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A context aware system for driving style evaluation by an ensemble learning on smartphone sensors data

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ABSTRACT

There are many systems to evaluate driving style based on smartphone sensors without enough awareness from the context. To cover this gap, we propose a new system namely CADSE system to consider the effects of traffic levels and car types on driving evaluation. CADSE system includes three subsystems to calibrate smartphone, to classify the maneuvers, and to evaluate driving styles. For each maneuver, the smartphone sensors data are gathered in three successive time intervals referred as pre-maneuver, in-maneuver, and post-maneuver times. Then, we extract some important mathematical and experimental features from these data. Afterwards, we propose an ensemble learning method on these features to classify the maneuvers. This ensemble method includes decision tree, support vector machine, multi-layer perceptron, and k-nearest neighbors. Finally, we develop a rule-based fuzzy inference system to integrate the outputs of these algorithms and to recognize dangerous and safe maneuvers. CADSE saves this result in driver's profile to consider more for dangerous driving recognition. The experimental results show that accuracy, precision, recall, and F-measure of CADSE system are greater than 94%, 92%, 92%, and 93%, respectively that prove the system efficiency.

1. Introduction

The dangerous driver refers to a driver who drives with some dangerous maneuvers, which could be caused an accident. Such driver may be recognized by insurance companies or police offices to limit the dangerous driving and to improve the drivers' behavior. Since, evaluation of drivers' maneuvers is an important task in the subject of transportation safety, many issues were considered for this problem, see e.g., Tijerina (2000). For this problem, Toledo et al. (2008) focused on data gathering processes. Duddle and Perham (2007), Raz et al. (2008), McCall and Trivedi (2006), and Olaverri-Monreal et al. (2010) developed different methods and systems for evaluating the quality of maneuvers and driving style recognition. The effect of such evaluation systems for driving profile was also mentioned by Raz et al. (2009). Also for insurance companies McMillan et al. (2000) and Raz et al. (2006) developed some driving evaluation applications.

On the other hand, the quality of maneuvers depends on changes of acceleration and the order of operations. Xu et al. (2015) showed that the lateral accelerations of vehicles can be converted into the lateral force coefficient, which is a key factor for vehicle lateral stability, driving safety and driving behavior. Usually a dangerous maneuver relates to high acceleration, but not at all. In the other words, some dangerous maneuvers happen under low acceleration; For example, when a driver changes his lane exactly before his U-Tern, the maneuver is dangerous even if the acceleration is low. This means the order of the operations is important for

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maneuver evaluation. Therefore, we divide maneuvers time into three intervals namely, pre-maneuver, in-maneuver, and post-maneuver times to recognize low-acceleration dangerous maneuvers. Furthermore, we define three type of feature sets for each of these intervals, and the maneuvers are classified based on these feature sets.

Furthermore, to gather the necessary data for maneuvers one can use smartphones as well as car devices. The benefits of smartphones for evaluating driver's style encourages the researchers to analyze the data provided by smartphone sensors for intelligent transportation systems, see e.g., Eftekhari and Ghatee (2016) or Zadeh et al. (2017). Also, White et al. (2011) used the data generated by smartphones to detect accidents; Perttunen et al. (2011) used them for monitoring traffic; Bantis and Haworth (2017) used them for travel mode detection, Dabiri and Heaslip (2018) used a convolutional neural network on them for the same purpose; Duclos et al. (2016) combined data from smartwatch and smartphone to recognize human activity such as walking, sitting, and reclining. In addition, for evaluation of driver behavior, Castignani et al. (2017) and Ma et al. (2017) developed some interesting methods; Batalla et al. (2017) collected some driving style evaluation approaches; Wahlström et al. (2017) also reviewed smartphone-based systems for a decade. However, in the previous driver's style evaluation works, the effect of context-awareness for maneuvers detection has been neglected; while, road condition and car type as two important concepts in driving context have great effects on maneuvers and in congested and normal roads, drivers behave differently. To consider context awareness in driver's style evaluation, machine learning algorithms can be used. For this end, we consider the drivers' profiles to decrease system's false-negative rate. In addition, for driver's style evaluation, the parameters of maneuvers need to be evaluated before and after maneuvers. We will show the performance of the proposed evaluation system is reasonable and so this can be used as a subsystem for insurance and enforcement purposes. Insurance companies are interested to such systems because of the following:

- As a business intelligent reason, based on the level of drivers' risk, insurance cost can be defined such that a high-risk driver pays more cost.
- CADSE system evaluates the drivers style before any accident. This is a part of a greater system which can be used to recognize dangerous driving. Such dangerous driving recognizer can be used by insurance companies to judge about the drivers responsibilities.

Another issue here is battery consumption of smartphone for drivers' style evaluation system. However, any car produces enough energy to charge smartphones battery when the smartphone connects to the car sockets. Thus, it is no worry about GPS energy consumption for the proposed system. Really, this limitation happens just for those applications work on human actions such as standing, walking or running. In these situations, one can prefer IMU sensors instead of GPS sensors, see e.g., Wahlström et al. (2015).

In the next sections, firstly, we review some related works and then we present the details of our proposed evaluation system.

2. Related work

Smartphone based systems are low cost while their processing abilities and sensing capacities enable us to propose many applications such as drivers' style evaluation. Castignani et al. (2017) proposed a system based on smartphones to evaluate driver behavior. This system is based on a probabilistic distribution. If a maneuver is detected with a specified property, the maneuver is used for updating the system. Also, Castignani et al. (2015) proposed a system based on fuzzy inference system for evaluation driver behavior. Saiprasert et al. (2017), Dhar et al. (2014) and Johnson and Trivedi (2011) used pattern matching models for drivers' style evaluation with dynamic time warping. The main application of these systems is in insurance companies as discussed by Handel et al. (2014). To further study the relationship of this paper with literature, Table 1 shows some of the most important references on driving style evaluation applying different sensors. Based on this table, following scientific gaps can be understood:

1. There is not a direct way to detect and recognize the context for driver style evaluation.
2. The previous works did not used a fusion of multiple machine learning techniques to evaluate the driving style; however, it is very hard to find a special technique for evaluating driving maneuvers.
3. The fixed thresholds for machine learning methods are not commonly usable to detect the maneuvers and driving styles.

In addition, to the best of our knowledge, there are not appropriate solutions for the following important questions for driver evaluation:

1. What is the effect of the different types of cars on felt acceleration by smartphone sensors when a maneuver occurs?
2. How does a driving evaluation system consider the drivers' characteristics?
3. When does a dangerous maneuver happen in low acceleration?

To respond to these challenges, in this paper a new system is developed to consider car type, driver profile, and low acceleration maneuvers to evaluate the driving styles more accurately.

3. Context aware driver style evaluation system

Context Aware Driver Style Evaluation or shortly CADSE system evaluates drivers' style based on their profiles and smartphones sensors data. Fig. 1 shows the architecture of *CADSE* system. This system consists of the following 4 subsystems: