Foreword to the Special Issue on Hyperspectral Image and Signal Processing

THIS SPECIAL issue presents state-of-the-art algorithms and applications for hyperspectral image and signal processing. Algorithms address topics such as spectral unmixing, classification, target and anomaly detection, compression, data fusion, noise reduction. Applications include monitoring of vegetation and environment. Seventy-four papers were selected for this issue. The large number of papers included in this special issue is indicative of the high level of research activity, interest, and applications for hyperspectral image and signal analysis.

The 5th Workshop on Hyperspectral Image and Signal Processing—Evolution in Remote Sensing (WHISPERS) was held on June 25–28, 2013 in Gainesville, FL, USA. WHISPERS 2013 received the technical sponsorship of the IEEE Geoscience and Remote Sensing Society (GRSS) and support from the University of Florida and the WHISPERS Foundation. The workshop was held on two parallel tracks over 3 days and was a great success, welcoming over 180 international researchers. At the workshop, 158 papers were presented, covering a wide range of topics related to hyperspectral image and signal processing.

Hyperspectral imagery provides a wealth of information about an imaged scene. Each pixel consists of a spectrum resulting from the combination of radiance information from one or more materials in a physical region. Different materials reflect and emit varying amounts of radiance across the electromagnetic spectrum and, as a result, generally have distinguishing signatures. These unique spectral signatures provide the promise of being able to distinguish, detect, and classify materials at the subpixel level [1]. Given the amount of information that can be obtained from hyperspectral imagery, many applications make use of hyperspectral data and the development of algorithms which leverage all the information is an active area of research. In this special issue, several current algorithmic methods and applications for hyperspectral image and signal analysis are presented. In the following, a brief overview of the algorithmic topics covered in this special issue is provided.

Spectral unmixing: Spectra of materials can mix in a variety of ways. Even with high spatial resolution, the measured spectrum at a pixel is a combination of materials in the pixel's field of view and dependent upon the point-spread function of the optical system. Spectral unmixing, the problem of decomposing each pixel into it's respective material signatures (i.e., *endmembers*) and the amount of each endmember (i.e., *abundances*), is a major area of study. Spectral unmixing algorithms depend on the assumption of a mixing model. Both linear and nonlinear mixing models have been considered in the literature [1]–[5]. In this special issue, 14 papers on spectral unmixing are presented. This includes a review and comparison of nonlinear methods. Sparse unmixing methods [5]–[7], which assume that each pixel is a mixture of a sparse subset of the endmembers in a scene, is a current area of research. Spectral unmixing methods that leverages spatial information is also a major area of research since neighboring pixels in a scene are likely to be composed of the same materials [8]–[10]. Methods that address and incorporate endmember spectral variability during unmixing can result in more physically accurate models and proportion estimates [11]. Finally, given the large number of spectral unmixing methods, algorithms that can be used to evaluate and compare spectral unmixing results is an important topic of study.

Classification: Classification methods provide algorithms to segment and classify pixels or regions in hyperspectral imagery. Like many spectral unmixing algorithms, many current classification algorithms investigate methods to incorporate spatial information during analysis [12]. Sparsity promotion has also been employed to help improve classification results [13]. In addition, many current topics in the machine learning literature such as multiple kernel approaches [14], [15] and swarm optimization [16], have been adapted and applied toward classification of hyperspectral data.

Compression and high-performance computing: Given the extremely large size of most hyperspectral data cubes, compression methods and methods that make use of high-performance computing approaches are an important area of study and development. Studies have been conducted on employing and evaluating various lossy and lossless compression approaches for hyperspectral imagery [17], [18].

Target and anomaly detection: Given the ability to perform subpixel analysis, target and anomaly detection at the subpixel level is an area of great interest in the hyperspectral community [19], [20]. Topics in this area include investigations into methods to accurately model background characteristics, predict detection performance, and the development of a new target and anomaly detection algorithms.

Data fusion: Data fusion between other imagery from other sensor types and hyperspectral imagery can provide more information about an imaged scene than either data set individually. For example, LIDAR provides elevation information that can be used in conjunction with hyperspectral data [21], [22]. Fusion between multispectral and hyperspectral data is also an area of interest [23], [24].

Noise reduction: As with all sensor data, hyperspectral imagery can be, and is often, corrupted with sensor noise. Often, particular wavelengths in a hyperspectral image have

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more noise than others. As such, methods for noise reduction are an important area of study [25].

As can be seen, there is a wide variety of topics for hyperspectral image and signal analysis that are under study. We believe that this issue provides a wide sampling of the interesting and promising research topics within this area. We thank all of the contributors who made this special issue such an interesting overview of many of the current areas of study.

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REFERENCES

[1] J. M. Bioucas-Dias *et al.*, "Hyperspectral unmixing overview: Geometrical, statistical, and sparse regression-based approaches," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 5, no. 2, pp. 354–379, Apr. 2012.

[2] A. Halimi, Y. Altmann, N. Dobigeon, and J.-Y. Tourneret, "Nonlinear unmixing of hyperspectral images using a generalized bilinear model," *IEEE Trans. Geosci. Remote Sens.*, vol. 49, no. 11, pp. 4153–4162, Nov. 2011.

[3] Y. Altmann, A. Halimi, N. Dobigeon, and J.-Y. Tourneret, "Supervised nonlinear spectral unmixing using a postnonlinear mixing model for hyperspectral imagery," *IEEE Trans. Image Process.*, vol. 21, no. 6, pp. 3017–3025, Jun. 2012.

[4] R. Heylen and P. Scheunders, "Calculation of geodesic distances in nonlinear mixing models: Application to the generalized bilinear model," *IEEE Geosci. Remote Sens. Lett.*, vol. 9, no. 4, pp. 644–648, Jul. 2012.

[5] Q. Qu, N. Nasrabadi, and T. Tran, "Abundance estimation for bilinear mixture models via joint sparse and low-rank representation," *IEEE Trans. Geosci. Remote Sens.*, vol. 52, no. 7, pp. 4404–4423, Jul. 2014.

[6] M.-D. Iordache, J. Bioucas-Dias, and A. Plaza, "Sparse unmixing of hyperspectral data," *IEEE Trans. Geosci. Remote Sens.*, vol. 49, no. 6, pp. 2014–2039, Jun. 2011.

[7] A. Castrodad *et al.*, "Learning discriminative sparse representations for modeling, source separation, and mapping of hyperspectral imagery," *IEEE Trans. Geosci. Remote Sens.,* vol. 49, no. 11, pp. 4263–4281, Nov. 2011.

[8] A. Zare and P. Gader, "Piece-wise convex spatial-spectral unmixing of hyperspectral imagery using possibilistic and fuzzy clustering," in *Proc. IEEE Int. Conf. Fuzzy Sys. (FUZZ)*, Jun. 2011, pp. 741–746.

[9] G. Martin and A. Plaza, "Spatial-spectral preprocessing prior to endmember identification and unmixing of remotely sensed hyperspectral data," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 5, no. 2, pp. 380–395, Apr. 2012.

[10] K. Canham, A. Schlamm, A. Ziemann, B. Basener, and D. Messinger, "Spatially adaptive hyperspectral unmixing," *IEEE Trans. Geosci. Remote Sens.*, vol. 49, no. 11, pp. 4248–4262, Nov. 2011.

[11] A. Zare and K. Ho, "Endmember variability in hyperspectral analysis: Addressing spectral variability during spectral unmixing," *IEEE Signal Process. Mag.*, vol. 31, no. 1, pp. 95–104, Jan. 2014.

[12] M. Cui, S. Prasad, W. Li, and L. Bruce, "Locality preserving genetic algorithms for spatial-spectral hyperspectral image classification," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 6, no. 3, pp. 1688–1697, Jun. 2013.

[13] J. Liu, Z. Wu, Z. Wei, L. Xiao, and L. Sun, "Spatial-spectral kernel sparse representation for hyperspectral image classification," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 6, no. 6, pp. 2462–2471, Dec. 2013.

[14] Y. Gu, S. Wang, and X. Jia, "Spectral unmixing in multiple-kernel hilbert space for hyperspectral imagery," *IEEE Trans. Geosci. Remote Sens.*, vol. 51, no. 7, pp. 3968–3981, Jul. 2013.

[15] D. Tuia, G. Camps-Valls, G. Matasci, and M. Kanevski, "Learning relevant image features with multiple-kernel classification," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, no. 10, pp. 3780–3791, Oct. 2010.

[16] H. Yang, Q. Du, and G. Chen, "Particle swarm optimization-based hyperspectral dimensionality reduction for urban land cover classification," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 5, no. 2, pp. 544–554, Apr. 2012.

[17] A. Karami, M. Yazdi, and G. Mercier, "Compression of hyperspectral images using discerete wavelet transform and tucker decomposition," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 5, no. 2, pp. 444–450, Apr. 2012.

[18] Q. Du and J. Fowler, "Hyperspectral image compression using JPEG2000 and principal component analysis," *IEEE Geosci. Remote Sens. Lett.,* vol. 4, no. 2, pp. 201–205, Apr. 2007.

[19] H. Kwon and N. Nasrabadi, "Kernel RX-algorithm: A nonlinear anomaly detector for hyperspectral imagery," *IEEE Trans. Geosci. Remote Sens.*, vol. 43, no. 2, pp. 388–397, Feb. 2005.

[20] D. W. J. Stein *et al.*, "Anomaly detection from hyperspectral imagery," *IEEE Signal Process. Mag.*, vol. 19, no. 1, pp. 58–69, Jan. 2002.

[21] M. Pedergnana, P. Marpu, M. Dalla Mura, J. Benediktsson, and L. Bruzzone, "Classification of remote sensing optical and LiDAR data using extended attribute profiles," *IEEE J. Sel. Topics Signal Process.*, vol. 6, no. 7, pp. 856–865, Nov. 2012.

[22] 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.

[23] N. Yokoya, T. Yairi, and A. Iwasaki, "Coupled nonnegative matrix factorization unmixing for hyperspectral and multispectral data fusion," *IEEE Trans. Geosci. Remote Sens.*, vol. 50, no. 2, pp. 528–537, Feb. 2012.

[24] 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.

[25] Y. Qian and M. Ye, "Hyperspectral imagery restoration using nonlocal spectral-spatial structured sparse representation with noise estimation," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 6, no. 2, pp. 499–515, Apr. 2013.

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