SOME RESEARCHES FOR THE DELAYED FEEDBACK CONTROL OF FLEXIBLE STRUCTURES

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Summary This paper presents our studies on delayed feedback control done in recent years, including the treating methods for time delay, robustness problem and delay experiment. The proposed controller can not only deal with small time delay and large time delay as well.

TIME-DELAY FEEDBACK CONTROLLERS

Time delay inevitably exists in active control systems. Time delay may result in non-synchronization of control force, making the actuator input energy into the controlled system when energy is not needed. This may cause the degradation of control efficiency or even the instability of the control system.

Recently, we have designed a discrete controller and a continuous delay controller. In design of the discrete time-delay controller [1], by a particular augmentation of state variables, the system state equation with multiple time delays is discretized and transformed into a standard discrete form without any explicit time delay, then the controller with time delays is designed using the discrete active control method. The detailed design process of this controller, the iterative algorithm for all parameters and the stability criteria for the delay system are all provided. In design of continuous multiple-time-delay controller, by a particular integral transformation for state variables, the system state equation with multiple time delays is first transformed into a standard form without any explicit time delay and system dimensions keeps invariant, and then the active controller can be designed based on the standard state equation. The design process of continuous multiple-time-delay controller and the iterative algorithm of integral term in the integral transformation are both detailed in [2]. These two time-delay controllers contain not only the state feedback of current step but also the linear combination of some previous steps of control. Since they are designed directly from the time-delay differential equation and no approximation and hypothesis involved, they tend to guarantee the stability of control systems, and are suitable for both small time delay and large time delay.

Based on a DSP control board, the experimental study is conducted for active control of the flexible manipulator [2], plate [3] and beam [4], in which single time delay and multiple time delays are both considered. All practical problems encountered in the experiment such as signal differential, circuit and friction compensation are effectively solved. Both the discrete and continuous time-delay processing methods prove effective in the experiment. For example [3], Figure 1 shows the numerical and experimental result of the tip response of the plate when the delayed time is 0.2s. It shows that the proposed controller is effective in suppressing the vibration of the structure, and is available for large time delay.

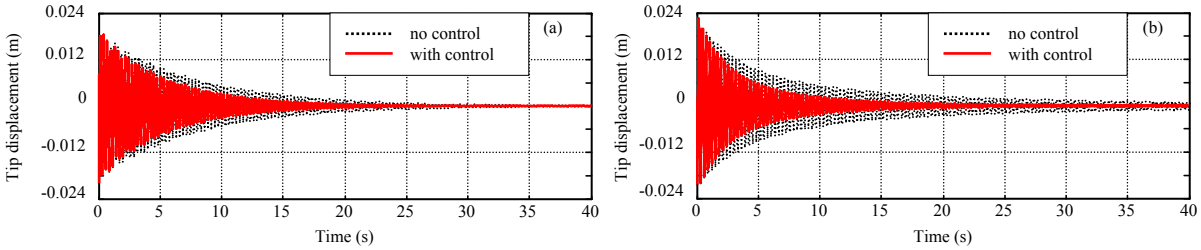

Figure 1 Tip response of the plate : (a) simulation result, (b) experimental result

ROBUST CONTROLLER WITH TIME DELAY

Errors may inevitably exist in the model due to uncertainty of physical parameters and boundary conditions of the structures. So the controller designed should have strong robustness so as to eliminate the effect of negative factors on control effectiveness. Furthermore, will the time-delay controller designed using strong robust control method is robust for time delay? H_∞ control method is applied to the time delay dynamic system based on the flexible plate [5]. Firstly, the dynamic equation of the plate with time delay is established with considering external disturbance. Then the standard state equation without explicit time delay is obtained using the above method. Finally, a H_∞ time-delay controller is designed based on the standard state equation using the method of linear matrix inequality. In the experiment, piezoelectric patches are used as actuators and sensors. The robustness of H_∞ controller against intrinsic parameter of the plate and time delay is experimentally investigated, respectively. Simulation and experimental results indicate that the control system may suffer from instability if time delay is not treated in control design. The time-delay controller presented in [5] can effectively deal with time delay in the system, and is available for small time delay and large time delay a well. Furthermore, this delay controller is robust to the variance of intrinsic parameter of the plate and time delay.

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In actual control system, the delay varies in a small range. H_∞ control with time-varying time delay is studied using a flexible plate as research object [6]. The time delay in control system is assume to be time-varying but has a known constant bound. Firstly, the matrix inequalities are obtained using Lyapunov-Krasovskii function and free-weighting matrices such that the closed-loop system is asymptotically stable with H_∞ performance index. Then a H_∞ time-delay controller is designed based on the parameter adjustment method and the genetic algorithms. Results indicate that the maximum stable delay is more close to real value using the proposed method in [6] when the feedback gain matrix is given. In addition, the maximum stable delay of the control system is studied when the feedback gain is uncertain. Furthermore, the control efficiency of the proposed method is better than that of the optimal control method when the maximum stable time delay is known. Figure 2 shows the results when the real delay τ=0.06s exists in the control system. It shows that the control effectiveness using the proposed method is better than that using the LQR controller.

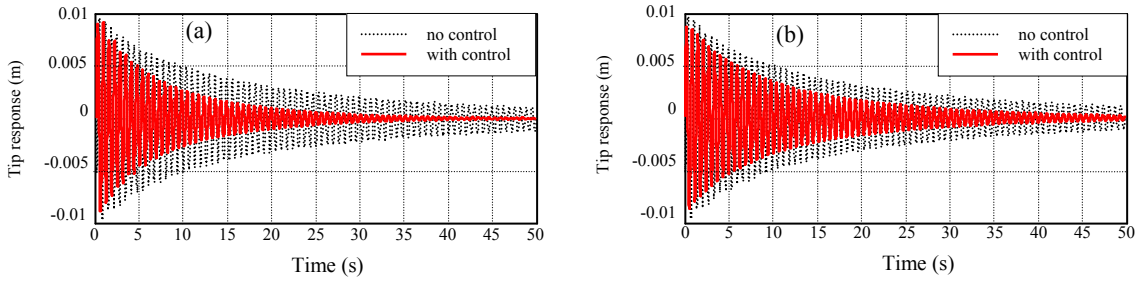

Figure 2 Tip response of the plate (τ=0.06s): (a) the proposed method, (b) the LQR controller

ACTIVE CONTROL OF A NONLINEAR AND HYSTERETIC STRUCTURE WITH TIME DELAY

Today time delay in linear systems has been more studied and some treating methods had been worked out. However, there are few treating methods for time delay in nonlinear systems. The active controller for a nonlinear and hysteretic building structure with time delay is studied in [7]. The nonlinear and hysteretic behavior of the system is illustrated by the Bouc-Wen model. By specific transformation and augmentation of state parameters, the motion equation of the system with explicit time delay is transformed into the standard state space representation without any explicit time delay. Then the fourth-order Runge-Kutta method and instantaneous optimal control method are applied to the controller design with time delay. The simulation in Figure 3 proves the proposed time delay controller in [7].

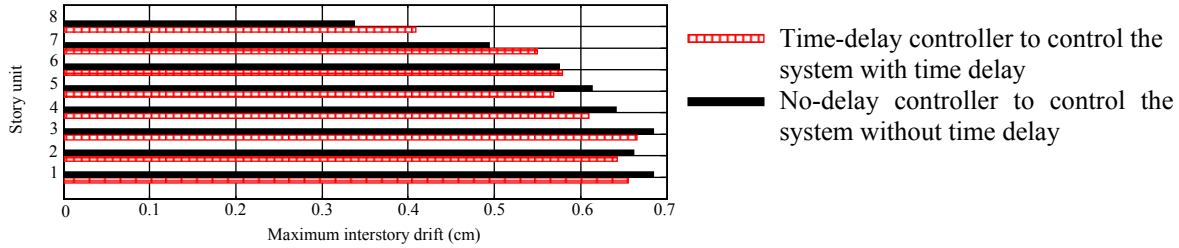

Fig. 3 Comparison of the maximum response quantities of each story unit

CONCLUSIONS

This paper presents our studies on delayed feedback control done in recent years. Simulation and experimental results show that the delayed feedback control could be applied to the active control of flexible structures.

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