

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

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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, because driving workload changes depending on the road environment and driving operation, it remains unclear whether this time-history effect appears in the same way under different workload conditions.

To clarify how driving workload influences the time-history effect, subjective evaluation experiments were conducted using a driving simulator. Engine sound was generated according to vehicle speed and acceleration and was presented together with background cabin noise through headphones. Participants evaluated the engine sound during driving using three categories: “Not noisy,” “Noisy,” and “Very noisy.” Vehicle parameters were recorded from the driving simulator.

The evaluation courses consisted of a city course used in the previous study and a mountain course. In the mountain course, the road width was varied among 2.5 m, 3.5 m, and 4.5 m to change driving workload. The 2.5 m condition represented a higher-workload condition requiring greater attention to lane keeping, whereas the 4.5 m condition represented a lower-workload condition with greater driving margin.

A random forest classifier was used to predict subjective engine noise perception. The basic explanatory variables were engine speed, driveshaft torque, and vehicle speed. To consider the time history of engine speed, the difference between the current engine speed and the value several seconds before the evaluation was added as an explanatory variable. The time-history length was varied from 1 to 20 seconds, and prediction accuracy was compared with the no-history model. To reduce the influence of data splitting, the training and test data were divided at a ratio of 8:2, and the average prediction accuracy was calculated over 100 random states.

Fig. 1 shows the prediction accuracy improvement relative to the no-history model. In the city course, prediction accuracy increased when several seconds of engine speed history were considered, confirming the time-history effect in engine noise perception. In the mountain course, the 2.5 m road-width condition showed only a small improvement, whereas the 3.5 m condition showed an intermediate tendency. In contrast, the 4.5 m condition showed a clear improvement, and its trend was close to that of the city course.

These results indicate that even on a mountain course, the time-history effect becomes clear under lower-workload conditions. In contrast, under higher-workload conditions, such as a narrow road requiring attention to lane keeping and steering operation, recent changes in engine speed are less likely to be reflected in the subjective evaluation. Driving-state distributions, represented by vehicle speed and longitudinal acceleration, were also compared among road-width conditions, and no large difference was observed. Therefore, the difference in the time-history effect cannot be explained simply by differences in driving-state distribution.

The results suggest that the time-history effect in engine noise perception depends on driving workload. When driving workload is high, evaluation tends to be based more on the vehicle state near the evaluation timing. In contrast, when road width is large and driving workload is low, the influence of engine speed history over several seconds becomes more apparent.

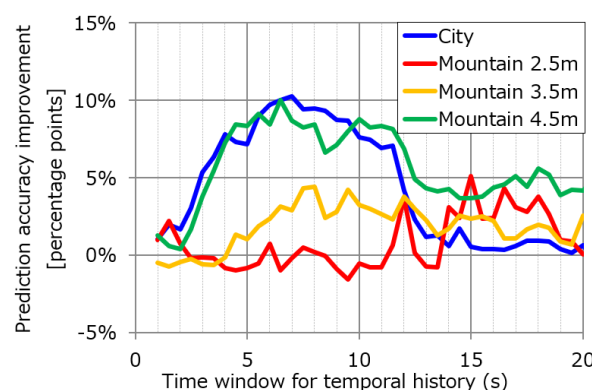


Fig.1 Prediction accuracy improvement by engine speed history