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Modulation recognition of non-cooperation underwater acoustic communication signals using principal component analysis

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ABSTRACT

The modulation classification of the non-cooperation underwater acoustic (UWA) communication signals is extremely challenging due to the adverse UWA channel transmission characteristics and low signal to noise ratio (SNR), which lead to considerable impairments of the signal features. In this paper, the principal component analysis (PCA) is proposed for efficient extraction of the power spectra and square spectrum features of UWA signals at the presence of multipath, Doppler, and noise induced in UWA channels. The employment of PCA enables extraction of the principal components associated with different modulation mode as the input vector of classier, thus reducing the feature dimension and suppressing the influence of UWA channels and environmental noise. With the features obtained by PCA, an artificial neural network (ANN) classifier is adopted for modulation recognition of UWA communication signals. The experimental modulation classification results obtained with field signals in 4 different underwater acoustic channels show that the proposed PCA based modulation recognition method outperforms the classifier using classic features in terms of classification performance and noise tolerance.

1. Introduction

With rapidly development of maritime rights protection, harbor monitoring and related fields of marine information acquiring and processing, the modulation recognition of underwater acoustic (UWA) communication signals has become an important research topic. Currently there have already been extensive modulation recognition methods developed for wireless communication signal, such as those based on instantaneous features [1,2], based on wavelet transform method [3] as well as based on signal spectrum correlation method [4,5]. However, these classic modulation recognition approaches generally need to obtain one or more modulation parameters as prior knowledge (such as accurate carrier frequency, initial phase, and the symbol rate). Unfortunately, being different from the wireless channels, it has been recognized that the adverse underwater acoustic channels exhibit much more complicated time-frequency variation characteristics [6–9], which lead to significant distortion of UWA signals. Thus, extraction of the accurate prior knowledge under UWA channels is extremely difficult.

Fan [10] presents a modulation recognition method based on spectral characteristics, by which the feature parameters are directly extracted from the spectra and square spectrum, thus no any prior knowledge is needed. As a result, good performance is achieved even at low SNR. However, severe instability and randomness of the adverse UWA channels will also cause substantial distortions of spectra or square spectrum features. Meanwhile, the ocean environmental noise generally exhibits non-Gaussian, non-stationary characteristics [11,12], which lead to significant performance degradation for methods adopting the spectrum for feature extraction.

The Principal component analysis (PCA) is a useful statistical signal processing technique that has been widely accepted to reduce the dimensionality of datasets for compression, pattern recognition, and data interpretation [13,14]. In mathematical terms, n correlated random variables are transformed into a set of $d \le n$ uncorrelated variables. These uncorrelated variables are linear combinations of the original variables and can be used to express the data in a reduced form. For high-dimensional data, PCA is capable of reducing the feature dimension and restraining the influence of noise, so as to effectively solve the problem of classification and recognition of high dimensional feature [13].

It has been recognized that the power spectrum and square spectrum of the underwater acoustic communication signal contain the modulation features, which traditionally correspond to a high-dimension feature space in time domain [1,2] or frequency domain [3–5],

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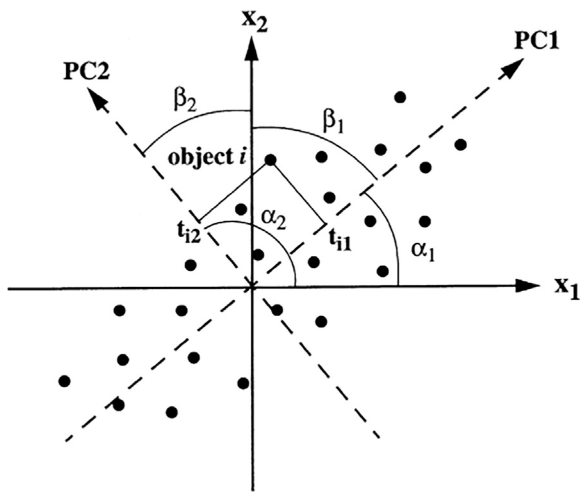

Fig. 1. Illustration of principal components analysis (PCA).

thus lead to huge computational complexity for the classifier. The shape features are directly obtained from the corresponding portions of the power spectra and square spectrum, which have been adopted to effectively reduce the feature dimension [10,15,16]. However, it is unfortunately found to be sensitive to the severe underwater acoustic channels under low SNR.

The PCA method offers an effective way to create an alternative, smaller set of variables, thus the original data would be projected onto the smaller set. In this paper, we adopt the PCA method to extract small dimension features from the power spectra and square spectrum as feature vector. The purpose is to retain most of the original data information in the form of principle component for dimensionality reduction. Moreover, through the suitable selection of the main component, PCA is able to remove the interference caused by UWA channels and the environmental noise. In other words, it can not only achieve the small-dimensional feature vector, but also yield signal and noise separation [17,18].

Based on the spectra and square spectrum of UWA communication signals, this paper adopted the PCA method for feature extraction to incorporate with an ANN [19–21] classifier for modulation recognition of BPSK, QPSK, MFSK modulation types, which are commonly used in practical UWA communication applications. The experimental modulation classification results obtained with field signals at 4 different underwater acoustic channels are provided to verify the effectiveness of the proposed method.

2. Theoretical basis of PCA

As a widely used statistical technique, principal component analysis (PCA) has in practice been employed to reduce the dimensionality of problems, and to transform interdependent coordinates into significant and independent ones. Because PCA has been well documented in multivariate analysis literature [22], its concept is only briefly introduced in this section.

The main basis of PCA-based dimension reduction is that PCA only picks up the dimensions with the largest variances. Mathematically, this is equivalent to finding the best low rank approximation (in L2 norm) of the data via the singular value decomposition [23]. Essentially, by rotating the data such that maximum variabilities are projected onto orthogonal axes, a set of correlated variables are transformed into a set of uncorrelated variables which are ordered by reducing variability. The uncorrelated variables are linear combinations of the original variables, and the last of these variables can be removed with minimum loss of real data [24].

Consider that there exists n objects and each object has k variables, and these objects can be composed into a $(n \times k)$-dimensional data matrix, X. In this investigation, each object is an experimentally obtained UWA communication signal data with k points. These n objects can be plotted in a k-dimensional variable space and objects (data sets) having similar appearance would be grouped close to each other and form a subspace. However, when the number of dimensions is large, this k-dimensional space is impossible to visualize. PCA is a multivariate procedure which fits an approximate model to represent the data matrix X with a reduced number of relevant dimensions by rotating the data such that maximum variabilities are projected onto the axes. Essentially, a set of correlated variables are transformed into a set of uncorrelated variables, i.e., principal components, which are ordered by reducing variability. The uncorrelated variables are linear combinations of the original variables, and the last of these variables can be removed with minimum loss of real data.

In Fig. 1, two principal components (PC1 and PC2) have been identified after the PCA. The score vector t_{i1} and t_{i2} associated with two principal components respectively. The angle between the positive x_1-axis and two principal components is α_1 and α_2, while the angle between the positive x_2-axis and two principal components is β_1 and β_2 respectively [25]. The PC1 matches the maximum variance and PC2 is

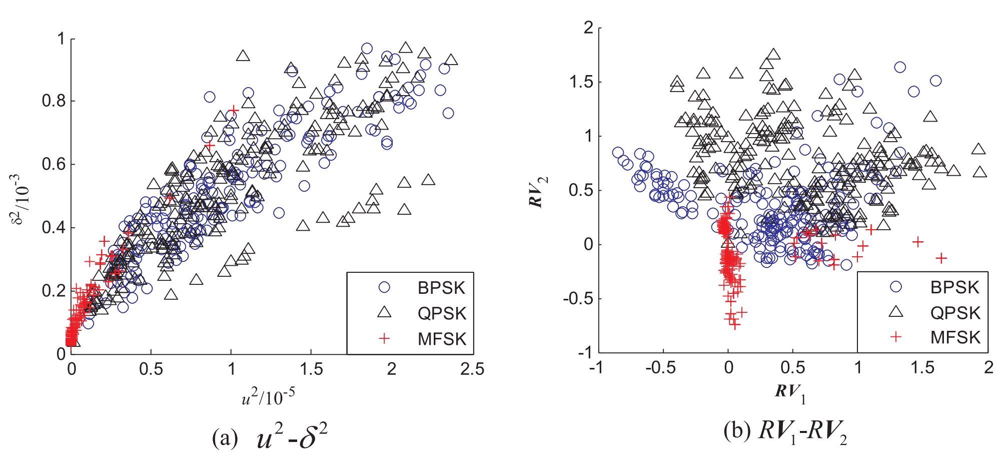

Fig. 2. Two-dimensional figure of shape features and principle components from PSD.