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Information-theoretic wavelet packet subband selection for texture classification

Ke Huang*, Selin Aviyente

Department of Electrical and Computer Engineering, 2120 Engineering Building, Michigan State University, East Lansing, MI 48824, USA

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Abstract

Wavelet packet decomposition has been successfully applied to image analysis and classification. The most common approach for wavelet packet-based texture classification is to decompose texture images with wavelet packet transform and to extract energy values for all subbands as features for the subsequent classification. Due to the overcomplete representation provided by the wavelet packet transform, it is suitable to select a set of subbands for sparse representation of the texture for classification. For better classification results, it is desired that the energy features corresponding to the selected subbands are as independent from each other as possible. However, most of the current subband selection methods do not take the dependence between energy values from different subbands into account. In this paper, we investigate the dependence between energy values from different subbands, which may be from the same wavelet basis, or from different wavelet bases. Based on the theoretical analysis and simulation, we propose an information-theoretic measure, mutual information, for selecting subbands for sparse representation of textures for classification. Experimental results show that the proposed method yields a sparse representation of the textures and achieves lower classification error rates than the conventional methods, simultaneously.

Keywords: Sparse representation; Mutual information; Wavelet packets; Feature extraction; Texture classification

1. Introduction

Texture image classification is an important problem in image analysis and pattern recognition. In recent years, wavelet analysis and its extension, wavelet packet analysis have gained popular applications in this field. A common approach for extracting features from wavelet packet analysis is the computation of energy distribution over different subbands.

The idea of extracting energy features from filtered images can be traced back to Laws [1], where a bank of band-pass filters were used for texture analysis. After wavelet decomposition and its extension wavelet packet decomposition were proposed [2,3], they have been successfully applied to the texture classification problem. The most common approach is to decompose the texture with orthogonal wavelet packet basis and extract the energy from each subband as features for classification [4]. Due to the overcomplete representation provided by the wavelet packet decomposition, several algorithms were proposed to prune the

*Corresponding author. Tel.: +1 517 432 8396.
E-mail address: kehuang@egr.msu.edu (K. Huang).

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wavelet packet decomposition tree to generate a sparse representation based on different cost functions, such as the well-known entropy cost function [3]. Other subband selection methods that aim at achieving sparse texture representation for classification have also been proposed. For example, in [5], the texture images were not decomposed using the whole wavelet packet tree. Only subbands with energy values higher than a pre-determined threshold value were further decomposed. The energy distribution over these subbands with high energy values were used as features for classification. In [6], each subband is evaluated based on the discriminant power of the extracted energy value, and the subbands with high discriminant power are chosen to get a sparse representation of the texture for subsequent classification. In [7], a neuro-fuzzy method is used for subband selection to obtain a sparse representation. It is also important to note that other filter bank-based algorithms are also used in a similar way for different applications, e.g., Gabor filters used for fingerprint verification [8] and iris identification [9].

The early research in wavelet packet-based feature extraction [4] focuses on extracting energy values from all subbands and using them for classification. However, it is common knowledge in the area of pattern recognition that proper feature selection is likely to improve classification accuracy [10]. At the same time, the structure of wavelet packet transform, i.e. the overcomplete tree representation, motivates the proper subband selection for classification. In texture classification, the goal of subband selection is to obtain a sparse representation of features that can achieve high classification accuracy. It is not required that the texture image is reconstructed from the selected subbands. To generate a sparse representation that can achieve accurate classification results, the energy values for the selected subbands should be as independent of each other as possible. In past research [3,5–7], each subband is evaluated separately based on a pre-determined criterion and the feature selection is based on the individual evaluation results. In this process, it is implicitly assumed that the energy values from different subbands are independent, which rarely holds in pratice. In order to have a sparse subband selection process that can achieve good performance for texture classification, we need to know the dependence between the energy values extracted from different subbands. The dependence between wavelet coefficients that have the 'parent–child' or 'sibling' relationship has been successfully measured by mutual information [11], or modelled by hidden Markov model (HMM) [12,13]. However, the energy value is a function of all coefficients in a subband. Thus, the dependence between energy values is more complex than the dependence between individual wavelet coefficients. Moreover, only the dependence between pairs of coefficients are considered in [11–13]. In the wavelet packet-based texture classification, we need to consider the dependence between the energy values from different sets of subbands. If the energy values from a set of subbands are dependent on the energy values from another set of subbands, the latter set of subbands should not be included in the sparse representation for texture classification. Thus, the models developed in [11–13] are not suitable for the problem of generating sparse representation for texture classification.

In this paper, we analyze the dependence of energy values from different subbands, which may be from the same wavelet basis or different wavelet bases. Based on the theoretical analysis and simulation, we propose an information-theoretic measure, mutual information, to select subbands for sparse representation of texture for classification. To compute the value of mutual information in high-dimensional space, we introduce a reduced order model. In past research, only subbands from one wavelet basis are used for sparse representation. The proposed algorithm can combine subbands from multiple wavelet bases for sparse representation of textures.

1.1. Organization of this paper

The organization for the rest of this paper is as follows. Section 2 briefly reviews the standard 2D wavelet packet decomposition and reviews the general process for wavelet packet-based texture classification. In Section 3, we analyze the dependence of energy values between different subbands. Due to the lack of an accurate statistical model for texture images, simulation results for covariance between energy values from different subbands are presented in Section 3. Based on the analysis provided in Section 3, Section 4 proposes an algorithm for combining different subbands from multiple wavelet bases for sparse representation of texture images. Experimental results and related discussions are given in Section 6. Section 7