Cross-validation based weights and structure determination of Chebyshev-polynomial neural networks for pattern classification

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A B S T R A C T

This paper first proposes a new type of single-output Chebyshev-polynomial feed-forward neural network (SOCPNN) for pattern classification. A new type of multi-output Chebyshev-polynomial feed-forward neural network (MOCPPN) is then proposed based on such an SOCPNN. Compared with multi-layer perceptron, the proposed SOCPNN and MOCPPN have lower computational complexity and superior performance, substantiated by both theoretical analyses and numerical verifications. In addition, two weight-and-structure-determination (WASD) algorithms, one for the SOCPNN and another for the MOCPPN, are proposed for pattern classification. These WASD algorithms can determine the weights and structures of the proposed neural networks efficiently and automatically. Comparative experimental results based on different real-world classification datasets with and without added noise prove that the proposed SOCPNN and MOCPPN have high accuracy, and that the MOCPPN has strong robustness in pattern classification when equipped with WASD algorithms.

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1. Introduction

Pattern classification is one of the most important areas of artificial intelligence [1–7]. In recent years, artificial neural networks have become powerful tools for pattern classification because of their remarkable features, such as nonlinear system modeling, self-learning, and self-adaptive capabilities [3–7]. The back-propagation (BP) neural network first proposed by Rumelhart and McClelland [8] is one of the most widely applied neural network models [7,9]. However, BP-type neural networks have inherent weaknesses such as slow convergence [10] and the existence of local minima [11]. Different from algorithmic improvements on the BP iterative-training procedure, activation function and network structure improvements are the focus of this paper, with the goal of achieving better efficacy [12–14]; one example of such structure improvements is the use of orthogonal polynomial neural networks [13,14].

Chebyshev polynomials, a sequence of orthogonal polynomials, are frequently used in various applications. Recently, different kinds of Chebyshev-polynomial-based neural networks have been developed for function approximation [12,15–17], pattern classification [18,19], and nonlinear system identification [20]. Our previous studies have found that a Chebyshev-polynomial-based neural network performs effectively in approximation, generalization, and prediction [13,14]. Therefore, Chebyshev polynomials have been chosen as the basis for activation-function construction in this paper. In light of the theories of Bernstein polynomial [21,22] and orthogonal polynomial approximation [12,15], a group of Chebyshev-polynomial-based basis functions are constructed in this paper for data approximation. A three-layer feed-forward neural network (including the input, hidden, and output layers) can approximate nonlinear continuous functions effectively [23,24].

Thus, a new type of single-output Chebyshev-polynomial feed-forward neural network (SOCPNN) that adopts a three-layer structure is proposed in this paper for pattern classification. The hidden-layer neurons of the new SOCPNN are activated by the Chebyshev-polynomial-based basis functions. The proposed SOCPNN can achieve satisfactory prediction performance in handling high-dimensional data. Based on the new SOCPNN, a new type of multi-output Chebyshev-polynomial feed-forward neural network (MOCPPN), which is a generalized form of the SOCPNN, is constructed for pattern classification. This new MOCPPN can also achieve satisfactory prediction performance. The proposed SOCPNN and MOCPPN have low computational complexity, making them alternatives for pattern classification. Weights and structures significantly influence the neural network performances of a feed-forward neural network. Thus, one important issue is designing effective and efficient algorithms to determine the appropriate weights and structures for the SOCPNN and MOCPPN such that their superior characteristics can be fully used in pattern classification.

Two types of learning algorithms are frequently used for weights learning, namely, the BP (or termed, gradient-based) type and the gradient-free type. However, the BP-type algorithm