An improved fuzzy adaptive predictive control method for network control system

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Abstract

In view of the random time-varying time delay of networked control system, a kind of method using least square support vector machine to forecast the network time delay is put forward. Network time delay is modelled as a nonlinear time sequence firstly, and then the radial basis function is used as kernel function of the least square support vector machine, so that the prediction model of time delay for network control system is established. Then the estimated time delay is used as the parameters of the fuzzy adaptive predictive controller for predictive control of networked control system. Simulation result shows that fuzzy adaptive predictive controller based on least square support vector machine time delay identification enables the system output to track the desired output very well.

Keywords: network control system, least square support vector machine, fuzzy neural network, adaptive predictive control

1 Introduction

In recent years, the intelligent method has significant advantages in dealing with nonlinear problem, making it play an incomparable role in the field of control, and especially adaptive fuzzy neural control method combing fuzzy inference and neural network attracts more attention. Early fuzzy neural control method [1] mainly took the fuzzy neural network as controller, the static multilayer forward network as uncertain object identification, and the gradient method was adopted for study training, which lacked of convergence guarantee of the algorithm and theoretical stability analysis. Then, stability analysis method based on the theory of Lyapunov [2] gradually obtained the development and application, and this kind of method mostly used static multilayer forward network to identify nonlinear part of the system, through constructing the dynamic inversion of system, it guaranteed the stability of the system in the learning process. However, static network can't better approximate a dynamic system, so that it is unable to produce the chaos behaviour and limit cycle, which makes it lose accurate expression of the original system, and affect control quality [3]. Therefore, improving the structure of the static network to describe dynamic behaviour of the system dynamically has become a very important research direction [4, 5]. The traditional fuzzy neural network as the controller itself is also a kind of static network, and topology optimization and dynamic improvement also has very important meaning. At the same time, the parameters of controller and identifier are related to the initial control performance of control system, steady-state performance and dynamic performance of on-line control. The optimization algorithm needs be further studied as much as possible to avoid algorithm converging to local minimum, which does not meet the requirements of precision [6, 7]. Stability and persistent disturbance attenuation properties for a class of networked control systems was given by Lin H [12]. Modelling and stabilization of continuous-time packet-based networked control systems was written by Zhao Y B [13]. Predictive controller design of networked systems with communication delays and data loss was given by Liu G P [14]. Stability analysis and practical design procedure of time delayed control systems with communication disturbance observer was given by Natori K [15]. Takagi-Sugeno fuzzy-model based fault detection for networked control systems with Markov delays was given by Zheng Y [16].The application of predictive sequence control in networked control system was given by He Z H [17]. Stability and persistent disturbance attenuation properties for a class of networked control systems was given by Lin H [18].

The paper is organized as follows. In the next section, principle of time delay identification based on least square support vector machine is investigated. In Section 3, adaptive predictive control based on PID fuzzy neural network [10,11] is proposed. In Section 4, the performance of proposed algorithm is tested. Finally, we conclude our paper in Section 5.

2 Time delay identification based on least square support vector machine

Early in the treatment of the uncertainty of the controlled object, the identifier was often the multilayer forward neural network, and the former network was proved that it can approximate nonlinear function in closed interval with any degree of accuracy in theory, and on the premise of low network structure complexity, training speed was faster, which made it has extensive applications in system identification. Despite of the inherent neural network

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fitting problem, it is still practical when dealing with nonlinear system identification.

As mentioned earlier, a static network can't better approximate a dynamic system, when using the forward network for dynamic system identification. Dynamic time modelling problem is transformed into static space modelling problem. At this time, in order to obtain accurate model structure, we need to assume class of system model and determine its order. And dynamic recursive network includes feedback structure, time factor is introduced, and it can express dynamic system using a simple structure without the system order, and has higher anti-interference ability. Recursive networks, however, when applied to the actual system identification, have no universal approximation conclusion of forward network in theory, and convergence speed of the training algorithms is slow. Besides, the convergence is not guaranteed.

Control systems taking fuzzy neural as core often use the multilayer forward network for identification when dealing with uncertain nonlinear object, which can satisfy the requirements of control performance. An improved scheme is to use the multilayer forward network for training, after achieving high accuracy, it is transformed into recursive network, the advantage of which is to improve the robustness of the system sensitive disturbance, and can better reflect the dynamic characteristics of the system, but essentially the convergence of network training still cannot be guaranteed.

Support vector machine [8] is a learning algorithm based on statistical learning theory put forward by Vapnik. Because the standard support vector machine needs to solve convex quadratic programming problem, there is large amount of calculation, which is not suitable for the network control. Least square support vector machine [9] replaces convex quadratic programming problem of standard SVM by solving a set of linear equations, which reduces the amount of calculation, and improves the convergence speed. The following section briefly describes its principle.

The observed network time delay sequence is $\{d(k),\ k=1,2,...,N\}$. It can be obtained by adding time delay to the transmitted packets (Timestamp), and then it is stored in the storage unit of controller according to the order. Input vector of SVM predictive model of N number of time sequences based on embedding dimension m is expressed as $D_k=[d(k),d[k-1],...,d(k-m)]$. Assuming there is the following delay sample set $\{(D_1,z_1),...,(D_N,z_N)\}$, $D\in R^n$, $z\in R$. The least square support vector machine expression of this sample is

$$\min J=\frac{1}{2}\,w\,w^T+c\sum_{i=1}^{N}e_i^2\ ,$$

$$s.t:\ z_i=w\varphi(D_i)+b+e_i\ ,$$

w represents weight coefficient vector, φ represents nonlinear mapping, which maps input vector to a higher dimensional Hilbert space. C represents regularization parameter, and b represents constant deviation. In order to solve the above constrained optimization problem, the Lagrange function is

$$L=\frac{1}{2}ww^T+c\sum_{i=1}^{N}e_i^2-\sum_{i=1}^{N}a_i[w\varphi(\mathrm{D}_i)+\mathrm{b}+\mathrm{e}_i-z_i],$$

$$\begin{bmatrix}0 & 1 & \cdots & 1\\ 1 & k(D_1,D_1)+\frac{1}{C} & \cdots & k(D_1,D_N)\\ \vdots & \vdots & \ddots & \vdots\\ 1 & k(D_N,D_1) & \cdots & k(D_N,D_N)+\frac{1}{C}\end{bmatrix}\begin{bmatrix}b\\ \alpha_1\\ \vdots\\ \alpha_N\end{bmatrix}=\begin{bmatrix}0\\ Z_1\\ \vdots\\ Z_N\end{bmatrix}.$$

$k(D_{i,},D_j)=<\varphi(D_i),\varphi(\mathrm{D}_j)>$ represents core function, which is

$$k(D_i,D_j)=\exp\left(-\left\|D_i-D_j\right\|^2/2\sigma^2\right).$$

The predictive value of network time delay is

$$\widehat{d}(k+1)=Z(D_k)=\sum_{i=1}^{N}a_ik(D_i,D_k)+b\ .$$

Then network control system can be described by time-varying parameter discrete ARMAX model.

$$A(q^{-1})y(k)=q^{-d(k)}B(q^{-1})u(k)+C(q^{-1})v(k)$$

$$A(q^{-1})=1-a_1(k)q^{-1}-\cdots-a_n(k)q^{-n}$$

$$B(q^{-1})=b_0(k)+b_1(k)q^{-1}+\cdots+b_m(k)q^{-m}$$

$$C(q^{-1})=1)+c_1(k)q^{-1}+\cdots+c_l(k)q^{-l}\ ,a_1(k),\cdots,a_n(k)$$

$b_1(k),...,b_m(k)$, and $c_1(k),...,\mathrm{c}_l(k)$ are time-varying parameter of the system. $u(k)$, $\mathrm{y}(k)$ and $v(k)$ are input sequence, output sequence and disturbance sequence respectively. When the time delay is estimated by means of least square support vector machine, time-varying parameter $\theta(k)$ is identified. Time-varying regression model of network control system model is

$$y(k)=\varphi^T(k)\theta(k)+v(k)\ .$$

$$\phi^T(k)=[y(k-1),\ldots,y(k-n),u(k-d(k)),\ldots,$$
$$u(k-d(k)-m),v(k-1),\ldots,v(k-l)]$$

$$\theta^T(k)=[a_1(k),\cdots,a_n(k),b_1(k),$$
$$\cdots,b_m(k),c_1(k),\cdots,c_l(k)]$$

The recursive method of time-varying parameter identification based on least square is

$$\theta(k)=\theta(k-1)+\frac{P(k-1)\phi(k-1)}{r+\phi^T(k-1)P(k-1)\phi(k-1)}\cdot$$
$$[y(k)-\phi^T(k-1)\theta(k-1)]$$

$$P(k)=P(k-1)-\frac{P(k-1)\phi(k-1)\phi^T(k-1)P(k-1)}{r+\phi^T(k-1)P(k-1)\phi(k-1)}$$

r represents forgetting factor, $0\le r\le 1$. $P(0)=\sigma^2 I$, $\theta(0)=0$, σ is a constant which is small enough and I represents unit matrix. After parameters are estimated, PID fuzzy neural network can be used for adaptive predictive control.

4 Adaptive predictive controller based on PID fuzzy neural network

The architecture of PID fuzzy neural network [10,11] is shown in Figure 1. Concrete structure is as follows. FNN is 4 layer networks, input quality of the first layer include the system error E and error change EC.

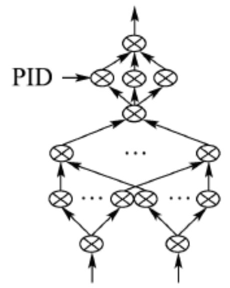

FIGURE 1 The architecture of PID fuzzy neural network

The number of nodes in the fuzzy layer is determined according to the number of fuzzy set of E and EC, and membership function can be designed according to prior knowledge of the problem. Node number of rule layer is determined according to the number of rules of prior knowledge and de-fuzzy layer is taken as the first layer of PID fuzzy neural network. The output is indirect control output U. Input layer has only one node, and the output is equal to the input. PID function layer has three nodes, which are respectively proportion P, integral I and differential D neuron. Output layer has only one node, and the output is *U*. The input and output relations of each layer neuron are as follows. The input layer is

$$O^{(1)}(k)=I^{(1)}(k)=U^{'}(k)$$

For the PTD layer:

$$I_{Hi}^{2}=\sum_{j=1}^{1}w_{ij}^{'}O^{(1)}(k), i=1,2,3$$

$$O_{Hi}^{(2)}(k)=\begin{cases} I_{Hi}^{(2)}(k), & i=1\\ I_{Hi}^{(2)}(k)+I_{Hi}^{(2)}(k-1), & i=2\\ I_{Hi}^{(2)}(k)-I_{Hi}^{(2)}(k-1), & i=3\end{cases}$$

The output layer is

$$O^{(3)}(k)=I^{(3)}(k)=\sum_{i=1}^{3}w_{i}^{'}O_{Hi}^{(2)}(k)$$

According to the network topology, output quality is as follows.

$$U(k)=w_1^{'}w_{11}^{'}U^{'}(k)+w_2^{'}w_{21}^{'}[U^{'}(k)+U^{'}(k-1)]$$
$$+w_3^{'}w_{31}^{'}[U^{'}(k)-U^{'}(k-1)]$$

U' represents output of fuzzy neural network, w_i' represents connection weight between PID layer andoutput layer, w_{ij}' represents connection weight between PID layer and PID fuzzy neural network. Schematic diagram of fuzzy PID control is shown in Figure 2.

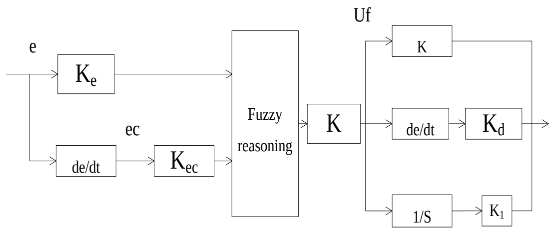

FIGURE 2 Schematic diagram of fuzzy PID control

5 Experiment and analysis

The network control system is composed of six nodes, and each node contains an internal True Time kernel based on Matlab/Simulink platform. The simulation model is shown in Figure 3. Sensor node is responsible for the sampling of the output signal of the controlled object, and then the sampling signal is sent to the controller node. The network time delay predicted by least square support vector machine is accepted by the controller node, and the current controlled quality is computed according to the fuzzy adaptive predictive control algorithm. The transfer function of controlled object is

$$G(s)=\frac{1000}{s(s+1)}.$$

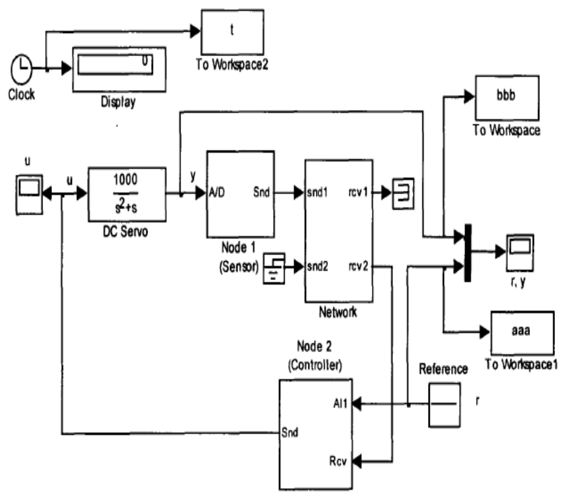

FIGURE 3 Simulation model

The output trace curve is shown in Figure 4. The blue line represents input of controller and the red line represents the output of network control system. The experiment result shows that the proposed algorithm can meet the demand of time delay accuracy and has better real time nature.

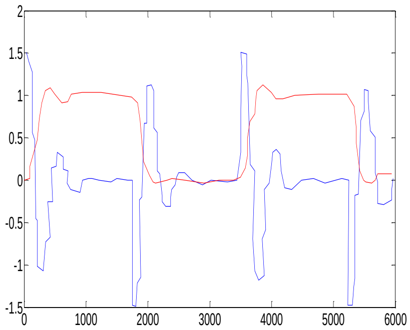

FIGURE 4 Output trace curve

Figure 5 is simulation effect when loss probability is 0, Figure 6 is simulation effect when loss probability is 0.2, Figure 7 is simulation effect when loss probability is 0.4, Figure 8 is simulation effect when loss probability is 0.6 and Figure 9 is simulation effect when loss probability is 0.65. Figure 10 is simulation effect when loss probability is 0.2 using PID control, Figure 11 is simulation effect when loss probability is 0.4 using PID control and Figure 12 is simulation effect when loss probability is 0.6 using PID control. The horizon axis represents time, the unit of which is second. The vertical axis represents output. It can be seen that the proposed algorithm has better control effectiveness than PID control.

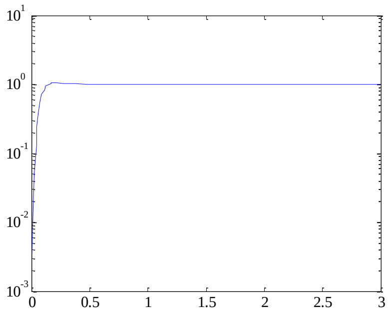

FIGURE 5 Simulation effect when loss probability is 0

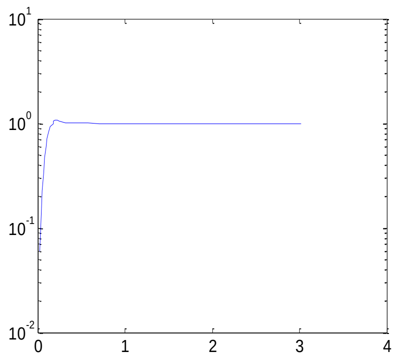

FIGURE 6 Simulation effect when loss probability is 0.2

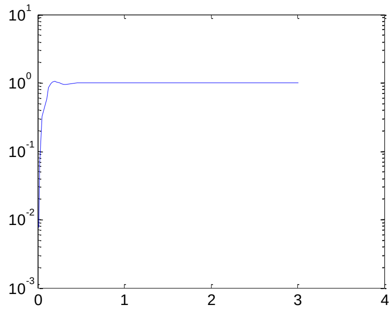

FIGURE 7 Simulation effect when loss probability is 0.4

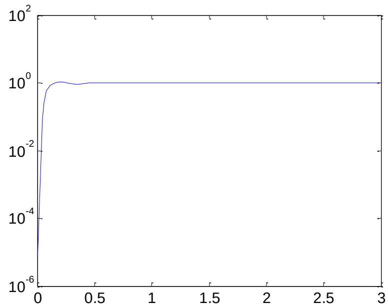

FIGURE 8 Simulation effect when loss probability is 0.6

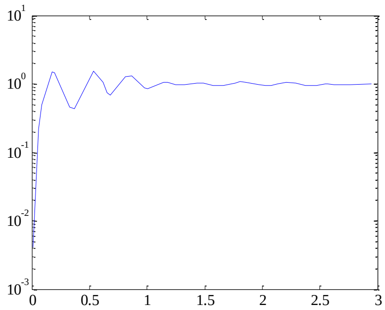

FIGURE 9 Simulation effect when loss probability is0.65

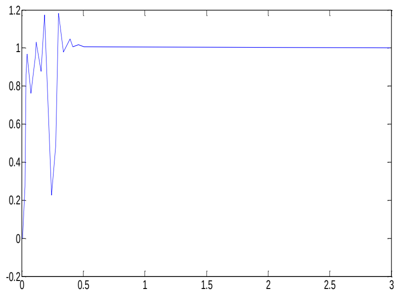

FIGURE 10 When loss probability is 0.2 using PID

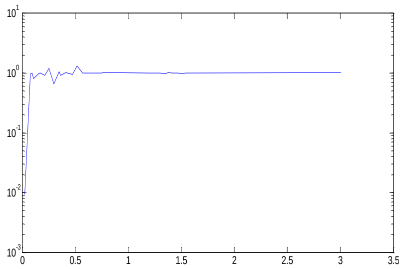

FIGURE 11 When loss probability is 0.4 using PID

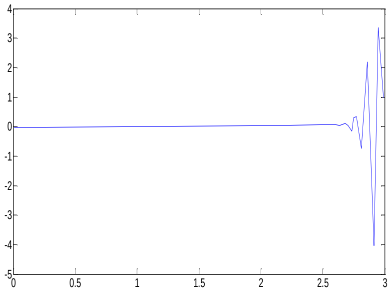

FIGURE 12 When loss probability is 0.6 using PID

6 Conclusions

Least square support vector machine is used to estimate random time-varying time delay of networked control system, and the estimated result is used for fuzzy adaptive predictive control. The simulation result shows that the least square support vector machine for real time control is feasible, and it can meet the requirement of time delay accuracy and has better real time nature.

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