Introduction to the Issue on Advances in Hyperspectral Data Processing and Analysis

OPTICAL sensing has come a long way from grayscale to multispectral and now to hyperspectral images. The advances in imaging hardware over recent decades have enabled availability of high spatial, spectral, and temporal resolution imagery for a variety of applications. Hyperspectral imagery, also called imaging spectroscopy, entails acquiring images using a large number (typically a few hundreds) of narrow and often contiguous spectral bands, covering a wide range of the electromagnetic spectrum from the visible to the infrared regions. Compared to conventional color imagery (with 3 spectral bands covering the red, green and blue wavelengths, respectively), or compared to conventional multispectral imagery (typically a few spectral bands), hyperspectral data provide a very fine spectral characterization of the sensed materials, which facilitates their detection and characterization.

Advances in hardware to acquire hyperspectral imagery have made such data easily accessible to a wide variety of application domains, but have also created unique challenges for researchers working on algorithms for the representation, exploitation, and analysis of such data. Unfortunately, this is often a double-edged sword. A direct consequence of the dense spectral sampling implies that each measurement corresponds to a vector with several hundreds of values. Consequently, the data are evolving in a vector space with several hundreds of dimensions. Traditional information-processing techniques cannot be used to process such data effectively. While it is a curse from an analytical, theoretical, and statistical point of view, the very high dimensionality of the data is also a blessing. The feature space being almost empty, a good separation of the classes is possible *a priori*, as well as an effective characterization of the data. The emergence of such imagery has thus created a unique need for fundamental theory and algorithms research to exploit the rich spectral-spatial-temporal data provided by such imaging modalities.

This special issue represents advances in hyperspectral image-processing research. Specifically, it focuses on novel algorithmic approaches related to the representation and analysis of hyperspectral images, as well as their application to real-world image-analysis needs. It also delves into theoretical insights, performance limits, and trade-offs on the class of emerging image-processing approaches tailored to hyperspectral images. This issue covers a gamut of broad topics, from representation and sensing (image coding, compressive sensing), feature extraction and channel selection, to image analysis (spectral unmixing, classification, detection, etc.).

Owing to the high data volumes that result from hyperspectral imagery, effective coding is strongly desired and has been an active focus of research. A related development has been the emergence of compressive-sensing architectures and recovery schemes tailored for hyperspectral imagery. In the paper by Yuan, Tsai, Zhu, Llull, Brady, and Carin, a blind compressive-sensing algorithm is proposed that reconstructs hyperspectral images from spectrally compressed measurements — the wavelength-dependent data are coded and superposed, in a process that maps the hyperspectral image to a two-dimensional image. The inversion algorithm then learns a dictionary *in situ)* from the measurements via what are referred to as *global shrinkage priors*. In the contribution by Zhang, Li, and Chen, a novel distributed coding scheme is presented for lossless, progressive, and low-complexity compression of hyperspectral images. The motivation is to design a scheme that shifts the complexity of data decoding to the decoder side to achieve a lightweight onboard processing after acquisition. At the encoder, images are sub-sampled in order to facilitate successive encoding and progressive transmission. At the decoder, side-information is generated using adaptive region-based predictors that take advantage of the decoded sub-sampled images and previously decoded neighboring bands. In the paper by Fan, Ely, Aeron, and Miller, algebraic and structural complexity is utilized for single-snapshot computed-tomography hyperspectral imaging systems. The proposed approach simultaneously denoises and recovers data cubes from a limited number of tomographic measurements that arise from single-snapshot imaging systems.

Feature extraction and dimensionality reduction are often important preprocessing stages to most hyperspectral image analysis — from finding a lower-dimensional subspace that is most suited for classification, anomaly detection, or unmixing, to finding specific spectral channels that are most relevant to the task at hand. In the contribution by Cui and Prasad, a feature-reduction approach is developed for hyperspectral image classification. The approach, referred to as Angular Discriminant Analysis, seeks a lower-dimensional subspace wherein classes are *angularly* well separated — the proposed approach learns a projection matrix that results in subspaces where classes form angularly compact clusters and are angularly well-separated from each other. It is demonstrated that such subspaces result in robust hyperspectral image analysis. In Santos, Guimaraes, and Santos, a spectral-band selection approach is proposed based on the notion of what is referred

to as spectral rhythms. The approach seeks to find the most relevant bands for the underlying hyperspectral classification. In Laparra, Malo, and Camps-Valls, dimensionality reduction based on regression is proposed for hyperspectral imagery. The approach identifies nonlinear features through multivariate regression and results in an interpretable and easy to apply framework.

While the design of algorithms that are capable of exploiting the rich information provided by hyperspectral imagery for classification and anomaly-detection tasks is a focus of much active research, methods that fuse information from multiple images for improved analysis have also witnessed a great deal of interest. This special issue includes contributions on topics related to single-sensor image analysis and multi-sensor data fusion. In Deleforge, Forbes, Ba, and Horaud, hyperspectral image analysis is proposed to exploit partially latent regression and spatial Markov dependencies, enabling handling of scenarios that deal with physical parameters that cannot be directly observed (or, more generally, with data contaminated by experimental artifacts that can not be explained with traditional noise models). In Zhao, Zhong, Wu, Zhang, and Shu, a sub-pixel mapping approach is proposed based on conditional random fields. The paper by Forero, Chen, Goh, and Pang provides a comparative evaluation of modern techniques for covariance-matrix estimation within the context of anomaly detection. In Sun, Zhong, Xiao, and Wang, active learning based on a Markov Random Field model is presented. In Du, Xue, Li, and Plaza, a new approach for discriminative sparse representation for hyperspectral image classification is developed. In Cariou and Chehdi, an unsupervised clustering approach is proposed for multi-dimensional data for scenarios wherein the number of clusters is not known *a priori*. In Wei, Dobigeon, and Tourneret, a Bayesian Fusion approach for fusion of multi-band images is investigated.

By its very nature, geospatial hyperspectral images often represent mixed pixels — that is, a pixel is often a mixture of dominant material types. This is particularly relevant for images that are of lower spatial resolution when compared to the size of objects in the image. Hyperspectral unmixing — a class of algorithms that estimates relative proportions of dominant materials in a pixel from the spectral reflectance in that pixel — is critical for effective analysis of such images. In Fu, Ma, Chan, and Bioucas-Dias, a self-dictionary sparse regression is presented for hyperspectral unmixing. Different from previous related efforts, this paper explores greedy pursuit approaches and reveals a link between the greedy algorithm developed by them and the pure-pixel search approach. In Qu, Nasrabadi, and Tran, subspace vertex pursuit is proposed for hyperspectral unmixing. The unmixing problem is formulated as a joint sparse-recovery problem and a quasi-greedy algorithm is developed. In Marinoni and Gamba, a new approach for efficient p-linear unmixing is presented. The paper addresses the problem of nonlinear unmixing, proposing a method that aims

at providing excellent reconstruction performance for arbitrary polynomial nonlinearities, by making use of the polytope decomposition method.

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SAURABH PRASAD, *Lead Guest Editor*
Hyperspectral Image Analysis Lab, Electrical and Computer
   Engineering Department
University of Houston
Houston, TX 77004 USA

JOCELYN CHANUSSOT, *Guest Editor*
GIPSA Lab
Grenoble Institute of Technology
38000 Grenoble, France

JAMES E. FOWLER, *Guest Editor*
Electrical and Computer Engineering
Mississippi State University
Mississippi, 39762 MS USA

JOSÉ BIOUCAS-DIAS, *Guest Editor*
Instituto Superior Técnico
Instituto de Telecomunicações
Universidade de Lisboa
1049-001 Lisbon Portugal

CHARLES D. CREUSERRE, *Guest Editor*
Electrical and Computer Engineering
New Mexico State University
Las Cruces, NM 88003 USA

Saurabh Prasad (S'05–M'09–SM'14) received the B.S. degree in electrical engineering from Jamia Millia Islamia, New Delhi, India, in 2003, the M.S. degree in electrical engineering from Old Dominion University, Norfolk, VA, in 2005, and the Ph.D. degree in electrical engineering from Mississippi State University, MS, USA, in 2008. He is currently an Assistant Professor in the Electrical and Computer Engineering Department at the University of Houston (UH), Houston, TX. He leads the Hyperspectral Image Analysis group at UH. His research interests include statistical pattern recognition and signal processing for geospatial and neural signal processing. The over-arching scope of research projects that he leads entails algorithm design for information fusion, Bayesian inference, sparse representation and subspace learning to address real-world challenges posed by geospatial and neural data. Dr. Prasad is the recipient of the best student paper award at the IEEE Geoscience and Remote Sensing Symposium in 2008, two research excellence awards (2007 and 2008) during his Ph.D. study at Mississippi State University, including the university wide outstanding graduate student research award, a state pride faculty award at Mississippi State University in 2010, and a NASA New Investigator (Early Career) award in 2014. He is an associate editor for the IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING.

Jocelyn Chanussot (M'04–SM'04–F'12) received the M.Sc. degree in electrical engineering from the Grenoble Institute of Technology (Grenoble INP), Grenoble, France, in 1995, and the Ph.D. degree from Savoie University, Annecy, France, in 1998. In 1999, he was with the Geography Imagery Perception Laboratory for the Delegation Generale de l'Armement (DGA – French National Defense Department). Since 1999, he has been with Grenoble INP, where he was an Assistant Professor from 1999 to 2005, an Associate Professor from 2005 to 2007, and is currently a Professor of signal and image processing. He is conducting his research at the Grenoble Images Speech Signals and Automatics Laboratory (GIPSA-Lab). His research interests include image analysis, multicomponent image processing, nonlinear filtering, and data fusion in remote sensing. He is a member of the Institut Universitaire de France (2012–2017). Since 2013, he is an Adjunct Professor of the University of Iceland. Dr. Chanussot is the founding President of IEEE Geoscience and Remote Sensing French chapter (2007–2010) which received the 2010 IEEE GRS-S Chapter Excellence Award. He was the co-recipient of the NORSIG 2006 Best Student Paper Award, the IEEE GRSS 2011 Symposium Best Paper Award, the IEEE GRSS 2012 Transactions Prize Paper Award and the IEEE GRSS 2013 Highest Impact Paper Award. He was a member of the IEEE Geoscience and Remote Sensing Society AdCom (2009–2010), in charge of membership development. He was the General Chair of the first IEEE GRSS Workshop on Hyperspectral Image and Signal Processing, Evolution in Remote sensing (WHISPERS). He was the Chair (2009–2011) and Cochair of the GRS 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). Since 2007, he has been an Associate Editor for the IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING. Since 2011, he is the Editor-in-Chief of the IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING. In 2013, he was a Guest Editor for the PROCEEDINGS OF THE IEEE and in 2014 a Guest Editor for the *IEEE Signal Processing Magazine*. He is a Fellow of the IEEE and a member of the Institut Universitaire de France (2012–2017).

James E. Fowler (S'91–M'96–SM'02) received the B.S. degree in computer and information science engineering and the M.S. and Ph.D. degrees in electrical engineering from The Ohio State University, Columbus, OH, USA, in 1990, 1992, and 1996, respectively. In 1995, he was an Intern Researcher at AT&T Labs in Holmdel, NJ, USA, and, in 1997, he held a National Science Foundation-sponsored postdoctoral assignment at the Université de Nice-Sophia Antipolis, France. In 2004, he was a Visiting Professor with the Département Traitement du Signal et des Images, Télecom ParisTech, Paris, France. He is currently Billie J. Ball Professor and Graduate Program Director of the Department of Electrical and Computer Engineering, Associate Director of the Distributed Analytics and Security Institute, and a Researcher in the Geosystems Research Institute at Mississippi State University Starkville, MS. Dr. Fowler is an Associate Editor for IEEE TRANSACTIONS ON COMPUTATIONAL IMAGING and the *EURASIP Journal on Image and Video Processing*; he formerly served as an Associate Editor for the IEEE TRANSACTIONS ON IMAGE PROCESSING, IEEE TRANSACTIONS ON MULTIMEDIA, and IEEE SIGNAL PROCESSING LETTERS. He is the Past Chair of the Image, Video, and Multidimensional Signal Processing Technical Committee of the IEEE Signal Processing Society and was a member of the Strategic Planning Committee of the IEEE Publication Services and Products Board. He was general co-chair of the 2014 IEEE International Conference on Image Processing, Paris, France, and is currently the publicity chair of the program committee for the Data Compression Conference.

José Bioucas-Dias (S'87–M'95) received the EE, MSc, PhD, and "Agregado" degrees from Instituto Superior Técnico (IST), Technical University of Lisbon (TULisbon, now University of Lisbon), Portugal, in 1985, 1991, 1995, and 2007, respectively, all in electrical and computer engineering.

Since 1995, he has been with the Department of Electrical and Computer Engineering, IST, where he was an Assistant Professor from 1995 to 2007 and an Associate Professor since 2007. Since 1993, he has also been a Senior Researcher with the Pattern and Image Analysis group of the Instituto de Telecomunicações, which is a private non-profit research institution. His research interests include inverse problems, signal and image processing, pattern recognition, optimization, and remote sensing. Dr. Bioucas-Dias has authored or co-authored more than 250 scientific publications including more than 70 journal papers (48 of which published in IEEE journals) and 180 peer-reviewed international conference papers and book chapters.
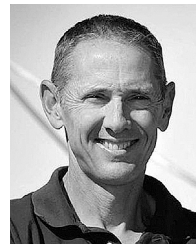
Charles D. Creusere (M'93–SM'04) received the B.S. degree in electrical and computer engineering from the University of California, Davis, in 1985, and the M.S. and Ph.D. degrees in electrical and computer engineering from the University of California, Santa Barbara, in 1991 and 1993, respectively. Since January 2000, he has been a Professor of Electrical and Computer Engineering at New Mexico State University, Las Cruces. In 2008, he was selected for NMSU's first International Foundation for Telemetering professorship and in January 2010 he was awarded the Frank Carden Chair in Telemetering and Telecommunications. Dr. Creusere is also highly active professionally in the IEEE and in particular the Signal Processing Society, having served as an Associate Editor for both the IEEE TRANSACTIONS ON MULTIMEDIA and the IEEE TRANSACTIONS ON IMAGE PROCESSING. His current research interests include remote sensing and neural signal processing.