

Occupant Head Motion Estimation Using an LSTM-Based Machine Learning Model

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Recent vehicle development requires evaluation not only of vehicle performance but also of occupant responses to vehicle behavior. To support human-centered vehicle development, the authors are developing a model framework linking vehicle behavior and occupant response. As shown in Fig. 1, the framework aims to enable forward prediction of occupant responses from vehicle behavior and future inverse investigation of vehicle characteristics required to achieve desired occupant responses. This study focuses on the first step of the framework and develops a forward prediction model for occupant head motion estimation.

Since occupant responses depend on both current and preceding vehicle states, a Long Short-Term Memory (LSTM) network was employed. The forward prediction model is expressed by Equation.(1).

$$\hat{y}_t = f_{\theta}(X_{t-T+1}, X_{t-T+2}, \dots, X_t) \quad (1)$$

where X_t represents 24 vehicle-related input factors and $\hat{y}_t$ represents six-axis occupant head motion.

Double lane change data obtained from vehicle tests were used for model development. The target outputs were six-axis head motions of a front-seat passenger. Hyperparameters were optimized using Optuna, where the minimum coefficient of determination (R^2) among the six axes was maximized to improve overall prediction performance.

The developed model achieved R^2 values ranging from 0.65 to 0.95 across the six head-motion axes, demonstrating the capability of estimating occupant head motion from vehicle-related time-series data.

To verify model validity, TimeSHAP analysis was applied over the entire time-series waveform. Fig. 2 shows the prediction result and corresponding TimeSHAP analysis for the representative axis. Factors related to steering operation, lateral vehicle motion, and vehicle attitude changes were identified as major contributors to the prediction. In addition, the dominant factors changed according to the driving phase during the lane-change maneuver.

These tendencies were consistent with engineering understanding of vehicle dynamics and occupant behavior, suggesting that the model utilized physically meaningful information. The results demonstrate the potential of the proposed approach as a foundation for linking vehicle behavior and occupant response in human-centered vehicle development. Future work includes improving model generalization for various driving scenarios and extending the framework toward inverse analysis for vehicle design.

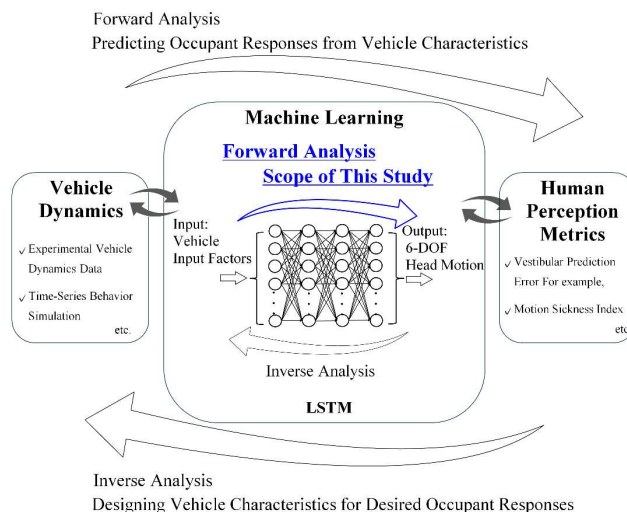


Fig.1 Overall concept of the model framework

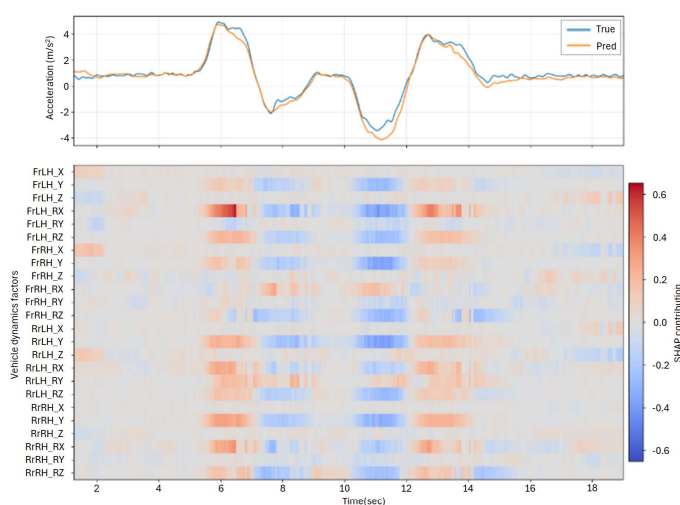


Fig.2 Comparison of predicted head motion and corresponding TimeSHAP analysis for the representative axis (Y direction)