Transportation Research Part C 86 (2018) 23–36

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

An online estimation of driving style using data-dependent pointer model

Evgenia Suzdaleva[a,*], Ivan Nagy[a,b]

[a] Department of Signal Processing, Institute of Information Theory and Automation of the Czech Academy of Sciences, Pod vodárenskou věží 4, 18208 Prague, Czech Republic
[b] Faculty of Transportation Sciences, Czech Technical University, Na Florenci 25, 11000 Prague, Czech Republic

ARTICLE INFO

Keywords:
Driving style
Fuel consumption
Mixture-based clustering
Data-dependent pointer
Recursive mixture estimation

ABSTRACT

The paper focuses on a task of stochastic modeling the driving style and its online estimation while driving. The driving style is modeled by means of a mixture model with normal and categorical components as well as a data-dependent pointer. The mixture parameters and the actual driving style are estimated with the help of a recursive algorithm under the Bayesian methodology. The main contributions of the presented approach are: (i) the online estimation of the driving style while driving, taking into account data up to the current time instant; (ii) the joint model for continuous and discrete data measured on a vehicle; (iii) the data-dependent model of the driving style conditioned by the values of fuel consumption; (iv) the use of the model both for detection of clusters according to the driving style and prediction of the fuel consumption along with other variables; and (v) the universal modeling with the help of mixtures, which allows us to use different combinations of components and pointer models as well as to specify the initialization approach suitable for the considered problem. Results of the driving style detection in real measurements and comparison with the theoretical counterparts are demonstrated.

1. Introduction

Modeling the driving style is important for many reasons. Timely recognition of the driving style in the online mode and its prediction can be beneficial in aspects of providing this information to a driver by means of driver assistance systems (Li et al., 2015).

Definitions of the driving style, which can be found in literature (Elander et al., 1993; Lajunen and Özkan, 2011; Sagberg et al., 2015) describe it as a way of driving (i.e., a set of individual driving habits), which is formed gradually with the accumulation of driving experience. The accumulated habits are reflected in a driver's activities while driving, which can be taken into account for performing the analysis of driving style (Cheng and and Fujioka, 1997; Toledo et al., 2007). The extensive multi-layer scheme of such driving activities is presented in Li et al. (2017), where they are generally divided among the primary driving tasks of route planning (Dia, 2002), maneuvering (Ehsani et al., 2015) as well as vehicle operating (Toledo et al., 2008) and the secondary tasks performed by the driver while driving (Ferdinand and Menachemi, 2014), e.g., phone using, talking, eating, smoking, etc. The mentioned scheme in Li et al. (2017) distinguishes the existing studies about modeling the driving style according to its definition.

Another way to categorize the studies on the driving style can be done in terms of the area where the driving style has a direct impact. As reported by a number of studies, driving style has a strong impact on driving safety (Evans, 1996), vehicle dynamics control (Plöchl and Edelmann, 2007) and the economic as well as ecologic efficiency of driving (Mensing et al., 2014).

* Corresponding author.
E-mail addresses: suzdalev@utia.cas.cz (E. Suzdaleva), nagy@utia.cas.cz (I. Nagy).

https://doi.org/10.1016/j.trc.2017.11.001
Received 29 December 2016; Received in revised form 22 August 2017; Accepted 1 November 2017

One of the study groups is related to the driving safety. In this area, the extensive overview of studies which deal with modeling the driving style is given by Sagberg et al. (2015). They introduced the systematic scheme for categorizing and operationalizing the driving styles in dependence on individual dispositions and sociocultural factors. Among recent related studies, Eboli et al. (2017) aimed at distinguishing cautious and aggressive driving styles. The relationship between the family driving-related atmosphere and young driver's driving styles was explored in Gil et al. (2016) and Taubman-Ben-Ari (2016). Taubman-Ben-Ari and Skvirsky (2016) investigated the young driver's driving style too and resulted in four driving styles with the suggestion of an insignificant effect of sociodemographic characteristics on the driving style.

Another group of studies with driving style modeling can be found in the area of applications concerned with the overall vehicle dynamics control. Specific control issues with the use of driving style models are discussed in Plöchl and Edelmann (2007), Zhang et al. (2010), Wang and Lukic (2011), Xu et al. (2015), and Bellem et al. (2016).

From an emissions' point of view, driving style modeling is discussed in the great number of publications, e.g., in Sentoff et al. (2015), Rangaraju et al. (2015), and Gallus et al. (2017), which deal with the ecological driving style. This area of the driving style analysis is closely related with its impact on fuel consumption as well (Mensing et al., 2014). This paper focuses on the modeling the driving style from the fuel economy point of view.

1.1. Related work

Studies, which are directed at exploring driving style in terms of reducing fuel consumption can be found in literature.

Murphey et al. (2009) in their study noticed that the information about a driver's driving style can be used for the aims of fuel economy. They took into account the driver's accelerating and decelerating, created jerk profiles for drivers and classified the driving style with the help of these profiles analysis. Manzoni et al. (2010) proposed a method to quantify the driving style from the fuel economy point of view using measurements of the longitudinal speed and the lateral acceleration. In Kamal et al. (2007), detection of abnormalities in driving style was solved by means of the adaptive fuzzy system. Malikopoulos and Aguilar (2012) investigated driving styles, which have a major effect on fuel consumption and optimized them via specific optimization framework with the use of polynomial metamodels. Categorization of the driving styles between normal and aggressive was considered by Vaitkus et al. (2014). They proposed using a pattern recognition approach to evaluate driving style automatically without expert intervention.

More recent studies are as follows: Ma et al. (2015) dealt with the effects of driving style on fuel consumption of city buses. Using a vehicle-engine combined model, they analyzed a great number of parameters related to fuel consumption found while accelerating, normal running and decelerating processes of vehicles. They reported that the influence of the driving style parameters on fuel consumption changed with road conditions and vehicle mass. A comparative study from two different countries was presented by Son et al. (2016), where they examined the relationship between driving style and real-world fuel consumption. Based on the analysis of data of fuel consumption, vehicle speed and acceleration pedal usage, they reported a high correlation of driving styles with the real-world fuel consumption and cultural factors. In a study by Ferreira et al. (2015), the driving styles, which are optimal from a fuel economy point of view were determined by means of data mining techniques. This study took data from public transportation buses and showed that the fuel consumption can be significantly reduced using the optimized driving practices. Mental models of three driving styles, which were defined as "normal","safe" and "fuel-efficient" were considered by Pampel et al. (2015). They conducted the experiment with a driving simulator, where participants had to drive according to instructions and then analyzed changes in their behavior. The used characteristics were accelerating, braking, coasting and car-following.

A question which factors have the greatest influence on driving style with respect to fuel economy was investigated by Akena et al. (2017). They identified and categorized such factors among driver factors, operating the vehicle, vehicle dynamics and driver awareness. Analysis of their impact on fuel economy was performed with the help of a multi-criterial hierarchical approach. According to the obtained results, driver awareness belongs to the most influential category. Factors related to vehicle control (primarily acceleration and speed) comprise the second most influential category and the driver-related factors have the least influence on fuel economy.

In addition, approaches to modeling the driving style can be also distinguished according to the formalisms they use. A variety of approaches are applied in all of the mentioned areas influenced by driving style, e.g., the correlation analysis (Eboli et al., 2017), fuzzy logic (Kamal et al., 2007; Dörr et al., 2014), *k*-means clustering (Guo and Fang, 2013), hierarchical clustering (Constantinescu et al., 2010), unsupervised learning (Nikulin, 2016), Bayesian networks (Amata et al., 2009), etc.

This paper considers the driving style estimation problem in the Bayesian context (Peterka, 1981; Kárný et al., 1998; Kárný et al., 2006; Nagy et al., 2011) and uses the mixture-based cluster analysis of data measured on a driven vehicle. The measurements are modeled by a mixture of normal and categorical components, where each of them describes variables within individual driving styles. A component, which is active at the current time instant, represents the actual driving style. To estimate which driving style is currently active, the recursive Bayesian mixture estimation algorithm is used. Bayesian methods were used for closely related problems in Mudgal et al. (2014) and Wang et al. (2016). However, the specific feature of the presented algorithm is its recursiveness, which (i) enables us to obtain a driving style estimate at each time instant and to update it online with the new data and (ii) guarantees the fixed computational time, which does not depend on algorithm convergence, which is characteristic for iterative techniques.

The presented paper continues the previous study (Suzdaleva and Nagy, 2014), where a stochastic data-based description of a driven vehicle was considered via the normal regression model within the context of the optimal (from the eco-driving viewpoint) control problem. Here, the focus is on the application of the recursive mixture estimation for the detection of the actual driving style and clustering the related measurements. The main contributions of the presented approach are: