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Key words: FORMOSAT-2, SPOT-6, fusion techniques, accuracy, land cover/use.

ABSTRACT

The term imagery fusion has been used to describe a variety of combining operations performed to increase the ground resolution of multispectral data. The objective of this study was to characterize and evaluate the impact of different pixel-level fusion methods on the accuracy level of land cover/use classification. Panchromatic FORMOSAT-2 data and multispectral SPOT-6 data were considered, and Brovey, Ehlers, and principal component analysis (PCA) algorithms were used as pixel-level fusion algorithms. The improvement in the accuracy of the fused images relative to the original images was determined. The land cover/use categories were classified into five groups by using a maximum likelihood algorithm. To verify and assess the accuracy of classification, training sites were selected for all land cover/use themes. The classification accuracy was calculated for all images by using error matrices. The greatest improvement in land cover/use classification was obtained by using the Brovey algorithm; the overall accuracy was 93.68% and the kappa coefficient was 0.9115. The next greatest improvement was obtained using the Ehlers algorithm, and the overall accuracy and kappa coefficient were 89.54% and 0.8620, respectively. Finally, the least accurate classification was obtained by using the PCA algorithm; the overall accuracy was 88.36% and the kappa coefficient was 0.8247. Comparing the fused images with the original images, the overall accuracy of 86.36% and kappa coefficient value of 0.8036, which were obtained for the original images, were used as benchmarks.

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I. INTRODUCTION

Image fusion is a potential method to perform integration and alliance of data from disparate sources. The fusion of multi sensor data has received substantial attention, as evidenced by the remote sensing literature (Yao and Gilbert, 1984; Chavez et al., 1991; Weydahl et al., 1995; Neimann et al., 1998; Pohl and Van Genderen, 1998; Stehman and Czaplewski, 1998; Welch and Ehlers, 1998; Gamba and Houshmand, 1999; Saraf, 1999; Zhang, 1999; Wald, 2002). The integration of spectrally and spatially complementary remote multi sensor data can facilitate visual and automatic image interpretation (Zhou et al., 1998). Image fusion can be performed at three different levels: pixel-level fusion (which considers pixels obtained from sensor outputs), feature-level fusion (which involves image features extracted from source images), and decision-level fusion (which is more comprehensive and merges the interpretations of different images obtained after image understanding) (Pohl and Van Genderen, 1998). Therefore, different methods have been proposed for merging panchromatic and multispectral data (Chavez et al., 1991). In this study, we focused on various pixel-level image fusion methods such as the Brovey transformation, Ehlers fusion (generalized as intensity-hue saturation, IHS), and principal component analysis (PCA) transformation-based method. These image fusion algorithms preserve spectral characteristics while increasing spatial resolution to produce images of enhanced quality. In particular, Ehlers fusion ensures the Red-Green-Blue (RGB) model for all dates and sensors. The overall accuracy and kappa analysis were used to perform a classification accuracy assessment based on error matrix analysis (Liou et al., 2013).

The remote sensing instrument on the FORMOSAT-2 satellite has a panchromatic channel covering a wavelength region from 0.45 to 0.90 μm. The satellite is in a sun-synchronized orbit at an altitude of 891 km, and it has an inclination of 99.10°. It has a ground sampling distance of 2 m, a swath width of 24 km (at nadir) to 62 km (at 45°), a point accuracy less than 0.7 km, and a ground control point (GCP) knowledge less than 70 m. The SPOT-6 satellite was launched on September 9, 2012 in a quadratic phase of 695 km with the Pleiades satellite orbit, and it has spatial resolution of 6 m for multispectral bands, a swath width of 60 km, and a GCP less than 10 m (Kramer, 2002). Wald (2002) showed that data fusion is a formal framework that has the means and tools for the alliance of multi sensor satellite data from different sources. It is useful for obtaining high-quality information; the integration of spectrally and specially complementary remote multi sensor data can facilitate visual and automatic image interpretation (Zhou et al., 1998). Therefore, combining panchromatic FORMOSAT-2 data and multispectral SPOT 6 data is crucial.

The objectives of the fusion process are manifold: (1) to sharpen multispectral images, (2) to improve geometric corrections, (3) to provide stereo viewing capabilities for stereo photogrammetry, (4) to enhance certain features not visible in either of the single datasets, (5) to complement datasets for improved classification, (6) to detect changes by using multi temporal data, and (7) to replace defective data (Pohl and Van Genderen, 1998). In this study, we focused on the image sharpening process and its influence on the thematic accuracy of land cover/use classification; panchromatic FORMOSAT-2 and multispectral SPOT-6 images were used as multi date and multi sensor data. To produce thematic maps by using multispectral classification, the input images should contain the original spectral response of the land cover/use. The performance of a spectral classifier improves with the separability of the different classes according to the different radiometric information contained in the different bands of the acquisition sensor. Therefore, preserving the spectral information inherent in images is crucial if further information extraction depends on image classification. Consequently, during the selection of fusion techniques, preference should be given to methods that have been proven to maintain spectral integrity while simultaneously improving spatial details. Both these aspects describe a high-quality pansharpening approach (Pohl, 2013). We then classified all the images into five categories by using the supervised classification approaches of a maximum likelihood classifier. The overall accuracy and kappa analysis were used to perform a classification accuracy assessment based on error matrix analysis. The three different fusion methods improved the classification accuracy of land cover/use to different extents compared with the classification accuracy of the original data.

Numerous studies have used various types of data and data fusion operations to increase the ground resolution of multi spectral data and to investigate the accuracy of land cover/use classification for various fusion algorithms. Wu et al. (2008) used different fusion methods that had different impacts on the fused images. After conducting image classification experiments, they found that all the fused images had higher spatial frequency information compared with the original images. Zhang et al. (2013) used multi algorithm fusion techniques to determine land cover/use changes and to evaluate the accuracy of change detection for each candidate algorithm. Multi date

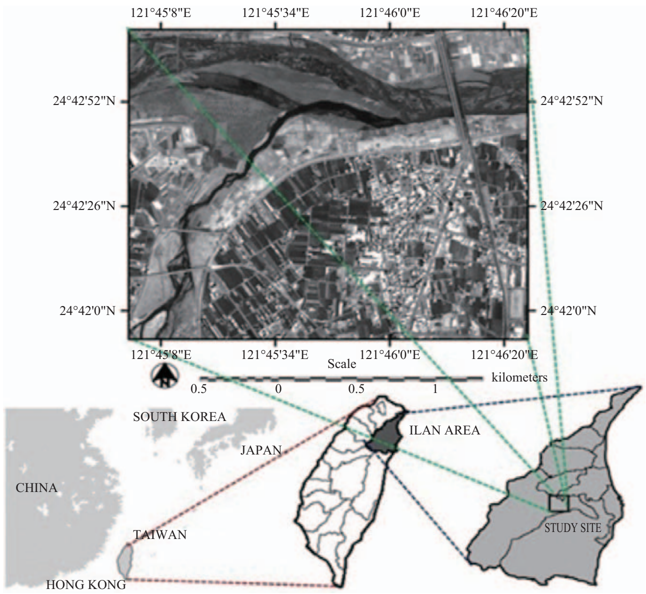


Fig. 1. Study site and the location of the panchromatic FORMOSAT-2 satellite.

data were fused to identify the appropriate algorithm for obtaining more accurate and reliable results for land cover/use systems. Deb and Nathr (2012) presented various methods that have been developed for land cover/use classification, particularly for multispectral and panchromatic imagery, and compared the results of the methods; the methods involved the use of different classifiers and image fusion techniques. Yuan et al. (2006) used multisource remote sensing data fusion methods to retrieve land cover/use information, and they used Landsat TM data as the information source. They presented the overall accuracy and kappa coefficient of various fused classified images in terms of percentages of land cover/use types.

The objective of the current study was to characterize and evaluate the efficiency of three different fusion methods based on the accuracy of land cover/use classification by using the classification result of the original multispectral image as a benchmark.

II. STUDY AREA

The study area was located in Ilan County in the northeast part of Taiwan between 24°43′09.96″N and 24°41′52.92″N latitude and between 121°46′31.28″E and 121°45′00.75″E longitude; it covers an area of approximately 6.60 km^2 (Fig. 1). In general, the foothills and tablelands merge into a broad alluvial plain at an average altitude of less than 100 m above sea level. The Ilan Plain is primarily composed of alluvial clastic sediments such as gravel, sand, and clay. All the large rivers running through the plain have their source in the high mountains. As they emerge from the foothills, they diverge into smaller channels that meander toward the ocean, forming the large alluvial plain. Many of these rivers and streams have been linked by irrigation and drainage canals. The Ilan Plain is one of the most important regions in Taiwan that have been changed substantially from an agricultural to a recreational area over the past decade. This area has a variety of land cover/use types and surface features such as urban built-up areas, fresh water, grassland, vegetation, and agricultural fields. The Ilan Plain primarily comprised agricultural areas before its development; it was then transformed from agricultural land into other land types that are considered essential for land-use management. It also consists of numerous infrastructure facilities such as industrial complexes, residential colonies, roads, and streets for transformation; the western side has a large highway network with natural features such as plantations, although barren lands without any anthropogenic activities continue to exist.

III. DATASETS AND METHODOLOGY

1. Datasets

In this study, we used a multispectral SPOT-6 image with a spatial resolution of 6 m acquired on August 19, 2013 and a panchromatic FORMOSAT-2 image with a spatial resolution of 2 m acquired on March 9, 2013. Secondary data including standard digital and hard-copy topographic maps (scale 1:2500) and aerial photographs were used for the rectification process. Moreover, these data were used to choose the training sites for collecting reference data and for performing accuracy assessment through a classification process.

2. Preprocessing

The accuracy level of land cover/use classification achieved by the different fusion methods was evaluated using digital image processing techniques. Image preprocessing was performed, including image enhancement and geometric correction. The panchromatic FORMOSAT-2 and multispectral SPOT-6 images were geometrically corrected using first-order polynomial equations. The images were rectified to a common Universal Transverse Mercator (UTM WGS 84) coordinate system by using image-to-map and image-to-image registration methods to ensure suitability for accurate fusion applications. During the registrations, four GCPs were initially used from the 1:2500 scaled standard topographic maps. However, eventually eight GCPs were used to improve the positional accuracy, and the root mean square error (RMSE) was 0.204. The nearest neighbor algorithm was used for resampling because it preserves the pixel value or nearest pixel value of the original image; this feature is useful for further image classification.

3. Merging High- and Low-Resolution Image Data

The EGC combines the received signals from multiple hydrophones at different spatial locations to form a signal with a higher signal-to-noise ratio (SNR). Three different pixel-level image fusion algorithms were employed for merging the images. The pixel-level image fusion method analyzes original information and loses an extremely small amount of information. Therefore, the accuracy of the pixel-level image fusion method is high; however, the amount of data transmitted and processed is the largest (Zhang, 1999). All three images were fused with the panchromatic FORMOSAT-2 image to produce images with enhanced spatial and spectral characteristics. The preservation of the spectral characteristics in the resulting images may be perceived as a disadvantage of the fusion techniques.

1) Brovey Transformation

The Brovey transformation was developed and introduced by Bob Brovey (Abedini, 2000) and is also called color normalization transformation because it involves an RGB color transformation method. It is a simple method for combining data from different sensors. It involves a combination of arithmetic operations and normalizes the spectral bands before they are multiplied with the panchromatic image. It retains the spectral features of each pixel and transforms all the luminance information into a high-resolution panchromatic image (Klonus and Ehlers, 2009). The formulas used for the Brovey transformation are as follows (Zhang and Wub, 2007):

$$\text{Blue} = (\text{band1}/\Sigma \text{ band n}) * \text{PAN} \tag{1}$$

$$\text{Green} = (\text{band2}/\Sigma \text{ band n}) * \text{PAN} \tag{2}$$

$$\text{Red} = (\text{band3}/\Sigma \text{ band n}) * \text{PAN} \tag{3}$$

2) Ehlers Method

The Ehlers fusion technique was developed to preserve the maximum spectral information for all dates and sensors. It is based on a common image fusion method called IHS transformation. Traditionally, this method converts three input bands from the RGB color space to IHS. In the IHS space, the intensity (I) is replaced by the high-resolution panchromatic channel. The reverse IHS transformation produces the fused image. Ehlers discovered that the traditional use of IHS is not suitable for many applications, especially if spectral content preservation is required. His research team modified this method by transferring the panchromatic image and the intensity component of the multispectral input data into the frequency domain by filtering using the Fourier transformation (Ehlers, 2004).

3) Principal Component Analysis

PCA is a statistical procedure that uses orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components. The image after fusion contains the characteristics of a high-spatial-resolution image and the high-spectral-resolution and high frequency of the original image (Wu et al., 2008). The PCA method treats multispectral bands as correlated multivariate data, transforms them into uncorrelated variables that are linear combinations

(a) (b) (c)

Fig. 2. Image fusion methods: (a) Brovey; (b) Ehlers; (c) PCA.

(a) (b)

Fig. 3. (a) Original panchromatic FORMOSAT-2 image; (b) Original multispectral SPOT-6 image.

of the original variables, and replaces the first principal component with the panchromatic high-resolution image information; the fused image is finally obtained by inverting the image back to the original color space (Liu, 1996).

4. Visual Comparison of the Merged Images

To compare the spectral and spatial effects of the merged images (Figs. 2(a), (b), and (c)) with those of the original image (Figs. 3(a) and (b)), which are used as a benchmark, visual image interpretation was performed. For visual analysis, we focused on color preservation and spatial improvement. Visual image interpretation analysis showed that the merged panchromatic FORMOSAT-2 and multispectral SPOT-6 images contained considerably superior spectral and spatial information compared with the original image. In particular, buildings, roads, and crossroads were more prominent in the merged images compared with those in the original multispectral SPOT-6 image (band 3, blue; band 2, red; band 1, green). Fig. 2 shows images merged using the three pixel-level fusion techniques. Clearly, only the Ehlers method (Fig. 2(b)) retained almost all the colors in the original image and achieved the optimal results in terms of spectral characteristic preservation. The other fusion methods—PCA (Fig. 2(c)) and Brovey (Fig. 2(a))—showed significant color distortions and deteriorations. In the case of PCA, the green representing the cultivated area and the reddish-brown representing the water body appeared substantially darker than those in the original image. Furthermore, the Brovey transformation changed the colors (green instead of yellow for cultivated land and reddish-brown instead of pale reddish-brown for water body). A comparison with the panchromatic FORMOSAT-2 image confirmed that the color changes were associated with the panchromatic information in these regions. PCA and the Brovey fusion method occasionally produced acceptable

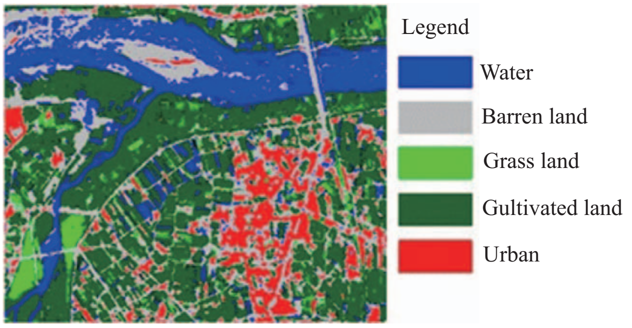
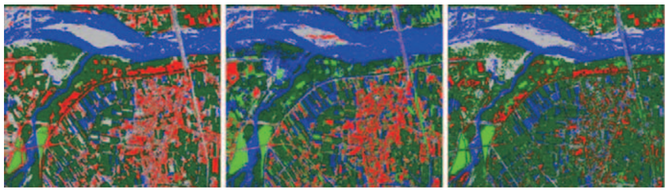


Fig. 4. Application of the maximum likelihood classifier to the original classified land cover/use image.



(a) (b) (c)

Fig. 5. Land cover/use classification of the fused images obtained using the (a) Brovey method; (b) Ehlers method; (c) PCA.

results but never without substantial color changes. Considering the spatial improvement in the fused images, all the tested fusion methods provided favorable spatial sharpening.

5. Classification

Supervised classification and classification accuracy assessment were performed for all fused images by using a maximum likelihood algorithm. The maximum likelihood classifier is the most widely adopted parametric classification algorithm (Weng, 2002; Currit, 2005; Jensen, 2005; Bailly et al., 2007). Therefore, we used it for the spectral classification of the fused images. On the basis of the spectral characteristics of the satellite images and existing knowledge of land cover/use in the study area, five categories were identified, and land cover/use classification was performed using the original (Fig. 4) and three fused images (Figs. 5(a), (b), and (c)). In addition to selecting training sites for the classification, 1:2500 scaled standard topographic maps and aerial photographs were used. Water, barren land, grassland, cultivated land, and urban areas were selected as the categories for the classification of the surface of the study area. Error matrices were used to calculate the accuracy of the classification, and the accuracy included the accuracy of both the producer and user. For the accuracy assessment, 506 pixels were randomly selected from each image. Land-use maps and aerial photographs were used as reference data to observe the true categories. To meet the criteria for accuracy assessment, the kappa statistic was used based on random sampling (Congalton, 1991; Stehman and Czaplewski, 1998). However, as is commonly the case with the collection of reference data, some categories

Table 1. Error matrices for the original and three fused images, used for accuracy assessment.

		Classification Reference data						
		Watr	Barlnd	Grslnd	Cullnd	Urbn	Row total	User's
Original: Overall accuracy 86.36%; Kappa coefficient 0.8036								
Map data	Watr	78	1	0	5	0	84	92.86
	Barlnd	3	110	12	12	13	150	73.33
	Grslnd	1	110	5	0	1	9	55.56
	Cullnd	4	6	4	210	0	224	93.75
	Urbn	0	2	3	0	34	39	87.18
	Column total	86	121	24	227	48	506	…
	Producer's	90.7	90.91	20.83	92.51	70.83	…	…
PCA: Overall accuracy 88.36%; Kappa coefficient 0.8247								
Map data	Watr	94	6	0	5	0	105	89.52
	Barlnd	2	74	0	4	0	80	91.36
	Grslnd	0	0	10	1	0	11	90.91
	Cullnd	11	13	4	232	5	265	87.55
	Urbn	1	0	1	5	38	45	84.44
	Column total	108	93	15	274	43	506	…
	Producer's	87.04	79.57	66.67	93.93	88.37	…	…
Ehlers: Overall accuracy 89.54%; Kappa coefficient 0.8620								
Map data	Watr	125	12	1	6	0	144	86.81
	Barlnd	3	48	1	1	0	53	90.57
	Grslnd	2	1	45	1	4	53	84.91
	Cullnd	16	2	1	160	2	181	88.4
	Urbn	0	1	1	0	73	75	97.33
	Column total	146	64	49	168	79	506	…
	Producer's	85.62	75	91.84	95.24	92.41	…	…
Brovey: Overall accuracy 93.68%; Kappa coefficient 0.9115								
Map data	Watr	71	3	0	2	0	76	93.42
	Barlnd	3	103	1	5	2	114	90.35
	Grslnd	0	0	3	0	0	3	100
	Cullnd	4	5	0	199	2	210	94.76
	Urbn	0	2	1	2	98	103	95.15
	Column total	78	113	5	208	102	506	…
	Producer's	91.03	91.15	60	95.67	96.08	…	…

The category labels are as follows: Watr = Water, Barlnd = Barren land, Grslnd = Grassland, Cullnd = Cultivated land and Urbn = Urban.

were substantially more abundant than others in the landscape. We did not obtain an equal distribution of sample points per category (see Table 1 for a distribution of samples by count). The accuracy assessment of the land cover/use classification performed using the supervised classification technique yielded an overall accuracy and a kappa coefficient based on an evaluation of error matrices. Table 1 shows the overall accuracies and kappa values for the classification of the fused images.

IV. RESULTS AND DISCUSSION

The land cover/use classification results by using the maximum likelihood classifier of the three different fusion methods indicate that compared with the original multispectral SPOT-6 data, which was used as a benchmark, the Brovey method was optimal for improving the land cover/use classification, with an overall accuracy of 93.68% and a kappa coefficient of 0.9115. By contrast, PCA was the poorest, with an overall accuracy of 88.36% and a kappa coefficient of 0.8247. The second most favorable image fusion method was the Ehlers method, which resulted in an overall accuracy of 89.54% and a kappa coefficient of 0.862. The original data with an overall accuracy of 86.36% and a kappa coefficient of 0.8036 were used as a benchmark for characterizing and evaluating the efficiency of the three different fusion methods based on the accuracy level of land cover/use classification. The reliability of land cover/use classification performed using individual automatic algorithms depends on the reliability factor of each individual candidate algorithm. Moreover, the error detection rate of candidate algorithms depends on the correctness rate values. Thus, we noticed that the overall accuracy and kappa coefficient of the Brovey algorithm were superior to those of the PCA algorithm, as shown in Table 1, because the correctness rate values of the Brovey algorithm were higher than those of the PCA algorithm. According to a comparative analysis of the classification accuracy results of the data fusion methods, the fusion methods improved the accuracy of land cover/use classification, and the differences among their accuracy values were small; in addition, there was a small difference between the classification accuracy values of the fused images and that of the original image.

Although the overall accuracy percentage for all the fused images and the accuracy of the producer and user were high for all categories, the original image had a relatively low overall accuracy of 86.36%, and the accuracy of the producer and user were less than 60%, especially for grasslands. In addition, some classified categories were sampled less comprehensively than others with more heterogeneous land cover/use classification; for instance, grassland was sampled by the three different fusion methods and in the original image with the least sampling. The problematic samples are caused by the mapped landscape being quite heterogeneous in areas dominated by human activity and by the mixing of some pixels located on class boundaries or in transitional zones. The reference dataset was compared with the map data by generating error matrices and associated accuracy measures. The error matrix represents the degree of agreement/disagreement between the highest quality reference dataset and the map data, and the reasons for disagreement are the changes in geolocation errors between dates. To characterize and evaluate the degree to which each of these errors affected the accuracy assessment, we visually inspected areas of potential change based on reference and map classifications by comparing such locations with those in classified maps generated in similar previous studies by following classification procedures identical to those of the present study. Thus, we confirmed that the disagreement between the reference data and the map was caused by geolocation errors and changes between dates.

V. CONCLUSION

This paper discusses the characterization and evaluation of the efficiency of three different multi sensor satellite data fusion methods based on the accuracy level of land cover/use classification performed for the Ilan County. The study area was classified into five categories—water, barren land, grassland, cultivated land, and urban areas. Visual interpretations of images were obtained using the fusion methods, and spatial improvement along with a satisfactory degree of spatial sharpening was observed in the three fused images. Spectral characteristic preservation varied among the fusion methods according to the rate of color distortion and deterioration. The accuracy of land cover/use information was improved in the classification performed using fused data. Both heterogeneous and irregular features were present in the study area, and the land cover/use types were spatially intermixed because of similar reflectance values of some categories, especially those categories located on class boundaries or in transitional zones. Error matrices showed disagreement between the reference dataset and the map data because of geolocation errors and changes between dates. According to the classification results and their accuracy assessment, with the results of the original image considered as a benchmark, the Brovey method provided the most accurate land cover/use classification, followed by the Ehlers method; the PCA technique provided the least accurate classification. Furthermore, differences between the values of the overall accuracy and kappa coefficient among the three methods were relatively small.

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REFERENCES

Abedini, M. (2000). Satellite image fusion using Brovey. Master Thesis, Geomatics engineering faculty, K.N. Toosi University of technology, Tehran, Iran.

Bailly, J. S., M. Arnaud and C. Puech (2007). Boosting: A classification method for remote sensing. International Journal of Remote Sensing 28, 1687-1710.

Chavez, P. S., S. C. Sides and J. A. Anderson (1991). Comparison of three different methods to merge multi resolution and multi spectral data: Landsat TM and SPOT panchromatic. Photogrammetric Engineering and Remote Sensing 75, 295-303.

Congalton, R. G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. Remote Sensing of Environment 37, 35-46.

Currit, N. (2005). Development of remotely sensed, historical land cover change database for rural Chihuahua, Mexico. International Journal of Applied Earth Observation and Geoinformation 7, 232-247.

Deb, S. K. and R. K. Nathr (2012). Land use/cover classification-An introduction review and comparison. Global Journal of researches in engineering 12, 0975-5861.

Ehlers, M. (2004). Spectral characteristics preserving image fusion based on Fourier domain filtering. Proceedings of SPIE, 5574. Remote Sensing for Environmental Monitoring GIS Applications, and Geology IV., Bellingham, WA, USA. 13 pages.

Gamba, P. and B. Houshmand (1999). Three-dimensional road network by fusion of polarimetric and lnterferometric SAR data. Proceedings of the IEEE International Geoscience and Remote Sensing Symposium 99, 302-304.

Jensen, J. R. (2005). Thematic information extraction: pattern recognition. In: Introductory Digital Image Processing – A Remote Sensing Perspective, 3rd ed., edited by Keith, C. C., Prentice Hall Series in Geographic Information, Saddle River, NJ, USA. 337-406.

Klonus, S. and M. Ehlers (2009). Performance of evaluation methods in image fusion. 12th International Conference on Information Fusion Seattle, WA, USA.

Kramer, H. J. (2002). Observation of the Earth and Its Environment: Survey of

Missions and Sensors. 4th ed, Springer.

Liou, Y. A., T. S. Wang and H. P. Chan (2013). Impacts of Pond Change on the Regional Sustainability of Water Resources in Taoyuan, Taiwan. Advances in Meteorology 2013, Article ID 243456, 6 pages.

Liu, G.-J. (1996). Land cover mapping in a salinised dry land farming area in southeastern Australia using Landsat TM data. Geocarto International 11, 47-59.

Neimann, K. O., D. G. Goodenough, D. Marceau and G. A. Hay (1998). Practical alternative for fusion of hyperspectral data with high resolution imagery. Proceedings of the IEEE International Geoscience and Remote Sensing Symposium 1, 174-176.

Pohl, C. (2013). Challenges of remote sensing image fusion to optimize earth observation data exploration. Europian Science Journal 4, 1857-7431.

Pohl. C. and J. L. Van Genderen (1998). Multisensor image fusion in remote sensing: concepts methods and applications. Intentional Journal of Remote Sensing 19, 823-854.

Saraf, A. K. (1999). IRS-IC-LISS-III and PAN data fusion: an approach to improve remote sensing based mapping techniques. Intentional Journal of Remote Sensing 20, 1929-1934.

Stehman, S. V. and R. L. Czaplewski (1998). Design and analysis for thematic map accuracy assessment: Fundamental principles. Remote Sensing of Environment 64, 331-344.

Wald, L. (2002). Data Fusion: Definitions and Archetctures of Images of Different Spatial Resolutions. Les Presses de l Ecole des Mines de Paris.

Welch, R. and M. Ehlers (1998). Catographic feature extraction with integrated SIR-B and Landsat TM images. Intentional Journal of Remote Sensing 9, 873-889.

Weng, Q. (2002). Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modeling. Journal of Environmental Management 64, 273-284.

Weydahl, D. J., X. Becquey and T. Tollefsen (1995). Combining ERS-1 SAR with optical satellite data over urban areas. Proceedings of the IEEE International Geoscience and Remote Sensing Symposium (IGARSS) 3, 2161-2163.

Wu, W., J. Yao and T. Kang (2008). Study of remote sensing image fusion and its application in image classification. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXVII, Part B7.

Yao, S. S. and J. R. Gilbert (1984). Registration of a synthetic aperture radar image to thematic mapper imagery for remote sensing applications. IEEE Transaction on Geoscience and Remote Sensing 6, 557-563.

Yuan, J., Z. Niu, W. Wang and Z. Shi (2006). Multi-source information integration based remote sensing information retrieval in north Hebei province. Commission VII Mid-term Symposium.

Zhang, N. and Q. Wub (2007). Effects of Brovey transform and wavelet transform on the information capacity of SPOT-5 imagery. International Symposium on Photoelectronic Detection and Imaging Proceedings of SPIE, 6623.

Zhang, P., W. Shi, M. S. Wong and J. Chen (2013). A reliability-based multialgorithm fusion technique in detecting changes in land cover. Remote Sensing 5, 1134-1151.

Zhang, Y. (1999). A new merging method and its spectral and spatial effect. Intentional Journal of Remote Sensing 20, 2003-2014.

Zhou, J., D. L. Civco and J. A. Silander (1998). A wavelet transform method to merge Landsat TM and SPOT panchromatic data. Intentional Journal of Remote Sensing 19, 743-757.