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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.

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