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Artificial Neural Network Model and Its Application in Signal Processing

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

The human brain is a powerful image and pattern recognition processor, and its basic processing element is neurons. Synapses are weighted interconnections between neurons, allowing learning and communication between neurons. Artificial neural network (ANN) is an information processing system established by simulating the structure and logical thinking mode of human brain. The uniqueness of ANN is that it is nonlinear and trained to complete processing tasks in a way similar to human brain learning. It is particularly suitable for processing signals sent by various sensors, signals sent by communication devices, and other signals that are difficult to identify. This paper introduces the origin, types and research progress of neural networks, and summarizes the application research progress of neural networks in the field of signal processing. This paper introduces the origin, types and research progress of ANN, and summarizes the application research progress of ANN in the field of signal processing.

Keywords: Signal processing; artificial neural network; BP neural network; CNN neural network; RBF neural network.

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1. INTRODUCTION

In people's production and living practice, there are many signals that need to be processed scientifically, such as electrocardiogram (ECG), electroencephalogram (EEG) and other signals in the medical field, electrical signals received by gas composition detection sensors in the chemical field, sensor signals of fully autonomous vehicle, communication signals and radio and television signals. In the process of industrial control and signal processing, the signals obtained from sensors are often accompanied by noise, which brings great trouble to signal recognition. As a common signal processing method, noise elimination is usually accomplished by autocorrelation analysis in time domain and various filtering methods in frequency domain, but autocorrelation analysis is only effective for periodic signals and instantaneous signals submerged in noise. Therefore, the time-domain signal obtained by direct sampling is often not well used, especially for the fast signal processing required by real-time control system, this method is completely unsuitable.

With the development of computer technology, artificial neural network is used for noise elimination and pattern recognition. At present, Hopfield network [1] and bidirectional associative network [2] are mostly used. These two networks use their associative memory ability to achieve noise reduction and pattern recognition, but their convergence speed is slow, and often can not get an accurate solution. With the continuous emergence of various new neural network models, it has been able to quickly process various control signals.

Artificial neural network is a branch of artificial intelligence. It is a computer system composed of many simple and highly interconnected processing units. These processing units can learn a group of target vectors from a group of associated input signals. The neural network learns by self adjusting a set of parameters, and uses some related algorithms to minimize the error between the expected output and the network output [3,4]. Neural network has made a lot of breakthrough development in theory, which brings new hope for the research of artificial intelligence pattern recognition and information processing. Because of the characteristics of self-organization, self-learning and parallel distributed information processing, neural networks have been widely used in pattern recognition, signal processing and optimization problems. The main application fields are intelligent driving [5-7], robot control, automatic control of power system, chemical process control and optimization [8-11], image processing [12-14], health care, medical treatment, signal processing [15,16].

This paper will introduce the development process of neural networks and several commonly used neural network models, and summarize the application research progress of neural networks in the field of signal processing.

2. DEVELOPMENT HISTORY OF ARTIFICIAL NEURAL NETWORK MODEL

Since 1943, McCulloch and Pitts [17] proposed a research method of mathematical simulation by simulating biological nerve cells, called M-P model. Hebb learning rule proposed by Hebb [18] is still a basic principle of neural network learning algorithm; In 1960, Widrow [19] proposed the adaptive (Adaline) linear element model. These models and algorithms enrich the neural network system theory to a large extent. However, due to the difficulty of crossing the limits of electronic circuits, the development of neural networks stagnated for nearly 20 years. Until the 1980s, marked by the Hopfield model proposed by Hopfield, the artificial neural network entered a new era of development [15]. In 1986, Rumelhart and Hinton [20] proposed “a multilayer feedforward network (BP) algorithm. BP algorithm includes forward propagation of signal and back propagation of error. This two-way feedback structure can reduce the error signal to the minimum at that time”. In 1998, Vapnik [21] proposed the concept of support vector machine and SVM algorithm. In 2006, Hinton [22] et al. described an effective method for initializing weights, which allows the deep automatic encoder network to learn lower dimensional codes better than PCA. As a tool to reduce data dimensions, it greatly alleviates the problem of local optimal solution of ANN.

3. TYPES AND RESEARCH PROGRESS OF ARTIFICIAL NEURAL NETWORKS

Since the appearance of Hopfield network model, artificial neural network has derived hundreds of models, which can realize data analysis and utilization by simulating other industries, such as thermodynamics, mathematics, medicine, etc. The following will introduce the three most used neural networks: feedforward neural network

(BP), radial basis function neural network (RBF) and convolutional neural network (CNN).

3.1 Feedback Neural Network (BPNN)

Rumelhart et al. [20] proposed "a feedback neural network (BP) to remedy the defects of multi-layer neural networks". Its basic architecture is shown in Fig. 1. The basic idea of BPNN is to provide learning samples to the neural network, and modify the weight according to the error between the actual output value and the expected output value, so that the output value obtained by the modified network is as close to the expected output value as possible. The specific steps are as follows [23]:

First, taking the sum of squares of the error of the output layer neurons as the objective function, the weights and offsets when the objective function reaches the minimum value are calculated. Then, the random gradient descent algorithm is used to optimize the error. The partial derivative is calculated by the chain derivative algorithm, and it is treated differently according to the location of the node (hidden layer or output layer).

The calculation of error terms needs to start from the output layer, calculate the error terms of the hidden layer and the input layer in turn, and update all weights [24]. The weight is adjusted once every sample is processed. After multiple iterations (that is, all training data are processed repeatedly for multiple rounds), the weight of the network model can be trained to achieve the objective function.

3.2 RBF Neural Network

"In the human cerebral cortex, there are local regulation and overlapping receptive regions. According to this feature of the human brain, Moody and Darken proposed a radial basis function (RBF) neural network, which is an abstraction and simplification of the human brain neural network system" [25]. "RBF neural network is a three-layer feedforward neural network, which contains input layer, hidden layer and output layer. The transformation from input node to hidden layer node is nonlinear, while the transformation from hidden layer node to output node is nonlinear, so it can force any continuous function with any precision, especially suitable for the control of nonlinear and time-varying dynamic systems" [26]. "Compared with BP neural network, RBFNN not only has superior clustering and classification capabilities, but also has better generalization capabilities and higher approximation accuracy" [27]. Because of its simple learning algorithm and network structure, RBFNN has fast convergence and can uniformly approximate any continuous function to achieve the expected accuracy.

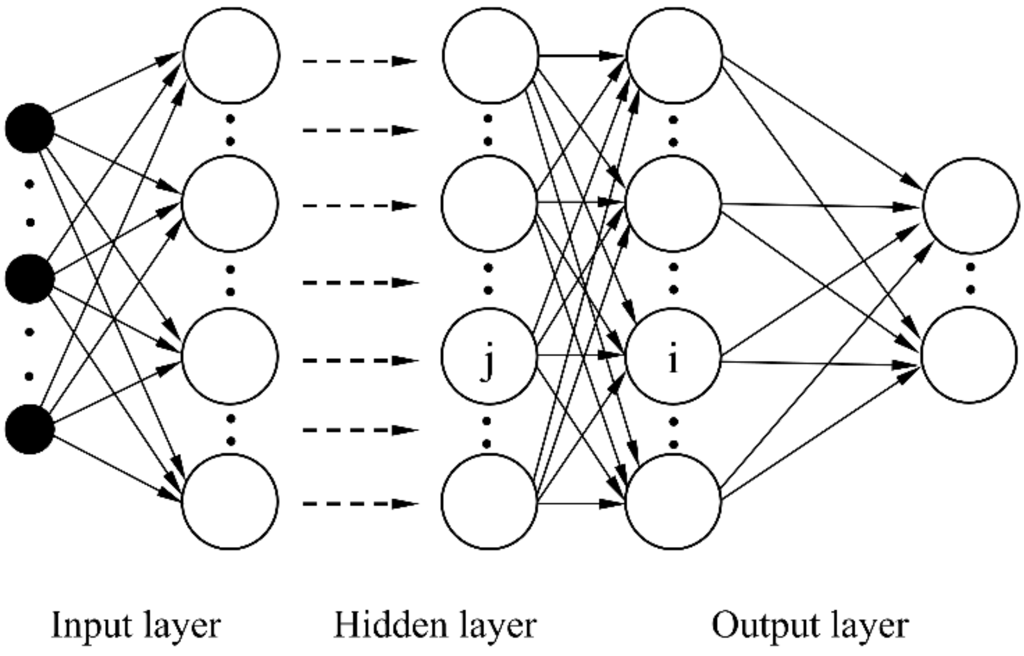

Fig. 1. Model for Feedback neural network (BPNN)

3.3 CNN Neural Network

Convolutional neural network (CNN) was first proposed by LeCun [28]. As a classifier for image recognition, its basic architecture can be divided into two parts: feature extractor (including input layer, convolution layer and pooling layer) and classifier (including full connection layer and output layer). Through continuous optimization and update, predecessors have done a lot of valuable work for these two parts, making the efficiency of feature extraction and classification of convolutional neural network continuously improve.

Lin et al. [29] put forward the network in network structure, which can improve the network's ability to fit complex nonlinear functions by replacing the convolution kernel with a micro multilayer neural network. Szegedy et al. [30] proposed the inception module, which sets convolution kernels of different sizes in the same convolution layer to extract features of different scales on the feature map of the previous layer.

Convolutional neural network is not only widely used in target recognition and classification, but also plays a key role in data generation and data transformation, such as style transfer of paintings [31], emotional transformation of human voice [32] and image super-resolution reconstruction [33].

4. PROGRESS IN THE APPLICATION OF ARTIFICIAL NEURAL NETWORKS IN THE FIELD OF SIGNAL PROCESSING

The electrical signals processed by artificial neural networks involve a wide range of fields, including medical diagnosis, chemical process control, chemical composition analysis, machinery manufacturing, precise guidance of military weapons, radio and television, etc. Some classic cases will be summarized below.

The electrocardiogram (ECG) is a biomedical electrical signal corresponding to the heartbeat activity [34]. There are many different waves and spikes in the ECG. The most significant deflection is the QRS wave group, which corresponds to the contraction of the ventricle, and thus corresponds to the heartbeat [35]. Therefore, the accurate detection of QRS complex is very important for the calculation of HR and other important parameters. In recent years, the progress of neural network technology has also led to the emergence of enhanced QRS detector based on artificial neural network. In this work, Morabito et al. [36] applied ANN to electrocardiogram (ECG) signals to classify QRS complex. Back propagation neural network (BP) and Kohonen characteristic map (KFM) are selected for ECG analysis. ANN received 8 groups of training, 20 QRS complex waves in each group, extracted from VALE database (DB); The results showed that BP network showed good specificity, and found that it could separate morphology with fuzzy DB annotation. KFM network can create QRS morphological clustering highly consistent with the original annotation. Chromik J et al. [37] proposed a method to evaluate the certainty of each detected QRS complex, that is, the confidence of the QRS detector that there is actually a QRS complex at the detected location [38].

Rai et al. [39] used multi-resolution wavelet transform and artificial neural network classifier to process electrical signals of arrhythmia data, and they proposed a technology that can use neural classifier to truly divide ECG signal data into two categories (abnormal category and normal category). ECG signals are classified based on MIT-BIH arrhythmia database and three neural network classifiers (BPN, FFN and MLP), and the accuracy is close to 100%.

Xing et al. [40] studied the application of artificial neural networks (ANNs) in signal processing of piezoelectric crystal sensors, which can be used for qualitative identification of complex component materials and quantitative determination of multi-component in gas or liquid. Suah et al. [41] discussed the application of artificial neural network in signal processing of bromophenol blue doped sol gel film optical fiber pH sensor, using three-layer feedforward network and back propagation (BP) algorithm for network training. The spectra generated from the pH sensor at several selected wavelengths are used as input data for ANN. The results show that the ANN training shows a higher pH dynamic range, and the calibration error is low. The sensor shows good analytical performance.

Zhou Yunlong et al. [42] proposed a fault diagnosis method for centrifugal pump vibration signal by combining HHT and RBF neural network. The HHT is used to extract the characteristics of the vibration signal of the centrifugal pump, and the energy ratio is used as the feature vector, which is input into the Elman neural network with strong classification ability. The diagnosis of the normal state, mass imbalance, rotor imbalance and foundation looseness of the centrifugal pump is well realized.

Fang Shi et al. [43] discussed the problem of magnetic field signal processing and extraction under the condition of complex noise based on the principle of neural network and adaptive filtering. According to the magnetic field characteristics of underwater targets, a low-pass filter is designed with the actual measured background noise and target signal data as samples, and the BP neural network algorithm is simulated with MATLAB software to achieve adaptive noise cancellation. The results show that this method can significantly improve the ability of target signal processing and extraction.

Gao et al. [44] proposed a non parallel data-driven affective speech conversion method. It can transmit the emotion related features of speech signals, while retaining the speaker's identity and language content. The transformation model consists of an encoder and a decoder for each emotion. Suppose that speech signal can be decomposed into an emotion invariant content code and a style code in an emotion related potential space. The emotion conversion is carried out by extracting and recombining the source content code, voice and target emotion style code. The test and evaluation results show the effectiveness of this method.

Alapuranen et al. [45] developed a radio receiver technology based on complex artificial neural networks. This technology uses a new type of neuron together with the network architecture to avoid most problems that hinder network convergence and training. Combined with a new neural network weight update algorithm and the use of layers with nonlinear selection functions and methods to avoid large single error values in backpropagation, the complex neural network can be trained with rapid convergence.

Igwe KC et al. [46] introduced the research progress of artificial neural network (ANN) model used to calculate the received signal strength (RSS) of VHF (very high frequency) broadcasting stations. The network is trained using Levenberg Marquardt back propagation (LMBP) algorithm. The results show that the signal strength calculated by ANN model is in good agreement with the measured value. The measured field strength is also compared with the ANN and ITU-R P. 526 diffraction models. It is found that there is a strong correlation between them, indicating that the artificial neural network can be used for signal strength estimation based on atmospheric parameters.

Balabanova et al. [47] proposed an innovative method to recognize human speech affected by unexpected noise and superimposed noise through back-propagation neural networks (BNNs) in different transfer functions. The BPN with linear, tangent S-shaped and logarithmic S-shaped transfer functions in the output layer is tested. A neural architecture is selected for noise recognition among the six neurons defined in the hidden layer. This architecture has a "tansig" activation output and achieves 98.3% accuracy. In speech processing, the same efficiency of 4, 3 and 4 hidden neurons is 93.7%.

The powerful function of autonomous vehicles lies in their ability to quickly detect road obstacles and various scenes by applying robust, fast and efficient AI based signal processing to radar data.

Valtl et al. [48] applied artificial neural network (ANN) directly to the raw data of frequency modulated continuous wave (FMCW) radar. The results show that if there is enough raw data, preprocessing is unnecessary. They collected 153648 frames of data with 60GHz FMCW radar, and systematically compared the options of using variational automatic encoder to preprocess data, applying traditional preprocessing or omitting data preprocessing, and directly applying ANN to raw data. Among them, the signal processing speed of the last option is improved by 28%, with the highest accuracy. This is a promising result because it can achieve edge computing and direct signal processing at the sensor level.

5. CONCLUSION

Neural network has the characteristics of large-scale parallel processing, self-learning and adaptability, distributed expression of knowledge and information, and strong fault tolerance. As a paradigm to solve fuzzy problems in the intelligent era, it has successfully processed various natural physiological signals and artificially generated control signals. In the future, with the development of hardware technology, the fragmentation and marginalization of cloud services, and the intelligence and informatization of cities, more signals need to be efficiently processed with the help of artificial neural networks.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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