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Estimation of driving style in naturalistic highway traffic using maneuver transition probabilities

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ABSTRACT

Accurately estimating driving styles is crucial to designing useful driver assistance systems and vehicle control systems for autonomous driving that match how people drive. This paper presents a novel way to identify driving style not in terms of the durations or frequencies of individual maneuver states, but rather the transition patterns between them to see how they are interrelated. Driving behavior in highway traffic was categorized into 12 maneuver states, based on which 144 (12 × 12) maneuver transition probabilities were obtained. A conditional likelihood maximization method was employed to extract typical maneuver transition patterns that could represent driving style strategies, from the 144 probabilities. Random forest algorithm was adopted to classify driving styles using the selected features. Results showed that transitions concerning five maneuver states – free driving, approaching, near following, constrained left and right lane changes – could be used to classify driving style reliably. Comparisons with traditional methods were presented and discussed in detail to show that transition probabilities between maneuvers were better at predicting driving style than traditional maneuver frequencies in behavioral analysis.

1. Introduction

Driving style is generally defined as the habitual ways drivers choose to drive, *i.e.*, the way individuals choose to drive or driving preferences that have developed over time (Elander et al., 1993; Lajunen and Özkan, 2011). Some definitions tend to emphasize ways of thinking (Ishibashi et al., 2007) or decision-making (Deery, 1999) rather than observable behavior. Despite the differences, these definitions are very much in accordance with each other in terms of their contents (Sagberg et al., 2015).

Driving style refers broadly to all activities performed by a driver, including strategic planning, tactical maneuvering, vehicle operation, as well as maintaining situation awareness and engaging in secondary tasks (Rasmussen, 1983; Cheng and Fujioka, 1997; Toledo et al., 2007). Fig. 1 summarizes the framework of driving style analysis. Strategic planning refers to knowledge-based activities, including the determination of route choice, the evaluation of the costs and risks involved, etc.

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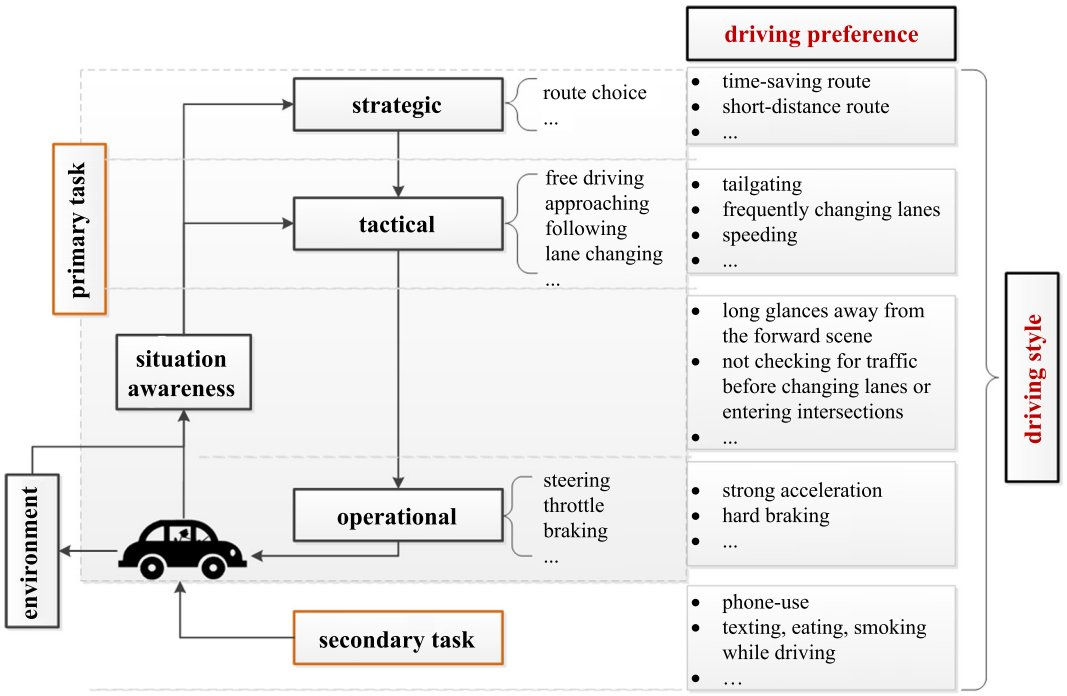

Fig. 1. A framework of driving style analysis.

Tactical maneuvering is how a driver selects and performs specific driving tasks according to the strategic goal and the situational awareness of traffic and environment. Vehicle operation refers to the behaviors that the driver performs to control the vehicle, including steering, accelerating, braking, shifting gears, etc. Strategic, tactical, and operational activities have different time frames. Vehicle operation is usually at the milliseconds level, tactical maneuvering is at the seconds level, and strategic planning occurs over a longer time period, usually much longer (Michon, 1985). Situation awareness includes the perception of vehicle state and traffic environment with respect to time or space, understanding based on the perceived information, and prediction of the future situation (Stanton et al., 2001). Secondary tasks include phone-use, texting, smoking, eating, etc., which interfere with completion of the primary driving task.

Existing studies on driving style can be categorized using this framework. Studies of the strategic aspects of driving style include preferences for time-saving or short-distance routes, etc. (Dia, 2002). Studies of the tactical aspects of driving style consider maneuver preferences such as tailgating, frequently changing lanes, etc. (Ehsani et al., 2015). Studies of the operational aspects of driving style include preferences for rapid acceleration, hard braking, etc. (Toledo et al., 2008). Studies of the situation awareness aspects of driving style include the acceptance of long glances away from the forward scene, not checking for traffic before changing lanes, etc. (Birrell and Fowkes, 2014). Secondary task aspects include preferences of phone-use, texting, smoking or eating while driving, etc. (Ferdinand and Menachemi, 2014).

Existing studies emphasized that driving style mainly concerned with tactical and operational aspects (Bellem et al., 2016). They categorized driving behavior into driving maneuvers (e.g., following, hard braking, lane changing, etc.). These studies extended previous efforts in estimating driving style using a multifaceted representation of driving maneuvers, both independently and jointly. However, this paper focuses on exploring driving style estimation not in terms of the durations or frequencies of individual maneuver states, but rather the transition patterns between them to see how they are interrelated.

2. Related work

Studies have been conducted to examine the tactical and operational aspects of driving style. Previous research revealed that high-risk drivers drove faster, exhibited shorter time headways (THWs) with lead vehicles, braked harder, and changed lanes more frequently than low-risk drivers did in naturalistic driving (Xiong et al., 2012; Sagberg et al., 2015). Simons-Morton et al. (2015) and Kusano et al. (2015), from field operational tests, found that low-risk drivers engaged in fewer risky maneuvers (e.g., near following). Thus, these studies identified the differences in driving style between groups, but did not go the next step to create a model that estimated driving style.

In contrast, based on the number of detected maneuvers from naturalistic driving data on various roads in the United States, Guo and Fang (2013) classified drivers into three risk groups using K-means cluster method, and developed a logistic model to predict driving style. Their model showed that frequency of emergency braking events was an effective indicator of