Introduction to the Special Issue on Analysis of Hyperspectral Image Data

THANKS to the high spectral resolution and/or the high number of spectral bands, remotely sensed hyperspectral data are very promising from the viewpoint of the information about the Earth surface that can be obtained from their analysis. Hyperspectral data may be especially useful to carry out some difficult tasks, such as small target detection, material identification, discrimination among very similar classes, and estimation of biochemical or geophysical parameters, for which dense sampling of the selected range of the electromagnetic spectrum is especially diagnostic.

In particular, in the case of high numbers of available spectral bands, the intrinsic complexity of hyperspectral data makes evident the necessity to provide semiautomatic computerized tools to support analysts in the data interpretation phase, for many kinds of applications (scientific, commercial, governmental, military, etc.). The dense sampling of the spectral range of the electromagnetic spectrum on the one hand provides a very rich and detailed source of information, but on the other hand, raises problems of theoretical complexity, increase of computational load, and optimization of huge numbers of variables. For instance, it has been proven that topological properties change dramatically when one moves from two-dimensional (2-D) or three-dimensional (3-D) spaces toward hyperdimensional spaces. Optimal band selection techniques cannot be applied due to combinatorial increase of the needed computation time for increasing numbers of bands; the application of the classical quadratic maximum likelihood classification scheme to data with some hundreds of bands requires the estimation of tens of thousands variables. Therefore, fundamentally sound techniques need to be applied for an effective analysis of hyperspectral image data.

Eighteen papers have been selected for this special issue, with the aim of describing to readers current advances in processing and analysis techniques for hyperspectral data and to provide a few representative examples that should highlight the potentialities of such data in some of the possible application fields. The issue is divided into several parts.

The "Georegistration and Viewing Geometry" section considers two preliminary aspects related to the acquisition phase. The first paper in this section deals with the rectification and georegistration of airborne hyperspectral images, under the challenging conditions of atmospheric turbulence. The second paper investigates the range of viewing geometrical conditions (proven to be quite wide) over which reliable material identification is possible.

Two papers are included in the "Feature Extraction and Classification" section, which propose suboptimal methods for feature extraction. The former proposes a method for band selection that applies a steepest ascent search technique, using the Jeffries-Matusita distance as an optimization criterion. The latter provides a set of transformations of the spectral bands, oriented to the optimization of classification accuracy and based on the technique of the projection along the Fisher direction.

Another kind of transformation, that is, the so-called projection pursuit, is applied in the first paper of the "Target Detection and Matched Filter Techniques" section to reduce the dimensionality of data before considering normalized third and fourth order moments to reveal the presence of outliers (often due to small targets) of background distributions. The second paper presents a unified framework for various subpixel target detection algorithms based on the linear mixing model, and an approach to evaluate how well the adopted model characterizes the data and how robust the detection algorithm is to model-data mismatches. Finally, it reports on an experimental comparison of three selected algorithms. The third paper shows that, by adopting clustering in conjunction with "clutter matched filter" formulations, it is possible to detect very weak signals in hyperspectral images, with a sharp improvement of performance (above one order of magnitude) over the simple matched filter technique.

A critical step in spectral mixture analysis of hyperspectral images of moderate-to-high scene complexity is the identification of the set of endmembers, that is, the fundamental materials that, variously combined, appear in the scene. Two papers of this Special Issue address this problem, one of which considers it for urban scene analysis and, therefore, has been placed in the section related to applications. The other one opens the "Spectral Mixture Analysis" section by proposing a technique to partition the image according to a multiscale Gibbs model of the scene, which incorporates a spectral mixing process as an underlying and unobserved process. As a consequence, spatial consistency of the spectral content of the sites in each partition is obtained, so allowing a more precise identification of local end-member sets. The second paper of the section presents a two-stage temperature/emissivity separation algorithm using spectral mixture analysis to extract temperature and pixel fractional constituents estimates from thermal infrared (TIR) radiance data.

Satellite hyperspectral images usually exhibit low-to-medium spatial resolution, in the order of some hundreds $\times$ some hundreds square meters. This resolution may represent a limitation in various real-world applications. Consequently, techniques that allow the spatial resolution of hyperspectral images to be improved, such as the one described in the first communication of this special issue, appear to be attractive. In this case, the authors adopt an extension of the unmixing-based multisensor multiresolution technique (MMT), proposed by B. Zhukov and D. Oertel, in order to make it applicable to hyperspectral images. Experimental results describe the improvement of the

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resolution of simulated MeRIS images by fusion with Landsat TM images.

Two intimately connected goals are considered in the first paper of the “Information Theoretical Analysis and Image Coding” section, that is, to measure the amount of useful information conveyed by a hyperspectral image (with special reference to the contribution of the high spectral resolution) and to develop a lossless compression scheme that exploits the redundancy in both the spatial and spectral domains. In the second paper of the section, a basic vector quantization (VQ) scheme and three speed-improved compression systems are considered and compared with reference to processing time and red-edge indices as endproducts. Experimental results with real data show that the considered systems are hundreds of times faster than the basic VQ, while performing fairly closely to it from the viewpoint of the error induced on end-products. The authors of the second communication of this Special Issue propose a compression scheme based on the joint optimization of mean-normalized VQ, in the spatial domain, and discrete cosine transform (for encoding of residuals), in the spectral domain. The proposed scheme has proved to be able to encode an AVIRIS image with compression ratios above 40:1, without significant loss, in terms of classification accuracy.

Four papers about vegetation studies open the “Applications of Hyperspectral Data” section and confirm that this field can greatly benefit from the use of hyperspectral data. The first paper illustrates some of the potential for use of hyperspectral imagery to discriminate variation in arid vegetation and underlines the benefits of using the whole spectral range from visible to short-wave infrared in vegetation studies. The subsequent paper confirms that hyperspectral data have the potential to detect ecosystems responses to interannual climatic variability that are undetected by broadband sensors and can be used to scale to coarser resolution global mapping sensors, such as AVHRR and MODIS; a natural coastal savanna was considered as a case study. The third paper deals with chlorophyll content estimation in closed forest canopies and shows that estimates of leaf pigment from hyperspectral data is feasible. Simulation results also proved that the pigment estimation by model inversion described in the paper for the *casi* sensor can in principle be readily transferred to the MeRIS sensor. The subsequent paper deals with a different application, namely, the estimation of the concentration of optically active constituents in sea water. Generalized radial basis function neural networks are applied to this problem, adopting a recently proposed learning strategy. Experiments with simulated MeRIS data show that the proposed approach outperforms classical estimation algorithms commonly applied to this purpose. The last paper of the special issue discusses the potential of hyperspectral image data for detailed inventories of urban surface cover types and proposes a new approach that enables reasonable material-oriented differentiation of urban surfaces. To this end, a pixel-oriented endmember selection is applied and combined with an iterative procedure based on contextual classification concepts.

In conclusion, times appear to be mature for the community of remote sensing to devote a proper attention to hyperspectral data, as they merit, thanks to the rich content of information they convey. Today it is possible for anyone to start practicing with such data and appreciate their usefulness in his or her own field, since some examples of hyperspectral datasets are available free from web sites (e.g., http://dynamo.ecn.purdue.edu/~biehl/MultiSpec/, http://www.aris.sai.jrc.it/dfc/announce.html), and a significant set of methods and algorithms for hyperspectral image data analysis have been developed, some of which have already been incorporated in commercial packages for remote sensing image analysis. We hope that further free-use well-characterized, datasets of hyperspectral images will soon be available, and that this condition, together with a more widespread knowledge about these data and the related processing techniques (to which this special issue is intended to contribute) will promote research, development, and applications in this field.

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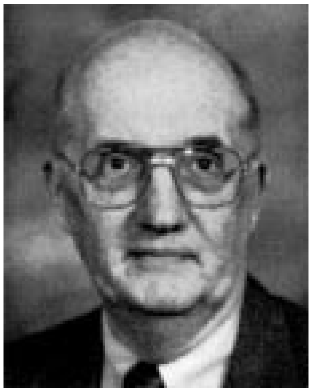

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