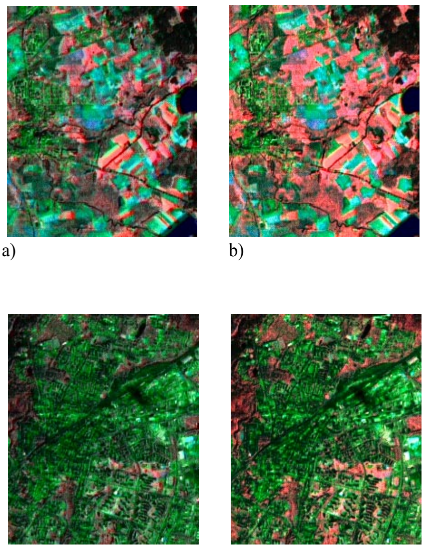
At this moment the following question arises: is it possible that the geometric shift is only due to the image geometry imperfection or does this misregistration result from time sampling errors (for example) ? In the second case the radiometric values (radiances, luminances) captured from the elementary areas and transformed into Digital Numbers representing pixels may not correspond properly to the same areas in all MS and PAN bands. Indeed, the a priori assumption that there is an energy equivalent (energy balance) between bands 2,3,4 and PAN may not be proved correctly.

In this situation the simpler methodology of PAN and MS bands fusion was adopted as described in chapter 3.

3 METHODOLOGY AND RESULTS

The MS data set was split into two subsets:

- bands 2,3,4 - spectrally correlated with PAN band,
- bands 4,5,7.



a) b) c) d)

Figures 3a,b,c,d. Differences in image sharpness without and with PAN shift applied

Each of them was then merged with PAN band following two approaches:

- well-known RGB-IHS-RGB transformation based on formulas implemented in EarthView software package ver.4.4.1. of Atlantis Scientific Inc., where *Intensity* component issued from 30-m color composition is replaced by the PAN band,
- using texture coefficient issued from PAN band, applied on *Intensity* component.

As can be seen in table 1, the bands 5 and 7 (middle infrared) are highly correlated with bands 2 and 3 (visible). Correlation coefficient is about 0.8 – 0.9. The bands 5 and 7 are characterized by higher Signal to Noise Ratio and a lower influence of atmospheric haze, so in many general applications of satellite images these bands can be used alternatively or even preferably for spacemaps creation and land cover classification.

Table 1. Correlation matrix of ETM+ channels

PAN	Etm2	etm3	etm4		etm5	etm7
etm2	1.00	0.95	0.40	0.80	0.87	0.67
etm3	0.95	1.00	0.30	0.80	0.92	0.60
etm4	0.40	0.30	1.00	0.67	0.42	0.86
etm5	0.80	0.80	0.67	1.00	0.91	0.81
etm7	0.87	0.92	0.42	0.91	1.00	0.67
PAN	0.67	0.60	0.86	0.81	0.67	1.00

3.1 *RGB-IHS transform*

This processing chain was used as an reference processing because it is rather simple to carry out, well documented, implemented in many software packages and largely used by remote sensing community.

- Subset 1

The first step was to create a color composition from bands 4,3,2 displayed as RGB plans (standard color composition). The original histograms were minimally stretched, about 0.2% on the right side and 0 % on the left one of the histogram. The resulting composition is shown in the fig.4.

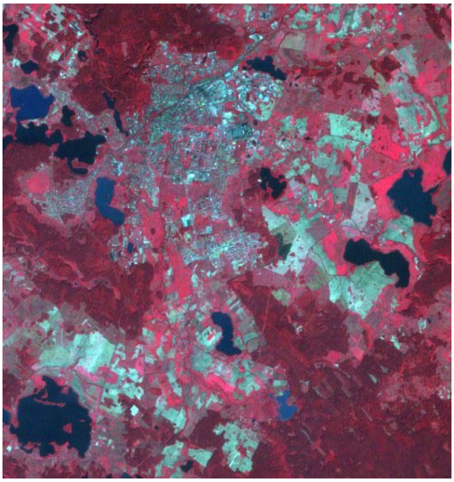


Fig 4. Color composition 4,3,2 as RGB (30m)

The histograms of the components RGB are shown in fig.5a,b,c.

a) b) c)

Figure 5.a,b,c. Histograms a),b),c) of the components RGB.

To perform the task of RGB-IHS-RGB transformation it is needed to have the Intensity and PAN images resized to the same number of rows and columns. This can be done by replication (multiplication) of the number of pixels of Intensity image in rows and columns by 2.

The above-mentioned shift of ¼ of linear size of MS pixel still exists. In order to avoid this misplacement the Intensity (30m) pixels must be “divided” by 4, it means in practice multiplied (replicated) by factor of 4 and PAN pixels divided by factor 2. Cutting the first row and first column of the resized images can lead to putting the PAN and Intensity pixels (having now dimensions 7.5 x 7.5m) center-to-center. The examples are given in figure 6. a,b,c.

However, geometric shift alone does not resolve the problem of proper radiometric fusion regardless of the method applied. New, the most probable values of new 15-m MS pixels must be found. As shown in Fig.6., the first values put in cases are assigned to MS bands and values after slash come from PAN band. For practical reasons the simple, linear interpolation method was used for calculation of new values for the new MS pixels correctly placed against PAN grid and having now 15x15m size.

MS pixel border -
PAN pixel border -

20	20	20	20	30	30	30	30
20	20/5	20/5	20/3	30/3	30/4	30/4	30
20	20/5	20/5	20/3	30/3	30/4	30/4	30
20	20/7	20/7	20/5	30/5	30/2	30/2	30
40	40/7	40/7	40/5	10/5	10/2	10/2	10
40	40	40	40	10	10	10	10
40	40	40	40	10	10	10	10
40	40	40	40	10	10	10	10

a) Original placement and pixel values

	C	U	T R	T O	E W	D	
C C	20/5	20/5	20/3	30/3			
U O	20/5	20/5	20/3	30/3			
T L	20/7	20/7	20/5	30/5			
T U	40/7	40/7	40/5	10/5			
E M							
D N							

b) Shifted placement

	C	U	T R	T O	E W	D	
C C	20/5		25/3				
U O							
T L	30/7		25/5				
T U							
E M							
D N							

c) New values for new MS pixels (15m)

Figure 6a,b,c. Geometric adjustment of grids with pixel values interpolation.

Having MS and PAN bands fully coregistered and resized RGB-IHS transformation was performed. The substitution of PAN image for the Intensity component needs some contrast stretch or other histogram modification in order to conserve initial image dynamics after IHS-RGB re-conversion.

In this work histogram matching (PAN-to-Intensity) procedure was implemented to avoid strong colors degradation after the substitution. Fig.7 shows three histograms: red for original PAN band, blue for Intensity component and green for PAN band after the application of the matching procedure.

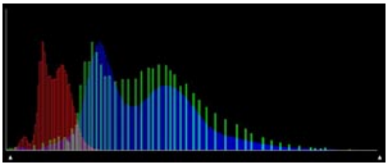


Fig 7. Histograms for PAN image, Intensity and PAN matched.

The final composition after RGB-IHS-RGB transformation is shown on fig.8. Of course the histograms have changed as shown below (Fig.9).

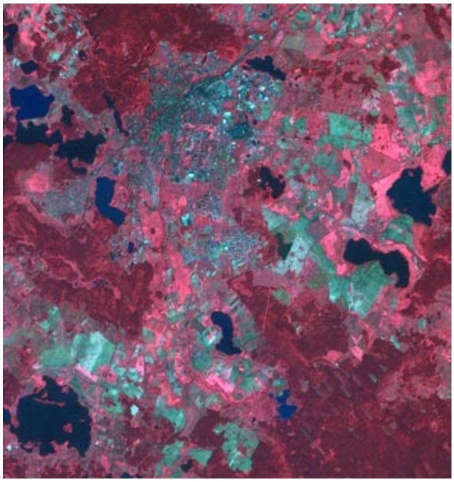


Fig. 8. The final composition after RGB-IHS-RGB transform.

Fig. 9. Histograms of RGB plans after fusion with PAN using RGB-IHS method.

- Subset 2

The subset two of bands 4,5, and 7 was processed as follows:

1. The main aim was to perform the color composition in pseudo-natural colors, easily interpreted even by those who are not specialists on remote sensing. As it was shown before there is a high correlation between visible and middle infrared channels. Additionally the infrared bands are not influenced by atmospheric haze as strongly as visible band. On the scene processed atmospheric effect was quite strong on large areas.
2. The original contrast of channels was enhanced using exponential and linear functions. Histogram equalization was performed for band 4.
3. The pseudo-natural colors were generated based on algorithm elaborated initially for SPOT [band 2 = ((3 * XS1 + XS3)) / 4].
4. The last operation to perform was the integration of this color composition with PAN channel to improve spatial resolution.

Figures10a. and b. show the result of the fusion using RGB-IHS-RGB transform as previously described for Subset 1. The use of RGB-IHS-RGB transformation as described for Subset 1 is not recommended at all. The new color composition becomes of course sharper and more details in urban and suburban areas can be distinguished but the colors are dramatically changed. The first reason is histogram shape and statistics different for both PAN and Intensity images same like in the case of Subset 1. The second reason is more complex and more important. Because of the spectral characteristics of soils (wet or dry) and vegetation, in the PAN band the pixel values for vegetation are higher than for soils, whereas in the Intensity image they are higher for dry soils than for vegetation.

As a consequence the green color representing vegetation becomes more and more clear (even yellow) and slightly pale pink color representing dry soils changes after transformation into magenta.

The changes in colors are also evident changes in histograms and statistics so alternative approach based on a texture image is proposed further on.

3.2 *Texture formulation*

The results of processing described in previous chapter lead to conclusion that the use of PAN channel for spatial resolution enhancement of Landsat 7 ETM+ MS color compositions must be based taking into account rather textural properties of PAN channel than simple values of the pixels.

There are many ways, less or more sophisticated, to describe, calculate and analyze the texture of the image According to the approach adopted in this work, the coefficient of texture should have two important properties:

1. The application of this coefficient should not change the statistics of input bands (the mean value before and after processing should be the same)
2. The coefficient issued from PAN band (15m pixel size) should express the texture of the imaged elementary ground area covered by each, homogeneous, 30-m MS pixel.

The most intuitive and simple texture coefficient (TEX_COEFF) was calculated with following formula:

$$TEX\_COEFF\_22 = DN_i / Average\ (DN_n) \qquad (1)$$

Where: DN_i - value of the i-th PAN pixel in window 2x2;
Average (DN_n) - average value of the "n" adjacent PAN pixels covering one MS pixel, here n=4.


a)

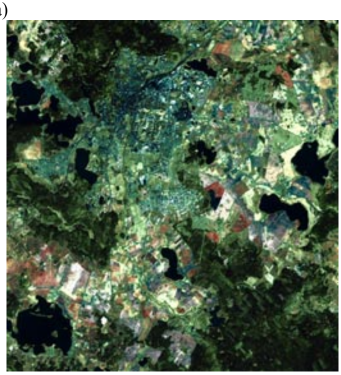

b)

Figure 10a,b. Color composition issued from preprocessed bands 5,4,7 before (a) and after (b) fusion with PAN band using RGB-IHS-RGB transformation.

This coefficient expressed in the form of "image of texture" is next multiplied by Intensity image. This way is justified because it was largely approved that "the texture of images is a result of spatial differentiation of the luminance of the scene what can be associated to the Intensity". It is analogue to the practice of color images filtering. Rather Intensity component is only filtered than all three RGB components.

As shown in figure 6.c. the value for new MS 30m shifted pixel must be averaged from 4 adjacent new MS 15m pixels. Otherwise the simple multiplication of texture coefficient by intensity image can affect original mean value of intensity image.

Another texture coefficient (TEX_7.5) was also tested. The principle of calculation of this coefficient was the same but the adjacent and neighbor pixels were differently defined. This approach is illustrated in the fig.11 where digital values are represented by gray levels. The spatial pattern of values coming from divided by 2 PAN band pixels was applied on geometrically corresponding Intensity pixel.

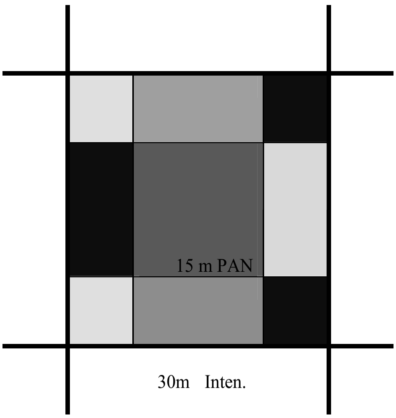


Figure 11. Idea of texture definition for coefficient TEX_7.5 calculation

- Subset 1

The texture coefficient TEX_COEFF_22 applied on Intensity component and followed by inverse transformation IHS-RGB gives the composition showed in figure 12a.

Figure 12.b represents the histograms of its RGB components. They look like the origin histograms (see figure 5a,b,c), so it can be expected to obtain the comparable results of image classification as in the case of origin bands.

The comparison of details distinction after application of different processing procedures is possible in figure13.a,b,c,d.

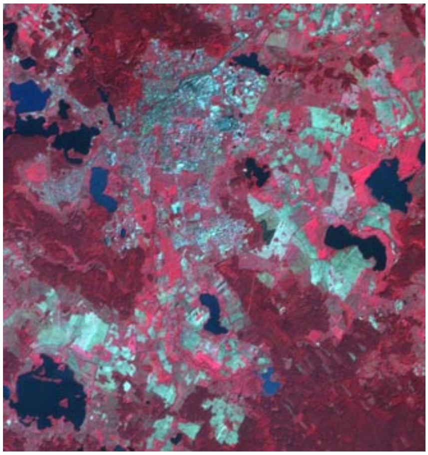


Figure 12a. Color composition 4,3,2 after TEX_COEFF_22 application.

Figure 12b. Histograms of RGB components after TEX_COEFF_22 application.

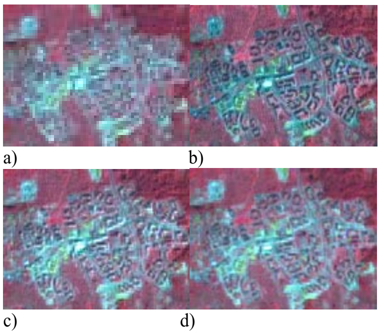


Figure 13. a) origin, b) RGB-IHS with PAN band, c) TEX_COEFF_22 applied, d) TEX_7.5 applied

- Subset 2

Figure 14 shows the image processed with TEX_COEFF_22 on the composition of origin, presented above in figure 10a. The reader is encouraged to compare the colors in these figures.

As in the case of subset 1 the comparison of details distinction after three different processing procedures applied is possible in figure 15.a,b,c.

Figure14. Color composition issued from preprocessed bands 5,4,7 after TEX_COEFF_22 application

a)

b)

c)

Figure 15.a) the image of origin, b) RGB-IHS with PAN band, c) TEX_COEFF_22 applied

4 DISCUSSION AND CONCLUSION

Spatial resolution enhancement of multispectral ETM+ color compositions using panchromatic band can be done properly after checking if the bands' co-registration is proper. The images generated using the ACS processing chain present also a constraint of coregistration center-to-center. As shown above an micro-adjustment should be performed for full geometric "compatibility" of bands. The spectral sensibility of panchromatic channel is shifted towards near infrared and this property can lead to strong color changes on the composition if transformation RGB-IHS-RGB is performed as commonly used. The application of texture coefficients may be another solution. In the presented work the simple coefficients were used and results of details detection were worse than using transformation RGB-IHS.

The methods of MS and PAN fusion using the images generated with the recent ACS software version and with cubic convolution signal resampling during image generation will be examined in the near future.

ACKNOWLEDGMENTS

The author wishes to thank ESA/ESRIN for reprocessing the ETM+ data with the latest version of the TMFR software. These images were not yet processed before the conference.

REFERENCES

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

Chavez, P. S. Jr., S. C. Sides, and J. A. Anderson, 1991. Comparison of three different methods to merge multiresolution and multispectral data: Landsat TM and SPOT panchromatic. *Photogrammetric Engineering & Remote Sensing*, 57(3):265-303. Irish R. 2001 Landsat 7 Science Data Users Handbook". NASA Goddard Space Flight Center, Greenbelt, Maryland.

Wald, L., T. Ranchin, and M. Mangolini, 1997. Fusion of satellite images of different spatial resolutions: assessing the quality of resulting images. *Photogrammetric Engineering & Remote Sensing*, 63(6): 691-699.