Application Research on BP Neural Network PID Control of the Belt Conveyor

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ABSTRACT: *In order to control reasonably the acceleration and dynamic tension in full-load starting process of conveyor system, accurate design techniques should be adopted. This paper selects the viscoelasticity model suiting to the belt by comparing dynamic performance of some kinds of models, and develops simulation model of driving device with feedback control, which indicating that motor rotation speed and its output torque vary with load and time. For belt conveyors, it has high nonlinear trait, PID controller with fixed parameter can not achieve good performance index. So the PID controller based on neural network is proposed. This design regards belt conveyors as a control object, by analyzing danamic model of belt conveyors, the design of related neural network PID control system based on BP neural network is provided. The BP-ANN is designed with three layers which are input-layer, hidden-layer and output layer in consideration of the control system real time requirement. The results show that the controller based on the neural networks can improve the robustness of the system and has better adaptabilities to the model and environments, compared with the classical PID control, therefore the simulation results are more close to practice.*

Categories and Subject Descriptors
C.1.3 [**Architecture Styles**]: Neural nets; **F.1** [**Computation By Abstract Devices**]: Neural networks; **B.4.2** [**Input/Output Communication Devices**]: Channels and controllers

General Terms
Neural Networks, Communication Controller

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1. Introduction

PID control is widely adopted in many fields because of its simple structure, high reliability and easily implementation. PID controller has good control effect if the parameters of system model have not big variation, but there are a lot of complex, non-linear control systems and many objects that can not be established with accurate mathematics model on industry, if these systems are controlled with the traditional PID controller,it is impossible to get ideal control effect. the traditional PID control used in nonlinear, time varying or large inertia systems will be not very effective.

For belt conveyors, it has high nonlinear trait, PID controller with fixed parameter can not achieve good performance index. So a kind of PID controller based on neural network is proposed. This design regards belt conveyors as a control object, by analyzing mathematics model of belt conveyors, the design of related neural network PID control system based on BP neural network is provided.

In order to assure the belt conveyor run reliably and safely, its structure system must have the good dynamic characteristic. In the full-load starting process, the design strength of various structural elements of conveyor is decided by the high dynamic tension produced in the belt, therefore it is important to find out a good control method for the belt conveyor on full-load starting process. [1]

2. Simulation Model of the Belt

2.1 Dynamic Model of the Belt

The viscoelasticity dynamic model used commonly of the belt mainly has the Maxwell relaxation model, the Vogit non-relaxation model and three elements solid viscoelasticity model, in which the Maxwell model can simulate the response to strain of the viscoelasticity material, but cannot simulate the response to stress; and the Vogit model is just opposite. Considering conveyor with high speed and great transportation capacity has automatic take-up device to be able to compensate automatically the distortion of the belt, therefore we may neglect the response to strain of the belt, and only consider the response to stress of belt.

Moreover it is required that the belt core material and the rubber cannot be stripped away in using, namely the distortion of two kinds of material must maintain uniformity, and the Vogit model can precisely meet this requirement. Moreover, the parameters of the Vogit model is very easy to be determined, therefore the dynamic model of belt is simplified as a series of Vogit models in series in this paper. According to force balance relations of each belt unit, the dynamic equation of each belt section is:

$$m_i\ddot{x}_i + w_i x_i = k_i(x_{i-1} - x_i) - k_i(x_i - x_{i+1}) + c_i(\dot{x}_{i-1} - \dot{x}_i) - c_{i+1}(\dot{x}_i - \dot{x}_{i+1}) \quad (i = 1, 2, ..., n) \tag{1}$$

where: m_i *- belt mass per unit length (kg/m);*

k_i *- equivalent spring coefficient (N/m);*

c_i *- equivalent viscous damping coefficient (N·s/m);*

F_i *- driving forces of belt units (N);*

w_i *- resistance force per unit length, (N·s/m) ;*

x_i *- displacements of belt units (m).* [2]

2.2 Simulink Model of the Belt

This paper analyzes the example of a belt conveyor on coal harbor, and adopts the newly popular Simulink simulation software based Matlab language. This software provides a new solution for system simulation technology. It not only improves the efficiency of computer programming, but greatly enhances programming equality and reliability.

The layout of a typical belt conveyor with inclined arrangement is shown in Figure 1.The Relevant data of the conveyor are listed below: Bulk solids material: coal ,density: $850kg/m^3$, Belt width: $B = 800mm$, Conveyor length: 300, Belt type: *EP500/5*, the upward transportation inclination angle: β =8°, Belt speed: $v = 3.5m/s$, Productivity: $Q = 720t/h$, Motor type: *Y280M - 4*, squirrel motor with hydraulic coupling, rated power: $Pe=90kw$.

This conveyor system is divided into twenty units, ten units on carrying and return side respective. Each unit includes equal belt length and each pulley is embodied in close units, as shown in Figure 2. At first, (1) are transformed into state space expression. The state variables are selected as follows: $Z_1= x_1$, $Z_2= \dot{x}_1$, $Z_3= x_2$, $Z_4= \dot{x}_2$,..., $Z_{39}= x_{20}$, $Z_{40} = \dot{x}_{20}$; the output variables are: $Y_1= Z_1$, $Y_2= Z_3$,..., $Y_{20}= Z_{39}$. Then the state space expression of the belt is: $x = AZ + BU$, $y = CZ + DU$, where U is input vector of driving forces. Then the state space block is adopted and masked, and corresponding parameters are input, so simulation block of belt is created. [3].

3. Simulation Model of Driving Device and Take-up Device

The output torque of squirrel-cage motor varies with its rotation speed, their relation expressions are as follows:

$$T =(2+q)\lambda_m T_n / S / S_m + S_m / S + q \tag{2}$$

$$(GD^2/38.2)(dn/dt) = (T - T_Z) \tag{3}$$

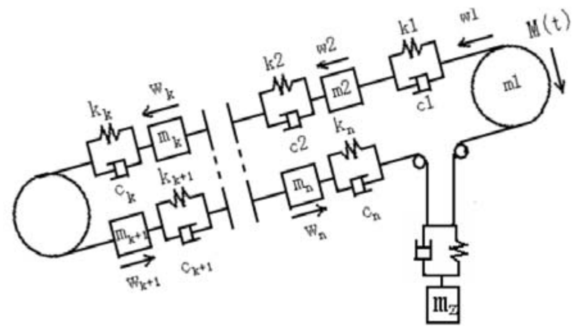

Figure 1. Finite Element Model of Conveyor System

where:

q - coefficient related with rotor resistance of motor;

λ_m *- allowable overload factor of motor;*

s - slip ratio of motor;

s_m *- slip ratio corresponding with maximal torque of motor;*

T - motor output torque;

T_n *- motor rated torque;*

T_z *- external load torque on the shaft of motor;*

GD^2*- sum of the inertia of the motor rotor,reducer, coupling, brake and load.*

S-function simulation model of motor is established by programming in this paper, the simulation model with feedback function indicates that rotation speed and output rorque of motor change with load and working time, therefore really reflects dynamic work process of the driving device. [4]

Weight take-up device is adopted in this sample, the take-up device is included in the close unit as a belt section considered, and its mass is transformed as equivalent mass of the corresponding belt section, so as to establish the unified state space simulation model. According to the stress of the take-up device, its discretization dynamic equation is:

$$m_z\ddot{x}_z = k_z(x_{z-1} - 2x_z) + c_z(\dot{x}_{z-1} - 2\dot{x}_z + \dot{x}_{z+1}) - w_Z \tag{4}$$

where:

z –the belt section with take-up device, that is i =z;

x_z *–displacements of take-up device (m);*

m_z *–mass of weight and take-up device (kg);*

w_z *–the friction resistance of the belt section with take-up device (N·s/m).*

4. BP Neural Network PID Controller of Conveyor System

4.1 PID Control on Conveyer Work Process

The PID controller has become one of main industry control technical by its simple structure, the high stability, the reliable working and the convenient adjustment. The parameter design of PID controller is key content of the process characteristic, defining the proportion factor and

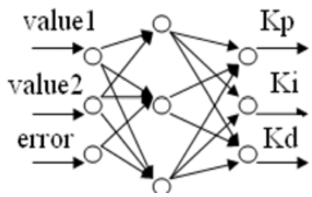

Figure 2. Structure of BP Neural Network

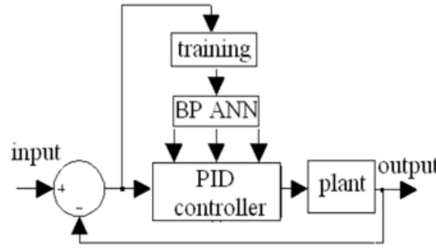

Figure 3.Structure of BP Neural Network PID Controller

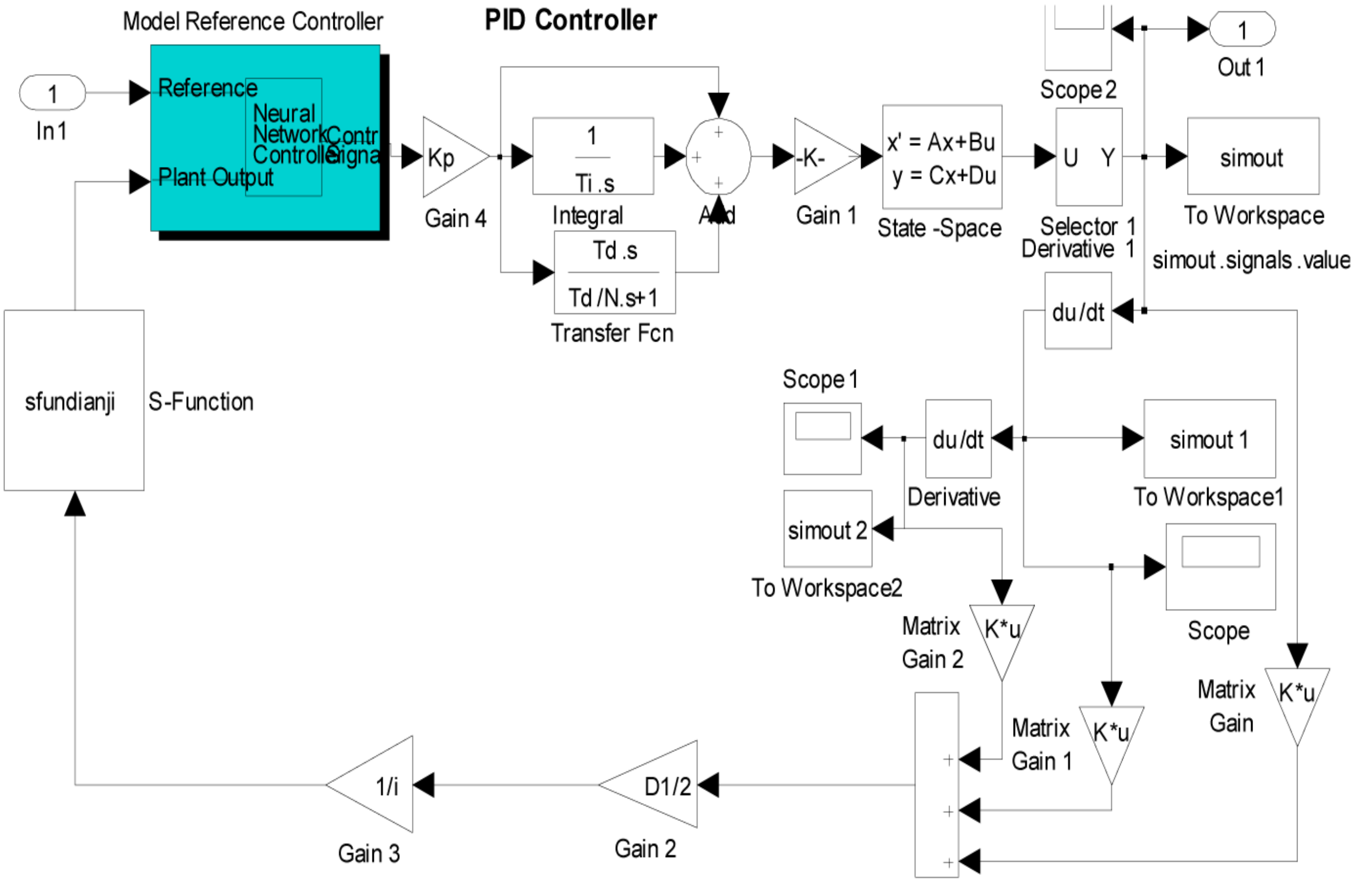

Figure 4. Simulation Model of Conveyor System with BP Neural Network PID Controller

the value of integration time and differential time of the PID controller. But, there are some disadvantages of PID control. Firstly, it is difficult to regulate the three parameters of PID controller: KP, KI and KD in some control systems. Secondly, the traditional PID control used in nonlinear, time varying or large inertia systems will be not very effective. [5]

4.2 Artificial Neural Network

Artificial neural networks (ANN) have been used in various control field of with the characteristics of self-adapting and learning, nonlinear mapping, strong robustness and fault-tolerance. Back-propagation ANN is used to construct an ANN PID controller. Generally, a three-layered BP ANN with appropriate network structure and weights can approach to any random continuous function.

PID Neural Network Controller consists of proportional (P), integral (I) and derivative (D) neurons and its weights are adjusted by the back-propagation algorithms. It can control different systems through quick learning process and has perfect performances. As shown in Figure 2, The BP-ANN is designed with three layers which are input-layer, hidden-layer and output layer in consideration of the control system real time requirement. The input-layer has three neurons, the hidden layer has four and the output-layer has three. Considering the output junctions directly corresponding to three parameters can't be minus, the activation function of the output-layer neural network is defined as non-minus Sigmoid function, the activation function of the hidden layer neural network is defined as non-minus symmetrical Sigmoid function. [6]

4.3 PID Control System Based on Neural Network

As shown in Figure 2, BP neural network PID controller adapt the weights according to the following steps:

1). Decide network structure at first. Because the nodes

Methods	Unit 1（on driving pulley）			Unit 11（on take-up pulley）			Stabilization time(s)
	Maximal velocity（m/s）	Maximal acceleration（m/s2）	Maximal tension (N)	Maximal velocity（m/s）	Maximal acceleration（m/s2）	Maximal tension (N)	
experiment output	11.91	2. 95	84605	8.64	2.76	46706	36.75
simulation output	11.09	2. 84	82751	8.29	2.64	45862	38.03

Table 1. Parameters Comparison Between Simulation and Experiment

of network input layers and output layers are known, only the nodes of hidden layers remained undecided.

2). Initialize the weights of hidden layers and the ones of output layers with less random number, select the speed of learning;

3). Sample the system and calculate the network inputs;

4). Calculate the outputs of hidden layer and output layer, get the controlling amount;

5). Calculate the system output;

6). According to the weights adapting rule of output layer and hidden layer, regulate each connection weight of output layer and hidden layer.

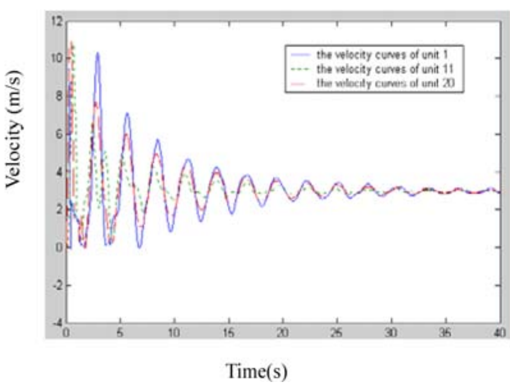

Figure 5. The Velocity Curves of Unit 1,11,20

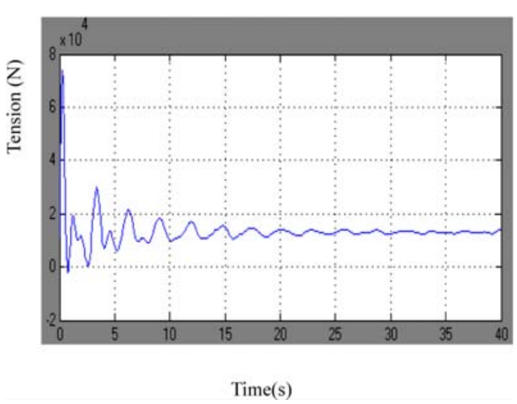

Figure 6. Tension curve of unit 1(on drive pulley)

4.4 BP Neural Network PID Controller of Conveyor System

According to relevant data of the conveyor above, the output torque of driving device is served as input source block of conveyor system, the state space block of the belt and take-up device as system block and the displacements, velocities, accelerations and dynamic tensions as output block of conveyor. The output module of nonlinear system control design is adopted in dynamic simulation in Simulink software, and is linked with the output port of the system. In addition, the torque produced from tensions difference of belt units on both sides of motor is served as loading torque, and the BP neural network PID controller module is called, consequently the simulation model of whole conveyor system is created, as shown in Figure 4. [7]

5. Simulation Results and Experimental Verification

The equations of the conveyor system are stiff, accordingly the ODE15s solver in variable-step is selected to solve the simulation model because this solver is stable, efficient and accurate to stiff equations, therefore the running efficiency and accuracy are improved.

According to the simulation model of conveyor system and the set proper simulation parameters and advanced options, the model is run and the varying process of each dynamic parameters are available during emergency braking, as shown in Figure 5, Figure 6, Figure 7.

As is known from simulation outputs, after starting the velocity of conveyor vary dramatic and the acceleration rapidly rise to 2.84m/s^2, then gradually reach stable by 38 seconds. And the conveyor tension of unit 1 on driving pulley rapidly rise to 82751N, then gradually reach stable by 37 seconds, thus the dynamic tension of conveyor is much larger than static tension on driving pulley. The actual velocity, acceleration and tension of conveyor simulated above are measured on spot and the output is at Table 1. The parameters in Table 1 are comparison between simulation output and experiment output. And experiment output is average value of several measurements. From the parameters in Table 1 we can see that experiment

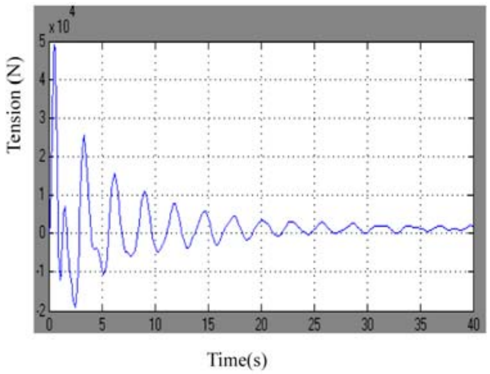

Figure 7. Tension curve of unit 11(on take-up pulley)

output and simulation output are almost identical.

6. Conclusion

The simulation on the performance of a typical time-varying nonlinear system was carried out by the PID controller based on the neural network, and the algorithm wasenvironments, compared with the classical PID control. The simulation on dynamic behavior of conveyor systems would provide accurate design techniques to control the acceleration and dynamic tension on starting process by the PID controller, so as to assure smooth starting and decrease production costs, thus enhance the running security and reliability of conveyor system. The simulation model still needs to be reviewed and improved by the experimental approach method.

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