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NOISE, VIBRATION AND HARSHNESS

Narrowband Active Noise Control with DDPG Based on Reinforcement Learning

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Abstract

This study investigates the use of deep reinforcement learning for active noise control (DRL-ANC) to cancel narrowband noise. The filtered-x least mean square algorithm for ANC, which includes the secondary path model in itself, has been widely used in various applications. If the path model is inaccurate due to the variations of the actual path, control performance and stability of the algorithm can be restricted. To eliminate the effect by the model inaccuracy, it is considered to remove the path model in the novel DRL-ANC strategy. A DRL approach using the deep deterministic policy gradient without any path model is adopted to learn the behavior of a physical environment including the effect of the actual secondary path in real time. However, a temporal credit assignment problem arises due to the time-delayed reward inherent in the secondary path, which means that the current action could not be evaluated by its true. To address this problem, this study proposes a novel definitions of the state and action of the RL agent, specialized in narrowband noise suppression. Additionally, a novel exploration noise is also suggested to enhance effectiveness and practicality of the learning process. Computer simulations and real-time control experiments were conducted, and the results demonstrated that the proposed DRL-ANC algorithm can robustly cope with changes in the secondary path.

Keywords Reinforcement learning · Active noise control · Secondary path model · Deterministic policy gradient · Control stability

1 Introduction

The adaptive filter-x least mean square (FxLMS) algorithm has been broadly adopted for implementing active noise control (ANC) systems in various applications (Elliott, 2001; Kuo & Morgan, 1995). It is well-known that control performance and stability of the FxLMS algorithm rely heavily on the accuracy of the predefined secondary path model which describes the electro-acoustic relationship between the secondary actuator and the error sensor, to compensate for the effect of the secondary path (Elliott, 2001).

However, the error between the modeled and actual secondary paths, due to variations like temperature changes in a car cabin, can lead to performance degradation or instability of the algorithm (Kuo & Morgan, 1995).

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In order to minimize the instability problem by the error in the algorithm, the regularization, the online secondary path modeling, and the perturbation approaches have been considered (Kajikawa et al., 2012; Lu et al., 2021).

The regularization approach modifies the cost function by incorporating a parameter to make the stability condition less sensitive to the path error (Darlington, 1994; Fraanje et al., 2004). It is known that the approach guarantees robust stability only if the changes in the secondary path are within a predefined range (Elliott, 2001; Fraanje et al., 2004).

The online secondary path modeling approach enables the FxLMS algorithm to re-adapt stably to unexpected changes in the secondary path continuously (Kajikawa et al., 2012; Kuo & Morgan, 1995). However, it was effective only when the changes in the secondary path were small (Elliott, 2001) and the convergence speed of the online model can be slow due to the complexity of the adaptation process (Carini & Malatini, 2008; Lopes & Gerald, 2015; Yang et al., 2018).

The perturbation approach does not contain the secondary path model in the algorithm to eliminate the modeling error,