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Methodological Advances in Remote Sensing Image Processing

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Abstract: Remote sensing image processing is nowadays a mature research area. The techniques developed in the field allow many real-life applications with great societal value. For instance, urban monitoring, fire detection or flood prediction can have a great impact on economical and environmental issues.

To attain such objectives, the remote sensing community has turned into a multidisciplinary field of science that embraces physics, signal theory, computer science, electronics, and communications.

From a machine learning and signal/image processing point of view, all the applications are tackled under specific formalisms, such as classification and clustering, regression and function approximation, image coding, restoration and enhancement, source un mixing, data fusion or feature selection and extraction.

This paper serves as a survey of methods and applications, and reviews the last methodological advances in remote sensing image processing.

Index Terms— Remote sensing, machine learning, signal and image processing, survey, applications.

I. INTRODUCTION

Remote sensing image processing is a mature research area allowing real-life applications with clear benefits for the Society. The main goals of remote sensing are (1) monitoring and modeling the processes on the Earth's surface and their interaction with the atmosphere; (2)measuring and estimating geographical, biological and physical variables; and (3) identifying materials on the land cover and analyzing the spectral signatures acquired by satellite or airborne sensors. Achievement of these objectives is possible because materials in a scene reflect, absorb, and emit electromagnetic radiation in a different way depending on their molecular composition and shape. Remote sensing exploits this physical fact and deals with the acquisition of information about a scene (or specific object) at a short, medium or long distance.

Attending to the type of *energy resources* involved in the data acquisition, remote sensing imaging instruments can be *passive* or *active*. Passive optical remote sensing relies on solar radiation as illumination source. The signal measured at the satellite by an imaging spectrometer is the emergent radiation from the Earth-atmosphere system in the observation direction. The radiation acquired by a (airborne or satellite) sensor is measured at different wavelengths and the resulting spectral signature (*spectrum*) is used to identify a given material. The field of *spectroscopy* is concerned with the measurement, analysis, and interpretation of such spectra [1]. Some examples of passive sensors are infrared, charge-coupled devices, radiometers, or multi and hyperspectral sensors [2].

In active remote sensing, the energy is emitted by an antenna towards the Earth's surface and the energy scattered back to the satellite is measured [3]. Radar systems, such as Synthetic Aperture Radar (SAR), are examples of systems for active remote sensing. In these systems, the time delay between emission and return is measured to establish the location, height, speed and direction of objects. The diversity of platforms and sensors implies a diversity and very articulated research area in which machine learning, signal and image processing are very active.

In fact, from a machine learning and signal/image processing viewpoint, all the applications are tackled under specific formalisms, such as classification and clustering or regression and function approximation. However, the statistical characterization of remote sensing images turns to be more difficult than in grayscale natural images because of pixel's higher dimensionality, particular noise and uncertainty sources, the high spatial and spectral redundance, and their inherently non-linear nature. It is worth to note that all these problems also depend on the sensor and the acquisition process. Consequently the developed methods for processing remote sensing images need to be carefully designed attending to these needs.

Even if scientific production is high, the cross-fertilization between the remote sensing and the image processing communities is still far from being a reality. In order to boost communication paths, this paper presents a survey of related methods and applications in both fields, and revises the hot topics and last methodological advances in remote sensing image processing.

II. THE FRAMEWORK OF REMOTE SENSING IMAGE PROCESSING

From acquisition to the final product delivered to the user, a remotely sensed image goes through a series of image processing steps, starting with efficient compression strategies and ending with accurate classification routines (Fig. 1). Each step is detailed in the next sections.

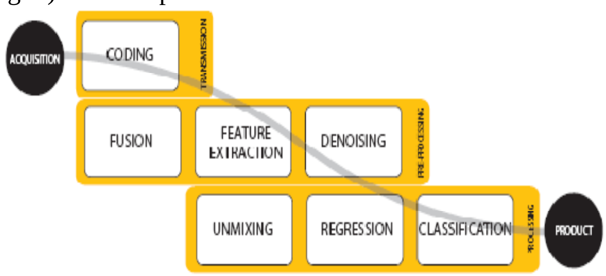

Figure: 1 Remote Sesing Image Processing Chain

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A. *Image Coding:*

Along with the increasing demand of hyperspectral data, the sensor technology used to capture these images has been significantly developed, improving, among others, the spatial and spectral resolution. Such improvement on quality leads to an increasing demand on storage and bandwidth transmission capabilities. Both lossy and lossless image coding have been investigated extensively in hyperspectral images [4]. The lossy coding systems in the Consultative Committee for Space Data Systems (CCSDS) [http://public.ccsds.org] recommendation are based on a transform stage, where data is decorrelated in the spatial domain using a wavelet transform (plus a bit plane encoder stage), thus following the latest standard JPEG2000 for grayscale images. Other well known wavelet-based coding system used for hyperspectral data are SPIHT-3D and SPECK-3D [5]. In order to improve the coding performance, a common strategy is to decorrelate first the image in the spectral domain [6].

B. *Feature Selection and Extraction:*

When dealing with high dimensional datasets, such as hyperspectral images, the computational time is increased and the high collinearity and presence of noisy bands can degrade the quality of the model. Feature selection and extraction are central issues in these situations because of the curse of dimensionality [7]. For feature selection, either *filters* or *wrappers* are proposed [7]. Although filters have been extensively studied in remote sensing [8], the recent advances focus on wrappers, which guarantees that the selected feature subset is iteratively optimized. SVM-based recursive feature elimination [9] and genetic algorithms [10] are some examples of recent successful applications of wrappers in remote sensing. Regarding feature extraction, the use of linear methods such as PCA is quite common. Recently, advances in embedding using non linear methods have been proposed such as local linear embedding or isometric mapping [11]. Also, multivariate kernel-based feature extraction methods have been presented recently to cope with nonlinearities in the data [12].

C. *Restoration and Denoising:*

Image restoration is an important step in the image processing chain. Several problems are encountered in this application: different noise sources and amounts are present in the data and scattered either in the spatial or specific spectral bands.

This makes necessary appropriate spatial smoothing *per* band. Note also that applying PCA captures second-order statistics only, and has no information about noise variance. A nice alternative is the widely used minimum noise fraction (MNF) algorithm [13]. The method performs nicely in multispectral imagery and moderate noise levels. In hyperspectral images the noise covariance estimation is a more challenging problem and other techniques have been recently proposed, such as anisotropic difussion [14], wavelet shrinkage [15], or kernel multivariate methods [12]. In radar signal processing, the main problem is about removing speckle noise in SAR images. Latest advances propose specific wavelet forms [16] and to include spatial information through Markov random fields [17]. Assessment of the obtained filtered images is another hot topic in the area [18]. A common problem is also found in removing the registration noise, with critical impact in change detection applications [19].

D. *Image Fusion and Enhacement:*

Spatial resolution of sensors is often limited with respect to their spectral resolution. Multi- or hyperspectral sensors give a unique amount of spectral information, but they often lack the spatial detail necessary for the application. On the contrary, panchromatic sensors provide information with higherlevel of spatial detail, but lack spectral information. Since the design of a high resolution sensor in both spectral and spatial domains would be extremely costly and challenging in terms of engineering, image fusion methods are often employed to create an image taking advantage of both panchromatic and multi- or hyperspectral sensors. Classical IHS or PCA methods are inadequate when applied to remote sensing images. Therefore specific approaches based on Laplacian Pyramids [20], wavelets [21], geostatistics [22], and Bayesian Maximum Entropy [23], have been proposed recently.

III. CONCLUSION

The fields of remote sensing and image processing are constantly evolving in the last decade, but cross-fertilization is still needed. This paper serves as a survey of methods and applications and highlights the hot topics and latest methodological advances in remote sensing image processing. The literature has been revised under the specific machine learning and signal processing paradigms, and attention has been paid to classification, regression, image coding, restoration, source unmixing, data fusion, feature selection and extraction.

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