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# Lane changing intention recognition based on speech recognition models ☆

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ABSTRACT

Poor driving habits such as not using turn signals when changing lanes present a major challenge to advanced driver assistance systems that rely on turn signals. To address this problem, we propose a novel algorithm combining the hidden Markov model (HMM) and Bayesian filtering (BF) techniques to recognize a driver's lane changing intention. In the HMM component, the grammar definition is inspired by speech recognition models, and the output is a preliminary behavior classification. As for the BF component, the final behavior classification is produced based on the current and preceding outputs of the HMMs. A naturalistic data set is used to train and validate the proposed algorithm. The results reveal that the proposed HMM–BF framework can achieve a recognition accuracy of 93.5% and 90.3% for right and left lane changing, respectively, which is a significant improvement compared with the HMM-only algorithm. The recognition time results show that the proposed algorithm can recognize a behavior correctly at an early stage.



## 1. Introduction

Advanced Driver Assistance Systems (ADAS) have been receiving increasingly more attention in recent years. However, some common poor driving habits tend to interfere with the proper functioning of such systems. For example, blind-spot warning systems (BSWs) and lane departure warning systems (LDWs) are two typical assistance systems relying on turn signals because an alarm sounds, if BSWs or LDWs have already detected exceptional cases, only when the driver activates the turn signal. However, in the United States and China, the turn signal usage rates are approximately 44% (Lee et al., 2004) and less than 40% (Dang et al., 2013), respectively. Therefore, for most drivers, the two assistance systems can be seen as a useless technology. Consequently, it is important to develop an accurate and early lane changing (LC) intention recognition system for ADAS.

Driver behavior is a time-varying, continuous process and can be seen as being analogous to human spoken behavior. Fig. 1 shows driving and spoken behaviors on three levels of hierarchical structure (Boer et al., 1998). At the strategic level, needs are goals that humans try to satisfy and, therefore, they translate them into local goals; for example, route in driving or purpose in speech. At the tactical level, the task manager orchestrates the maneuvers or low-level tasks (e.g., lane changing or whisper) and the task scheduler communicates the performance-related information to the strategic level. At the two upper levels, the intentions of the two behaviors are inner mental states of humans, which cannot be observed directly. The operational level models the execution of the maneuvers that are learned as well as the automatic processes. At this

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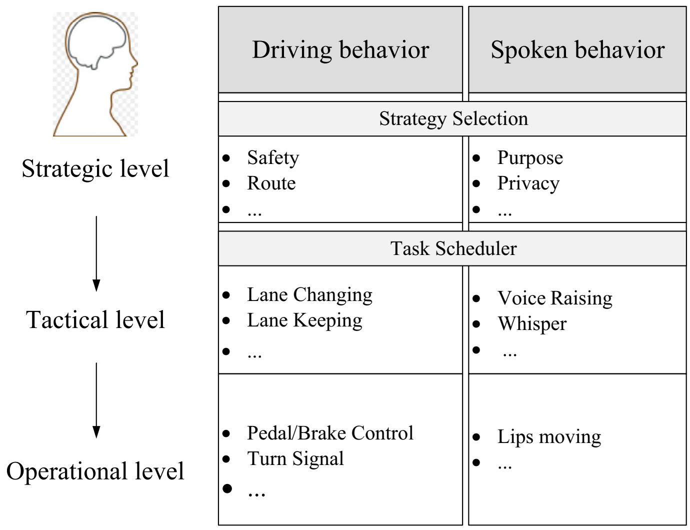


**Fig. 1.** Hierarchical driving and spoken behaviors. Performance is structured at three levels and the two behaviors can be seen to be analogous.

level, signals can be observed through vehicle movements or sound waves. In these ways, driving behavior is analogous to human spoken behavior on the three levels of a hierarchical structure, thus motivating us to expect that the study of LC intention recognition can learn from classical and mature speech recognition models.

In this study, a novel algorithm combining the hidden Markov model (HMM) and Bayesian filtering (BF) technique is proposed to improve the capability of drivers' LC intention recognition. In the HMM component, the definition of grammar is inspired by speech recognition models. Driving behavior is split into sub-behaviors, and corresponding sub-HMMs are developed. The input parameters are three signals from the controller area network bus (CAN bus), where the output is a preliminary behavior classification. To improve the recognition performance, a BF is used to produce the output of the final behavior classification based on the current and preceding outputs of the HMMs. Naturalistic data collected on various kinds of roads in Beijing, China are used to train and validate the proposed algorithm. The results reveal that the proposed algorithm can get good results both on recognition ratio and time.

The remainder of this paper is organized as follows. Related work from literature is introduced in Section 2, and Section 3 describes the principles of speech recognition models and explains how they can be applied to LC models. In Section 4, the system architecture and the theory of the HMM and BF are introduced. The data collection and post-processing will be discussed in Section 5. Section 6 presents the experimental results with the validation of the model, and finally, Section 7 draws out the conclusions of this study.

## 2. Related work

Substantial research has been conducted regarding LC models, with Gipps-type and Markov process-based models being representative (Zheng, 2014). Gipps (1986) conducted a pioneering work to introduce an LC structure in an urban street context. In that model, a driver's LC decision must consider the possibility, necessity, and desirability of changing lanes, with six factors and their effects being considered most important: safe gap distances, location of permanent obstructions, presence of transit lanes, driver's intended turning movement, presence of heavy vehicles, and speed. These factors are determined by a set of deterministic rules; thus, the driver behavior according to the Gipps's model is considered deterministic (Zheng, 2014).

Based on Gipps's study, Yang and Koutsopoulos (1996) developed an LC model and implemented it in a microscopic traffic simulator. In the model, an LC was classified as either mandatory or discretionary and consisted of three steps: checking if a change is necessary and defining the change type, selecting the target lane, and executing the lane change if the gap distances are acceptable. A difference between the models of Gipps (1986) and Yang and Koutsopoulos (1996) is that the latter model introduced an LC probability to replace the deterministic LC.

Another limitation of the work of Gipps (1986) is that the method ignores the interaction between the lane changer and the follower in the target lane, which is unrealistic when the traffic is heavy, congested, or impacted by an incident (Zheng et al., 2013). To address this limitation, Hidas (2002, 2005) proposed an improved model that classified an LC into three categories: free, cooperative, and forced. However, this LC model was only tested on two simple hypothetical road networks using simulation, and no detail was provided on how these parameters were calibrated.

Markov processes are another widely used method for modeling LC. Worrall et al. (1970) proposed a stochastic LC model that was developed as a homogeneous Markov chain and calibrated using naturalistic data collected on a section of a six-lane freeway in Chicago.