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

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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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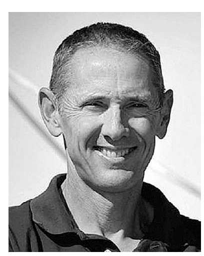

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