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A lane-change trajectory model from drivers' vision view

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ABSTRACT

Car-following and Lane-changing are two fundamental tasks during driving. While many car-following models can be applied, relatively, only a few lane-changing models have been developed. Classical lane-changing models mainly focus on drivers' lane selection and gap acceptance behaviors, but very limited research has paid attention to formulating detailed lane-changing trajectories. This research aims to fill the gap by proposing a lane-changing trajectory model, which is built directly from drivers' vision view, to model detailed lane-changing trajectories. A large amount of data of reference angles, defined as the angle changes between the drivers' vision angle and left or right lane line, were first extracted from the videos recorded by the vehicle traveling data recorders (VTDRs) installed in 11 taxies. A comprehensive data analysis indicates that same drivers show similarity of their daily lane-changing habit but with variety, and different drivers' lane-change trajectory data show different lane-change "personality" including aggressive or non-aggressive behaviors. Based on these findings, this paper then proposed a hyperbolic tangent lane-change trajectory model to describe drivers' detailed lane-change trajectories. The model is verified using both real data and simulation. The results show the proposed lane-change trajectory model can successfully describe drivers' lane-changing trajectories. More importantly, some parameters in the model are directly associated to drivers' driving characteristics during lane-change. With this unique feature, the proposed model can generate driver-specific lane-change trajectories. Such improvement could contribute to the future development of Advanced Driver Assistance Systems (ADAS).

1. Introduction

Car-following and Lane-change (LC) are two fundamental tasks during driving. While many car-following models can be applied (Gazis et al., 1961; Gipps, 1981; Newell, 1959, 1961; Pipes, 1953), relatively, only a few LC models have been developed. Classical LC models mainly focus on drivers' lane selection and gap acceptance behaviors (Ahmed, 1999; Choudhury, 2007; Daganzo, 1981; Gipps, 1986; Zheng, 2014). Among the earliest LC models, the model developed by Gipps in 1986 is one of the most famous ones. Gipps proposed a standard two-level LC framework. Following that, Hidas (2002), Hidas and Behbahanizadeh (1999) and Halati et al. (1997) developed similar LC models. However, most of above mentioned LC models focus on drivers' lane selection and gap acceptance behaviors (for a detailed review on traditional LC models, please refer to Zheng, 2014), only very limited research has paid attention to formulating detailed LC trajectories. Nelson (1989) proposed a model which formulates LC trajectories using a quintic polynomial. Enke (1979), on the other hand, applied a sinusoidal function to describe LC trajectories. Chovan (1994) described the LC process with sinusoidal and trapezoidal functions. Shamir (2004) developed an optimal LC trajectory using polynomial equations by considering safety and smoothness during driving. Recently, Li et al. (2010) suggested using the sinusoidal and hyperbolic tangent

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function to describe LC trajectories; and Glaser et al. (2010) proposed a maneuver-based vehicle trajectory planning algorithm, in which, the maneuvers in the lateral direction, i.e. changing lanes, were also considered. Although these models can achieve a fit between data and modeling results, most of them are purely mathematical equations without any physical meaning related to drivers' LC behaviors. Furthermore, most of above mentioned research was built based on simulation data, which brings some potential bias to these models.

Knowing the importance of the real LC trajectory data to the modeling, some researchers began to collect detailed LC data including velocity, acceleration, position, and steering wheel angle using a variety of sensors such as Differential Global Positioning System (DGPS), acceleration sensors, angle sensors and cameras. For example, Xu et al. (2012) used the Real Time Kinematic DGPS and steering angle sensor to collect LC data to verify the proposed LC dynamic model. Salvucci and Liu (2002) used a fixed-base, medium-fidelity driving simulator to record the steering wheel angle, turn signal ratio, and gaze dwell ratio to describe LC behaviors. Xuan and Coifman (2006) used DGPS to collect LC maneuvers from a probe vehicle. Reimer et al. (2013) collected the real number of LC times and analyzed the driving characteristics while the driver was distracted by a second task. The rough position and the steering angle is used by Li et al. (2016), to researching LC intention. Yao et al. (2013) collected LC data including the GPS information, turn signal ratio, and images by an instrumental vehicle running on urban arterial roads.

With the rapid development of image processing techniques, cameras have been used to collect detailed LC data. For example, a bunch of notable researches on LC were using the vehicle trajectories data extracted from video streams provided by the NGSIM (Next Generation Simulation) program, including Toledo and Zohar (2007), Leclercq et al. (2007), Thiemann et al. (2008), Choudhury et al. (2007), Jin and Li (2007), Vu et al. (2007). Furthermore, Milanés et al. (2012) proposed a LC model for self-driving using a vision-based vehicle detection system with two cameras, mainly for detecting preceding vehicles and determining their width, length and distance; and Luo et al. (2016) designed the automated LC maneuvers using the information about the surrounding traffic, provided by vehicle-to-vehicle communication.

Our paper also uses the video data to study LC maneuvers, different with NGSIM data which were collected from roadside cameras, our cameras, i.e. vehicle traveling data recorders (VTDRs), were mounted on the front windshield inside the vehicle. These inside cameras in fact provide a direct view from the drivers' vision. During the LC, such view essentially indicates the angle changes between the drivers' vision angle and left and right lane lines (see Fig. 1). We define such angle as reference angle (the θ on the Fig. 1). Compared to other data, such as GPS data, reference angle is a more direct measure of drivers' LC maneuverers as it directly comes from drivers' vision view; therefore, it is expected to provide more insights of drivers' LC behaviors. Note reference angle has been used by Wang et al. (2010) and Wu et al. (2012) for developing a lane departure warning system.

This research first extracts a large amount of reference angle data from the videos recorded by the VTDRs installed in 11 taxies running in Beijing, China. Using these data, we first conducted a comprehensive data analysis and the results indicate that same drivers show similarity of their daily lane-changing habit but with variety, and different drivers' LC trajectory data show different LC "personality" including aggressive or non-aggressive behaviors. Based on these findings, a new LC trajectory model is developed in this paper using reference angles. Note, to the best of our knowledge, such a model has never been developed before, particularly using the unique data of reference angles. The proposed model is further comprehensively analyzed and evaluated. The analysis results show the proposed LC model can successfully describe drivers' LC trajectories. Particularly, the proposed model directly relates to drivers' driving characteristics, i.e. personalities, during LC; therefore, it generates driver-specific and more comfortable LC trajectories. Note, during the evaluation, we use the lateral acceleration index, as suggested by other research (e.g. Kosecka et al., 1997; Shamir, 2004; Gartner et al., 2001), to evaluate the comfortableness of LC derived from the proposed LC trajectory model. Such improvement could contribute to the further development of Advanced Driver Assistance Systems (ADAS). In ADAS, we need to design a perfect (or near perfect) LC trajectory so drivers or passengers in vehicles will not feel abrupt but comfortable during the LC process. Our model which can generate driver-specific and more comfortable LC trajectories might fit this need exactly. Furthermore, the proposed LC model could be beneficial to alleviating congestion and increasing capacity in the urban network (Geroliminis and Boyacı, 2012).

The remainder of this paper is organized as follows: Section 2 introduces the data collection, followed by data analysis in Section 3. Section 4 proposes a new LC model based on the reference angle. Section 5 presents some theoretical analysis and experimental verifications of the proposed model. At the end, Section 6 concludes this paper with some remarks.

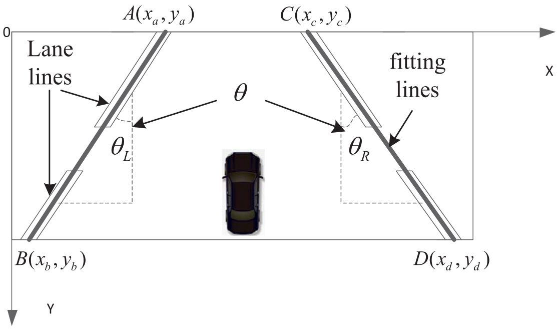

Fig. 1. Schematic of the reference angle, where θ is the reference angle.