RECENT 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 viewpoint, all the applications are tackled under specific formalisms, such as classification and clustering, regression and function approximation, image coding, restoration and enhancement, source unmixing, 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.

1. 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 modelling 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.

2. 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.

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2.1. 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].

2.2. 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]. Although filter methods, such as the correlation or the mutual information between bands and class labels, have been extensively studied in remote sensing [8], the recent advances focus on wrappers, which select features that minimize the classification error. 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 nonlinear methods for data description have been proposed such as locally 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].

2.3. 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. An alternative is the widely used minimum noise fraction (MNF) algorithm [13]. In hyperspectral images the noise covariance estimation is a more challenging problem and other techniques have been recently proposed, such as anisotropic diffusion [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].

2.4. Image Fusion and Enhancement
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 higher level 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.

2.5. Signal Unmixing
An important problem in remote sensing is the development of automatic extraction of spectral endmembers directly from the input hyperspectral data set. With these pure pixels in the image identified, all pixels can be synthesized as a linear (or non-linear) combination of them, and this, in turn, allows subpixel detection [2] or mineral mapping [24]. Some classic techniques for this purpose include the N-FINDR algorithm [25], the vertex component algorithm (VCA) in [26], and an orthogonal subspace projection (OSP) technique in [27], among others [28]. Selection of the free parameters and inclusion of spatial information in the unmixing process are key issues nowadays [29]. Recently support vector domain description (SVDD) has been also used [12].

2.6. Regression and Model Inversion
In remote-sensing data analysis, the estimation of biophysical parameters is of special relevance in order to better understand the environment dynamics at local and global scales [1]. The inversion of analytical models introduces a higher level of complexity, induces an important computational burden, and sensitivity to noise becomes an important issue. Consequently, the use of empirical models adjusted to learn the relationship between the acquired spectra and actual ground measurements has become very attractive. Parametric models have some important drawbacks, which typically lead to poor
Table 1. A taxonomy for remote sensing methods and applications.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Fields &amp; Tools</th>
<th>Objectives &amp; Problems</th>
<th>Examples</th>
<th>Methods &amp; Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coding</td>
<td>Transform coding and vision computing</td>
<td>Compress the huge amount of acquired data</td>
<td>Transmission of data to Earth station, avoid redundancy and errors, realistic quick-looks</td>
<td>PCA, DCT, Wavelets, SPIHT</td>
</tr>
<tr>
<td>Feature Sel./Extract.</td>
<td>Filters/Wrappers</td>
<td>Ranking and channel selection</td>
<td>Efficient transmission, model development, compression</td>
<td>PCA, SFFS, RFE, Network pruning, GA</td>
</tr>
<tr>
<td>Restoration</td>
<td>Denoising, deblurring</td>
<td>Interpretation, feat. extract.</td>
<td>Rem. acq. noise, transmission</td>
<td>Wiener, wavelets, advanced de-noising</td>
</tr>
<tr>
<td>Data fusion</td>
<td>Image/Signal Proc.</td>
<td>Different sensors, temporal acquisitions, resolutions</td>
<td>Multi-temp., change detection</td>
<td>Multi-resolution, fusion</td>
</tr>
<tr>
<td>Signal Unmixing</td>
<td>Signal Processing and machine learning</td>
<td>Unmixing the mixture of spectra, restoration, classification with pure pixels</td>
<td>ICA, linear-non-linear unmixing, kernels and pre-images</td>
<td></td>
</tr>
<tr>
<td>Model inversion</td>
<td>Regression</td>
<td>Monitoring Earth’s Cover at a local/global scale</td>
<td>Water quality, desertification, vegetation indexes, T, biomass, ozone, ...</td>
<td>Linear regression, statistical approaches, neural networks, SVR,</td>
</tr>
<tr>
<td>Classification</td>
<td>Pattern recognition</td>
<td>Monitoring evolution and changes of Earth’s cover</td>
<td>Urban monitoring, mineral detection, change detection, ...</td>
<td>k-NN, LDA, neural nets, kernel methods</td>
</tr>
</tbody>
</table>

prediction results on unseen data. As a consequence, non-parametric and potentially non-linear regression techniques have been effectively introduced for the estimation of biophysical parameters from remotely sensed images. Different models and architectures of neural networks have been considered for the estimation of biophysical parameters [30]. Recently the support vector regression (SVR) method has been presented as an alternative for modeling some biophysical parameters [31].

2.7. Image Classification

Classification maps are probably the main product of remote sensing image processing. Important applications are urban monitoring, catastrophe assessment, change or target detection. Broadly speaking, classification methods can be divided in three families. Unsupervised methods aim at clustering the image pixels into a pre-defined number of groups by measuring their similarity. One of the main applications for such methods is change detection, where the method should be able to recognize changes in real time [32, 33]. Supervised methods use labeled information to train a model capable to recognize pre-defined classes. At present, this field is probably the most active in remote sensing image processing. The most successful methods are neural networks [34] and support vector machines [35]. The latter have been applied in a wide range of domains, including object recognition [36], multi-temporal classification [37] and urban monitoring [38]. Target and anomaly detection is also very active and kernel methods have been lately payed attention [39, 40]. Finally, semi-supervised methods exploit the information about the unlabeled samples to improve the performance of supervised methods. In remote sensing, the data manifold has been modeled with either graphs [41, 42] or cluster kernels [43] algorithms. Also, the transductive SVM has been applied [44].

3. 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.

4. REFERENCES
