



HAL
open science

Foreword to the special issue on hyperspectral image and signal processing

Jocelyn Chanussot, Melba M. Crawford, Bor-Chen Kuo

► **To cite this version:**

Jocelyn Chanussot, Melba M. Crawford, Bor-Chen Kuo. Foreword to the special issue on hyperspectral image and signal processing. *IEEE Transactions on Geoscience and Remote Sensing*, 2010, 48 (11), pp.3871-3876. 10.1109/TGRS.2010.2085313 . hal-00578882

HAL Id: hal-00578882

<https://hal.science/hal-00578882>

Submitted on 27 Mar 2011

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Foreword to the Special Issue on Hyperspectral Image and Signal Processing

ALMOST A DECADE after the milestone special issue of the IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING (TGRS) dedicated to the analysis of hyperspectral image data, edited by Prof. Landgrebe, Prof. Serpico, Prof. Crawford, and Prof. Singhroy [1], it is a great pleasure to introduce this new special issue on hyperspectral image and signal processing. In the intervening years, interest in hyperspectral sensing has increased dramatically, as evidenced by advances in sensing technology and planning for future hyperspectral missions, increased availability of hyperspectral data from airborne and space-based platforms, and development of methods for analyzing data and new applications. The proposal for this special issue was also related to the launch of a series of specialized workshops on hyperspectral sensing that had technical sponsorship of the IEEE Geoscience and Remote Sensing Society. The first Workshop on Hyperspectral Image and Signal Processing—Evolution in Remote Sensing (WHISPERS) was held in Grenoble, France, in 2009, with 200 attendees from 33 countries. The second was hosted in Reykjavik, Iceland, in 2010 and featured a commercial exhibition of sensors and data products, as well as an outstanding technical program. The third WHISPERS workshop is scheduled for June 2011 in Lisbon, Portugal, and will be followed by venues in Asia in 2012 and America in 2013. Following the inaugural 2009 workshop and the open call for papers, an impressive number of submissions (66) were received for this special issue, which contains 24 papers. A few of the submissions will be published in the following regular issues of TGRS, after the final reviews and revisions are completed.

The strong interest in hyperspectral remote sensing, also referred to as imaging spectroscopy, has resulted in significant research and contributions to the literature in the geoscience and remote sensing community. In the remainder of this foreword, we review key issues and topics of current interest related to hyperspectral data processing. While the topics are very similar to those covered by the previous special issue a decade ago, the techniques have evolved, both improving existing methods and advancing in new directions to improve the performance of sensing systems and algorithms, as well as tackling increasingly more challenging applications.

Simulation. Simulating realistic hyperspectral data is a very challenging task that is critical to both the design of new sensors and planning of new missions [2]–[4] and in a quantitative assessment of the performance of sensors and processing algorithms [5]. In this special issue, three papers deal with this problem, in different contexts: planetary exploration and

the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) instrument [6], simulation of a complex woodland area [7], and simulation of a different sensor from a given spectrum with super spectral resolution [8].

Compression. Hyperspectral measurements result in hundreds of values (one for each wavelength). Thus, hyperspectral sensors acquire enormous quantities of data. Advanced compression methods are important for onboard storage and transmission, as well as processing and storage of data products. This topic has received significant attention in the recent literature, where issues related to both lossy and lossless compression have been addressed [9]–[18]. In this special issue, a BOI-preserving-based method for compression is proposed [19].

Calibration. Calibration, which impacts the quality of all data and data products, is critical but particularly challenging in hyperspectral sensing. Significant effort is focused on both prelaunch and postlaunch of space-based platforms and continues throughout the mission for operational platforms. In this special issue, [20] investigates this problem for on-orbit spectrometers. Imaging spectroscopy has been used in astrophysics and in planetary exploration over the past decades, with pioneering instruments and missions to Mars, Venus, and Saturn. In this special issue, the observation of Mercury is explored in [21], while [22] focuses on the calibration of the Visual and Infrared Thermal Imaging Spectrometer that is onboard Venus Express, and [23] presents an original method to reduce the spectral “smile” for the CRISM instrument orbiting Mars.

Band Selection, Feature Extraction, and Subspace Identification. While the spectral diversity provided by hyperspectral data enables a detailed description of targets of interest, the very high dimensionality of the data is problematic for both estimation and computational complexity. Very often, not all the bands are useful for a given application. As a consequence, band selection can be performed. Alternatively, feature extraction and subspace identification seek to project meaningful information onto a lower dimensional space, reducing dimensionality while preserving important information. Band selection and feature extraction are addressed in the following recent papers: [24]–[31]. On the other hand, subspace identification is specifically investigated in [32]–[35]. Both feature selection and extraction are usually performed as a preprocessing step prior to other operations such as classification and target detection. In this special issue, [36] estimates the virtual dimensionality of hyperspectral data using linear spectral mixture analysis.

Target and Anomaly Detection. Most often related to critical defense and security issues, target and anomaly detection is a very important topic to which hyperspectral imagery

can contribute. The spectral diversity of the data enables the detection of very small objects that are statistically spectrally abnormal with respect to a background that is unknown and often nonuniform [37]–[41]. In this special issue, it is proposed in [42] to project the data using an anomalous component pursuit method, where an unsupervised approach is employed to discriminate potential targets from the background.

Mixture Analysis, Endmember Extraction, and Spectral Unmixing. A given pixel frequently represents several different materials which are contained within the resolution cell. As a consequence, the observed spectrum is a mixture of the spectra of these elements. Analyzing these mixtures, determining the corresponding endmembers and the associated abundances, and ultimately unmixing the data are also key issues in hyperspectral remote sensing. The literature contains a wide range of models (linear and nonlinear mixtures), approaches (supervised and unsupervised), and strategies (geometrical and statistical models) [43]–[48]. In this special issue, the following four papers focus on this problem: 1) In [49], fully constrained linear spectral unmixing is addressed with an analytic solution using fuzzy sets; 2) in [50], the unmixing is approached using Bayesian statistical strategies; 3) in [51], the result of spectral unmixing is used to map forest heterogeneity; and 4) in [52], a superpixel endmember detection method is proposed.

Classification. Within the hyperspectral processing chain, classification is probably the topic that has garnered the attention of most researchers and resulted in the largest number of published papers. Be they unsupervised (clustering) or supervised (algorithms based on training and machine learning), most of the published methods are explicitly or implicitly based on statistical modeling of the spectral characteristics of the classes [53]–[67]. In a recent trend, contextual information is also taken into consideration to improve the classification performance obtained with only spectral information (pixel-wise classification). These methods, which are referred to as spectral–spatial classifiers, typically focus on local spatial information and are particularly successful for data with large homogeneous regions or where spectral signatures of multiple classes overlap [68]–[72]. In this special issue, eight papers directly address the problem of classification and propose new algorithms.

In [73], the classification is performed using a double nearest proportion feature extraction. In [74], reflectance data are fused with derivative information for classification. In [75], automated labeling of different materials is investigated. In [76], empirical mode decomposition of the data is introduced as a preprocessing step for support vector machine classification. In [77], active learning on a multinomial logistic regression is used to perform semisupervised image segmentation. In [78], the classification is addressed by learning the local structure of the distribution of the spectra (the manifold) using the k nearest neighbors. In [79], an adaptive classification scheme based on manifold regularization kernel machines is investigated. In [80], a framework for multiple spectral–spatial classifiers is proposed.

Monitoring of the Environment and Retrieval of Biogeophysical Parameters. Numerous applications related to monitoring of the environment have been addressed using hyperspectral

imagery, such as the classification of soils [81], the characterization of forests [82] or agriculture [83], the estimation of crops [84], sensing the chlorophyll content of lakes [85], mapping bathymetry [86], determining cloud optical properties [87], temperature and emissivity separation [88], monitoring of weeds in citrus orchards [89], etc. In this special issue, discrimination of savanna tree species through a multiple-endmember spectral-angle-mapper approach is proposed in [90].

A related problem involves understanding, modeling, and accounting for the bidirectional reflectance distribution function (BRDF) [91]. In this special issue, [92] investigates the influence of furrow microrelief on the BRDF of soils under various illumination conditions.

Other critical problems and challenges associated with the specific nature of hyperspectral data are not investigated in this special issue but were nevertheless extensively addressed in the recent literature. Some are summarized in the following.

Visualization. When the number of spectral bands exceeds three, simple visualization of the data becomes an issue. Designing optimal color representations of hyperspectral data, thereby enhancing the information of interest, has been investigated in the following papers: [93]–[98].

Noise Estimation and Removal. Hyperspectral data are corrupted by wavelength-dependent and sensor-specific noise, which significantly impacts data and resulting data products. Modeling this noise [99], [100] and removing it via appropriate filters [101]–[103] are also important topics related to hyperspectral sensing.

JOCELYN CHANUSSOT, *Guest Editor*
GIPSA-Lab
Grenoble Institute of Technology
Grenoble 38402, France

MELBA M. CRAWFORD, *Guest Editor*
Schools of Agronomy, Civil, and Electrical and
Computer Engineering
Purdue University
West Lafayette, IN 47907 USA

BOR-CHEN KUO, *Guest Editor*
Graduate Institute of Educational Measurement
and Statistics
National Taichung University
Taichung 40306, Taiwan

REFERENCES

- [1] D. A. Landgrebe, S. B. Serpico, M. M. Crawford, and V. Singhroy, "Introduction to the special issue on analysis of hyperspectral image data," *IEEE Trans. Geosci. Remote Sens.*, vol. 39, no. 7, pp. 1343–1345, Jul. 2001.
- [2] L. Guanter, K. Segl, and H. Kaufmann, "Simulation of optical remote-sensing scenes with application to the EnMAP hyperspectral mission," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 7, pp. 2340–2351, Jul. 2009.
- [3] K. Segl, L. Guanter, H. Kaufmann, J. Schubert, S. Kaiser, B. Sang, and S. Hofer, "Simulation of spatial sensor characteristics in the context of the EnMAP hyperspectral mission," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 7, pp. 3046–3054, Jul. 2010.
- [4] S. Sarkar and G. Healey, "Hyperspectral texture synthesis using histogram and power spectral density matching," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 5, pp. 2261–2270, May 2010.

- [5] J. P. Bellucci, T. E. Smetek, and K. W. Bauer, "Improved hyperspectral image processing algorithm testing using synthetic imagery and factorial designed experiments," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 3, pp. 1211–1223, Mar. 2010.
- [6] M. Parente, J. T. Clark, A. J. Brown, and J. L. Bishop, "End-to-end simulation and analytical model of remote-sensing systems: Application to CRISM," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 3877–3888, Nov. 2010.
- [7] J. Zhang, X. Zhang, B. Zou, and D. Chen, "On hyperspectral image simulation of a complex woodland area," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 3889–3902, Nov. 2010.
- [8] H. Zhao, G. Jia, and N. Li, "Transformation from hyperspectral radiance data to data of other sensors based on spectral superresolution," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 3903–3912, Nov. 2010.
- [9] J. Mielikainen and P. Toivanen, "Lossless compression of hyperspectral images using a quantized index to lookup tables," *IEEE Geosci. Remote Sens. Lett.*, vol. 5, no. 3, pp. 474–478, Jul. 2008.
- [10] A. Abrardo, M. Barni, E. Magli, and F. Nencini, "Error-resilient and low-complexity onboard lossless compression of hyperspectral images by means of distributed source coding," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 4, pp. 1892–1904, Apr. 2010.
- [11] C. C. Lin and Y. T. Hwang, "An efficient lossless compression scheme for hyperspectral images using two-stage prediction," *IEEE Geosci. Remote Sens. Lett.*, vol. 7, no. 3, pp. 558–562, Jul. 2010.
- [12] Q. Du, W. Zhu, H. Yang, and J. E. Fowler, "Segmented principal component analysis for parallel compression of hyperspectral imagery," *IEEE Geosci. Remote Sens. Lett.*, vol. 6, no. 4, pp. 713–717, Oct. 2009.
- [13] Q. Du, J. E. Fowler, and W. Zhu, "On the impact of atmospheric correction on lossy compression of multispectral and hyperspectral imagery," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 1, pp. 130–132, Jan. 2009.
- [14] C. Huo, R. Zhang, and T. Peng, "Lossless compression of hyperspectral images based on searching optimal multibands for prediction," *IEEE Geosci. Remote Sens. Lett.*, vol. 6, no. 2, pp. 339–343, Apr. 2009.
- [15] L. Wang, J. Wui, L. Jiao, and J. Shi, "Lossy-to-lossless hyperspectral image compression based on multiplierless reversible integer TDLT/KLT," *IEEE Geosci. Remote Sens. Lett.*, vol. 6, no. 3, pp. 587–591, Jul. 2009.
- [16] A. B. Kiely and M. A. Klimesh, "Exploiting calibration-induced artifacts in lossless compression of hyperspectral imagery," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 8, pp. 2672–2678, Aug. 2009.
- [17] E. Magli, "Multiband lossless compression of hyperspectral images," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 4, pp. 1168–1178, Apr. 2009.
- [18] G. Carvajal, B. Penna, and E. Magli, "Unified lossy and near-lossless hyperspectral image compression based on JPEG 2000," *IEEE Geosci. Remote Sens. Lett.*, vol. 5, no. 4, pp. 593–597, Oct. 2008.
- [19] H. Chen, Y. Zhang, J. Zhang, and Y. Chen, "A BOI-preserving-based compression method for hyperspectral images," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 3913–3923, Nov. 2010.
- [20] T. Wang, G. Yan, H. Ren, and X. Mu, "Improved methods for spectral calibration of on-orbit imaging spectrometers," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 3924–3931, Nov. 2010.
- [21] F. Capaccioni, M. C. De Sanctis, G. Filacchione, G. Piccioni, E. Ammannito, L. Tommasi, I. Fici Veltroni, M. Cosi, S. Debei, L. Calamai, and E. Flamini, "VIS-NIR imaging spectroscopy of Mercury's surface: SIMBIO-SYS/VIHI experiment onboard the BepiColombo mission," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 3932–3940, Nov. 2010.
- [22] A. Cardesín Moinelo, G. Piccioni, E. Ammannito, G. Filacchione, and P. Drossart, "Calibration of hyperspectral imaging data: VIRTIS-M onboard Venus express," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 3941–3950, Nov. 2010.
- [23] X. Ceamanos and S. Douté, "Spectral smile correction of CRISM/MRO hyperspectral images," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 3951–3959, Nov. 2010.
- [24] Q. Du and H. Yang, "Similarity-based unsupervised band selection for hyperspectral image analysis," *IEEE Geosci. Remote Sens. Lett.*, vol. 5, no. 4, pp. 564–568, Oct. 2008.
- [25] P. Zhong and R. Wang, "Learning sparse CRFs for feature selection and classification of hyperspectral imagery," *IEEE Trans. Geosci. Remote Sens.*, vol. 46, no. 12, pp. 4186–4197, Dec. 2008.
- [26] M. Pal and G. M. Foody, "Feature selection for classification of hyperspectral data by SVM," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 5, pp. 2297–2307, May 2010.
- [27] B. Waske, S. van der Linden, J. A. Benediktsson, A. Rabe, and P. Hostert, "Sensitivity of support vector machines to random feature selection in classification of hyperspectral data," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 7, pp. 2880–2889, Jul. 2010.
- [28] L. Bruzzone and C. Persello, "A novel approach to the selection of spatially invariant features for the classification of hyperspectral images with improved generalization capability," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 9, pp. 3180–3191, Sep. 2009.
- [29] J. M. Yang, P. T. Yu, and B.-C. Kuo, "A nonparametric feature extraction and its application to nearest neighbor classification for hyperspectral image data," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 3, pp. 1279–1293, Mar. 2010.
- [30] B.-C. Kuo, C. H. Li, and Y. J.-M. Yang, "Kernel nonparametric weighted feature extraction for hyperspectral image classification," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 4, pp. 1139–1155, Apr. 2009.
- [31] B. Mojaradi, H. Abrishami-Moghaddam, M. J. V. Zoej, and R. P. W. Duin, "Dimensionality reduction of hyperspectral data via spectral feature extraction," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 7, pp. 2091–2105, Jul. 2009.
- [32] N. Acito, M. Diani, and G. Corsini, "A new algorithm for robust estimation of the signal subspace in hyperspectral images in the presence of rare signal components," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 11, pp. 3844–3856, Nov. 2009.
- [33] N. Acito, M. Diani, and G. Corsini, "Hyperspectral signal subspace identification in the presence of rare signal components," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 4, pp. 1940–1954, Apr. 2010.
- [34] J. M. Bioucas-Dias and J. M. P. Nascimento, "Hyperspectral subspace identification," *IEEE Trans. Geosci. Remote Sens.*, vol. 46, no. 8, pp. 2435–2445, Aug. 2008.
- [35] H. Bagan, Y. Yasuoka, T. Endo, X. Wang, and Z. Feng, "Classification of airborne hyperspectral data based on the average learning subspace method," *IEEE Geosci. Remote Sens. Lett.*, vol. 5, no. 3, pp. 368–372, Jul. 2008.
- [36] C.-I. Chang, W. Xiong, W. Liu, M.-L. Chang, C.-C. Wu, and C. C.-C. Chen, "Linear spectral mixture analysis based approaches to estimation of virtual dimensionality in hyperspectral imagery," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 3960–3979, Nov. 2010.
- [37] J. Theiler, C. Scovel, B. Wohlberg, and B. R. Foy, "Elliptically contoured distributions for anomalous change detection in hyperspectral imagery," *IEEE Geosci. Remote Sens. Lett.*, vol. 7, no. 2, pp. 271–275, Apr. 2010.
- [38] S. Prasad and L. M. Bruce, "Limitations of principal components analysis for hyperspectral target recognition," *IEEE Geosci. Remote Sens. Lett.*, vol. 5, no. 4, pp. 625–629, Oct. 2008.
- [39] S. Prasad and L. M. Bruce, "Decision fusion with confidence-based weight assignment for hyperspectral target recognition," *IEEE Trans. Geosci. Remote Sens.*, vol. 46, no. 5, pp. 1448–1456, May 2008.
- [40] Y. Gu, Y. Liu, and Y. Zhang, "A selective KPCA algorithm based on high-order statistics for anomaly detection in hyperspectral imagery," *IEEE Geosci. Remote Sens. Lett.*, vol. 5, no. 1, pp. 43–47, Jan. 2008.
- [41] S. Prasad and L. M. Bruce, "Information fusion in kernel-induced spaces for robust subpixel hyperspectral ATR," *IEEE Geosci. Remote Sens. Lett.*, vol. 6, no. 3, pp. 572–576, Jul. 2009.
- [42] A. Huck and M. Guillaume, "Asymptotically CFAR-unsupervised target detection and discrimination in hyperspectral images with anomalous-component pursuit," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 3980–3991, Nov. 2010.
- [43] A. Huck, M. Guillaume, and J. Blanc-Talon, "Minimum dispersion constrained nonnegative matrix factorization to unmix hyperspectral data," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 6, pp. 2590–2602, Jun. 2010.
- [44] S. A. Robila and L. G. Maciak, "Considerations on parallelizing nonnegative matrix factorization for hyperspectral data unmixing," *IEEE Geosci. Remote Sens. Lett.*, vol. 6, no. 1, pp. 57–61, Jan. 2009.
- [45] S. Jia and Y. Qian, "Constrained nonnegative matrix factorization for hyperspectral unmixing," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 1, pp. 161–173, Jan. 2009.
- [46] X. Tao, B. Wang, and L. Zhang, "Orthogonal bases approach for the decomposition of mixed pixels in hyperspectral imagery," *IEEE Geosci. Remote Sens. Lett.*, vol. 6, no. 2, pp. 219–223, Apr. 2009.
- [47] C.-I. Chang, C. C. Wu, C. S. Lo, and M. L. Chang, "Real-time simplex growing algorithms for hyperspectral endmember extraction," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 4, pp. 1834–1850, Apr. 2010.
- [48] J. Plaza and A. Plaza, "Spectral mixture analysis of hyperspectral scenes using intelligently selected training samples," *IEEE Geosci. Remote Sens. Lett.*, vol. 7, no. 2, pp. 371–375, Apr. 2010.
- [49] J. L. Silván-Cárdenas and L. Wang, "Fully constrained linear spectral unmixing: Analytic solution using fuzzy sets," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 3992–4002, Nov. 2010.

- [50] F. Schmidt, A. Schmidt, E. Tréguier, M. Guiheneuf, S. Moussaoui, and N. Dobigeon, "Implementation strategies for hyperspectral unmixing using Bayesian source separation," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 4003–4013, Nov. 2010.
- [51] J. Verrelst, J. G. P. W. Clevers, and M. Schaepman, "Merging the Minnaert- k parameter with spectral unmixing to map forest heterogeneity with CHRIS/PROBA data," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 4014–4022, Nov. 2010.
- [52] D. R. Thompson, L. Mandrake, M. S. Gilmore, and R. Castaño, "Superpixel endmember detection," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 4023–4033, Nov. 2010.
- [53] F. Ratle, G. Camps-Valls, and J. Weston, "Semisupervised neural networks for efficient hyperspectral image classification," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 5, pp. 2271–2282, May 2010.
- [54] A. C. Jensen, M. Loog, and A. H. S. Solberg, "Using multiscale spectra in regularizing covariance matrices for hyperspectral image classification," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 4, pp. 1851–1859, Apr. 2010.
- [55] J. M. Yang, B.-C. Kuo, P. T. Yu, and C. H. Chuang, "A dynamic subspace method for hyperspectral image classification," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 7, pp. 2840–2853, Jul. 2010.
- [56] T. C. Bau, S. Sarkar, and G. Healey, "Hyperspectral region classification using a three-dimensional Gabor filterbank," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 9, pp. 3457–3464, Sep. 2010.
- [57] A. Paoli, F. Melgani, and E. Pasoli, "Clustering of hyperspectral images based on multiobjective particle swarm optimization," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 12, pp. 4175–4188, Dec. 2009.
- [58] T. V. Bandos, L. Bruzzone, and G. Camps-Valls, "Classification of hyperspectral images with regularized linear discriminant analysis," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 3, pp. 862–873, Mar. 2009.
- [59] M. Chi, Q. Kun, J. A. Benediktsson, and R. Feng, "Ensemble classification algorithm for hyperspectral remote sensing data," *IEEE Geosci. Remote Sens. Lett.*, vol. 6, no. 4, pp. 762–766, Oct. 2009.
- [60] M. Marconcini, G. Camps-Valls, and L. Bruzzone, "A composite semisupervised SVM for classification of hyperspectral images," *IEEE Geosci. Remote Sens. Lett.*, vol. 6, no. 2, pp. 234–238, Apr. 2009.
- [61] A. Daamouche and F. Melgani, "Swarm intelligence approach to wavelet design for hyperspectral image classification," *IEEE Geosci. Remote Sens. Lett.*, vol. 6, no. 4, pp. 825–829, Oct. 2009.
- [62] B. Demir and S. Ertürk, "Clustering-based extraction of border training patterns for accurate SVM classification of hyperspectral images," *IEEE Geosci. Remote Sens. Lett.*, vol. 6, no. 4, pp. 840–844, Oct. 2009.
- [63] J. A. Richards and X. Jia, "Using suitable neighbors to augment the training set in hyperspectral maximum likelihood classification," *IEEE Geosci. Remote Sens. Lett.*, vol. 5, no. 4, pp. 774–777, Oct. 2008.
- [64] A. C. Jensen, A. Berge, and A. S. Solberg, "Regression approaches to small sample inverse covariance matrix estimation for hyperspectral image classification," *IEEE Trans. Geosci. Remote Sens.*, vol. 46, no. 10, pp. 2814–2822, Oct. 2008.
- [65] S. Rajan, J. Ghosh, and M. M. Crawford, "An active learning approach to hyperspectral data classification," *IEEE Trans. Geosci. Remote Sens.*, vol. 46, no. 4, pp. 1231–1242, Apr. 2008.
- [66] Y. Tarabalka, J. A. Benediktsson, and J. Chanussot, "Spectral-spatial classification of hyperspectral imagery based on partitioned clustering techniques," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 8, pp. 2973–2987, Aug. 2009.
- [67] S. K. Das and R. Singh, "Performance of kriging-based soft classification on WiFS/IRS-1D image using ground hyperspectral signatures," *IEEE Geosci. Remote Sens. Lett.*, vol. 6, no. 3, pp. 453–457, Jul. 2009.
- [68] J. Bolton and P. Gader, "Random set framework for context-based classification with hyperspectral imagery," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 11, pp. 3810–3821, Nov. 2009.
- [69] J. Chen, C. Wang, and R. Wang, "Using stacked generalization to combine SVMs in magnitude and shape feature spaces for classification of hyperspectral data," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 7, pp. 2193–2205, Jul. 2009.
- [70] S. Velasco-Forero and V. Manian, "Improving hyperspectral image classification using spatial preprocessing," *IEEE Geosci. Remote Sens. Lett.*, vol. 6, no. 2, pp. 297–301, Apr. 2009.
- [71] M. Fauvel, J. A. Benediktsson, J. Chanussot, and J. R. Sveinsson, "Spectral and spatial classification of hyperspectral data using SVMs and morphological profiles," *IEEE Trans. Geosci. Remote Sens.*, vol. 46, no. 11, pp. 3804–3814, Nov. 2008.
- [72] G. Licciardi, F. Pacifici, D. Tuia, S. Prasad, T. West, F. Giacco, C. Thiel, J. Inglada, E. Christophe, J. Chanussot, and P. Gamba, "Decision fusion for the classification of hyperspectral data: Outcome of the 2008 GRS-S data fusion contest," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 11, pp. 3857–3865, Nov. 2009.
- [73] H.-Y. Huang and B.-C. Kuo, "Double nearest proportion feature extraction for hyperspectral image classification," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 4034–4046, Nov. 2010.
- [74] H. R. Kalluri, S. Prasad, and L. M. Bruce, "Decision-level fusion of spectral reflectance and derivative information for robust hyperspectral land cover classification," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 4047–4058, Nov. 2010.
- [75] B. D. Bue, E. Merényi, and B. Csathó, "Automated labeling of materials in hyperspectral imagery," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 4059–4070, Nov. 2010.
- [76] B. Demir and S. Ertürk, "Empirical mode decomposition of hyperspectral images for support vector machine classification," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 4071–4084, Nov. 2010.
- [77] J. Li, J. M. Bioucas-Dias, and A. Plaza, "Semisupervised hyperspectral image segmentation using multinomial logistic regression with active learning," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 4085–4098, Nov. 2010.
- [78] L. Ma, M. M. Crawford, and J. Tian, "Local manifold learning-based k -nearest-neighbor for hyperspectral image classification," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 4099–4109, Nov. 2010.
- [79] W. Kim and M. M. Crawford, "Adaptive classification for hyperspectral image data using manifold regularization kernel machines," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 4110–4121, Nov. 2010.
- [80] Y. Tarabalka, J. A. Benediktsson, J. Chanussot, and J. C. Tilton, "Multiple spectral-spatial classification approach for hyperspectral data," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 4122–4132, Nov. 2010.
- [81] F. Tavin, A. Roman, S. Mathieu, F. Baret, W. Liu, and P. Gouton, "Comparison of metrics for the classification of soils under variable geometrical conditions using hyperspectral data," *IEEE Geosci. Remote Sens. Lett.*, vol. 5, no. 4, pp. 755–759, Oct. 2008.
- [82] M. Dalponte, L. Bruzzone, and D. Gianelle, "Fusion of hyperspectral and lidar remote sensing data for classification of complex forest areas," *IEEE Trans. Geosci. Remote Sens.*, vol. 46, no. 5, pp. 1416–1427, May 2008.
- [83] C. Chion, J. A. Landry, and L. Da Costa, "A genetic-programming-based method for hyperspectral data information extraction: Agricultural applications," *IEEE Trans. Geosci. Remote Sens.*, vol. 46, no. 8, pp. 2446–2457, Aug. 2008.
- [84] D. Haboudane, N. Tremblay, J. R. Miller, and P. Vigneault, "Remote estimation of crop chlorophyll content using spectral indices derived from hyperspectral data," *IEEE Trans. Geosci. Remote Sens.*, vol. 46, no. 2, pp. 423–437, Feb. 2008.
- [85] D. Sun, Y. Li, and Q. Wang, "A unified model for remotely estimating chlorophyll a in Lake Taihu, China, based on SVM and *in situ* hyperspectral data," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 8, pp. 2957–2965, Aug. 2009.
- [86] C. M. Bachmann, T. L. Ainsworth, R. A. Fusina, M. J. Montes, J. H. Bowles, D. R. Korwan, and D. B. Gillis, "Bathymetric retrieval from hyperspectral imagery using manifold coordinate representations," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 3, pp. 884–897, Mar. 2009.
- [87] T. Maestri and R. E. Holz, "Retrieval of cloud optical properties from multiple infrared hyperspectral measurements: A methodology based on a line-by-line multiple-scattering code," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 8, pp. 2413–2426, Aug. 2009.
- [88] J. Cheng, S. Liang, J. Wang, and X. Li, "A stepwise refining algorithm of temperature and emissivity separation for hyperspectral thermal infrared data," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 3, pp. 1588–1597, Mar. 2010.
- [89] B. Somers, S. Delalieux, W. W. Verstraeten, and J. Verbesselt, "Magnitude- and shape-related feature integration in hyperspectral mixture analysis to monitor weeds in citrus orchards," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 11, pp. 3630–3642, Nov. 2009.
- [90] M. A. Cho, P. Debba, R. Mathieu, L. Naidoo, J. van Aardt, and G. P. Asner, "Improving discrimination of savanna tree species through a multiple-endmember spectral angle mapper approach: Canopy-level analysis," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 4133–4142, Nov. 2010.
- [91] S. Collings, P. Caccetta, N. Campbell, and X. Wu, "Techniques for BRDF correction of hyperspectral mosaics," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 10, pp. 3733–3746, Oct. 2010.
- [92] J. Cierniewski and M. Guliński, "Furrow microrelief influence on the directional hyperspectral reflectance of soil at various illumination and

- observation conditions," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 11, pp. 4143–4148, Nov. 2010.
- [93] M. Cui, A. Razdan, J. Hu, and P. Wonka, "Interactive hyperspectral image visualization using convex optimization," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 6, pp. 1673–1684, Jun. 2009.
- [94] S. Cai, Q. Du, and R. J. Moorhead, "Feature-driven multilayer visualization for remotely sensed hyperspectral imagery," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 9, pp. 3471–3481, Sep. 2010.
- [95] K. Kotwal and S. Chaudhuri, "Visualization of hyperspectral images using bilateral filtering," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 5, pp. 2308–2316, May 2010.
- [96] B. Demir, A. Celebi, and S. Erturk, "A low-complexity approach for the color display of hyperspectral remote-sensing images using one-bit-transform based band selection," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 1, pp. 97–105, Jan. 2009.
- [97] J. He, L. Zhang, Q. Wang, and Z. Li, "Using diffusion geometric coordinates for hyperspectral imagery representation," *IEEE Geosci. Remote Sens. Lett.*, vol. 6, no. 4, pp. 767–771, Oct. 2009.
- [98] Y. Zhang, S. De Backer, and P. Scheunders, "Noise-resistant wavelet-based Bayesian fusion of multispectral and hyperspectral images," *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 11, pp. 3834–3843, Nov. 2009.
- [99] L.-R. Gao, B. Zhang, X. Zhang, W.-J. Zhang, and Q.-X. Tong, "A new operational method for estimating noise in hyperspectral images," *IEEE Geosci. Remote Sens. Lett.*, vol. 5, no. 1, pp. 83–87, Jan. 2008.
- [100] J. Martin-Herrero, "Comments on a new operational method for estimating noise in hyperspectral images," *IEEE Geosci. Remote Sens. Lett.*, vol. 5, no. 4, pp. 705–709, Oct. 2008.
- [101] D. Letexier, S. Bourennane, and J. B. Talon, "Nonorthogonal tensor matricization for hyperspectral image filtering," *IEEE Geosci. Remote Sens. Lett.*, vol. 5, no. 1, pp. 3–7, Jan. 2008.
- [102] D. Letexier and S. Bourennane, "Noise removal from hyperspectral images by multidimensional filtering," *IEEE Trans. Geosci. Remote Sens.*, vol. 46, no. 7, pp. 2061–2069, Jul. 2008.
- [103] N. Renard, S. Bourennane, and J. Blanc-Talon, "Denoising and dimensionality reduction using multilinear tools for hyperspectral images," *IEEE Geosci. Remote Sens. Lett.*, vol. 5, no. 2, pp. 138–142, Apr. 2008.



Jocelyn Chanussot (M'04–SM'04) received the M.Sc. degree in electrical engineering from the Grenoble Institute of Technology (INPG), Grenoble, France, in 1995 and the Ph.D. degree from the University of Savoy, Annecy, France, in 1998.

In 1999, he was with the Geography Imagery Perception Laboratory, Délégation Générale pour l'Armement (French National Defense Department). Since 1999, he has been with INPG, where he was an Assistant Professor from 1999 to 2005, was an Associate Professor from 2005 to 2007, and is currently a Professor of signal and image processing. He is currently conducting his research at the Grenoble Images Speech Signals and Automatics Laboratory, INPG. His research interests include image analysis, multicomponent image processing, nonlinear filtering, and data fusion in remote sensing.

Dr. Chanussot is the founding President of the IEEE Geoscience and Remote Sensing French Chapter (2007) which was the recipient of the 2010 IEEE GRS-S Chapter Excellence Award "for excellence as a Geoscience and Remote Sensing Society chapter demonstrated by exemplary activities during 2009." He is a member of the IEEE Geoscience and Remote Sensing AdCom (2009–2011). He was the General Chair of the first IEEE GRS-S Workshop on Hyperspectral Image and Signal Processing—Evolution in Remote Sensing. He is the Chair (2009–2011) and was the Cochair of the GRS-S Data Fusion Technical Committee (2005–2008). He was a member of the Machine Learning for Signal Processing Technical Committee of the IEEE Signal Processing Society (2006–2008) and the Program Chair of the IEEE International Workshop on Machine Learning for Signal Processing (2009). He was an Associate Editor for the IEEE GEOSCIENCE AND REMOTE SENSING LETTERS (2005–2007) and for *Pattern Recognition* (2006–2008). He has been an Associate Editor for the IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING since 2007.



Melba M. Crawford (M'89–SM'05–F'07) received the B.S. and M.S. degrees in civil engineering from the University of Illinois, Urbana, in 1970 and 1973, respectively, and the Ph.D. degree in systems engineering from The Ohio State University, Columbus, in 1981.

From 1990 to 2005, she was a Faculty Member of the University of Texas, Austin. She is currently with Purdue University, West Lafayette, IN, where she holds the Purdue Chair of Excellence in Earth Observation and is the Director of the Laboratory for Applications of Remote Sensing and the Associate Dean of Engineering for Research. She has more than 100 publications in scientific journals, conference proceedings, and technical reports and is internationally recognized as an expert in the development of methods for the analysis of hyperspectral and LIDAR remote sensing data.

Dr. Crawford was a Jefferson Senior Science Fellow at the U.S. Department of State in 2004–2005. She is a member of the IEEE Geoscience and Remote Sensing Society, where she is currently the Vice President for Meetings and Symposia, and an Associate Editor of the IEEE

TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING. She has also served as a member of the NASA Earth System Science and Applications Advisory Committee and was a member of the NASA EO-1 Science Validation team for the Advanced Land Imager and Hyperion.



Bor-Chen Kuo (S'01–M'02) received the B.S. degree in mathematics education and the M.S. degree in statistics and assessment from National Taichung Teachers College, Taichung, Taiwan, in 1993 and 1996, respectively, and the Ph.D. degree in electrical engineering from Purdue University, West Lafayette, IN, in 2001.

From 2002 to 2005, he was an Associate Professor with National Taichung University, Taichung, where he is currently a Professor and the Director of the Graduate Institute of Educational Measurement and Statistics. His research interests include pattern recognition, feature extraction and classification of high-dimensional data, computerized adaptive testing, and nonparametric functional estimation.

Dr. Kuo is a member of the Chinese Association of Psychological Testing AdCom and the Editor of the *Journal of Educational Measurement and Statistics*, Taiwan. He was the recipient of an Outstanding and Excellence Research Award from the R.O.C. Education and Research Society in 2009.