ISSN 2616-5775 Vol. 5, Issue 6: 83-88, DOI: 10.25236/AJCIS.2022.050612

Train a correct BP neural network as the input layer and as the training sample

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Abstract: *For this problem, we train a correct BP neural network with the number of layers, material and thickness of each layer, emission spectrum pollution index as the input layer, as the training sample, and comprehensive thermal efficiency as the output layer, to obtain the network mapping relationship between comprehensive thermal efficiency and design parameters of multilayer structure. Then, through particle swarm optimization algorithm and genetic algorithm, six layers are obtained, which adopt silica silicon silica germanium silicon germanium structure, with refractive index of 21.7832 and thickness of 130.819. Currently, the corresponding thermoelectric conversion efficiency is the highest.*

Keywords: *BP neural network model, input layer, training sample*

1. Introduction

The topic requires us to design a multilayer heat emitter to make its emission as narrow and high as possible and give the design parameters of the multilayer structure (including the number of layers, material and thickness of each layer), as well as its emission spectrum. Taking the number of layers, material and thickness of each layer and emission spectrum pollution index as the input layer, as the training sample, and the comprehensive thermal efficiency as the output layer, we train a correct BP neural network to obtain the network mapping relationship between the comprehensive thermal efficiency and the design parameters of multilayer structure. Then, through particle swarm optimization algorithm and genetic algorithm, six layers are obtained, which adopt silica silicon silica germanium silicon germanium structure, with refractive index of 21.7832 and thickness of 130.819. Currently, the corresponding thermoelectric conversion efficiency is the highest.

2. Problem restatement

To improve the spectral control ability of the radiator, sometimes the thermal transmitter is designed as a narrow-band emission, that is, the emission is concentrated in a very small band, so as to improve the thermoelectric conversion efficiency of thermophotovoltaic. Devices, such as multilayer narrowband transmitters designed by Sakurai et al. [6] It contains silicon, silicon dioxide and germanium. Please select a reasonable material, design the multi-layer heat emitter to make its emission as narrow and high as possible, and give the design parameters of the multi-layer structure (including the number of layers, material and thickness of each layer), as well as its emission spectrum. Please note that the idea heat emitter in this topic has sharp and high heat emission at 1.5 microns, and the calculated wavelength range is 0.3-5 microns.

3. Establishment and solution of model

Based on the above analysis of the problem, the following will start to establish the mathematical model and explain the establishment process, and then use the mathematical model to solve the problem.

4. Design of multilayer heat emitter based on neural network model

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4.1 Neural network model

To solve this problem, we established a variable screening model based on BP neural network. Combined with BP neural network, this question will use the method of mean impact value (MIV) to explain how to use neural network to screen variables, find the input items that have a great impact on the results, and then realize variable screening. MIV is one of the best indicators to evaluate the correlation of variables in neural network. It is used to determine the influence of input neurons on output neurons, and its absolute value represents the importance of influence.

BP network is a multi-layer network interconnected by input layer, output layer and one or more hidden layer nodes. This structure enables the multi-layer feedforward network to establish an appropriate linear or nonlinear relationship between input and output without limiting the network output between - 1 and 1. The network structure is shown in Figure 1.

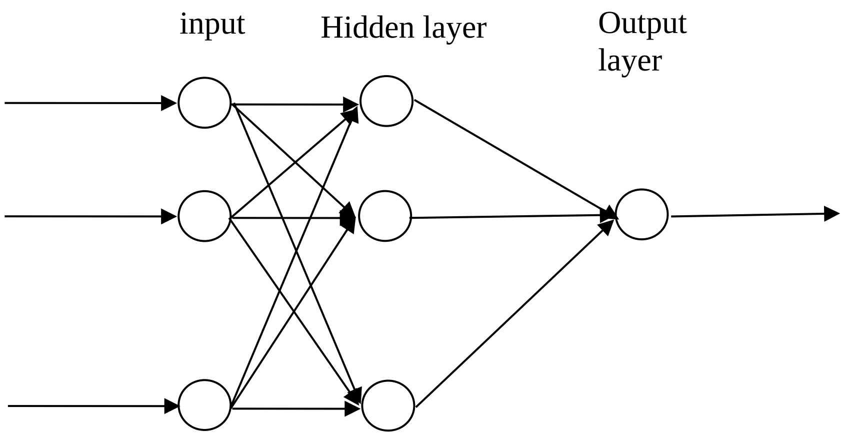

Figure 1: BP neural network structure

Neural network has strong learning ability, especially suitable for uncertain reasoning, judgment, recognition and classification with complex causality. For any group of random, neural network algorithm can be used for statistical analysis, fitting and prediction. The learning process consists of two processes: forward propagation of signal and reverse propagation of error.

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In forward propagation, the mode acts on the input layer. Let the index of the input layer affecting the thermoelectric conversion efficiency of thermophotovoltaic be, the actual thermoelectric conversion efficiency of thermophotovoltaic is, and the thermoelectric conversion efficiency of thermophotovoltaic obtained through neural network learning is. BP neural network can establish a nonlinear relationship in the hidden layer between the input layer and the output layer:

$$y' = f(\omega, B, x)$$

Where, f represents this nonlinear relationship; ω represents the weight of each neuron connected in the network; B represents the threshold connecting each neuron.

After being processed by the hidden layer, the back propagation stage of the incoming error. The output error is returned to the input layer layer by layer through the hidden layer and "allocated" to all units of each layer, so as to obtain the reference error or error signal of each layer unit, and set the reference error as E'.

$$E' = \sum (y' - y)^2$$

The reference error can be used as the basis for modifying the weight and threshold of each unit. Set the standard error as E: when $E' > E$, modify the weight and threshold of each neuron; When $E' < E$, the network training ends.

The process of constantly modifying weights and thresholds is also the process of network learning. The adjustment formula of weight and threshold of conventional BP network is as follows:

$$\begin{cases} \omega_{ij}(t+1) = -\eta \dfrac{\partial E'}{\partial w_{ij}} + \omega_{ij}(t) \\ \omega_{jk}(t+1) = -\eta \dfrac{\partial E'}{\partial w_{jk}} + \omega_{jk}(t) \end{cases}$$

$$\begin{cases} B_{ij}(t+1) = -\eta \dfrac{\partial E'}{\partial B_{ij}} + B_{ij}(t) \\ B_{jk}(t+1) = -\eta \dfrac{\partial E'}{\partial B_{jk}} + B_{jk}(t) \end{cases}$$

Where, E' is the reference error; (22) In (23), η is the learning rate of the network, that is, the adjustment range of the weight; $w_{ij}(t)$ represents the connection weight between the t neuron in the input layer and the j neuron in the hidden layer at time t; $w_{ij}(t+1)$ represents the connection weight between the i neuron in the input layer and the j neuron in the hidden layer at the time t; $w_{jk}(t)$ represents the connection weight between the i neuron in the hidden layer and the j neuron in the output layer at time t. The meaning of the threshold subscript is the same as the weight.

The adjustment process is carried out until the error level of network output is gradually reduced to an acceptable level or reaches the set learning times, and the network training is completed.

To solve this problem, we take the number of layers, material and thickness of each layer, emission spectrum pollution index as the input layer, take it as the training sample M, and take the comprehensive thermal efficiency as the output layer, train a correct BP neural network, and obtain the network mapping relationship between the comprehensive thermal efficiency and the design parameters of multilayer structure.

4.2 principle of particle swarm optimization neural network optimization algorithm

Particle swarm optimization (PSO) is a random search algorithm based on group cooperation, which is developed by simulating the foraging behavior of birds. In biological groups, there are interaction and interaction behaviors between individuals and between individuals and groups. This behavior reflects an information sharing mechanism existing in biological groups. Particle swarm optimization is a simulation of this social behavior, that is, using the information sharing mechanism, individuals can learn from each other's experience, so as to promote the development of the whole group. This idea is abstracted into a mathematical model: let a community composed of N particles, the search space is D-dimensional, and the position of the i particle is expressed as vector $\left(x_{i1}, x_{i2}, \cdots, x_{id}\right)$; The optimal position in the "flight" history of the i-th particle (i.e. the position corresponds to the optimal solution) pbest is $\left(p_{i1}, p_{i2}, \cdots, p_{id}\right)$. So far, the optimal position gbest of the whole particle swarm is $\left(p_{i1}, p_{i2}, \cdots, p_{id}\right)$. The velocity of the i th particle is vector $V_i = \left(V_{i1}, V_{i1}, \cdots, V_{id}\right)$. The position of each particle is iteratively changed ("flying") according to the following formula:

ISSN 2616-5775 Vol. 5, Issue 6: 83-88, DOI: 10.25236/AJCIS.2022.050612

$$v_{id}(t+1)=\omega V_{id}(t)+c_1 r_1\left[p_{id}-X_{id}(t)\right]+c_2 r_2\left[p_{gd}-X_{id}(t)\right]$$

$$X_{id}(t+1)=X_{id}(t)+V_{id}(t+1)$$

Where ω is the inertia weight c_1, c_2 is the normal number, known as the acceleration factor, usually $c_1=c_2=2$. r_1 and r_2 are random numbers with uniform distribution in $[0,1]$ interval. The particle swarm size N can also be calculated according to the dimension D of the search space with the following formula:

$$N=12+\sqrt{2D}$$

In addition, when the particle constantly adjusts its position according to the speed, it is also limited by the maximum speed $V_{\max}$. when vi exceeds $V_{\max}$, it will be limited to $V_{\max}$. the initial position and speed of the particle swarm are generated randomly, and then iterated until the termination conditions are met.

Formula (24) consists of three parts. The first part is the previous velocity of the particle, which explains the current state of the particle; The second part is the "cognition" part, which represents the thinking of the particle itself and encourages it to fly to the best position it has found; The third part is the "social" part, which represents the information sharing and mutual cooperation among particles, and encourages them to fly to the best position once found by the whole particle swarm. The three parts together determine the spatial search ability of particles.

4.3 genetic algorithm optimization

Genetic algorithm is a computational model of biological evolution process simulating the natural selection and genetic mechanism of Darwin's biological evolution theory. It is a method to search the optimal solution by simulating the natural evolution process. The steps of combining BP neural network are as follows:

Step 1: parameter setting. The parameters to be selected in genetic algorithm are: code string length 1, population size20. The crossover probability is 0.6. The probability of variation is 0.2. Termination algebra 100.

Step 2: use real number coding and generate the initial population.

Step 3: calculate the evaluation function of each individual, and select the appropriate individual according to the evaluation function $P_i=f/\sum_{i=1}^{N} f_i$, f_i is the fitness value of individual i, where f is the fitness function, and its value is the reciprocal of the output value of BP network, i.e. $f=1/Z$. The selection operator, crossover operator and mutation operator are used to generate new individuals and the next generation population.

Step 4: insert the new individual into the population and calculate the evaluation function of the new individual.

Step 5: judge whether the algorithm ends. If the maximum algebra is reached, the fitness value and corresponding variables are retained,

Otherwise, continue the cycle.

In order to intuitively express its modeling idea, the optimization flow chart of genetic algorithm based on BP neural network is made as follows:

The training process of BP neural network is the process of adjusting the connection weight and threshold between neurons according to the sample set. The training process of neural network based on particle swarm optimization is the same. Firstly, all connection weights and thresholds between neurons are encoded into real vectors to represent individuals in the population; Randomly generate the groups of these vectors, and then iterate according to the original steps of the algorithm: the newly

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generated individual vectors in the iteration are restored to the weights and thresholds of the neural network. Calculate the mean square deviation index (fitness) generated by all samples through neural network. If the mean square deviation is less than the error accuracy specified by the system. Then the training process stops, otherwise the iteration continues until the maximum number of iterations is reached.

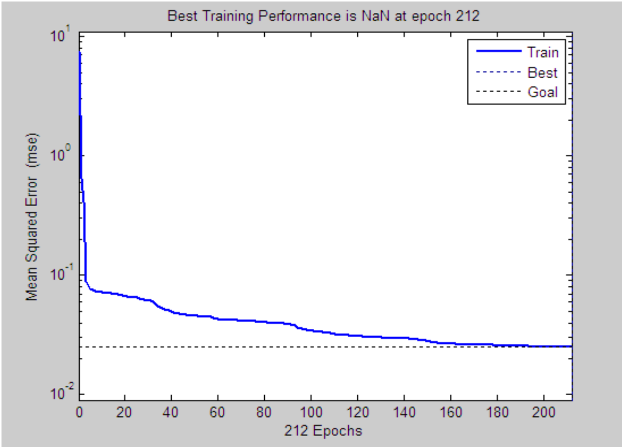

Figure 2: Schematic diagram of error reduction

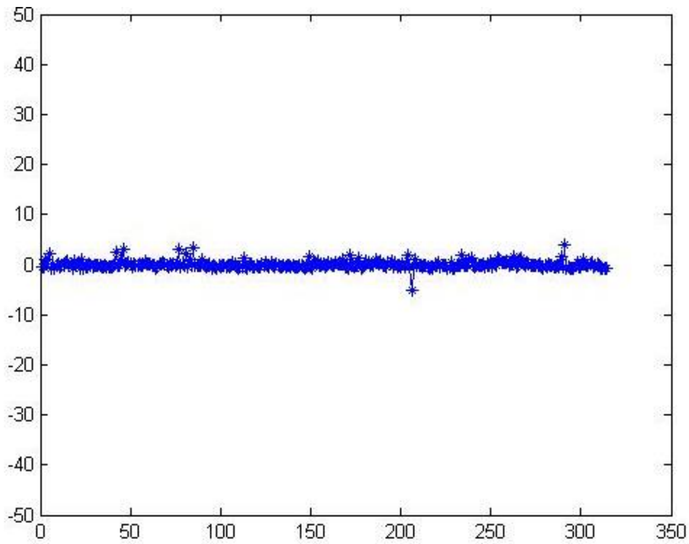

Figure 3: Error analysis diagram

The relative error basically fluctuates around 0, and a few errors are relatively large. Therefore, the trained neural network can well reflect the relationship between the thermoelectric conversion efficiency and the design parameters of the multilayer structure. At this point, the relevant characteristics can be well described.

It can be seen from the above figure that after about 26 generations, the fitness function basically converges, the corresponding fitness function value is 0.01428, and the optimal solution is: (6, 21.7832130.819). Currently, the corresponding thermoelectric conversion efficiency is the highest. The six layers adopt silica silicon silica germanium silicon germanium structure respectively, with a refractive index of 21.7832 and a thickness of 130.819.

5. Strengths and Weakness

5.1 Strengths

The genetic algorithm based on BP neural network is used to find the extreme point, which avoids the cumbersome modeling process.

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5.2 Weakness

For the neural network method, the method itself needs to be effectively trained with a large amount of data to determine the rationality of the weight of secondary factors, but it can provide sufficient data in more aspects, so it takes a long time and process to popularize and use the model.

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