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A rule-based neural network approach to model driver naturalistic behavior in traffic

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ABSTRACT

This paper proposes a rule-based neural network model to simulate driver behavior in terms of longitudinal and lateral actions in two driving situations, namely car-following situation and safety critical events. A fuzzy rule based neural network is constructed to obtain driver individual driving rules from their vehicle trajectory data. A machine learning method reinforcement learning is used to train the neural network such that the neural network can mimic driving behavior of individual drivers. Vehicle actions by neural network are compared to actions from naturalistic data. Furthermore, this paper applies the proposed method to analyze the heterogeneities of driving behavior from different drivers' data.

Driving data in the two driving situations are extracted from Naturalistic Truck Driving Study and Naturalistic Car Driving Study databases provided by the Virginia Tech Transportation Institute according to pre-defined criteria. Driving actions were recorded in instrumented vehicles that have been equipped with specialized sensing, processing, and recording equipment.

1. Introduction

Driver behavior determines vehicle actions in traffic. The task of driving could be different when the surrounding traffic condition is different. Consequently, driver behavior and the resulting vehicle actions should be different. For instance, in congested situations when a driver is not able to drive freely, the driving task should be to follow a leading vehicle. When a driver observes a sudden break from the leading vehicle, the driving task should be to avoid the incoming conflict.

In this research, we focus on modeling two types of driving behavior: car-following behavior and evasive behavior. Car-following behavior usually appears in conditions when a driver is interacting with a leading vehicle before their relative distance becomes too close. Longitudinal action acceleration is considered to be the only action. Evasive behavior appears in safety critical events and vehicles should take evasive actions to avoid upcoming conflicts, especially rear-end collisions. During a safety critical event, both longitudinal and lateral actions are considered.

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1.1. Car-following models

In the last 50 years, a large number of car-following models have been proposed to model the process of drivers' "follow" behavior with leading vehicles (Brackstone and McDonald, 1999). According to literature, relative speed and relative distance between two vehicles are the most common underlying factors that would eventually lead to the construction of car-following models.

Most car-following models fall into two categories: safety distance models and psycho-physical models. Safety distance models assume that the following vehicle is able to stop before becoming too close to its leader. The minimum distance of two vehicles is guaranteed to be greater than a safety distance threshold (Gazis et al., 1961; Wiedemann, 1974; Gipps, 1981; Wiedemann and Reiter, 1992; Fritzsche, 1994; Kesting and Treiber, 2008). Psycho-physical models divide traffic situations into several regimes based on human's recognition on different traffic patterns where drivers' tasks and behavior are different (Wiedemann, 1974; Wiedemann and Reiter, 1992; Fritzsche, 1994).

1.2. Car-following model calibration efforts

Car-following models could be calibrated using macroscopic or microscopic data. Macroscopic data are usually obtained from aggregated traffic stream while microscopic data include more information on individual vehicle trajectories. Rakha et al. (2007) purposed a macroscopic calibration method that used loop detector data. Menneni et al. (2008) used microscopic and macroscopic data both in the process of model calibration. Kesting and Treiber (2008) used publicly available microscopic trajectory data to study car-following behavior on individual drivers. Their data were collected from an instrumented car with a radar sensor. Two models: Intelligent Driver Model (IDM) and Velocity Difference Model (VDM) were calibrated using genetic algorithm. Ossen and Hoogendoorn (2004) pointed out that the development of accurate and robust models reply on appropriate microscopic data, especially when analyzing heterogeneous behavior in different individual drivers.

1.3. Modeling safety critical events in traffic

We consider crash and near crash events as safety critical events in this study. To model driver behavior during safety critical events, most researchers modify car-following model and enable crashes to happen. Hamdar and Mahmassani (2008) adjusted several existing car-following models such that congestion dynamics and model accident-prone behaviors could be captured. The revised car-following and lane-changing models were developed under different degrees of relaxation on the safety constraints and implemented in a microscopic simulation framework. Xin et al. (2008) extended the capability of a car-following model (Gipps model) to simulate unsafe driving conditions. When a driver is in a subconscious driving state, an unsafe driving behavior is triggered.

1.4. Drawbacks of model calibration methods

Several drawbacks from previous model calibration methodologies were pointed out. Firstly, errors from data measurement can deteriorate model performance significantly. Ossen and Hoogendoorn (2008) discussed about three findings of a calibrated car-following model (GHR model) performance: (1) measurement errors can yield a considerable bias; (2) parameters that minimizing the objective function do not necessarily capture car-following dynamics best and (3) measurement errors can substantially reduce model sensitivity and reduce reliability. Similarly, Brockfeld et al. (2004) used the same data to calibrate 10 different car-following models. As a result, all models shared the same problem with particular sets of data. They pointed out that no model appears to be significantly better than any other model and models with more parameters did not necessarily provide better results.

Secondly, since different car-following models were developed from different data resources, no model is expected to match all sample data resources well. So if no prior knowledge about data is provided, it is difficult to choose the "best" model.

In the study of modeling driver evasive behavior, no systematic methodologies have been fully developed, probably due to the lack of events data of individual drivers.

1.5. Traffic states and actions

We think driver behavior in traffic is a state-action mapping problem that driver's actions depend on the traffic situation. Traffic states are defined by a set of variables that can represent vehicle kinematic conditions and its surrounding environment. Relative distance from the leading vehicle, relative distance and the acceleration of leading vehicle have been used as state variables in existing car-following models.

During safety critical events, driver actions are more complicated and not limited to longitudinal actions only. For instance, a driver may take a maneuver and execute a lane change simultaneously. Developing lateral action models are necessary.