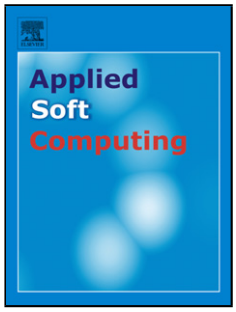

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A self-organizing deep belief network for nonlinear system modeling

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Highlights:

1. A self-organizing deep belief network (SODBN) with growing and pruning algorithms is proposed for nonlinear system modeling, The SODBN can automatically determine its structure using growing and pruning algorithms instead of artificial experience.
2. The self-organizing strategy in this paper is a kind of forward learning algorithm and accelerates the learning process of SODBN, which can be proved from experimental results.
3. The applications of the proposed SODBN in nonlinear systems modeling significantly improve the effectiveness of structure design, which accords with the development direction of deep learning and artificial intelligence.
4. The success of SODBN (theory and applications) can generalizes the self-organizing strategy in the other deep learning-based neural networks, such as convolutional neural network (CNN).

Abstract In this paper, a self-organizing deep belief network (SODBN) with growing and pruning algorithms is proposed for nonlinear system modeling. Although deep learning-based DBN has been widely used in recent years, actually more detailed researches about how to dynamically determine its structure are seldom observed in the existing literatures. The SODBN can automatically determine its structure using growing and pruning algorithms instead of artificial experience. Firstly, the structure of SODBN is constructed automatically by changing the number of both hidden layers and the hidden neurons during the training process. The self-organizing strategy is implemented by automatic growing and pruning algorithm (AGP), which is actually equivalent to adding and pruning the connecting weights between neurons. Secondly, the weights are dynamically adjusted during the process of structure self-organization. SODBN is able to adjust the weights in the dynamic process of self-organizing structure, and is helpful to improve the network performances, including running time and accuracy. Finally, the proposed SODBN has been tested on three benchmark problems, including nonlinear system modeling, water quality prediction in practical wastewater treatment system as well as air pollutants concentrations prediction. The corresponding experimental results show that SODBN has better performances than some existing neural networks.

Key words Self-organizing deep belief network; Deep learning; Automatic growing and pruning algorithm; Dynamic weights adjustment; wastewater treatment system.

1. Introduction

In recent years, nonlinear systems modeling is becoming more and more important for controller design [1-3], process analysis [4] and soft computing [5, 6]. An excellent model can efficiently describe the dynamic behavior of nonlinear systems, especially the industrial systems, which is a vast demand for economic growth of a country to some extent. In fact, it is difficult to model nonlinear systems due to the existence of uncertainty, including structure and parameters [7]. As a result, artificial neural networks (ANNs) have been widely used to modeling nonlinear systems [8-10], and corresponding improvements have been also achieved. However, these methods have not met the high demand of modeling accuracy in complex industrial systems. The main reason is that these methods only consider the single hidden layer structure [11], which leads to a poor description for dynamic behavior of nonlinear systems.

Recent researches show that deep learning-based deep belief network (DBN) can achieve any desired modeling accuracy with less hidden neurons [11, 12]. According to universal approximation theory, DBN with a single hidden layer can approximate any nonlinear systems with any accuracy if sufficient neurons are provided [13]. However, a single hidden layer with too many hidden neurons always leads to training failure [11]. Consequently, when it comes to those nonlinear systems with high complexity and nonlinearity, DBN need to properly increase