Data fusion for a better knowledge of urban areas

Lucien Wald, Thierry Ranchin

Data Fusion for a Better Knowledge of Urban Areas

Lucien Wald and Thierry Ranchin

***Abstract*--This paper demonstrates the benefits of fused products for the analysis and mapping of urban areas. The fused products result from the synthesis of multispectral images at higher spatial resolution *h*, starting from a panchromatic image at resolution *h* and multispectral images at a lower resolution *l*. The application of the method ARSIS- RWM to the city of Marseille is discussed. It is further demonstrated that synthetic images may support further image processing dealing with the high frequencies.**

***Index Terms*--methods for data fusion, fusion of images, ARSIS, Marseille**

I. INTRODUCTION

IN various applications, the benefit of having images with the highest spectral resolution (or the largest number of relevant modalities) and the highest spatial resolution has been demonstrated. On the one hand, the high spatial resolution is necessary for an accurate description of the shapes, features and structures. On the other hand, depending on the application and the level of complexity of the observed scene, the different objects are better identified if high spectral resolution images are used. Hence, there is a desire to combine the high spatial and the high spectral resolutions with the aim of obtaining the most complete and accurate description of the observed scene. However the sensors offer either high spectral resolution and low spatial resolution, or low spectral resolution (broadband) and high spatial resolution. Hence research has developed, which aims at proposing algorithms for fusing both types of images, in order to synthesize images with the highest spectral and spatial resolutions available in the sets of images. These synthesized images should be as close as possible to reality and should simulate what would be observed by a sensor having the same modalities but the highest spatial resolution.

There exists several methods, which provide a better visual representation of the image (see e.g. [1]). They are very useful for photo-interpretation. This is particularly true when the number of spectral bands is much larger than the usual three bands for describing colors: red, green, blue. However, such methods have their limitations, especially with the new space-borne sensors and the most recent techniques, which allow the reconstruction of high spatial resolution landscapes with objects having their natural colors. Here, in this context, natural colors mean the colors that are perceived by the human eye. Examples are the recent commercial space missions (Ikonos, Orbview, ...), which provide, or will provide, images with high spatial resolution images at 1 m, and three multispectral images at 4 m, taken in the red, green and blue bands. Ikonos has an additional near infrared band at 4 m. These fusion methods are sometimes called "band sharpening". Care should be taken. "Band sharpening" may be performed to increase the utility of a set of images for visual analysis, while the synthesis of image aims at producing actual images of higher spatial and spectral resolutions. This type of methods is not dealt with here.

The accurate synthesis of the multispectral character is very important to many applications, including those calling upon classification or the reproduction of the natural colors. Classification processes often use bases of spectra (multi-modality signatures), which result from measurements or simulations by models or from the experience of image analysts. In the course of the classification, the observed spectra are compared to the known ones and a decision is taken according to their similarities. Accordingly, any error in the synthesis of the multi-modality signatures at the highest spatial resolution induces an error in the decision.

This paper examines the fusion of optical images with emphasis on urban areas. These landscapes offer a very large diversity of both spectral signatures and high spatial frequencies. Accordingly, they enhance the qualities and drawbacks of a method [2].

II. DIFFERENT METHODS IN DATA FUSION AND THEIR PROPERTIES

Several methods for fusion have been published or are available in commercial softwares. They differ in the way they respect the three properties. Considering the methods that are used and known, reference [3] distinguished three groups of methods: the projection and substitution methods, the relative spectral contribution methods and the methods relevant to the ARSIS concept. Evidently, there are some hybrid methods belonging to more than one group.

The methods belonging to the first group perform a projection of original data sets into another space, a substitution of one vector by the high resolution image and finally an inverse projection into the original space [1]. The IHS (Intensity, Hue, Saturation) method is certainly the more

Manuscript received September 30, 2001. The French space agency CNES provided the images over Marseille.

Both authors are with the Ecole des Mines de Paris, BP 207, 06904 Sophia Antipolis, France, (telephone: 00-33493957449, e-mail: lucien.wald@ensmp.fr).

popular. The PCA (Principal Component Analysis) method is also well-known.

The second group is called relative spectral contribution. In these methods, it is assumed that the modality A_l is the weighted sum of the spectral images B_{kl} at resolution l. The ratio A_h to the sum of B_l (i.e., A_l in this hypothesis) is used to modulate each B_{kl} to provide B_{kh}. Among the most known of these methods are the Brovey transform [4] and the CNES P+XS method [5].

In the third group, methods perform a scale by scale description of the information content of both images and synthesis of the high-frequency information missing to transform the low spatial resolution images into high spatial resolution high spectral content images. This concept is called ARSIS and reference [3] showed that it has developed in several methods. Among them are the High-Pass Filtering (HPF) method [6], and three models presented in reference [3], making use of wavelet transform: Model 1, Model 2 and RWM.

Not all fusion methods provide equivalent results. A careful selection of the appropriate algorithm should be made. Otherwise, it may result into major drawbacks.

From the survey of the literature dealing with the comparisons of the methods above-cited [2, 3, 6-14], the operational properties of these methods were drawn out by [10]. It was found that the ARSIS-Model 2 and -RWM methods perform the best. They achieve very good quality products. The quality of the synthesis of the predominent triplets is impressive. Another striking feature compared to the other methods is that they are capable of achieving good results for all modalities [12]. All published comparisons with existing methods show that the ARSIS concept, combined with the wavelet transform and the multiresolution analysis leads to the best presently achievable results.

III. ILLUSTRATION IN URBAN MAPPING: THE CASE OF MARSEILLE

Fused products are of high benefits in the study of urban areas [15]. This is illustrated in this section, where airborne images are used for the synthesis of multispectral images of highest spatial resolution. The method used is the ARSIS-RWM method. The urban area under concern is the oldest part of Marseille, France.

Airborne images were acquired in 1993 by the CNES, the French space agency, to simulate the future satellite SPOT 5. The original images were processed to simulate multispectral bands XS similar to those of the systems SPOT 1-3, with a spatial resolution of 5 m.

The panchromatic image P (A_h) has a resolution of 2.5 m (Fig. 1). Many details can be seen. The old harbor is seen in the middle left in black tones. Docks are clearly visible, but boats are not discernible. The network of streets appear clearly though sometimes a street is masked by high buildings. One can distinguish vehicles. Blocks of houses are well defined; their inner courts are visible.

In the middle of the upper part is a large building in clear tones, having a "L" shape. It is a commercial center; one can see some structural elements on the roof. A garden is enclosed in the interior of the "L". It is hardly visible in dark gray levels but some paths can be distinguished in white. This garden contains the oldest remains of the city founded by the Phoenicians. A magnification of this sub-area is shown in Fig. 3 (upper left).

Analysis of such panchromatic images is very useful for urban mapping. However, several published studies reveal that image analysts find profitable to have also color composite along the panchromatic band. The color composite better displays vegetation and trees along the streets. They may also offer details in the black areas of the panchromatic image. A color composite has been built from the three original images *XS* with a resolution of 5 m and is displayed in Fig. 2. In the old harbor, docks and boats are in blue and cannot be distinguished. Streets are in blue, large buildings and bare soils, too. Blocks of houses are in green, vegetation is in red. The large red spot in the upper middle is the garden. The blue mass on its side is the commercial center.

The color compositing is performed by a dynamic allocation of color codes to color classes respective to the frequencies of the triplets [16]. However, in this case, the coding is performed for each set separately. This permits a better exploitation of the information contained in the sets of images, and explains why the color composites may vary from one image to the other.

Three multispectral images *XS*1, XS*2* and *XS*3* were synthesized at the resolution of 2.5 m by the means of the method ARSIS-RWM using the panchromatic image *P*. The color composite of these synthesized images for the sub-area above-mentioned is shown in Fig. 3 (middle left). This image offers much more details than the color composite of the original images *XS* (upper right). Docks are more separate; streets are better defined and trees are better delineated. The color tables of both images are not the same, but the colors of both images are very close. This means that the statistical distributions of the spectra are very close between both images, which is expected. It demonstrates the quality of the transformation of the spectral content when increasing the spatial resolution.

Compared to the panchromatic image, the use of color at this high resolution is highly profitable. Streets are more visible, because on the one hand of the various hues of the asphalt, and on the other hand of the trees bordering them. Even boats are more distinguishable because they offer some colors that are not noticeable in the panchromatic image.

Fig. 3 helps in judging the quality of the fused product and the benefit of the fusion. The panchromatic image is in the upper left. The color composite of the original images *XS* is in the upper right. Comparing those two, one may see that the panchromatic image offers more structural details, owing to its better spatial resolution: see e.g., the structural elements on the roof of the commercial center, or the network of the streets.

On the other hand, owing to its better spectral resolution and its multi-modality properties, the color composite displays information that cannot be seen in the panchromatic image. Vegetation is an example of such information: it appears in red. The color composite shows the garden, the flowerbeds close to the old harbor (bottom left) at the entrance of the famous avenue "la Canebière" (ranging from lower left to middle right) and the trees along the large avenue on the right part, perpendicular to "la Canebière". Looking to both images, one feels the need of fusing both images to obtain a better description of the city.

The flowerbeds are better delineated. The trees along the avenue are better seen; the width of the streets can be assessed with more accuracy. This high-quality transformation of the spectral content of set of images *XS* when increasing the resolution allows the application of a classifier, automatic or not, in order to extract the roads and the buildings. Hence, these synthesized images can be used for classification, or for other methods that need to use the multispectral content provided by the whole set of images with the best spatial resolution available.

Further processing may be performed on these synthesized images *XS**. A Laplacian filter was applied to sharpen the contours. The resulting color composite is displayed in the middle right in Fig. 3 and exhibits striking features. The elements on the roof of the commercial center are well delineated. Each tree appears individually and vehicles are visible. In the garden, the paths are clearly distinguished. The small spots in blue tones are the Phoenicians remains. This color composite can be compared to the photograph of the garden exhibiting the paths and the remains (lower left in Fig. 3). The author took this photograph with his back towards the commercial center and looking to the West, *i.e.* the left side of the airborne image.

IV. Conclusions

Only a very few methods achieve presently satisfactory results in fusing images for the synthesis of multispectral images at a better spatial resoltuion. These methods are the ARSIS-Model 2 and ARSIS-RWM methods. Further investigations are needed to improve these methods or design new ones that perform better on the one hand, and to verify that these two methods can enter a production system delivering fused products with a controlled quality on the other hand.

The benefits of the fused products for the analysis and mapping of the center of the city is demonstrated through an example of the fusion of airborne images over the city of Marseille, France. The use of color images having a high spatial resolution permits clearly a more accurate interpretation of the features in the city. Furthermore, such fused products may be the object of further image processing techniques, without creation of visible artefacts. This is exemplified by the analysis of that part of the city, wherein remains of the old Phenician city are visible. It illustrates the capability of the synthetic images to support further image processing dealing with the high frequencies.

References

[1] W. J. Carper, T. M. Lillesand, and R. W. Kiefer, "The use of Intensity Hue Saturation transformations for merging SPOT panchromatic and multispectral image data," *Photogrammetric Engineering & Remote Sensing*, vol. 56, pp. 459-467, 1990.

[2] L. Wald, T. Ranchin, and M. Mangolini, "Fusion of satellite images of different spatial resolutions: assessing the quality of resulting images," *Photogrammetric Engineering & Remote Sensing*, vol. 63, pp. 691-699, 1997.

[3] T. Ranchin and L. Wald, "Fusion of high spatial and spectral resolution images: the ARSIS concept and its implementation," *Photogrammetric Engineering & Remote Sensing*, vol. 66, pp. 49-61, 2000.

[4] C. Pohl, and J. L. van Genderen, "Multisensor image fusion in remote sensing: concepts, methods and applications," *International Journal of Remote Sensing*, vol. 19, 5, pp. 823-854, 1998.

[5] Anonymous, "Guide des utilisateurs de données SPOT," 3 tomes, Editeurs CNES et SPOT-Image, Toulouse, France, 1986.

[6] P. S. Jr. Chavez, S. C. Sides, and J. A. Anderson, "Comparison of three different methods to merge multiresolution and multispectral data: Landsat TM and SPOT panchromatic," *Photogrammetric Engineering & Remote Sensing*, vol. 57, pp. 265-303, 1991.

[7] M. Mangolini, T. Ranchin, and L. Wald, "Fusion d'images SPOT multispectrales (XS) et panchromatique (P), et d'images radar," *In* De l'optique au radar, les applications de SPOT et ERS, pp. 199-209. Cépaduès-Editions, 111 rue Vauquelin, Toulouse, France, 574 p., 1993.

[8] C. K. Munechika, J. S. Warnick, C. Salvaggio, and J. R. Schott, "Resolution enhancement of multispectral image data to improve classification accuracy," *Photogrammetric Engineering & Remote Sensing*, vol. 59, 1, pp. 67-72, 1993.

[9] T. Ranchin, and L. Wald, "Comparison of different algorithms for the improvement of the spatial resolution of images," *In* Proceedings of the third conference "Fusion of Earth data: merging point measurements, raster maps and remotely sensed images," Sophia Antipolis, France, January 26-28, 2000, Thierry Ranchin and Lucien Wald Editors, published by SEE/URISCA, Nice, France, pp 33-41, 2000.

[10] V. S. Raptis, R. A. Vaughan, T. Ranchin, and L Wald, "Assessment of different data fusion methods for the classification of an urban environment," *In* Proceedings of the second conference "Fusion of Earth data: merging point measurements, raster maps and remotely sensed images", Sophia Antipolis, France, January 28-30, 1998, T. Ranchin and L. Wald Editors, published by SEE/URISCA, Nice, France, pp. 167-182, 1998.

[11] P. Terretaz, "Comparison of different methods to merge SPOT P and XS data: Evaluation in an urban area," *In* Proceedings of 17th Symposium of EARSeL, Future trends in remote sensing, Lyngby, Denmark, 17-20 June 1997, P. Gudmansen editor, A. A. Balkema, Rotterdam, Brookfield, pp. 435-445, 1997.

[12] L. Wald and J. M. Baleynaud, "Observing air quality over the city of Nantes by the means of Landsat thermal IR data," *International Journal of Remote Sensing*, vol. 20, pp. 947-959, 1999.

[13] R. Wiemker, B. Prinz, G. Meister, R. Franck, and H. Spitzer, "Accuracy assessment of vegetation monitoring with high spatial resolution satellite imagery," *International Archives of Photogrammetry and Remote Sensing*, vol. XXXII, Part 7, pp. 285-292, 1998.

[14] J. Zhou, D. L. Civco, and J. A. Silander, "A wavelet method to merge Landsat TM and SPOT panchromatic data," *International Journal of Remote Sensing*, vol. 19, pp. 743-757, 1998.

[15] Couloigner I., Ranchin T., Valtonen V. P., Wald L., 1998. Benefit of the future SPOT 5 and of data fusion to urban mapping. *International Journal of Remote Sensing*, 19, 8, 1519-1532.

[16] M. Albuisson, "Codage trichrome et classification.," In *Outils micro-informatiques et télédétection de l'évolution des milieux : troisièmes journées scientifiques du réseau de télédétection de l'UREF*, pp. 167-

173. Presses de l'Université du Québec, Sainte-Foy, Québec, Canada, 444 p., 1993.

Figure 1. Panchromatic image of the oldest part of the city of Marseille, France. The spatial resolution is 2.5 m. © CNES 1993

Figure 2. Color composite of the same area of Marseille. Spatial resolution is 5 m. © CNES 1993

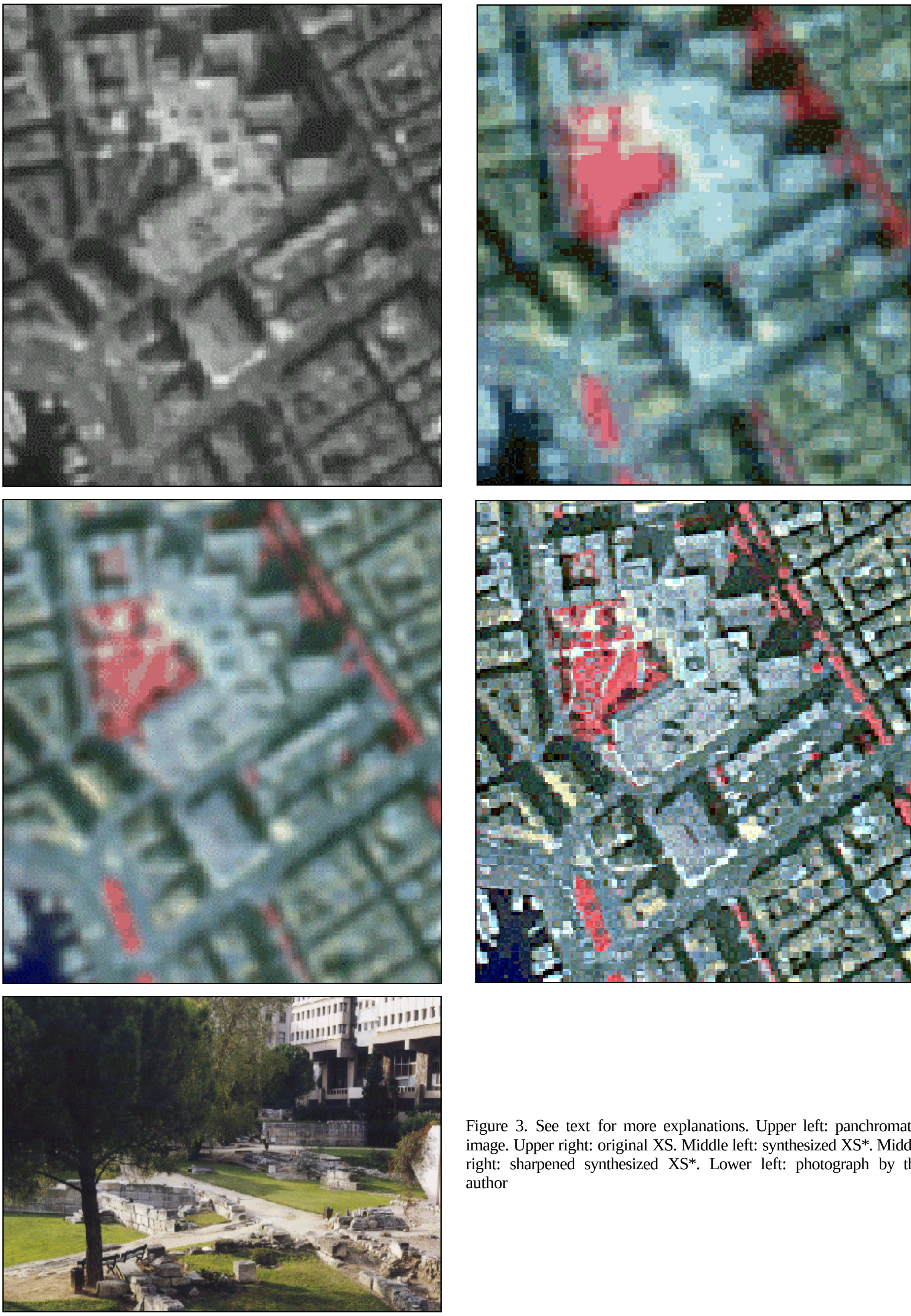

Figure 3. See text for more explanations. Upper left: panchromatic image. Upper right: original XS. Middle left: synthesized XS*. Middle right: sharpened synthesized XS*. Lower left: photograph by the author