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BP neural network prediction-based variable-period sampling approach for networked control systems

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Abstract

The biggest problem that networked control systems face is the random time-varying delay, which often causes system instability and even collapse. Aiming at this problem, a new modeling scheme for the networked control systems, motivated from a variable-period sampling approach, is presented in this paper. Here, the time delay to occur at current sampling step is taken as the sampling period between current sampling step and next sampling step. To predict online the time delay induced in the networked control systems, a BP feedforward neural network is adopted and the training algorithm of the BP neural network is given. To make the BP neural network adapt to the changing environment of the networked control systems and improve its prediction accuracy, the BP neural network is designed to further update according to its prediction error after each prediction. At each sampling step, good approximation to actual time delay becomes available and different sampling period is obtained. Control simulations using the variable sampling period and fixed sampling period are compared. Simulation results show that this new approach can alleviate the influence of time delay to the greatest extent and improve the performance of the networked control systems.

Keywords: BP algorithm; Control; Networked control system; Neural network; Modeling; Prediction; Sampling

1. Introduction

Over the past decade, major advancement in communication, computer networks, and control theories, etc., has made many ideas available to realize. This has opened a new research field, i.e., networked control systems where instantaneous flow of control signals is no longer sufficient, and the feedback loop of the control systems is closed through a real-time communication network [1]. When a feedback control system is closed via a communication channel, which might be shared with other nodes outside the control system,

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the control system is then called a networked control system (NCS). Many attractive advantages (for example, high system testability and resource utilization, as well as low requirement to weight, space, power and wiring) of introducing a communication network into a control system motivate the research on NCS. NCS is now widely used in process control [2], remote control [3], tele-manipulation [4], robotics [5], etc.

Generally an important issue of NCS is the network-induced delay that occurs during data exchanging among devices connected to the shared medium. In an NCS, time delay usually varies even at random. Therefore, many scholars have endeavored to study the modeling and analysis of NCS.

In the analysis of time delay and stability of NCS, Branicky et al. [6] discussed the influence of the sampling rate and network delay on system stability, and further studied the stability of NCS using a hybrid system stability analysis technique. Mahmoud and Ismail [7] indicated the impact of delay sources on the stability and performance of NCS, and showed a complete diagnostic profile of the role of delays in NCS. Nilsson [8] analyzed NCS in discrete-time domain, and further modeled the network delay as constant, independently random, and random but governed by an underlying Markov chain. By solving a LQG optimal control problem, he generated a controller that guaranteed the system stability. However the design of the controller used the knowledge of known distribution or the state of Markov chain. Liu and Yao [9] used hidden Markov models to analyze NCS with delay governed by an underlying Markov chain with unknown probability distribution, and designed a stochastic optimal controller for NCS. Zhang et al. [10] also investigated in discrete-time domain the stabilization problem of NCS with random delay, and modeled the sensor-to-controller delay and the controller-to-sensor delay as two Markov chains. They established the necessary and sufficient conditions on the existence of the stabilizing controllers, and used an iterative linear matrix inequality approach to calculate the state-feedback gains.

In the sampling control of NCS, Montestruque and Antsaklis [11] adopted fixed-rate sampling of continuous plant to do an extended structural analysis of NCS. They also presented a model plant that provided state estimation, and used the error between the actual plant and the model plant to construct an augmented state vector. Walsh et al. [12] introduced a try-once-discard (TOD) protocol, where the next node to transmit data on a multi-node network was decided dynamically based on the highest weighted error from the last transmission, and defined a maximum allowable transfer interval (MATI) supposing that successive sensor messages were separated by at most MATI seconds. They further showed an analytic proof of global exponential stability for the new protocol. Its goal was to find MATI so that the desired performance of NCS was guaranteed.

To compensate the time delay, Li et al. [13] regarded the time-varying delay as the sum of the mean delay and uncertain delay, and modeled an NCS with long time delay as a discrete-time model with structural uncertainty for its time-varying network-induced delay. Based on the model, a new control law via an iterative linear matrix inequality approach was presented. Wang et al. [14] showed a delay-dependent stabilization condition of discrete-time linear system with time-varying delay. Based on this condition, a stabilization controller was constructed and the solutions were given through an iterative procedure of a linear matrix inequality minimum problem. Based on the analysis of both the network-induced delay and the data packet dropout in transmission, Yue et al. [15] proposed a delay-dependent approach for NCS controller design, and determined the feedback gain of a memoryless controller and the maximum allowable value of the network-induced delay by solving a set of linear matrix inequalities.

There are also several approaches to estimate and predict time delay or plant outputs. Beldiman et al. [16] separately designed an open-loop structure predictor and a closed-loop structure predictor for estimating the plant outputs in between two successive transmission times, and improved NCS performance without affecting system stability. By using an event-driven actuator and a time-driven actuator simultaneously, Wang et al. [17] designed a new undelayed plant state estimator and predicted current control signals in every sampling interval to compensate the long delay. Wu et al. [18] adopted a generalized predictive control approach and established an error predictive model based on BP neural network. The error predictive value was used to compensate output predictive value. Hur et al. [19] presented a predictive controller based upon stochastic methods to compensate the time-delay. The predictive controller estimated future outputs using a linear prediction function and a probability function in terms of previous outputs. To find the bounds on the delay induced by the network, Zhang et al. [20] discussed the stability of NCS using a hybrid systems stability analysis technique, and captured the relationship between the sampling rate and the network-induced delay using a