Transportation Research Part F 58 (2018) 782–796

Contents lists available at ScienceDirect

Transportation Research Part F

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

# Hybrid of discrete wavelet transform and adaptive neuro fuzzy inference system for overall driving behavior recognition

Hamid Reza Eftekhari, Mehdi Ghatee *

*Department of Computer Science, Amirkabir University of Technology, Tehran, Iran*

ARTICLE INFO

*Article history:*
Received 11 October 2017
Received in revised form 25 June 2018
Accepted 29 June 2018

*Keywords:*
Driver behavior evaluation
Wavelet transform
Aggressive driving
Smartphone sensors
ANFIS
Decision fusion
Pattern recognition

ABSTRACT

Monitoring and evaluating of driving behavior is the main goal of this paper that encourage us to develop a new system based on Inertial Measurement Unit (IMU) sensors of smartphones. In this system, a hybrid of Discrete Wavelet Transformation (DWT) and Adaptive Neuro Fuzzy Inference System (ANFIS) is used to recognize overall driving behaviors. The behaviors are classified into the safe, the semi-aggressive, and the aggressive classes that are adopted with Driver Anger Scale (DAS) self-reported questionnaire results. The proposed system extracts four features from IMU sensors in the forms of time series. They are decomposed by DWT in two levels and their energies are sent to six ANFISs. Each ANFIS models the different perception about driving behavior under uncertain knowledge and returns the similarity or dissimilarity between driving behaviors. The results of these six ANFISs are combined by three different decision fusion approaches. Results show that Coiflet-2 is the most suitable mother wavelet for driving behavior analysis. In addition, the proposed system recognizes the overall driving behavior patterns with 92% accuracy without necessity to evaluate the maneuvers one by one. We show that without longitude acceleration data, the driver behavior cannot be recognized successfully while the results do not disturb substantially when the gyroscope is not available.



## 1. Introduction

Monitoring and evaluating of drivers' behaviors are important factors to improve driving safety (Astarita, Festa, Giofrè, Guido, & Mongelli, 2016). Researchers have showed that the monitoring and logging the driving events mitigates dangerous and aggressive driving behaviors (Hauber, 1980; Hickman & Geller, 2005). Consequently, this reduces 20% of accidents (Bos & Wouters, 2000). In addition to safety, the aggressive behaviors increase 40% in fuel consumption and mitigate the passengers' mental convenience (Alessandrini, Cattivera, Filippi, & Ortenzi, 2012). Therefore, some transportation companies incorporated some tools like GPS and camera into their vehicles to monitor and to evaluate the driver's behavior. Moreover, some insurance companies equip vehicles with several sensors to evaluate drivers' behaviors (Händel et al., 2014; Wahlström, Skog, and Händel, 2015). This evaluation has provided a measure to determine the rewards for safe driving behaviors (Kanarachos, Christopoulos, & Chroneos, 2018).

* Corresponding author at: Department of Computer Science, Faculty of Mathematics and Computer Science, Amirkabir University of Technology, Tehran, Iran.

*E-mail addresses:* hreftekhari@aut.ac.ir (H.R. Eftekhari), ghatee@aut.ac.ir (M. Ghatee).

*URL:* http://www.aut.ac.ir/ghatee (M. Ghatee).

https://doi.org/10.1016/j.trf.2018.06.044

To evaluate driving behavior, many extremely valuable researches have been done. The traditional approach is self-reported questionnaires that shows driving styles, driver's personality and the reaction of the driver to specific scenarios. Driving Anger Score (DAS) (Deffenbacher, Oetting, & Lynch, 1994), driver behavior questionnaires (Reason, Manstead, Stradling, Baxter, & Campbell, 1990), aggressive driving behavior scale (Houston, Harris, & Norman, 2003) and the propensity for angry driving scale (DePasquale, Geller, Clarke, & Littleton, 2001) are some of these questionnaires. Studies show that there is a strong correlation between these questionnaires (Li, Li, Long, Zhan, & Hennessy, 2004; Sullman & Stephens, 2013), thus it is not very important to opt one of them for driving evaluation. Other approach is to examine the driver behavior by an expert (Hong, Margines, & Dey, 2014). Using a driving simulation environment is another approach for driving evaluation (Kee, Shamsul, & Goh, 2009). Despite the validity of such approach, the cost of the necessary installed equipment is high. Nevertheless, using smartphones for assessing driving behavior is a new idea that does not have a high cost for drivers. Since the smartphones include a set of various sensors, e.g. accelerometers, gyroscopes, and location tools like GPS, they can be used for the safety aims. In addition, they access to communication networks, consists of an operating system and a processor to execute applications. Thus, they provide an appropriate framework for various domains like transportation (Johnson & Trivedi, 2011; Hong et al., 2014; Zadeh, Ghatee, & Eftekhari, 2017; Bejani & Ghatee, 2018). As some important highly relevant surveys, Engelbrecht, Booysen, van Rooyen, and Bruwer (2015) have categorized sensing techniques in vehicles by smartphones and Wahlström, Skog, & Händel (2017) have presented the state-of-the-art methods of smartphone systems for intelligent transportation purposes. Kervick (2016) demonstrated that smartphone-based driver support systems have potential value in mitigating young drivers' risk, while these systems are more acceptable than traditional in-vehicle data recorders. Table 1, summarizes the advantage and the disadvantages of different approaches to evaluate driver's behavior (Hong et al., 2014).

In this study, we use Inertial Measurement Unit (IMU) sensors of smartphone to define some new features. After choosing appropriate mother wavelets (Daubechies, 1990), we apply a discrete wavelet transform (DWT) to extract features in the forms of time series. Then their energies are sent to six ANFISs. Finally by decision fusion techniques on ANFISs outputs, we evaluate overall driving behavior. We also, use DAS self-reported questionnaire to train our learning machine and to validate our results. Furthermore, we analyze sensitivity of parameters of the proposed model.

In the next section, a literature review on aggressive behavior is presented. In the third section, we introduce some features and we propose a new model for overall driving evaluation. Afterward, the evaluation of the model and the analysis of model parameters are presented. The final section ends the paper with a brief conclusion.

## 2. Literature review

The fundamental researches show that the aggressive driving is difficult to define because of its many different manifestations (Vanlaar, Simpson, Mayhew, & Robertson, 2008). For some basic definitions, one can see Kervick (2016) or Daubechies (1990). Assessment of aggressive driving usually depends on driving events. Table 2 illustrates some maneuvers that are related to the perception about the dangerous or the aggressive behavior. Also, in some papers, harsh acceleration, harsh cornering and lane changing have been considered as three important events that are emerged by using thresholds or some rule-based fuzzy inference engines. The other techniques classifies the individual driving events based on similarity between patterns. To see a survey on these approaches, one can refer to Section IV.E written by Wahlström et al. (2017). However, driving behavior evaluation by labeling on individual driving events has the following opportunities and challenges:

- It is a simple task to extract some specific driving events, such as turns or brakes, by determining some initial thresholds. In these cases, maybe we lost some maneuvers and events that are not included in our maneuvers list. By the other word, each research focuses on several maneuvers and just evaluates them without considering all of the events. For example,

**Table 1**
Characteristics of different approaches for driving behavior evaluation.

| Evaluation approach | Advantage | Disadvantage |
|---|---|---|
| Self-reported questionnaire | Their data collects easily<br>Their cost is low | They are biased on drivers' memory<br>Their usage is limited |
| Driving Simulation environment | They can simulate different accident scenarios to examine drivers; reactions | They are expensive<br>There is a risk that these systems cannot simulate reality |
| Examination by expert | These examinations are real-time | They are very expensive<br>Variety of judgment about driver behavior, does not lead to a unique evaluation |
| In-vehicle data recorders | They are real-time and can save the driver's reaction | They are expensive<br>The driver can manipulate them |
| Smartphone-based | They are low cost<br>They are real-time and can save the driver's reaction | They need a time to prepare for recording<br>They need to remove the noise and irrelevant data<br>Smartphone sensors have some limitations |