

Prediction of the Occupant Lower-Extremity Injury Criterion (Tibia Index) in Frontal Collisions Using Machine Learning

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We propose a method for predicting lower-extremity injuries to occupants using machine learning. This method predicts lower-extremity injuries through a two-stage process as shown in Figure 1. This reduces the number of computationally expensive vehicle crash simulations required and enables efficient prediction of lower-extremity injuries. In this study, we constructed a machine learning model to predict lower-extremity injury, which is the second stage in this process, and evaluated the prediction accuracy of the proposed model.

Figure 1 shows an overview of the proposed two-stage prediction framework. In the first stage, a machine learning model is constructed to generate the vehicle deformation data and crash pulse used in the second-stage occupant sled analysis. By constructing a surrogate model for vehicle deformation, the number of computationally expensive crash analyses required to generate training data can be reduced. In the second stage, the generated vehicle deformation and crash pulse are used to construct a machine learning model for predicting lower-extremity injuries. Since the second-stage model utilizes the data generated in the first stage, it is possible to efficiently generate a large amount of occupant-sled analysis data for constructing the second-stage training dataset and prepare datasets for specific purposes, thereby improving prediction accuracy. Figure 2 shows an example of the sled analysis. As a preliminary investigation of the proposed two-stage prediction framework, data generated in the first stage were not used. Instead, a dataset consisting of 14 sled analyses under different conditions was used to evaluate the feasibility of lower-extremity injury prediction. A Transformer model was trained using the first five principal components (PC1–PC5) obtained by applying principal component analysis to the dashboard panel displacement data, together with the sled displacement, velocity, and acceleration. The model predicted the axial force and bending moment at the upper and lower tibia of both legs, from which the Tibia Index was calculated. To improve the prediction accuracy of peak values, the weighted mean squared error (WMSE), defined by the following equations, was used as the loss function.

$$\text{WMSE} = \frac{1}{n} \sum_{i=1}^n w_i (y_i - \hat{y}_i)^2, \quad w_i = 1 + 3 \frac{|y_i|}{y_{\max}}$$

Table 1 lists the prediction error at each measurement point. Figure 3 shows the predicted waveforms for the left lower leg (best) and the right upper leg (worst). The overall waveform trend was reproduced reasonably well, although the peak was noticeably underestimated for the right leg, indicating that reproducing sharp local peaks remains a challenge. Further improvement is expected by preparing a larger training dataset through the two-stage process.

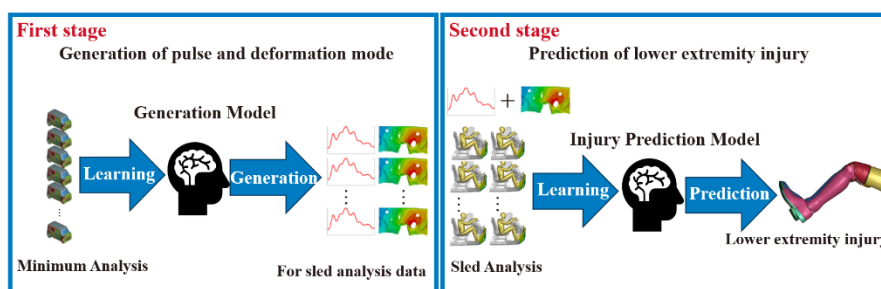


Fig.1 Two-stage prediction process

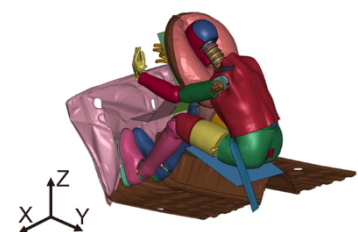


Fig.2 Simulation model

Table 1 Prediction error metrics

Measurement Point	MAE	MSE
Left lower	0.0787	0.0140
Left upper	0.0800	0.0166
Right lower	0.1521	0.0492
Right upper	0.1406	0.0452

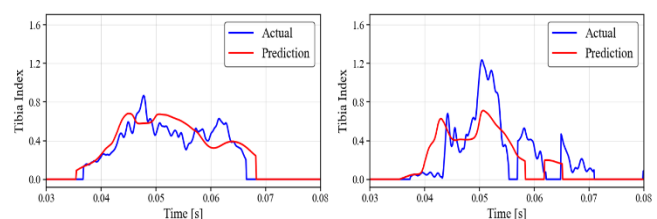


Fig.3 Prediction results