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Analysis of the Cognitive Structure of Engine Noise Perception Considering Temporal Driving Conditions under Different Sensory Stimuli

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In hybrid vehicles, the acoustic contrast between engine-off and engine-on states makes engine noise more noticeable compared to conventional vehicles. To support the development of engine control strategies for less annoying engine noise, subjective annoyance was quantified using machine-learning models to predict engine noise perception. In previous work, a prediction model was developed to estimate subjective engine noise ratings using in-cabin sound and vehicle parameters based on synchronized on-road measurements. A random forest classifier using psychoacoustic metrics derived from in-cabin sound achieved 57% accuracy, which improved to 67% by adding vehicle parameters—engine speed, driveshaft torque, and vehicle speed—and further to 75% by incorporating 5.5 seconds of engine speed history. However, the factors determining the effective time-history length remain unclear.

To clarify how sensory stimulus conditions influence the time-history effect, subjective evaluation experiments were conducted using a driving simulator. The effects of sound level and driving operation on the contribution of temporal information were investigated to analyze the cognitive structure of engine noise perception

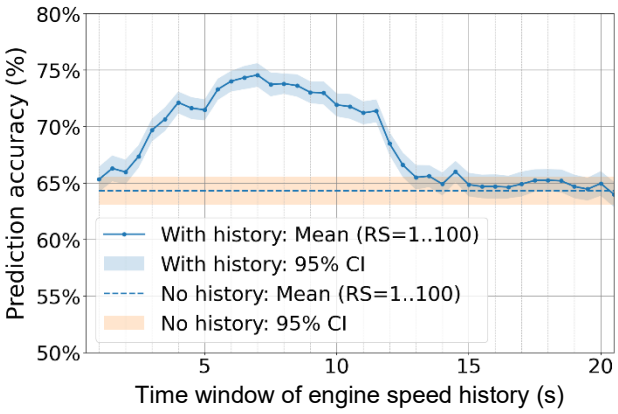
Experiments were performed under four conditions: driving with vehicle-equivalent sound level, driving with enhanced engine sound level, non-driving with vehicle-equivalent sound level, and non-driving with enhanced engine sound level. Engine sound was generated in real time according to vehicle states and presented together with background noise. Engine speed, driveshaft torque, and vehicle speed were recorded, and subjective ratings (“Not noisy,” “Noisy,” “Very noisy”) were collected.

A random forest classifier was used to predict subjective ratings. Time-history features were defined as the difference between current and past engine speed, and the history length was varied from 1 to 20 seconds. Prediction accuracy was evaluated using a random forest classifier with engine speed, driveshaft torque, vehicle speed, and engine speed time-history as input features, while varying the time-history length.

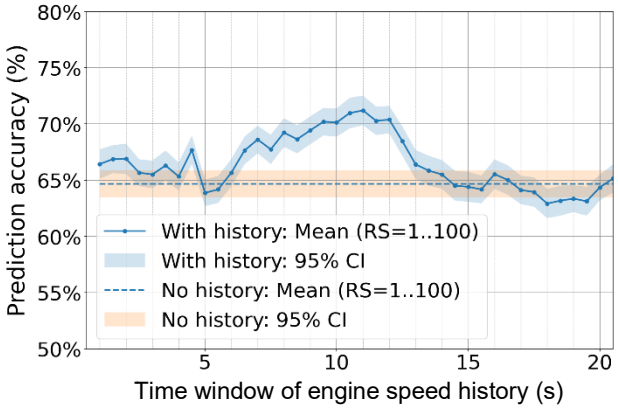
As shown in Fig. 1(a), under the driving condition with vehicle-equivalent engine sound level, prediction accuracy increased with history length and reached a maximum at approximately 7 seconds, indicating a clear contribution of temporal engine speed history. In contrast, as shown in Fig. 1(b), under the non-driving condition with vehicle-equivalent engine sound level, prediction accuracy exhibited a smaller improvement compared to Fig. 1(a), and the influence of time-history length was less pronounced. These contrasting results demonstrate that the effectiveness of time-history information strongly depends on the presence of driving tasks.

Feature importance analysis revealed that the contribution of engine speed history increased with history length under driving with vehicle-equivalent sound level, whereas instantaneous engine speed remained a dominant or comparable factor under enhanced engine sound and non-driving conditions.

These results suggest that subjective engine noise perception depends on how attention is distributed between auditory and driving-related stimuli. When sound levels are high or driving tasks are absent, perception tends to rely more on instantaneous acoustic information. In contrast, under realistic driving conditions, temporal changes in vehicle state over several seconds are more likely to influence perception.



(a) Vehicle-equivalent level + Driving



(b) Vehicle-equivalent level + Non driving

Fig.1 Prediction accuracy of subjective ratings vs. engine speed history length