Research of Network Closed-loop Control System Based on the Model Predictive Control

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***Abstract*—Uncertainty latency of the remote closed-loop control system in information transmission through Internet, Analysis delays how to influence closed-loop control system. Based on predictive control method of neural network, research the application of closed-loop control system control methods under a random network delay. Simulation results show that: This method is able to reflect and predict the delay characteristics of between network path represented by the measured data, and can be replace actual network to research in application based on Internet closed-loop control system; the methods used is fast and accurate, it can be used for online learning network model and predict the network delay value, provides a new way of remote closed-loop control based on Internet.**

Keywords-Remote Control; Neural Network; Network Delay; Model Predictive Control

I. INTRODUCTION

The remote control system is an integration of control technology and network communication technology, it applications in many fields more and more common as ocean development, space station maintenance, remote surgery, virtual reality in recent years, and stable, fast, accurate is the highest target remote control system pursue[1].

Closed-loop controller is to control by the disturbances of feedback, which is by comparative behavior of the system output and the deviation between expectations to make the appropriate control action to eliminate the bias in order to achieve the desired system performance. It has the ability to suppress interference, is not sensitive to changes in device characteristics, and can improve the response characteristics of the system.

The delay phenomenon exist in the field of remote control is a common problem exists in the remote closed-loop control applications. Delay does not only exist in the before control channel of system and in feedback channel. The delay in before control channel Makes the control signal unable to act on the controlled object, the delay in the feedback channel makes the controller can not found the change of controlled object immediately[2].

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Delay value influence by the inherent properties of control information transmission network such as the network structure, the amount of data transmission, the transmission timing and transmission agreements and other factors[3], the size of the delay values are reasonable from a few hours to several days[4], the approximate value will bring a big problem of the stability and dynamic quality of the remote control system[5], analysis and research the delay problems of the remote control system is a long-term in this area.

II. ISSUES PROPOSE

A. *The influence of delay on the stability of remote control system*

Delay has a lot of influence on real-time, accuracy and stability performance of the remote control system. Kinetic of equation a single-link robotic arm second-order remote control system as follows[6]:

$$\frac{d^2\phi}{dt^2} = -10\sin\phi - 2\frac{d\phi}{dt} + u$$

Among them, ϕ represent the angle of robot arm; μ represent the behalf of DC motor torque. simulink block diagram of Mechanical Arm shown in Figure 1.

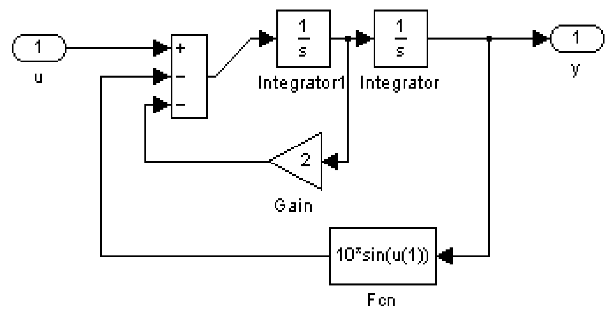


Figure 1. Simulink Block Diagram of Mechanical Arm

Since the forward channel and feedback channel in remote control system is generally the same physical link, the article assumes that the forward channel and feedback channel delay values equal. First set the delay time Delay to 0, that is without delay, adjust the PID parameters (how much) to get the response curve satisfied. Secondly, to maintain the constant of the PID parameters, increase the network delay value gradually when the network delay value is set to 0.02s to get feedback curve in Figure 2 (a), the performance of the system compared with without delay gradual deterioration this time , when the network latency increased to 0.05s, the feedback curve in Figure 2 (b), system becomes a oscillation system, and continue to increase the delay to 0.06s, the feedback curve in Figure 2 (c), system response divergence, that is system becomes unstable. It can be seen that increase the delay gradually make the control systems become increasingly unstable.

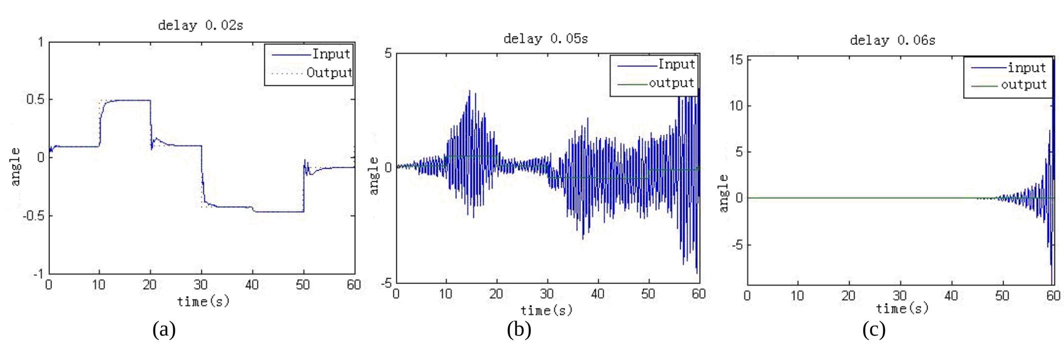


Figure 2. The Influence on the Stability of the Control System from Remote Control Delay

B. Research for the stability of remote control system

There are a lot of research on the stability improvement of the remote control system, in 1965, Ferrel put forward network delay problem of need to pay attention to time-varying in the network control [7]. Halevi and Ray in the literature[8] augmented deterministic discrete-time model for the periodic network delay, Gregory C. Walsh in the literature[9] considered controller and controlled object is nonlinear time-varying assuming no observation noise, based on nonlinear perturbation method theory, the network delay impact the system is described as a perturbation of the continuous-time systems. Walsh and Bushnel in the literature [10] to prove this method and conclusions can applicable equally to linear systems. Goktas in the literature [11] saw τ_{sc} and τ_{ca} as a multiplicative uncertainty bounded perturbation and provided the method of use robust control theory design of NCS controller in frequency domain. Studied robust passive control problem of class of long delay networked control systems in the literature [12], and derive the passive controller design method and proved the validity of the method through simulation. Short delay network control system disturbs by white noise in the literature[13], transformed impact of the random delay on the system into the unknown bounded uncertainties using robust control theory give the H_2/H_∞ system state observer design method. Literature[14] make delay uncertainty convert to the perturbation of the closed-loop system parameters, propose the conditions for the existence of robust guaranteed cost control law based on the robust control theory and Lyapunov stability principle, and gives the method of design of network control Robust guaranteed cost state feedback controller to solve linear matrix inequality. Research show that actually adjust the controller parameters PID makes the instability of the closed-loop control system becomes stable and meet the requirements of remote control system which need less real-time demand. Modify PID parameters of the control system and set the network delay to 0.06s again get feedback curve shown in Figure 3.Research show that modify the PID control parameters has indeed improved the stability of the control system.

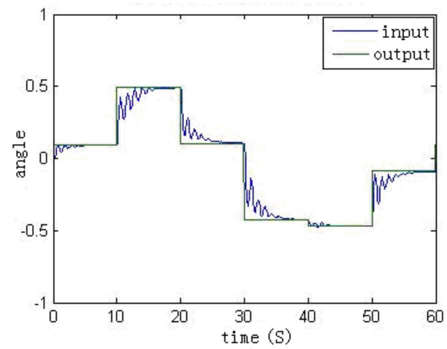


Figure 3. Response after regulate PID parameters at 0.06 seconds time delay

C. Question propose

The adjustments of the PID control parameters need to be dynamic adjustment constantly with the size of the control system delay and values and other parameters of systems, which makes controlled object in the work environment unknown to dynamically adapt adjust PID values become remote intelligent control systems that are experiencing another problem. This paper based on the method of modify the control parameters of PID values to improve the stability of the remote control system, and propose intelligent remote control system design methods with adaptive function under a random delay based on neural network theory.

III. QUESTION ANALYSIS

Remote control single-link manipulator, set the sampling period in figure 1 is 0.05s, and take the delay value of 0.05s, the control information in time k transmitted to the controller after 0.05s, as opposed to the system sampling time 0.05s, the controller receives status information at the moment of k has pass a sampling point, the state of the system has become the state in time k +1, that is state of the k time fed back to the PID controller at time k +1, the PID controller for time k, the state at time k+1 has not yet come, but this time system status values at k-1 after a sample time delay before it is passed controller, therefore, the controller can only decision at time k should be imposed control value u (k) based on the state of the k-1 times, and this control value can be a real work on the system after a time delay, while at the time k +1 and the state of the system has been turned into a time k+1 the state of X(k+1), while u (k) produce at the state time k-1, so u (k-1)grieved and u (k +1) required difference two sampling cycles. In these two sampling cycle, the state of the system state transition, that is x (k-1) transfer to the x (k+1), x (k-1) and x (k+1) often is different lead to u (k-1) and u (k +1) is different. In other word, the system control value produced offset and the greater delay the greater offset, which is the root source of result in deterioration of the system closed-loop control performance and even instability.

The above analysis shows that the system performance deterioration caused by the remote network delay because of can not correctly calculate the amount of control exerted by the controller to the system ,if the system model is known and the size of delay is known, then forecast the state of system in accordance with the principle of the system predict compensation, and calculate the size of control value need to be added the control system in accordance with the predicted state, that is time k applications to predict the state $\hat{x}$ (k+1) at time k+1 yet not the state of x(k-1) at time k-1 calculation to be applied to the system state at time k, then the control value u (k +1) at actual time k +1, the u (k +1) after a delay transmission in the time k +1 transfer to the system just after a sampling period, the state of the system change into x (k +1) ,

So, if the predicted state $\hat{x}$ (k+1) is infinitely close to the actual state x (k +1), the performance of control network delay closed-loop control system can be infinitely close the performance of the closed-loop control system without delay links, which is the basic idea of the predictive control model. However, the delay of the control network is time-varying and controlled objects are often immediately confounding factors, it is can not use an inconvenience model to predict the state of system and can not use a specific delay time to do the fixed step predictive control, neural network has the advantages of online learning the state of the system, predictive control based on neural network has strong robustness to be adaptive to the change of system status and network delay aspects ,it is a way to solve the network latency closed-loop control.

IV. BUILD THE MODEL PREDICTIVE CONTROL LAW

According to the running state of the system over the past time and present moment, more accurate forecasting system desired output value in the future moment, calculated control value of the system should be added according to output value desired depending on certain optimization algorithm [15] is adaptive computer control of online solving control value [16], the method includes three steps: prediction model, rolling optimization and feedback correction[17].

A. The prediction model

For a module description of the alleged object behavior in the predictive control based on neural network belong to forward model of system, there use the training methods as shown in Figure 4, where dashed box picture shows the actual controlled object, here is the simulink block diagram of the robotic arm, at random input signal u to produce output y. Selected BP neural network with one hidden layer as training model of a controlled object , set the number of hidden layer neurons is 10, using the Levenberg-Marquartdt learning rules, with the group [u, y] data training neural network model of the charged object, the results shown in Figure 5, where Figure 5 (a) is the data used for training, Figure 5 (b)is convergence diagram for training [18].

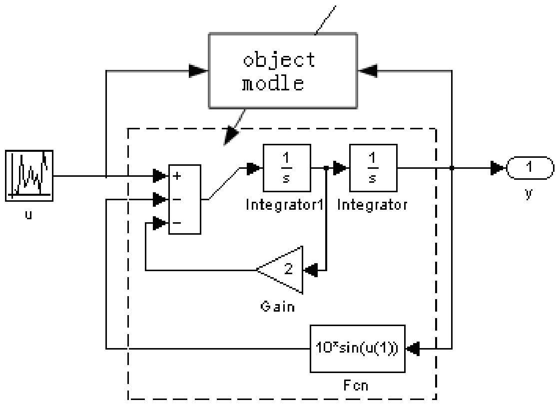
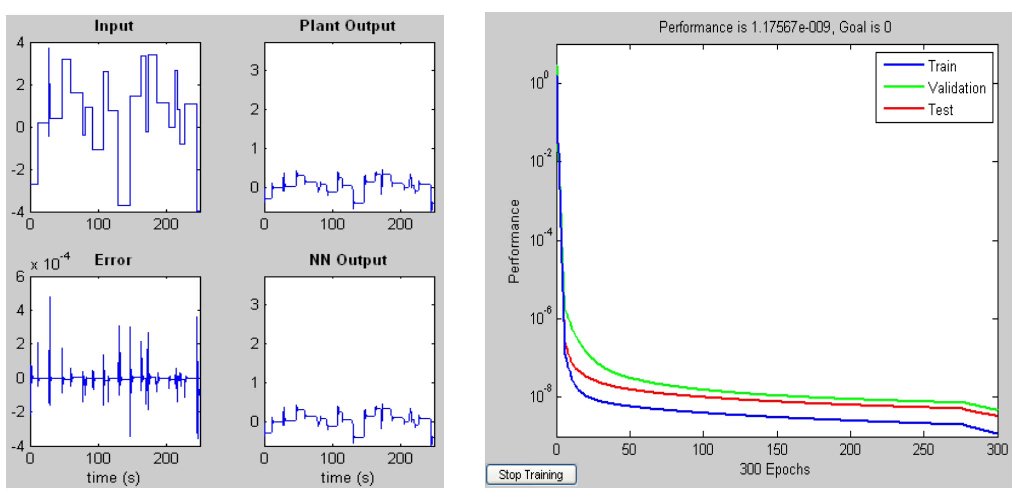


Figure 4. Neural Network Training Block Diagram of the Manipulator

B. *Receding Horizon Optimization*

Rolling optimization is an optimal control algorithm, which uses the output of the rolling finite domain optimization that is the goal of optimization over time. Predictive control proposes optimization index based on the moment in every time instead of using global optimization indexes. Rolling optimization index locality through make it can only get the global optimal solution in the ideal case, but when the model mismatch or time-varying and non-linear or confounding factors can take into account this uncertainty in a timely manner compensate, reducing the deviation, keeping the actual optimal control ,and it is also easy to use input/output value of finite difference time domain to identify rapidly the state of controlled object so as to implement the online adjustment to the control law and need for repeated optimization .



(a) Data for Training

(b) Convergence Diagram for Training

Figure 5. Neural Network Model Training Results of Manipulator

Optimization algorithm in this article also uses neural network to achieve, set the time-domain involved in the optimization value of 2, using the BP network neural of hidden layer neuron number 7, the same learning rule Levenberg-Marquartdt do the online training to achieve the control signal to the continuous optimization. Training block diagram is shown in the dashed box in Figure 4. Neural network optimization device in accordance with a given input signal u produce predictable output u1, u1 is imposed to the neural network model of the controlled object to produce predictable output y1, y1 compare with the desired output u of the system, and both the difference to train the neural network optimization. Then, the output u2 of the e2 enough litter as the actual amount of control applied to the actual controlled object. Visible, the optimizer in the regulation system is the inverse model of the charged object. Y1 can also be compared with actual output y2, and the error e1 and the actual input u2 of charged object, output y2 as the data of training charged object neural network model.

C. Feedback correction

Feedback correction is forecast control to keep the dynamic correction forecasting model to ensure that the prediction model with infinitely close to the actual controlled object, and make optimization algorithm establish on the basis of the correct prediction of the system state then the new optimization. Error e1 in Figure 6 is the amendment process of the neural network model of the controlled object. Neural network prediction model is built on the basis of the past run data in system, the new operating environment and the actual system has the nonlinear, time-varying, interference and other factors make prediction model based on neural networks need to constantly learn to modify their weights and even structure to ensure that it can well represent the actual controlled object to a control signal prediction.

V. SIMULATION ANALYSES

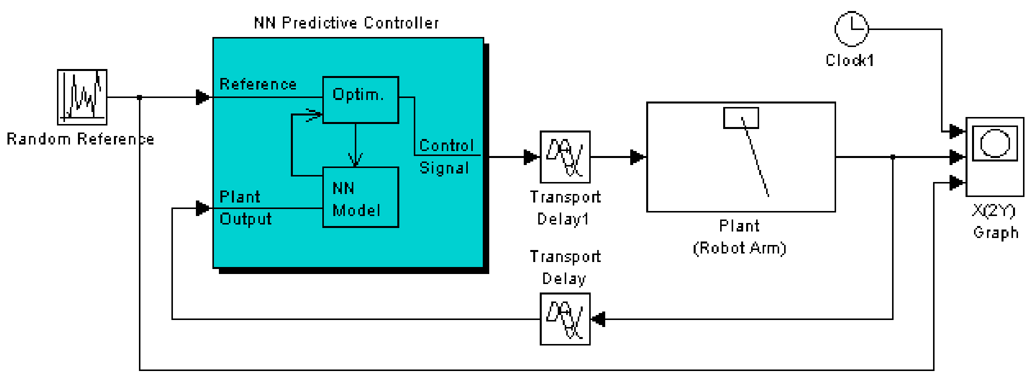
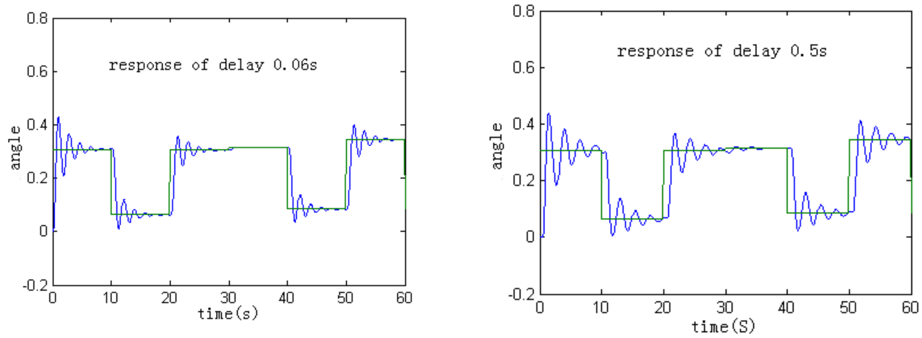


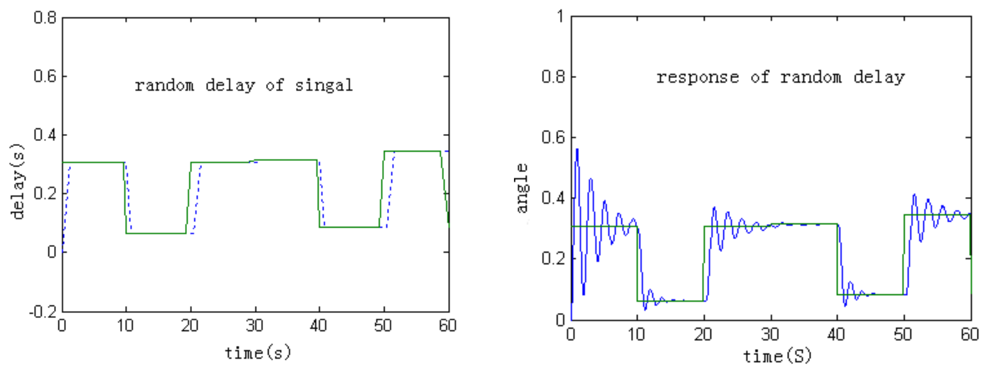
Figure 6. Simulink Simulation of Network Closed-Loop Control System based on Predictive Neural

Build the Simulation block diagram shown in Figure 6 under robotic arm Smulink environment, network training based on neural network predictive control by the steps in Figure 4-Figure5, and at the role of the same random input signal gradually adjust the value of delay to simulation. The results in Figure7 show that the prediction control based on neural network has a good control performance to the fixed delay network. Further used random delay module shown in Figure 8(a) instead of fixed delay module in Figure 5 immediately delay module for delay characteristics of input shown in Figure8 (b), where In.mat file stored random input signal in Figure 5.There are used random input signal stored in this file in order to compare the simulation results in the simulation. Finally, simulation under the random delay conditions and results shows in Figure8 (c). Whether a fixed delay or random delay neural network predictive controller can satisfy the closed-loop control requirements in the network delay conditions.



(a) Response Curve delay 0.06s (b) Response Curve delay0.5s

Figure 7. Predictive Control Random Responses Curve based on Neural Network



(a) Delay Curve under Random Delay (b) Response Curve under Random Delay

Figure 8. Responses under Random Delay

VI. CONCLUSION

This article discusses the difficulties of remote closed-loop control, that is different from the general control system of the difficulty lies in channel and feedback channel network of system existence uncertain delay which greatly reduces the stability of system and improve the design difficulty of control system. This paper elaborated network closed-loop control problems form uncertain network delay to includes network delay controller design method, and study the impact of network transmission delay on the network closed-loop control system, proposed by predictive control based on neural network to solve feasibility of the network control system which existence random delay closed-loop control, and verified the validity of the method by simulation.

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