Introduction to the Special Section on Image Information Mining for Earth Observation Data

EARTH observation (EO) data have increased significantly over the last decades with orbital and suborbital sensors collecting and transmitting to Earth receiving stations several terabytes of data a day. This data acquisition rate is a major challenge to the existing data exploitation and dissemination approaches used by the various agencies (e.g., ESA, NASA, NOAA, or national agencies) charged with extracting information from these images. And, with plans for more EO systems (NPOESS, ENVISAT, TerraSAR-X, GMES, and commercial systems) the challenge is increasingly going to be how to enlarge the usability of the millions of images being stored in archives to a larger and larger group of end-user applications (e.g., climate change, security, land use, weather). To help support knowledge discovery from EO images and archives, researchers around the world have begun to tackle the formidable challenge of developing concepts, tools, and applications for extracting information from the petabytes of EO images archived globally.

Image information mining (IIM) is a new field of study that has arisen to seek solutions to automating the mining (extracting) of information from EO archives that can lead to knowledge discovery and the creation of actionable intelligence (exploiting). Image information mining is more than just an extension of data mining principles to images. Also, the mining of EO images for content information is different from mining images of facial characteristics or of other living things (e.g., lions or tigers) due to the fact there are no features (e.g., ears, stripes, or wings) that have known relationships to help differentiate classes in an EO scene. Therefore, IIM is an interdisciplinary approach to automating remote sensing analysis that draws on signal/image analysis, pattern recognition, artificial intelligence, machine learning, information theory, databases, semantics, ontologies, and knowledge management.

IIM includes novel concepts and methods to help humans to access and discover information in large image archives, to rapidly gather information about courses of action. Interesting applications involve complicated spatial, structural, and temporal relationships among image objects. Thus, new concepts have been introduced on the basis of intensive preprocessing of images to extract relevant features, structures, and objects and automatically record and analyze their interrelationships to learn their behavior so as to be able to detect relevant information. The methods are integrated in systems, which can be operated using intelligent interfaces able to correlate the information content of the images with the relevant goals of the application. The users have at their disposition tools for the definition of specific goals using semantics. The problem of the large dimensionality, which for computationally efficient data analysis is of primary concern, is solved using preextracted representative features instead of raw images. These are difficult tasks which require cooperative solutions integrating a variety of methods of soft computing, information semantics and the semantic web, advanced statistics, and probabilistic reasoning. The goal is to have machines more closely interacting at human conceptual levels (i.e., automate the human remote sensing analyst). Unlike the respective hard computing methods, soft computing may cope with problems that deal with imprecision, uncertainty, and learning, and are better candidates to construct systems and models which are simple, applicable, user-friendly, and fast.

Over the past several years the IEEE Geoscience and Remote Sensing Society, through its Data Archiving and Distribution Technical Committee, has sponsored several sessions at IGARSS, and the European Image Information Mining Coordination Group (IIMCG) has supervised four conferences jointly organized by the European Space Agency and the European Union Satellite Centre to provide a forum for IIM researchers. The focus of this special section is to describe some of the recent advances made in the field of IIM for Earth Observation in the development of tools, methods, and applications. It is composed of eight papers selected according to the standard review process of the IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING. These contributions have been organized into four sections: Feature Extraction, Learning, Inference, and Semantic-Based Retrieval.

The section on *Feature Extraction* contains two manuscripts. The two contributions examine two different approaches for extracting a set of primitive features that can be used across a broad range of EO images and classes—artificial neural networks and wavelets. Image retrieval based on a semantic query is dependent on the primitive features used to describe the classes (e.g., water, agriculture, mountains) in an image and can become computationally intensive if the number of features is large and the archive being searched has many images. The paper by Del Frate *et al.* presents new results of designing neural networks, specifically a multilayer perceptron for the extraction of land cover features from large volumes of EO images. One of the main difficulties of information extraction from large image volumes is the variability of the spectral signatures. The selection of the training data is an important factor to obtain the needed generalization for the large data set. The generalization power comes from the similarity in shape of the spectral signatures, and thus, biases (e.g., illumination, atmospheric effects, etc.) become irrelevant for the classification. The developed method is demonstrated for relevant case

Digital Object Identifier 10.1109/TGRS.2007.894401

studies on urban areas for both medium-resolution and high-resolution sensors, Landsat and QuickBird, respectively. The short communications paper by Shah *et al.* proposes a systematic approach to selecting an appropriate wavelet decomposition level that is based on the energy (i.e., frequency content) of the image. Four classes (forest, water bodies, agricultural land, and fallow land) and three sets of imagery were used to validate the applicability of the technique. In all cases, it was shown that the results obtained with an adaptive selection were more robust than using a fixed decomposition level.

The section on *Learning* has two contributions of high relevance for mining the new generation of meter-resolution EO images. They refer to the need of nonimage information or external knowledge to help in the creation of a context for understanding or extracting the image information. While EO image resolution is increasing, the information content in its geometrical (spatial) context aspects becomes more and more important. The article by Gautama *et al.* introduces an image mining method based on spatial queries between images and GIS data. An error-tolerant graph matching technique is introduced and used to find correspondences between the detected image information and the road vector data, thus enabling spatial queries. The work of Fercatu and Boujemaa is aiming at the use of human knowledge, as interpretation context, to help the image retrieval process. Mainly for high-resolution EO images, due to their increased information details, the content interpretation depends on some hypothesis or prior knowledge of the user. Thus, the same part of an image can be assigned to different classes by different users. The proposed method is based on optimizing the transfer of information between the user and the system, and focuses on the criterion employed by the system for selecting the images presented to the user in a relevance feedback loop. The learning process is based on a support vector machine algorithm with a specific kernel design to obtain invariance to scale.

The *Inference* methods are represented by Gueguen and Datcu's paper, which deals with the problem of how to infer, in an unsupervised manner, the models of EO data, and thus, how to discover their information content. The paper presents a new information bottleneck algorithm used jointly with Bayesian methods for inferring and selecting the models explaining the observed data. The developed algorithms are demonstrated for data mining of spatio–temporal structures in high-resolution satellite image time series obtained by the SPOT sensors observing on a daily base a suburban-agriculture site for a period of more than eight months.

The *Semantic-Based Retrieval* section has three contributions. These papers provide examples of systems being developed to provide the user community with access to EO archives using semantic queries. The paper by Shyu *et al.* describes the Geospatial Information Retrieval and Indexing System (GeoIRIS) that is designed to enable scalable processing and retrieval of a large volume of data by automatically preprocessing and indexing satellite images. Its application area is the intelligence community. The paper covers the design of the system framework, as well as its approaches to feature extraction, database indexing, information ranking, semantic modeling, and queries. The contribution by Li and Bretschneider proposes a context-sensitive Bayesian network for semantic inference of segmented scenes. The segmented scene's semantic concepts are inferred in a multistage process based on their spectral and textural characteristics as well as the semantics of adjacent regions. A comparison was made with an approach that uses the feature space directly to infer the region's semantics. The result was the proposed Bayesian network approach outperformed the direct approach. The paper by Molinier *et al.* presents a search engine for detection, retrieval, and semantic annotation of man-made structures and for monitoring their changes from multi-temporal high-resolution EO images. Robust feature extraction algorithms are used to describe image tiles. The proposed features are adapted to the nature of high-resolution images. The image tile size is also carefully chosen. The learning mechanism is based on self-organizing maps to train the input and assigns a model vector to a visual label from the image tiles. The method is demonstrated using QuickBird images, and the results are evaluated quantitatively.

ACKNOWLEDGMENT

The Guest Editors would like to thank the IEEE Geoscience and Remote Sensing Society for its support to publishing this special section. Thanks are due to Professor J. A. Benediktsson, Editor-in-Chief, for his constant support and encouragement during the preparation of this special section's preparation. A special acknowledgement is also given to the reviewers of the papers, who played the most important role in the final selection and quality of the contributions published in this special section. Finally, we would like to thank Alison Larkin of the IEEE staff for her valuable assistance in all the phases of preparation of the special section.

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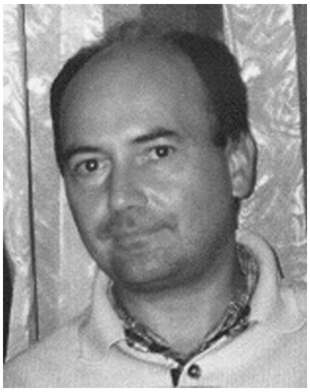

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