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Enhanced Variational Mode Features For Hyperspectral Image Classification

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ABSTRACT

Variational Mode Decomposition (VMD) is a recent method and is gaining popularity in the area of signal and image processing. The use of this decomposition technique in hyper spectral image classification is discussed in detail in this paper. The role of VMD as a feature extraction technique is exploited here. The proposed method includes an initial stage of dimensionality reduction so as to reduce the computational complexity. A final stage of recursive filtering is also added to further enhance the results. Results obtained by the proposed method on two hyper spectral image datasets –Indian Pines and Salinas-A, suggests that VMD is a promising method in the area of image analysis and classification. Quality indices used for experimental analysis include overall accuracy (OA), average accuracy (AA) and kappa coefficient. Notable classification accuracy has been obtained for both the datasets and a final stage of recursive filtering has further improved the results (more than 98% accuracy in the case of Indian Pines).

KEY WORDS: VMD, EMD, EEMD, EWT, ADMM, IMF, PCA, Recursive filtering.

1. INTRODUCTION

Study of any process deals with, breaking it down into smaller bits and analyzing the behaviour of each part, so as to get a good understanding of the technique. In signal analysis, this happens through a process called decomposition through which unobserved patterns in the data can be identified. In this case, decomposition results in functions those were not actually present in the original data and may be referred to as artificially created ones. Properties of these functions play a crucial role in helping us identify the nature of the signal. In this paper, we aim at the utilization of a newly proposed decomposition method called VMD (Variational Mode Decomposition) in hyper spectral image classification.

Decomposition techniques have succeeded in becoming an attractive element in many areas of signal processing. Various methods like Fourier transform, Empirical Wavelet Transform (EWT), Empirical Mode Decomposition (EMD), etc. has created great impact over the years. Unlike in the case of Fourier and wavelet transforms, EMD has the advantage that the transform is adaptive and thus depends on the original sequence of data. But, as the name suggests, the method is empirical, i.e., it lacks proper mathematical support and is based on observations. EMD forms an important part of Hilbert Huang Transform (HHT), which can even be applied to non-stationary and non-linear cases to obtain the instantaneous frequency spectrum. EMD adaptively decomposes a signal into modes, referred to as Intrinsic Mode Functions (IMF) which satisfy the property of compact frequency support. IMF's are oscillatory, i.e, their amplitude and frequency vary with time axis and are ordered such that each successive mode contains lesser oscillations compared to the previous one. EMD extracts IMF's through a repeated process called sifting. Each sifting cycle relies on a stoppage criterion and results in an IMF and the whole process continues until all the modes are extracted. The sifting process involves a smoothing procedure – finding the extremal points, creating the lower and upper envelopes and removing the mean of these envelopes, resulting in the high frequency oscillations which forms a mode. Thus, it largely depends on the stoppage factor and methods involved in finding the extremal points. The limitations of various decomposition techniques have paved a way for further developments and has resulted in a totally non-recursive procedure for decomposition, termed as vibrational mode decomposition (VMD).

In this work, we have proposed a method for hyper spectral image classification based on the enhanced vibrational mode features. In our proposed method, we have utilized VMD as a feature extraction technique where a single mode, out of the three extracted modes, has been chosen as the feature, based on signal to noise ratio (SNR) value. Dimensionality reduction technique, namely PCA, and a recursive filtering stage have also been made as a part of the proposed method and the final classification is done using SVM classifier.

Variational mode decomposition: VMD is a method proposed by Konstantin Dragomiretskiy and Dominique Zosso and has gained appreciation within a short span of time. It can be used as an alternative technique to other decomposition methods in a wide range of applications. The advantages of VMD over other methods have been discussed. Empirical Mode Decomposition (EMD) has a major disadvantage of being affected by noise which has made EEMD (Ensemble Empirical Mode Decomposition) as an alternative solution. However, Empirical Wavelet Transform (EWT) has replaced EMD in various applications owing to its effectiveness. In EWT, wavelet filters are designed in a well-chosen boundary and the Intrinsic Mode Functions (IMF) are extracted. Here, the filters satisfy the need for perfect reconstruction. As discussed earlier, many recent articles point out the fact that VMD can outperform all these methods. Compares VMD over EWT in detection of power quality disturbances. Their results highlight the fact that better classification accuracy is obtained in the case of VMD even though computational complexity is comparatively higher. The number of modes extracted using VMD is three, which may be increased at the cost of computation. The extracted modes have been utilized as features for classification, by taking the sines and cosines of the associated parameters like variance, median, etc. Another work highlighting the significance of VMD is, where its contribution in vibration analysis is studied. The process of vibration signal analysis deals with the utilization of multicomponent signal extraction, so as to decompose it into individual components. This is done with the intention of detecting all the faulty signatures present in system response, which are the impacts, caused by rubbing and will not be visible in time or frequency domain. The work makes a comparison between EMD, EEMD, EWT and VMD and concludes that VMD is the best method among all these. While EMD and EEMD extract signatures only partially, EWT has the disadvantage of creating distortions. VMD has been thus suggested here as a more refined method and its wavelet-like filtering property is also explained.

VMD has been developed as a non-recursive method and thus all the modes are extracted at once. These modes reproduce the original signal optimally. The number of modes is selected manually. Like EMD, VMD is also an adaptive technique and the modes produced are band-limited about a central frequency. Let us assume that the decomposition produces k number of modes. An optimization process using the method of ADMM (Alternate Direction Method of Multipliers) is adopted to find the unknowns, i.e, the k modes and the k central central frequencies. The problem is defined such that the bandwidth is minimum and the sum of k modes should result in the original signal. Bandwidth estimation procedure has been well explained in and involves the creation of a frequency translated analytic signal with the help of Hilbert Transform. The strong mathematical foundation of VMD paves a way to replace it with techniques like EMD which lack mathematical support. Each mode of VMD is iteratively updated as a Wiener filtering operation and aids VMD in being robust to noise. Central frequency of the mode is then updated, using its power spectrum, as:

$$\omega_k^{n+1} = (\int_0^\infty \omega \left| u_k \hat{(\omega)} \right|^2 dw) / (\int_0^\infty \left| u_k \hat{(\omega)} \right|^2 dw) \quad (1)$$

Signal reconstruction can be done to ensure that the modes obtained using VMD reconstruct the original. For example, say we decompose a signal using wavelet decomposition. The coefficients obtained here can be further decomposed using VMD. Wavelet reconstruction can be done on these modes to ensure that the original signal can be retained. The works related to VMD have motivated us to examine its application in hyper spectral image classification, which is a rapidly developing area of research.

2. PROPOSED METHOD

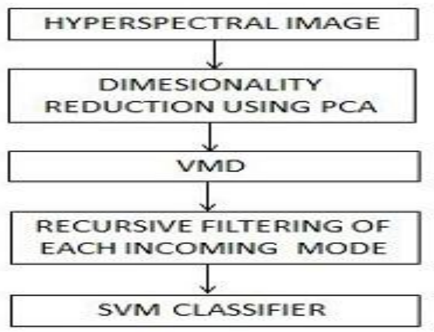

Figure.1.Proposed method

Our work aims at using the decomposed modes, obtained using VMD, as a feature for hyper spectral image classification problems. Two datasets have been chosen for our experiments – AVIRIS Indian Pines and Salinas-A scene. Hyper spectral images are considered as image data cubes containing hundreds of narrow spectral bands. Owing to the computational complexity of VMD, a dimensionality reduction technique, namely Principal Component Analysis (PCA), has been utilized to reduce the number of bands. PCA is a transformation of the data into its principal components such that maximum variance will be contained in the first principal component. VMD has been applied to the resulting bands to decompose them into three modes each. Flowchart for the proposed method is shown in Figure 1.

While analysing the properties of these modes, we found that one mode of each band has a very high value of signal to noise ratio (SNR) compared to the other two. This mode has been chosen as the feature for classification. The results suggest that this mode retains maximum information for classification. Further, a stage of recursive filtering has also been included to improve the classification accuracy. Feature extraction based on image fusion and recursive filtering (IFRF) is a recent method where transform domain recursive filtering approach has been effectively employed and has been utilized here in a similar context. SNR value has been calculated using equation (2):

$$snr = mean(\mathrm{mode}.\wedge 2) / mean(\mathrm{noise}.\wedge 2) \qquad (2)$$

Where noise is the difference between the original band and the mode considered.

The final classification stage is carried out using Support Vector Machine (SVM) classifier. It is a widely utilized learning model to solve classification problems. In SVM, the aim is to find the best separating hyper plane which will classify the data with minimum error and the formulation involves an optimization problem. SVM, where the class of a new sample of data is predicted, can be applied to multi-class problems which have been employed here. A library for SVM, namely LIBSVM, is available for free download and has been utilized in our work.

3. EXPERIMENTAL RESULTS

Indian pines dataset, captured by AVIRIS sensor, contains 145x145 pixels in 224 spectral bands out of which 20 absorption bands have been manually removed. Salinas-A scene is a sub-scene of Salinas image captured by the same sensor and containing only 86x83 pixel values. The former represents sixteen classes while the latter contains only six. In our experiments, background pixels were neglected in the case of Indian Pines dataset while it was included as an additional class for Salinas-A. In both cases, the proposed method has been implemented and observations have been tabulated. The first stage involved the utilization of PCA to reduce the number of bands to ten. These ten bands were decomposed into three modes each, using VMD, and their characteristics were analyzed based on SNR. The results, including and excluding the recursive filtering stage, has been included. It indicates that this additional step of filtering improves the classification accuracy to some extent (resulting in more than 98% overall accuracy in the case of Indiana Pines). However, the results obtained suggest that VMD provides notable classification accuracy and can thus be included at various stages of hyper spectral image processing. The process validates our proposed idea of using VMD as a feature extraction step. Here, only a single mode has been utilized effectively for classification. Various properties of different modes can be made use of depending upon the application.

Table.1 gives the mean value of SNR for the three modes, indicating a very high value for the first mode. Table 2 and Table 3 tabulates the classification accuracy of the proposed method on the two datasets used, the former containing values excluding the recursive filtering stage. Quality indices used for experimental analysis include overall accuracy (OA), average accuracy (AA) and kappa coefficient.

Table.1.Mean SNR value of the three modes

Dataset	Mean SNR of mode 1	Mean SNR of mode 2	Mean SNR of mode 3
Indian Pines	529.2583	0.0418	0.0481
Salinas-A	224.6119	0.0982	0.0491

Table.2.Classification results of the proposed method excluding recursive filtering stage

Dataset	Overall Accuracy(OA)	Average Accuracy(AA)	Kappa
Indian Pines	96.10	96.67	0.9551
Salinas-A	90.68	88.93	0.8860

Table.3.Classification results of the proposed method with recursive filtering stage

Dataset	Overall Accuracy(OA)	Average Accuracy(AA)	Kappa
Indian Pines	98.71	95.97	0.9851
Salinas-A	90.99	90.41	0.8898

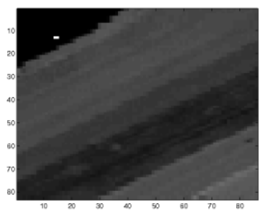

Figure.2.Sample band of (a) Indian Pines (b) Salinas-A scene

Figure.3.Classification Map obtained on experimentation of the proposed method (including recursive filtering stage) (a) Indian Pines (b) Salinas-A scene

4. CONCLUSION

VMD, being one of the latest promising developments in the area of signal processing, can be effectively utilized for replacing techniques like EMD and EWT. Applications include seizure detection of EEG signals, analysis of ECG signals and the use of 2-D VMD in image processing applications like compression, de noising, texture analysis and image fusion. It can also be used in the study of earthquakes and meteorological applications. Speech recognition is another promising area, an example being polarity detection of speech signals. VMD can be effectively utilized for studying various signals like wave data from near off-shore sea, remote sensing data analysis, applications in fields like chemistry, finance, structural engineering, medicine and much more. Applications involving wavelets can also be brought into the framework of VMD. This way, one could explore huge possibilities of VMD in the near future.

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