Application of deep Q-network for semi-active vibration control of frame structures

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Despite decades of research on semi-active vibration control of mechanical structures, the development of an effective control system for frame structures with multiple lockable joints remains a significant challenge. The primary difficulty arises from the nonlinear operational characteristics of such systems: switching the joint states alters the structural configuration and, consequently, its natural frequency spectrum [1]. In addition, the complex frictional and sliding behavior of lockable joints makes accurate modeling of the system dynamics inherently approximate [2].

In this study, we propose a reinforcement learning (RL)-based semi-active vibration control strategy. Control decisions are determined using a Deep Q-Network (DQN), one of the fundamental algorithms in reinforcement learning [3]. The method is applied to an eight-bay cantilever frame structure equipped with two pairs of lockable joints, operating without prior knowledge of the system dynamics. The joints allow the relative rotational motion between vertical and horizontal beams to be locked or released.

The structure is discretized using a finite element (FE) model with one beam element per bay side, resulting in a total of 24 beam-type finite elements. The RL controller learns through direct interaction with the system by estimating the effect of joint locking on the structural response. The resulting control signals are compared with an instantaneous optimal control strategy, which greedily reduces vibration energy by transferring it from low-frequency to high-frequency modes. The close agreement between the reinforcement learning–based control and the analytical optimal solution demonstrates the capability of RL algorithms to achieve effective vibration mitigation in complex, nonlinear structural systems.

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