Foreword to the Special Issue on Hyperspectral Image and Signal Processing

THE very high spectral resolution of remotely sensed hyperspectral data [1], rooted in technological, modeling and processing advances, has fostered a strong interest in this image modality at an unprecedented rate in recent years. In fact, the very high spectral resolution of hyperspectral data offers very significant potential in the identification of materials and their properties [2]. However, the high dimensionality of hyperspectral data (and its usually low spatial resolution) raises a series of new challenges on several fronts, namely, in signal and image processing, physical modeling, sensor design and calibration, applications and computationally efficient processing [3].

The aforementioned topics were addressed in the IEEE Geoscience and Remote Sensing Society (GRSS) Workshop on Hyperspectral Image and Signal Processing: Evolution in Remote Sensing (WHISPERS).[1] After two successful editions in Grenoble, France (2009), and Reykjavik, Iceland (2010), the 2011 edition of WHISPERS took place in Lisbon. The venue was the Instituto Superior Técnico (IST), the largest and most reputed school of Engineering, Science and Technology and Architecture in Portugal. The general chairs of WHISPERS 2011 were Prof. José M. Bioucas-Dias from IST and Prof. Antonio Plaza from the University of Extremadura, Spain. The program chair was Prof. Jocelyn Chanussot from GIPSA-Lab, Grenoble Institute of Technology, France. After a careful review process, in which each submission received an average of 2.5 anonymous reviews, a total of 126 papers were accepted for presentation and publication in the proceedings of WHISPERS 2011. Of these, 92 were orally presented while the remaining 34 were presented as posters. In total, fourteen regular sessions (five on signal and image processing, three on physical modeling, two on sensor design, and five on applications) were organized, covering a wide spectrum of techniques and disciplines in this research area). Three special dedicated sessions were organized on advanced topics for hyperspectral data exploitation, including spectral unmixing, machine learning, and target detection. The technical program promoted the dissemination of research results and technical advances in the aforementioned topics and offered a fertile discussion forum for researchers coming from different areas and backgrounds.

The technical program of WHISPERS 2011 also featured three plenary talks delivered by prestigious and highly recognized experts worldwide. Prof. Melba Crawford, from Purdue University, USA, delivered a talk entitled "Nonlinear manifolds for feature extraction: opportunities and challenges." Dr. Alexander Held, from CSIRO Division of Marine and Atmospheric Research, Canberra, Australia, delivered the talk "Coordination of international spaceborne imaging spectroscopy missions." Dr. James Burger, from BurgerMetrics, Riga, Latvia, delivered the talk "The interplay of chemometrics and hyperspectral chemical imaging." A panel discussion on "Data sets and performance measures" was organized by Prof. Paul Gader from the University of Florida, USA, with other distinguished panelists including Prof. Jon Atli Benediktsson from the University of Iceland, Prof. Melba Crawford, and Prof. David Goodenough from the University of Victoria/Pacific Forestry Centre, Canada. The discussion focused on standardizing hyperspectral data sets and performance measures for algorithm evaluation and comparison. In addition, two public Ph.D. defenses of distinguished candidates (Dr. Jun Li, from IST and the University of Extremadura, and Dr. Alberto Villa, from GIPSA-Lab, Grenoble Institute of Technology and the University of Iceland) were organized during WHISPERS 2011, addressing cutting-edge advances in image and signal processing applied to remotely sensed hyperspectral imaging. Several leading companies sponsored and/or exhibited their latest products during the event: Analytical Spectral Devices, Inc., Bonsai Advanced Technologies, Headwall Photonics, HySpex, IM Publications, ITRES, Specim, SpecTIR, and Spectral Evolution.

Following the 2011 edition of WHISPERS, this special issue of the IEEE JOURNAL OF SELECTED TOPICS ON APPLIED EARTH OBSERVATIONS AND REMOTE SENSING (JSTARS) is intended to present the current state-of-the-art and the most recent developments in the area of hyperspectral image and signal processing. The special issue comprises extended versions of papers presented at WHISPERS 2011 and also other papers, since the special issue was open to the wide scientific community working on hyperspectral image and signal processing in order to bring together recognized international experts from many different institutions and provide a remarkable sampling of the latest advances in this field. A large number of submissions were received for this special issue, of which 25 papers were selected for publication after rigorous review. A few of the submissions will be published in the following issues of JSTARS, after the final reviews and revisions are completed. The accepted papers can be grouped into the following main categories.

A. *Spectral Unmixing*

Regardless of the available spatial resolution, the spectral signals collected in natural environments are invariably a mixture of the signatures of the various materials found within the spatial extent of the ground instantaneous field view of the hyperspectral imaging instrument [4]. To address this issue, spectral unmixing infers a set of pure spectral signatures, called *endmembers*, and the fractions of these endmembers, called *abundances*, in each pixel of the scene. This relevant

Digital Object Identifier 10.1109/JSTARS.2012.2194598

[1]http://core.ieee-whispers.com.

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topic is addressed in the first paper of the special issue [5], which provides an overview of the principal research directions and state-of-the-art methodologies in hyperspectral unmixing developed mostly in the last 10 years after Keshava and Mustard's tutorial paper published in the IEEE *Signal Processing Magazine* [4]. The paper covers different topics in this area, namely spectral mixing models, signal subspace identification techniques, geometrical-based spectral unmixing, statistical-based spectral unmixing, sparse regression-based unmixing, and methods using spatial-contextual information for spectral unmixing purposes. For each topic, the mathematical problems involved are summarized, relevant pointers to state-of-the-art algorithms to address these problems are given, and the potentialities and limitations of these algorithms are experimentally illustrated using both simulated and real hyperspectral unmixing case studies and examples.

In [6], the issue of how to include spatial-contextual information in spectral unmixing applications is further explored. Specifically, the paper develops a new spatial-spectral preprocessing framework which guides the endmember identification process to spectrally pure and spatially homogeneous regions. The assumption is that pure spectral signatures in the scene are likely to be found in those regions. Experimental results with both synthetic and real hyperspectral data indicate that such preprocessing can improve unmixing results without increasing computational complexity and without the need to modify existing unmixing algorithms.

In [7], another important issue related with spectral unmixing, the variation in endmember spectral signatures, is addressed. Specifically, a simple strategy to adapt available endmember identification algorithms to select multiple endmembers (or bundles) per scene component is developed. The proposed technique is applied to several common endmember identification algorithms and combined with an endmember variability reduction technique for unmixing purposes, showing that the proposed strategy can significantly improve fractional abundance estimations by accounting for endmember variability in the original hyperspectral data.

B. Classification and Segmentation

As opposed to spectral unmixing, which is an estimation problem, hyperspectral image classification and segmentation techniques aim at assigning a class label to each pixel in the scene. Due to many factors such as high dimensionality, linear and nonlinear spectral mixing, spectral variability, atmospheric effects, and noise, hyperspectral image classification and segmentation is a challenging problem, which, arguably, has garnered the attention of most researchers and resulted in the largest number of published papers in the area of hyperspectral image analysis [8]. It comprises developments in both the unsupervised (clustering and segmentation) or supervised (algorithms based on training and machine learning) domains. In this special issue, three contributions are directly related with this topic.

In [9], a variety of data-driven algorithms for spectral image analysis were applied to spatial tiles of a large area scene to improve segmentation results across a variety of sensor types, scene contents, and spectral and spatial resolutions. A false color visualization of the estimated feature maps was used to display a detection plane to indicate the degree and type of interest contained within a tile based on the brightness and color of the tile in the display. This approach improved the detection capability at the expense of increased false alarms.

In [10], a new unmixing-based feature extraction technique is introduced. This technique integrates spatial and spectral information using a combination of unsupervised clustering and partial spectral unmixing. A quantitative and comparative assessment of unmixing-based versus traditional (supervised and unsupervised) feature extraction techniques in the context of hyperspectral image classification, using the well-known support vector machine (SVM) classifier, is conducted. This study, using a variety of hyperspectral scenes collected by different instruments, provides practical observations regarding the utility and type of feature extraction techniques needed for different classification scenarios and bridges the gap between spectral unmixing and classification.

Following with the relevant topic of supervised classification, in [11] a comparison between the SVM and two enhanced methods, namely the relevance vector machine (RVM) and the import vector machine (IVM), is presented for simulated hyperspectral data from the upcoming Environmental Mapping and Analysis Program (EnMAP)[2] mission. The results suggest that all three classifiers yield useful classification results on simulated EnMAP data; however, the IVM produces the most accurate results and the advantage of IVM and RVM over SVM is significant according to McNemar's test.

C. 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 [12]. In this special issue, two contributions are directly related with this topic. In [13], an efficient method for hyperspectral image compression based on the discrete wavelet transform and the Tucker decomposition is presented. The method exploits both the spectral and the spatial information of the hyperspectral datasets. The discrete wavelet transform is used to effectively separate the hyperspectral data into different sub-images and the Tucker decomposition is used to efficiently compact the energy of these sub-images. The effectiveness of the proposed method is illustrated in an experimental comparison with other well-known compression methods. The impact of the proposed compression scheme on both supervised classification and spectral unmixing applications is also addressed.

In [14], a performance evaluation of the state-of-the-art H.264/AVC video coding standard is carried out with the aim of determining its feasibility when applied to remotely sensed hyperspectral image compression. A methodology is established presenting a pre-processing of the hyperspectral image in order to convert it into a file format acceptable by the H.264/AVC encoder. Then, the impact of compression

[2]http://www.enmap.org.

on spectral unmixing applications is evaluated showing that this modification barely affects the accuracy of the unmixing process. These results open new avenues in the design of hardware implementations for lossy compression of hyperspectral images based on the H.264/AVC encoder.

D. Target Detection

Often related to critical defense and security issues, target detection is a very important topic in hyperspectral data exploitation [15]. The wealth of spectral information in hyperspectral data allows uncovering rare or spectrally distinct objects, thus allowing to discriminate them from complex backgrounds. In this special issue, three contributions are directly related with this topic. In [16], the theoretical properties of the max-min and min-max detectors are investigated as a special case of generalized fusion for hyperspectral image and signal processing. The detection power of these target detection approaches is illustrated under several scenarios, providing new analytical results on the performance of those detectors and analyzing in detail the relationship between these two detectors and other approaches widely used for target detection purposes.

In [17], the consequences of using a misspecified model when some of the pure spectral signatures (endmembers) are missing in the context of target detection applications. To this end, two detectors, one that uses all endmembers and another one that uses only some endmembers are compared in terms of their relative efficiency, which is a useful tool for comparison of detectors without directly calculating the detection power. Numerical results are given in both simulated and real analysis scenarios in this contribution, which bridges the gap between spectral unmixing and target detection approaches. In [18], detection of amorphously shaped objects is considered using a neighborhood model that operates on a concept of loose spatial contiguity, where there is a significant probability that a pixel surrounded by the object of interest itself contains that object of interest. A single-parameter prior probability model is used in a maximum a posteriori hypothesis test, and the method is then evaluated using hyperspectral imagery using data created using the digital imaging and remote sensing image generation model (DIRSIG) program. Quantitative analyses with receiver operating characteristics (ROC) curves show improvement relative to alternate methods.

E. Information Extraction, Fusion and Simulation

An important issue in hyperspectral data exploitation is to manage the massive amount of hyperspectral data which has already been collected and transmitted to Earth [19]. For this purpose, information extraction and fusion of hyperspectral data obtained from large repositories becomes a very important task. Simulation of hyperspectral data from the new generation of imaging spectrometers is also crucial for their future development. These areas are addressed in this special issue in the form of four different contributions.

In [20], a novel content-based image retrieval (CBIR) system for hyperspectral image databases is introduced. The system allows the user to retrieve hyperspectral images containing materials similar to the query image and in a similar proportion. Both spectral and spatial features are exploited. The former are based on the set of endmembers obtained from the image by an endmember induction algorithm. The latter are computed as abundance image statistics. Both kinds of information are combined into a dissimilarity measure between two hyperspectral images. This dissimilarity measure guides the search for answers to database queries. Validation results using both synthetic and real hyperspectral data are provided.

In [21], a new approach for visualization-oriented fusion of hyperspectral image bands is proposed. The fusion weights are optimally computed in order to provide better visualization results. The novelty of the proposed approach lies in the fact that the fusion process is driven by the desired output characteristics. As the proposed technique is completely output-driven, it does not require any extra input information. Both visual and quantitative results are provided to substantiate the quality of the proposed approach using different hyperspectral image data sets.

In [22], classification of multisource data consisting of contextual features from a high spatial resolution color image and spectral features from a low spatial resolution hyperspectral image are used to produce thematic maps at the spatial resolution of the color image by means of a new decision fusion framework. In classification experiments on both simulated and real multisource data, the proposed approach is shown to outperform other methods for performing multisource classification.

In [23] a new software tool for the end-to-end simulation of future data collected within the framework of the EnMAP mission is presented. The system is comprised of a modular structure and includes the entire image data acquisition and processing chain from spatially and spectrally oversampled data. The analysis of intermediate and final simulation products demonstrate that the system can support technical decision-making processes required for the development of the EnMAP sensor.

F. Band Selection

While the spectral resolution and dimensionality of hyperspectral data provides competitive advantages in many application domains, it also creates important computing challenges [24]. One way to deal with such computational complexity of algorithm analysis is to discard the spectral bands that are not useful for a given application. This special issue contains two contributions related with this strategy. In [25], a new approach to automatically select bands without manual removing of the noisy bands is proposed. The method starts by applying wavelet shrinkage to denoise the hyperspectral image bands. Then affinity propagation, a recently proposed feature selection approach, is used to choose representative bands from the denoised data. Experimental results on three real hyperspectral data collected by two different sensors show that the bands selected by the proposed approach on the whole data (containing noisy bands) achieve higher overall classification accuracies than those achieved by other state-of-the-art feature selection techniques on the manual-band-removal (MBR) data.

In [26], a band selection approach based on particle swarm optimization (PSO) is proposed. The method has low computational cost and the selected bands are independent of the detector or classifiers used in the following data analysis step. Owing to the low computational complexity of the proposed scheme, the PSO-based optimization finds the global optimal solution efficiently. The performance of the proposed method is evaluated in the context of SVM-based classification for urban land cover mapping. The obtained accuracy using PSO-selected bands is much higher than that of using all the original bands, or dimensionality-reduced data from principal component analysis (PCA), or linear discriminant analysis (LDA).

G. High Performance Computing

Another widely used strategy to address the computational requirements introduced by hyperspectral image and signal processing applications is to resort to high performance computing techniques [27]. Specifically, the development of parallel implementations of hyperspectral imaging algorithms has become an active research area in recent years [28], and is also represented in this special issue. In [29], an efficient implementation of the Goddard shortwave radiance scheme available within the weather and research forecasting (WRF) model using commodity graphics processing units (GPUs). These kinds of specialized hardware platforms are gaining significant popularity due to their low cost and high programmability. The proposed GPU implementation is shown to run 116 times faster than a serial implementation using the Fortran programming language using 4 latest-generation GPUs from NVidia,[3] the main GPU vendor worldwide. This sets the path towards the goal of having the full WRF model implemented on GPUs in the near future.

H. Monitoring of the Environment

Numerous applications related to monitoring of the environment have been addressed using hyperspectral imagery. In this special issue, several different papers deal with this topic which is ultimately related with the generation of advanced products and the retrieval of biogeophysical parameters for improved characterization of our environment. In [30], the spectral response of poplar, wheat, and canola leaves subjected to fumigation with gaseous phase toxic industrial chemical (TIC) gases is investigated. This study aimed to determine if such vegetation could be distinguished from background vegetation during varying growth stages and environmental stresses. Furthermore, identification of the chemical gases was attempted based on the spectral response of the vegetation. The results showed that both environmental and TICs induced similar spectral features inherent to plants that can be related primarily to chlorophyll and water loss.

In [31], a semi-empirical approach is used to estimate vegetation biochemical properties, canopy chlorophyll and N contents, important plant stress indicators. The PROSAIL[4] radiative transfer model is employed to simulate hyperspectral reflectance data and a range of different vegetation indices are tested to explore their potentials in estimating the parameters. The simulations show strong linear relationship between the red-edge chlorophyll index and canopy chlorophyll content and non-linear relationship between chlorophyll content and traditional red-edge indices. The red-edge chlorophyll index is found to be a good and linear estimator of canopy N content.

In [32], the effects of the canopy structure on estimating chlorophyll concentration using field and hyperspectral imagery and LiDAR data is addressed. The approach taken is to compare the change in the ability of a linear model to describe observed chlorophyll concentration using leaf, top of canopy and whole canopy scale reflectance measurements. The paper demonstrates that we can relate leaf chlorophyll to canopy chlorophyll better for illuminated dense vegetation rather than for more complex parts of the canopy. The specialized dataset required to test this hypothesis makes the paper novel.

In [33] the classification of individual trees into different conifer and deciduous species in mixed Baltic forests is conducted using a combination of airborne hyperspectral imagery and LiDAR data. The proposed approach includes an initial determination of training sets for each species of interest, creation of clusters for each species by adding randomly selected trees from the whole analyzed forest area, and a final classification of all trees using a Bayesian classifier designed based on the clusters properties.

In [34] a statistical analysis on the discrimination of Mediterranean species with hyperspectral field measurements is presented. The objective is to discriminate between five maquis and phrygana plants using a non-parametric multivariate statistical approach. The multivariate classificatory technique indicates that the majority of the plants possess distinct signatures. The univariate tests show the existence of wavelengths where the plants can be discriminated. The approach used emphasizes detectable differences induced by the optical properties of the plants, as well as by variation of internal water of the plants.

In [35] infrared space-based hyperspectral data are employed to monitor volcanic activity, and to study temperature field and power output for a lava lake at Halema'uma'u crater, Hawaii. The measurements show strong radiance elevation at short-wave infrared (SWIR) optical spectra. The method used illustrates the approach of correcting the data for solar radiance and atmospheric water vapour and it employs the modeling of at-pixel level spectrum using a weighted approach of both cool and hot components. Radiant flux (power) emitted from each pixel and from the lake as a whole is calculated based on temperature and fractional area calculations.

Combined, the different topics included in this special issue provide an excellent snapshot of the state of the art in the area of hyperspectral image and signal processing, offering a thoughtful perspective on the potential and emerging challenges in this area. Last but not least, the Guest Editors would like to particularly thank the Editor-in-Chief of JSTARS, Prof. Jocelyn Chanussot, for his constant support and encouragement to this special issue. The Guest Editors would also like to take this opportunity to gratefully thank all the contributors and reviewers who participated in the evaluation of manuscripts for the special

[3]http://www.nvidia.com.

[4]http://teledetection.ipgp.jussieu.fr/prosail.

issue. Without their outstanding contributions, the special issue could not have been completed.

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