Optimizing Wavelets for Hyperspectral Image Classification

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ABSTRACT

It is well known that a classification process needs a good data representation for best performance in terms of between-class discrimination capability. In this context, the discrete wavelet transform (DWT), which is based on a time-frequency analysis of the considered signal [1]-[2], has been found particularly interesting for remote sensing image classification problems and in particular for hyperspectral image analysis. For instance, in [3], DWT has proved to be a promising tool for texture analysis in both spatial and spectral domains. In [4], it has been shown that wavelet coefficients extracted from hyperspectral data represent useful features for detecting weeds. Experimental studies have shown that the performance of wavelets in classification is very good for vegetation detection in Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data [5].

Despite wavelets typically used in the literature have been developed for best representation in terms of signal compactness, they proved to be very useful also for classification purpose. We think however that their performance can be further boosted if the wavelet design is classification-driven. In this work, it is wanted to design wavelets that best represent hyperspectral data in terms of between-class discrimination power. This is achieved by exploiting the recursive algorithm developed by Sherlock and Monro [6]. This algorithm allows to generate two-channel perfect reconstruction quadrature mirror filter banks corresponding to orthonormal wavelets. In particular, its underlying idea starts from a factorization of the polyphase matrix associated to the coefficients of finite impulse response (FIR) low-pass and high-pass filters of length $2N$, respectively. Such factorization is particularly useful since, after an opportune rewriting, it allows generating by simple recurrence and from N arbitrary parameters $\{\theta_0, \theta_1, \ldots, \theta_{N-1}\}$ whose values are in the interval $[0, 2\pi)$ the $2N$ coefficients $\{h_0, h_1, \ldots, h_{2N-1}\}$ of a low-pass filter. To complete the corresponding filter bank, the $2N$ high-pass filter coefficients $\{g_0, g_1, \ldots, g_{2N-1}\}$ are derived by alternating flip construction ($g_i=(-1)^{i+1}h_{2N-1-i}$). Therefore, the design of an optimal wavelet transform for a specific application can be formulated as an optimization problem in the $\Re^N$ space of the parameters $\{\theta_0, \theta_1, \ldots, \theta_{N-1}\}$. In our case, the problem is the one to search for the best wavelet in terms of between-class discrimination capability. We formulate such optimization problem within a particle swarm optimization (PSO) framework. PSO is a stochastic search method that has shown good performance in many applications [7]. The coordinates of the particles of the swarm encode the parameters $\{\theta_0, \theta_1, \ldots, \theta_{N-1}\}$. As fitness function, we make use of a between-class statistical distance based on the well-known Bhattacharyya distance measure [8]. This measure is derived from the Chernoff bound, i.e., an upper bound of the probability of error of the Bayes classifier. In particular, for a classification problem

with C classes, the Bhattacharyya distance is computed for all possible pairs of classes and then the average of the $C(C-1)/2$ computed Bhattacharyya distances is taken as the fitness function.

In order to thoroughly assess the proposed optimal wavelet design method, we conducted experiments on the basis of a benchmark hyperspectral AVIRIS real dataset known for the complexity of the conveyed classification problem. The state-of-the-art support vector machine (SVM) classifier was adopted to classify the hyperspectral data transformed with the best wavelet found at convergence by the proposed PSO method. We compared our classification results against those yielded by the popular Daubechies wavelets of various orders (2, 4, 6, 8, and 10). In general, the classification-driven optimized wavelets showed significant improvements of the overall classification accuracy compared to Daubechies wavelets with the same order.

Keywords: classification, hyperspectral images, particle swarm optimization (PSO), support vector machine (SVM), wavelets.

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