Research on Intelligent Shift Control Strategy of The Loader Based on Radial Basis Function Neural Network

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Abstract. One of the key issue of the automatic shift control of the loader is how to find the best gear for the current conditions according to certain mapping relation, but this complex and non-linear mapping is difficult to express by mathematical relation. However, to solve such non-linear problems, RBF neural network is the very choice. This paper presents an RBF neural network intelligent shift control strategy method based on improved genetic algorithm. The genetic algorithm's global search ability is improved by adaptively adjusting the crossover probability and mutation probability. The genetic algorithm is used to optimize the RBF neural network expansion coefficient and reduce the tediousness of adjusting parameters during the network learning process. The feasibility of this method was validated by the bench test of the intelligent shift test system for loader automatic shift control. The theory was provided for the development of intelligent automatic shift control for construction machinery. The basis has high engineering application value.

1. Introduction

The loader is a typical cycle work engineering vehicle, the operating environment conditions are relatively complicated, the shifting operation is very frequent, the driver is labor-intensive, and the shifting operation at an untimely time will greatly reduce the engine working efficiency, and the shocks also has a great impact on the reliability and comfort of the vehicle. Therefore, in order to reduce the driver's labor intensity, improve the shift quality of the loader, and enhance the working efficiency of the loader transmission, it is urgent to study and design a reasonable and feasible intelligent control method to realize the intelligent automatic shifting control strategy of the loader.

At present, neural networks have done a lot of research on automatic shift control of engineering vehicles, but most of them use neural network for shift control[1]. Only a few documents mention the application of some optimization algorithm to improve neural network[2]. Compared with other neural networks, radial basis function (RBF) neural networks have the advantages of strong adaptive ability, absence of local minimum and optimal value, and strong approximation ability. Therefore, RBF neural network algorithm is introduced in this paper to study the automatic shifting of loader, and the global approximation property and the optimal approximation performance of RBF neural network are utilized to improve the dynamic characteristics, adaptability and generalization recognition ability of the network, so as to better realize the intelligent shifting control strategy of a loader.
2. Intelligent Shift Control Strategy Design

2.1. Design of RBF Neural Network

RBF neural network is a three-layer neural network, including the input layer, hidden layer and output layer\(^3\).

Because this control shift scheme uses two parameters, the input layer selects two input parameters of vehicle velocity and engine speed, and the output layer is four forward gear shift signals. The gear shift model of RBF neural network is established, as shown in figure 1.

![Figure1. The shift model of RBF neural network with two parameters and four forward gears](image)

Whether the hidden layer expansion coefficient being reasonable or not, will be a key factor for RBF neural network performance. Therefore, the hidden layer selects a Gaussian function with simple form, radial symmetry and smoothness\(^4-5\). The output of the \(i^{\text{th}}\) \((i = 1, 2, \ldots, q)\) node of the hidden layer is rewritten as:

\[
u_i = \exp\left[-\frac{(\mathbf{x} - \mathbf{c}_i)^T(\mathbf{x} - \mathbf{c}_i)}{2\sigma_i^2}\right]
\]

Where \(u_i\) is the output of the \(i^{\text{th}}\) hidden node, \(\sigma_i\) is the output standardized variance of the \(i^{\text{th}}\) hidden node, \(q\) is the number of hidden nodes, \(\mathbf{x} = (x_1, x_2, \ldots, x_q)^T\) is the input vector, \(\mathbf{c}_i\) is the Gaussian function’s central node vector of the \(i^{\text{th}}\) hidden node, this vector is the same as an input vector \(\mathbf{X}\) dimension column vector, that is \(\mathbf{c}_i = (c_{i1}, c_{i2}, \ldots, c_{iq})^T\).

The hidden layer of RBF neural network though a linear mapping \(u_i(x) \rightarrow y_i\) to form the output layer, that is:

\[
y_k = \sum_{i=1}^{q} w_{ki} \theta_k \quad (k = 1, 2, \ldots, q)
\]

Where: \(y_k\) is the \(k^{\text{th}}\) node output of the output layer, \(w_{ki}\) is the weighting coefficients of the hidden layer to the output layer; \(\theta_k\) is the threshold of the output; \(q\) the number of nodes in the hidden layer.

2.2. Improved Design of Genetic Algorithm

Genetic algorithm can get the optimal solution within the search range, and the algorithm crossover and mutation operations are key, because the size of the crossover and mutation probability values will directly affect the development of the individual\(^6-7\). In order to further improve the global search ability of genetic algorithm, this paper improve crossover and mutation of genetic algorithm, to achieve automatic adjust \(p_c\) and \(p_m\), adjustment programs: When the fitness value is lower than the average of all the individual fitness of the population, \(p_c\) and \(p_m\) select a larger value; when the fitness value is higher than the entire populations of individual fitness of average fitness, \(p_c\) and \(p_m\) select a smaller value. This improved optimization algorithm not only can maintain the diversity of population, but also to ensure convergence of the algorithm.
The algorithm of genetic algorithm adjusts the formula is as follows:

\[
\begin{align*}
\rho_c &= \begin{cases} 
\frac{\rho_c - \rho_{c1}(\lambda - \lambda_{avg})}{\lambda_{max} - \lambda_{avg}}, & \lambda \geq \lambda_{avg} \\
\rho_c, & \lambda < \lambda_{avg}
\end{cases}, \\
\rho_m &= \begin{cases} 
\frac{\rho_m - \rho_{m1}(\lambda - \lambda_{avg})}{\lambda_{max} - \lambda_{avg}}, & \lambda \geq \lambda_{avg} \\
\rho_m, & \lambda < \lambda_{avg}
\end{cases}
\end{align*}
\]

(3) (4)

Where Two cross operation to be performed; \(\rho_c\) is crossover probability; \(\rho_m\) is mutation probability; \(\rho_{c1}\) is initial crossover probability; \(\rho_{m1}\) is initial mutation probability; \(\rho_{c2}\) is crossover probability can be increased to maximum value; \(\rho_{m2}\) is mutation probability can be increased to maximum value; \(\lambda_{max}\) is the maximum fitness of all individuals; \(\lambda_{avg}\) is the average of all individual fitness; \(\lambda\) is the individuals in the larger fitness value; \(\lambda\) is the fitness mutation individuals to be performed.

2.3. Algorithm Implementation

The RBF neural network intelligent shift model of the improved genetic algorithm was learned and trained by using with real vehicle test sample data. The center \(c_j\), of the expansion coefficient, the variance \(\sigma_j\),the connection weight \(w_{kj}\) of the hidden layer, and the output threshold \(\theta_i\) of the output layer were obtained. The learned and trained network model can realize intelligent automatic shift control according to the determined shifting rules. The improved genetic algorithm is optimized RBF neural network automatic shift control. The specific steps are as follows:

1. The input parameters of the loader are extracted and normalized.
2. The initial parameters of the algorithm and search the interval are determined. The initial population is established.
3. The RBF neural network is established. The error matrix norm of the predicted and actual values of the RBF neural network is used with the fitness function.
4. The individual fitness is calculated. The fitness value is assigned by using the ranking method. The individuals of the large fitness are selected in the population. The fitness values are recalculated. The crossover probability is calculated and the crossover operation is performed by using the single-point crossover method according to formula3. The probability of mutation is calculated and the operation of mutation is performed by according to formula4. The objective function value is calculated.
5. The step 6 will be executed if the best individual of the algorithm is selected. Otherwise the step 4 will be executed until the maximum genetic algebra is obtained.
6. The optimal individual is used as the input parameter of RBF neural network. The vehicle velocity and engine speed of the loader are used as the network input vector to train the RBF neural network. The trained genetic algorithm RBF neural network is used to identify the gears of the loader. The identified results will be provided.

3. Intelligent Shift Control Experiment

The intelligent gear shifting test system is mainly composed of the test bench transmission device, control and acquisition parts[8]. The test bench transmission device mainly includes: power device, hydraulic transmission, coupling, speed increasing box and loading device, as shown in Figure 2; the control and acquisition part mainly includes: inverter, operation bench, acquisition card and control program, as shown in Figure 3.

In order to realize two-parameter automatic shifting, the shifting program was completed by using MATLAB program, and then implement the mixed programming of LabVIEW and MATLAB through the MATLAB script node. Through the LabVIEW program interface, the speeds of the motor
and the increasing box output collected in real time are sent to the shift program for loader engine speed and vehicle speed for processing and settlement, and the real-time gear under this condition is finally output. The LabVIEW program based on the two-parameter automatic shift of the vehicle speed and engine speed, as shown in figure 4.

![Figure2. Test bench transmission](image1)

![Figure3. Control part](image2)

![Figure4. The LabVIEW program](image3)

Through bench tests, the correctness of the intelligent shift control strategy of the RBF neural network based on the improved genetic algorithm proposed in this paper is verified. The results show that there has been great progress in terms of convergence speed, training time, and output accuracy. This paper provides a better intelligent, non-linear control method for the automatic shift control of the cyclic work loader.

### 4. Conclusion

This paper presented an RBF neural network intelligent shift control strategy method based on an improved genetic algorithm. By adaptively adjusting the crossover probability and mutation probability, the global search ability of the genetic algorithm was improved. By optimizing the RBF neural network expansion coefficient, the tediousness of adjusting parameters during the learning process was reduced. By the bench test of the intelligent shift test system, the feasibility of the method for automatic shift control of loaders was verified. It provided a theoretical basis for the development of intelligent automatic shift control of construction machinery. This paper has high engineering application value.

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