Experimental Study on Intelligent Gear-Shifting Control System of Construction Vehicle Based on Chaotic Neural Network

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Abstract: In this paper, taking power-shifting transmission of ZL50 wheel loader as control object, an autocontrol system based on Intel-51 single-chip microcomputer has been developed. Chaotic neural networks (CNN) control technology in which chaotic optimizing algorithms is applied to improve neural networks' learning efficiency makes gear-shifting control system possess intelligentized characteristics. The results of experiment show that the intelligent control system could reliably and exactly realize an automatic transmission according to changed working conditions after gear-shifting strategy has been successfully regulated. The intelligent electronic control unit (ECU) works steadily and can accurately and duly complete gear-shifting. Finally, the study is helpful for designing intelligentized construction machinery. [Nature and Science 2003;1(1):86-90].

Keywords: construction vehicle; chaotic neural network; intelligent gear-shifting control; micro-controller

1. Introduction

The automatic transmission (AT) is a key technology to improve performance of vehicles. With the synthesized applications of mechatronics technology, computer technology, autocontrol technology on vehicles, development of modern vehicle technology is stepping into a completely new age with the characteristics of intelligence, in which one of the most primary symbols is automatization of vehicle transmission system, i.e., to realize automatic gear-shifting of the transmission. As a kind of special vehicle, construction vehicles possess very important status in vehicle family. As view of the complexity of operation, the badness of working condition and the variety of working tasks, which result in the frequent gear-shifting of the drivers for meeting the demands of vehicle power force, to realize automatic transmission on construction vehicle have special significance on improving vehicle performance, promoting working efficiency, lightening labor intension and utilizing in reason energy sources (Yi, 1998).

At present, in China, the driver makes decision on current gear of construction vehicle based on working tasks, conditions of road surface and vehicle running status, which brings on that the work efficiency of vehicle mainly depends on the experience of the driver. Moreover, automatic gear-shifting control system with the characteristics of intelligence can simulate the driver's operation and learn the optimal gear-shifting strategy and realize complex control by making use of learning and memory capability of chaotic neural network (CNN) technology that does not have to analyze control process and inner structure of the system. So intelligent gear-shifting control system is adopted on automatic transmission of the powertrain system of modern construction vehicle.

In this paper, theory analysis and experiment research have been combined. A set of intelligent gear-shifting controller with CNN technology for construction vehicle, which has auto-adaptability and on-line learning capability, is developed and a testing experiment is carried out on test-bench of the powertrain system.

2. Control Principle

2.1 Gear-shifting Strategy

Gear-shifting strategy is the core of intelligent control system of automatic transmission, because it is related to whole performance of the powertrain system and it directly affects vehicle's driving power, fuel economy and auto-adaptability to environment. Gear-shifting strategy is the rules of changing the time of automatic shifting between gears, and that the time varies with control parameters. It is a one-to-one correspondence, that there is only one output variable to every group of input variable. In order to assure the optimal driving output of construction vehicle and exert power potential of engine, gear-shifting point should be the intersection point of two gears' driving power curves in the traction trait picture when the angle of throttle is kept no change (Wang, 2001), as Figure 1 shows. According to the principle, gear-shifting rules under each angle of throttle can be obtained. When speed of vehicle is as x-axis and angle of throttle as y-axis, the optimal driving power gear-shifting curves may be drawn. In Figure 2, the real lines are rising-gear curves and the broken lines are falling-gear curves. It is seen from Figure 2 that the gear-shifting curves are composed of two or more changed rules segments, which is called the combination gear-shifting strategy. It is the integration of equal-delay type, radiating type and converging type gear-shifting strategy. The assembled rules make it possible to attain different vehicle performances under each angle of throttle (Ge, 1993).

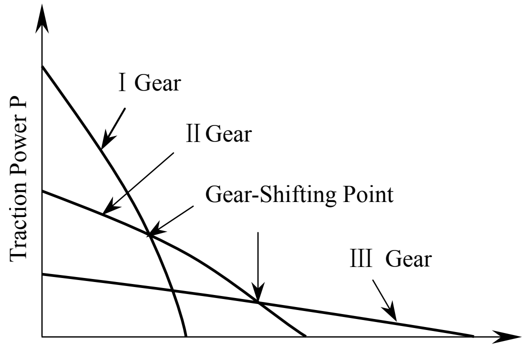

Figure 1. Principle of Optimal Driving Power Gear-Shifting

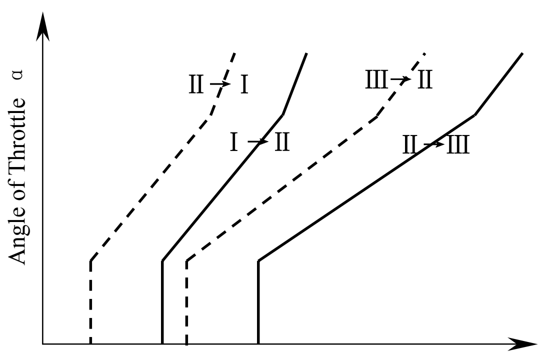

Figure 2. Sketch Map of Gear-Shifting Strategy

2.2 Design of Neural Network Control System

The optimal gear-shifting strategy is a nonlinear and multipartite function that describes the relation between vehicle state parameters (speed, angle of throttle, etc.) and the optimal gear. Owing to the complex mathematic model, it is hard to obtain the proper gear only with generic seeking methods. At the same time, the gear-shifting curves above-mentioned are altered all the time along with constantly changed working conditions of construction vehicle. In this instance, the proleptic control goal can not be achieved if old gear-shifting rules continue to be used. Neural network control methods possess great predominance on resolving nonlinear problems and distilling control rules from experimental data. So in this paper auto-adaptability and auto-learning mechanism of neural networks is introduced to construct the intelligent control system, which makes construction vehicle obtain automatically gear-shifting rules and adapt automatically to working conditions and realize the function of learning on-line, so as to assure that construction vehicle can exert optimal working efficiency and control performance （Baumann, 1998）.

For automatic transmission control of construction vehicle, the gear of transmission is controlled output parameter. The angle of engine throttle and speed of vehicle can describe running states of vehicle and ascertain traction power by selecting appropriate gear （Hiroshi, 1993）.

Model of three layers forth-feedback neural network is designed based on the theory above-mentioned, as Figure 3 shows. Neural networks adopt two inputs x_1 （angle of engine throttle）, x_2（speed of vehicle）, one output y （gear of transmission） and one middle layer （seven nerve cells）, that is to say, the structure of neural networks employed in the study is 2-7-1 format. $x_i^{(k)}$ is the output of No.i nerve cell in No.k layer nerve networks, $w_{ij}^{(k)}$ is the connection right from No.j nerve cell in No.k-1 layer to No. i nerve cell in No.k layer; n is the number of nerve cells in No.k layer; $\theta_i^{(k)}$ is the threshold value of No.i nerve cell in No.k layer, hereby, the output of nerve cells in No.k layer can be educed in the light of the states of nerve cells in No.k-1 layer according to formula（1）and（2） (Yuan, 1999)：

$$x_i^{(k)} = f(o_i^{(k)}) = [1 + \exp(-o_i^{(k)})]^{-1} \quad (1)$$

$$o_i^{(k)} = \sum_{j=0}^{n-1} w_{ij}^{(k)} x_j^{(k-1)} - \theta_i^{(k)} \quad (2)$$

2.3 Chaotic Optimizing Algorithm

The former multilayer nerve networks often adopt error-back propagation algorithms to modify right values and threshold values, which has the flaws of slow convergence speed and easily getting into part extremum. Even though the algorithms could be improved on by adding momentum item to the adjusting formula for right values, this method is so hard to meet the demands of making neural networks' total error converge to admissible error limit that it has influenced actual effect of control system. Therefore in this study chaotic nerve networks optimizing algorithms are put forward to carrying through networks' learning. The method, in which a nonlinear feedback item is joined in dynamics equation of nerve networks' connection right, is a iterative algorithms on the basis of grads descending method that can accelerate networks' convergence speed. The nerve networks employing chaotic optimizing algorithms, which make networks hold chaotic kinetic action in right space, can synthetize the virtues of randomicity and definitude so as to take on more flexible dynamics characteristics and higher search efficiency (Li, 2001).

Define that error function is square type. The equation is:

$$E_p = \frac{1}{2} \sum_j (y_{jp} - d_{jp})^2 \quad (3)$$

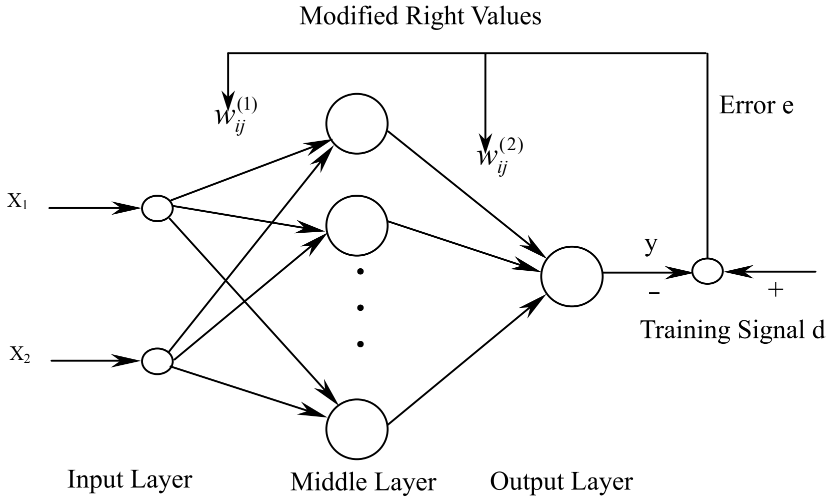

Figure 3. The Model of Three Layers Neural Networks

In above formula, y_{jp} and d_{jp} respectively is anticipant output and factual output; p is the swatch number of trained aggregate. The total error is:

$$E = \sum E_p \qquad (4)$$

Defining two variables:

$$\delta_i^{(k)} = -\frac{\partial E_p}{\partial o_i^{(k)}} = -\frac{\partial E_p}{\partial x_i^{(k)}}\frac{\partial x_i^{(k)}}{\partial o_i^{(k)}} \qquad (5)$$

$$\Delta w = \frac{dw_{ij}^{(k)}}{dt} = -\eta \frac{\partial E_p}{\partial w_{ij}^{(k)}} \qquad (6)$$

$$= -\eta \frac{\partial E_p}{\partial o_i^{(k)}}\frac{\partial o_i^{(k)}}{\partial w_{ij}^{(k)}} = -\eta \delta_i^{(k)} x_j^{(k-1)}$$

① If nerve cell i is output nerve cell of the networks, thus

$$\delta_i^{(k)} = (y_{jp} - d_{jp}) f'(o_i^{(k)}) \qquad (7)$$

② If nerve cell i isn't output nerve cell of the networks, defining that m is No. m nerve cell in middle layer, thus

$$\delta_i^{(k)} = f'(o_i^{(k)}) \sum_m w_{mj}^{(k+1)} \delta_{mj}^{(k+1)} \qquad (8)$$

Dynamics equation of right values modified:

$$w_{ij}^{(k)}(t+1) = w_{ij}^{(k)}(t) - \eta \delta_i^{(k)}(t) x_j^{(k-1)}(t) + f[w_{ij}^{(k)}(t) - w_{ij}^{(k)}(t-1)] \qquad (9)$$

$$z = W(t) - W(t-1) \qquad (10)$$

$$f(z) = \tanh(az)\exp(-bz^2) \qquad (11)$$

In above formula, η is learning rate; a and b is adjustable parameters, and different parameters can result in different feedback equation, in this paper, a=0.6, b=0.1.

3. Design Control System

3.1 Function Design of Control System

The function of intelligent control system is to realize gear-shifting manipulation based on gear-shifting strategy. The types of control system include hydraulic-pressure control model and electron-hydraulic control model according to the production of gear-shifting signal and the mode of controlling gear-shifting values (Toyama, 1992; Jiao, 1997). In the paper, the autocontrol system with electronic control unit (ECU) adopts electron-hydraulic control mode by which electromagnetic values and gear-shifting values are controlled to complete automatic gear-shifting. Intelligent gear-shifting ECU is in charge of gathering the running state parameters of vehicle and making use of chaotic optimizing algorithms equations to learn all kinds of working conditions and gain correct gear-decision based on the well-trained CNN. In succession, ECU sends out gear-shifting signal to drive gear-shifting performing machine to accomplish gear-shifting of transmission. In order to avoid circulatory gear-shifting, it is required not to make rising-gear curves and falling-gear curves overlapped, i.e., to enactment a speed difference of gear-shifting. So two gear-decision neural networks in intelligent control system are introduced to respectively carry through learning and managing rising-gear and falling-gear instances.

3.2 Hardware Design of Intelligent Control System

Because the matrix operation in computer inner of neural networks learning algorithms is relatively complex, the hardware frame of control system consists of 2 parts: main unit and child unit in order to increase operation speed of the process and assure real time sampling and controlling. The main unit equipped with industry-using control computer with PC bus is in charge of training the parameters of CNN while the child unit assembled with 8032 micro-controller of Intel MCS-51 series is responsible for controlling gear signal output and sampling vehicle state parameters. The two parts carry out data-exchange by extending common Random Access Memory (RAM). The main computer puts the well-calculated data into common RAM and meanwhile analyses the running data imported from micro-controller while single-chip controller reads the control data in common RAM and drives the electromagnetic values to perform gear-shifting operation (Wang, 2002). The hardware structure of control system is shown in Figure 4.

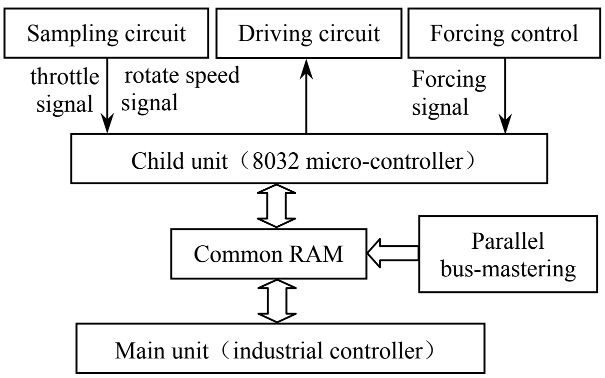

Figure 4. Hardware Design of Control System

4. Experiment and Results Analysis

4.1 Structure of Test-Bench for Powertrain System

In this experiment, the powertrain system equipped on ZL50 wheel loader is taken as controlled object. The main devices include X6130 diesel engine, YJ355 hydrodynamic torque converter （three components, single grade, single posture）, 4D180 hydrodynamic transmission box equipped with 4 forward-gear and 4 back-gear, torque sensor, rotate speed sensor and PD-WC575 power-measure machine with electric vortex. To test the whole performance of the gear-shifting controller, the designed intelligent gear-shifting control system is connected with the performing machine, and torque and rotate speed sensors are laid on the output port of the engine and transmission, and the measuring and controlling apparatus for engine and power-measure machine is employed to respectively control the angle of engine throttle and the output of power-measure machine. During the running process of the system, data-watch system ever and again transmits the vehicle state parameters to the intelligent electronic control unit. The structure of experimental system is shown in Figure 5.

4.2 Self-Learning Experiment of Neural Networks

The experiment begins after having completed electromotive demarcation of the control system. The trained-data acquired from many groups which working conditions is provided for networks with the control aim of keeping the powertrain system exert optimal driving power. The system is loaded by controlling power-measure machine. Under this condition of keeping maximal power output of the powertrain system, the gears of transmission and the throttle of engine are artificially chosen and registered as trained-data when the system has steadily run. The process above is repeatedly carried out till 40 groups running data as a batch is collected for the learning of neural networks. During the learning course, the parameters of nerve networks are continually adjusted in order to make it possible to improve the intelligent gear-shifting control system's identification capability on running rules of the powertrain system. Define that learning rate of nerve networks is 0.01 and training precision of networks is 0.002.

4.3 Gear-Shifting Control Experiment and Results Analysis

The experimental aims are to prove the correct of CNN gear-shifting theory mentioned above and to test the reliability of CNN controller on the test-bench for hydrodynamic mechanical transmission. At the same time, it is important for the control system utilizing the acquired running rules to test its gear-decision-making capability on any working conditions. The powertrain system is loaded by adjusting power-measure machine while the running data is registered by data-watch system. Here, intelligent electronic control unit makes gear-decision and export gear-shifting signals. The results of experiment on 100 points drawn in Figure 6 show that the powertrain system can normally work, and the design of CNN gear-shifting controller is successful. Under continuously changed load conditions the gear-shifting control system can realize automatic transmission by means of gear-shifting strategy acquired from working. So, it may be proven that the decision-making precision and velocity of CNN can meet control demands and ECU can duly and exactly respond to any testing working condition.

5. Conclusions

In this paper, design problems of the intelligent gear-shifting control system from experiment have been solved. Conclusions have been gained as follows：

1．The algorithms and structure of nerve networks in intelligent gear-shifting control system have been improved. The feasibility of chaotic nerve networks （CNN） technology applied to gear-shifting control of construction vehicle has been proved by the experiment on test-bench of the powertrain system.

2. Gear-shifting electronic control unit (ECU) with the core of 8032 micro-controller has been developed.

3. The intelligent gear-shifting control system designed in this study has conquered nerve networks technology's own defect on delayed and imprecise control aspects. The system that possesses the haracteristic of adapting automatically to working conditions by means of learning from operation can realize automatic transmission of construction vehicle.

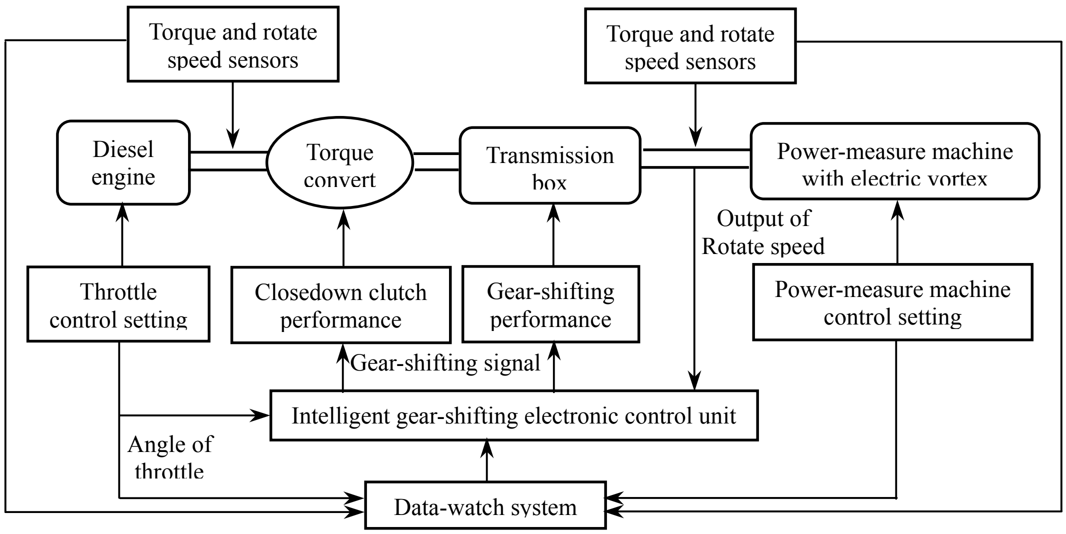

Figure 5. The Structure of Experimental System

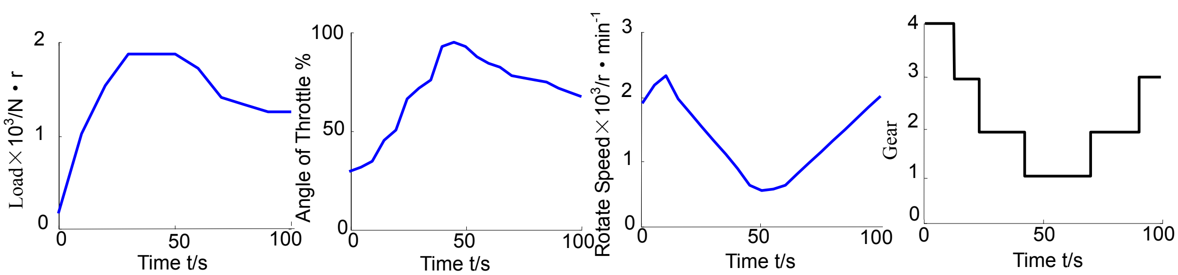

Figure 6. The Results of Experiment

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