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VEHICLE DECELERATION PREDICTION BASED ON DEEP NEURAL NETWORK AT BRAKING CONDITIONS

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ABSTRACT−The smart regenerative braking system in electric vehicles implements automatic control of the regeneration torque of motor to improve driver's comfort and energy efficiency. To apply this system, the accurate prediction of the vehicle deceleration states is the preliminary step to reflect the driver's behaviors. In this paper, we proposed a vehicle deceleration prediction model via deep neural network, which consists of a sequential recurrent neural network model with long-short term memory cell and a two-layer conventional neural network model. This model accommodates the physical constraint to designate the vehicle stop location in front of the traffic signals. The model is trained by vehicle experiment data with three drivers through the hyper-parameter optimization method. Using this model, the deceleration characteristics are characterized by two explicit parameters such that deceleration point, maximum point according to the initial slope and the shape of the braking profile. Using these two parameters as clustering variables through a K-means clustering method, the deceleration types are classified. These deceleration types to the input to the prediction model results in higher prediction accuracy of the vehicle states. The driving style of the three drivers at braking situations is analyzed according to the deceleration types as well.

KEY WORDS : Deep neural network model, Recurrent neural network model, Deceleration characteristics, Deceleration types, Regenerative torque control, Electric vehicles

NOMENCLATURE

x : input vector of sequence model
h : hidden state of sequence model
σ : activation function of neural network
b : bias parameters of neural network node
W : weight parameters of neural network node
i : input gate of LSTM cell
f : forget gate of LSTM cell
o : output gate of LSTM cell
c : cell state of LSTM cell
y : output value of prediction model
t : prediction time, s
d : relative distance to stop location, m
v : vehicle velocity, m/s
a : vehicle acceleration, m/s^2

SUBSCRIPTS

ts : input data index at prediction start time
te : input data index at prediction end time
ni : number of input vector of sequence model
i : input gate of LSTM cell
o : output gate of LSTM cell
g : gate of LSTM cell
ref : reference acceleration

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1. INTRODUCTION

The grown necessity of the intelligent transfer system to enhance driving safety as well as energy efficiency motivates to develop advanced driver assistance systems (ADAS) not only in internal combustion engine vehicles but also in hybrid vehicles, electric vehicles. For the ADAS implementation on the vehicle, the forecasting information like predicted vehicle velocity has been widely accepted as an input to the system for the efficient operation (Demir and Çavuşoğlu, 2012; Mansour and Clodic, 2012; Zhang *et al.*, 2013; Lang *et al.*, 2014; Malinauskas, 2014; Qi *et al.*, 2018).

As one of ADAS applications, a smart regeneration system of electric vehicles uses the forecasting information at braking situations (McCall and Trivedi, 2007; Sun *et al.*, 2015; Balasubramanian and Huzefa, 2017). This system automatically controls the regeneration torque of electric motor to brake the vehicle instead of the driver's physical braking through pushing the brake pedal, leading to the driver convenience. In addition, avoidance of frequent braking through regeneration torque control harnesses