EVALUATION OF ROBUST PERFORMANCE OF FUZZY SUPERVISORY CONTROL TECHNIQUE

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ABSTRACT

This paper describes the robust performance of fuzzy supervisory control (FSC) approach for the seismic response control of cable-stayed bridges. FSC is a hybrid control method with the hierarchical structure of several sub-controllers and fuzzy supervisor. Each sub-controller is preliminarily designed to reduce the selected response of the structure only, and a fuzzy supervisor is introduced to improve the overall control performance by modulating the pre-designed static gains into time-varying dynamic gains. To demonstrate the robust performance of the proposed strategy, the FSC and linear quadratic Gaussian (LQG) controller are optimally designed and their seismic performances are compared according to the variation of the bridge stiffness in the phase I benchmark control problem. The comparative results show that the FSC system can clearly guarantee the robust performance against the uncertainties of the bridge model.

FUZZY SUPERVISORY CONTROL

For the active control of the structure, optimal control methods such as LQR, LQG [1], H_2, and H_∞ are commonly used. These optimal controls specify a cost function characterized as single control gain. However, it is not easy to aggregate all the performance requirements into a single-valued cost function. Since there exist a number of operation conditions which need to be considered for the control system, a satisfactorily performing control system may not be achieved by a single gain controller. One of the effective approaches is FSC technique which can modulate several types of well-developed controllers continuously during controlling a structure. To improve the control performance of active control system, therefore, we adopt fuzzy supervisory control method.

Since the fuzzy supervisory control approach takes a form of a hierarchical structure as shown in Figure 1, it involves a two-step design procedure comprising design of sub-controllers and fuzzy-tuning of the pre-designed sub-controllers [2]. In this paper, LQG control method is used for the design of the sub-controllers, and then a fuzzy tuner is introduced to modulate the pre-designed static gains into time-varying dynamic gains. The fuzzy tuner is composed of four elements, i.e., a fuzzification interface, an inference mechanism, a rule-base and a defuzzification interface, which are characterized as an input membership function, a fuzzy rule table and an output membership function. Fuzzy rule table can be illustrated graphically as a fuzzy rule surface in Figure 2. It identifies the current behavior of the structural system and reasonably determines the contribution factors of the sub-controllers in accordance with the structural response information. As a result, the fuzzy tuning process for various earthquake excitations differently modulates the sub-controllers.

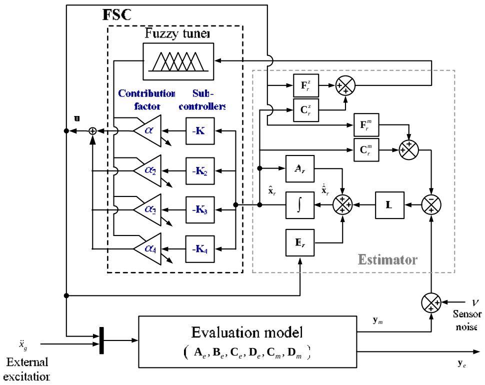


Figure 1. Block diagram of FSC system

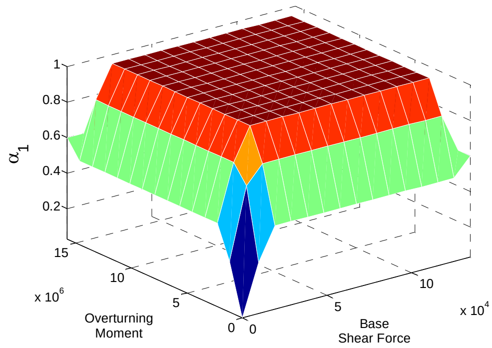
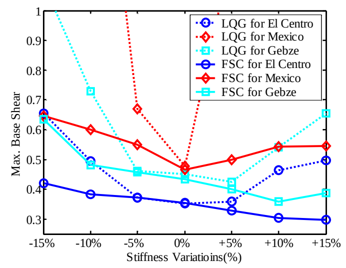


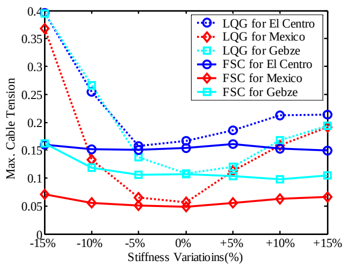
Figure 2. Fuzzy rule surface of a fuzzy tuner

ROBUSTNESS EVALUATION OF LQG CONTROL AND FSC SYSTEMS

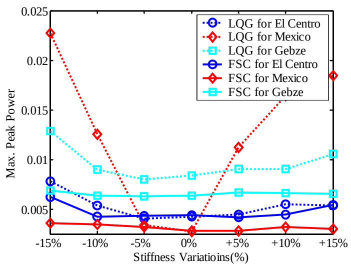
To investigate the robustness of the FSC and LQG control systems, the stiffness of the bridge structure is varied from -15% to +15%, and the numerical simulation of the benchmark cable-stayed bridge subject to three historically recorded earthquakes, El Centro, Mexico and Gebze earthquakes has been performed. The comparative results of FSC and LQG control systems for the stiffness-varied bridge system are depicted in Figure 3. Figure 3(a) represents the variations of the maximum controlled shear forces at the base of the tower. The horizontal axis means the variations of the stiffness, and the vertical axis represents the ratio of the shear forces between control system and uncontrolled system. For LQG control system, the reduction effect on base shear is quite poor; however, FSC system exhibits great robustness performance in spite of the stiffness variations of the bridge. Similarly in Figure 3(b), FSC system show more stable reduction effect on the cable tensions than LQG control system. Hence, FSC system shows the more improved robustness than the LQG control system for all three earthquakes. The comparative results of required peak power between both systems are also illustrated in Figure 3(c). For Mexico earthquake, LQG controller requires the greatly increased amount of powers compared with FSC; however, the overall powers required for both systems are quite similar. Finally, it can be concluded that the proposed control technique can successfully guarantee the robustness performance against the uncertainty of the bridge model while maintaining the similar level of power system.



(a) Base shears of the towers



(b) Tensions in the stay cable



(c) Required control power

Figure 3. Comparative results of robust performance between LQG control and FSC systems

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2. Park, K.-S., Koh, H.-M., Ok, S.-Y. and Seo, C.-W., "Fuzzy supervisory control of earthquake-excited cable-stayed bridges," *Engineering Structures, in press*, 2005.