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Driving analytics using smartphones: Algorithms, comparisons and challenges

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A B S T R A C T

The present work investigates the use of smartphones as an alternative to gather data for driving behavior analysis. The proposed approach incorporates i. a device reorientation algorithm, which leverages gyroscope, accelerometer and GPS information, to correct the raw accelerometer data, and ii. a machine-learning framework based on rough set theory to identify rules and detect critical patterns solely based on the corrected accelerometer data. To evaluate the proposed framework, a series of driving experiments are conducted in both controlled and "free-driving" conditions. In all experiments, the smartphone can be freely positioned inside the subject vehicle. Findings indicate that the smartphone-based algorithms may accurately detect four distinct patterns (braking, acceleration, left cornering and right cornering) with an average accuracy comparable to other popular detection approaches based on data collected using a fixed position device.

1. Introduction

Driving analytics is a research field where smartphones are starting to have significant impact. Driving analytics mainly include the identification of extreme driving patterns, for example speeding, harsh braking/acceleration, harsh cornering (left or right turn with high speed), and harsh lane changing (Handel et al., 2014; Johnson and Trivedi, 2011). The above information can be leveraged to develop individual-based Intelligent Transportation Systems (ITS), connected fleet systems, as well as Usage Based Insurance (UBI) schemes (Eren et al., 2012; Handel et al., 2014; Husnjak et al., 2015; Johnson and Trivedi, 2011; Meseguer et al., 2013; Saiprasert and Pattara-Atikom, 2013; Tselentis et al., 2016; Wahlstrom et al., 2015; White et al., 2011). For a recent review of smartphone-based applications for driver's behavior monitoring see (Predic and Stojanovic, 2015).

The main advantage of using smartphones for extracting driving analytics is that they can form a non-intrusive environment for continuously collecting rich and more granular data on the actual driving task. As opposed to current naturalistic driving experiments, smartphone probes are a much more sustainable solution, when compared to instrumented vehicles. Instrumentation is costly and difficult to install and maintain, especially when experiments involve a large volume of vehicles (Vlahogianni et al., 2013, 2014). Smartphones are equipped with a variety of sensors (e.g. global navigation satellite system-GNSS, inertial measurement unit-IMU) and can alleviate the cost constraints.

The use of smartphones for monitoring vehicle's driving characteristics comes as a novel direction at a series of other telematics solutions, such as in-vehicle data recorders (Paefgen et al., 2014; Toledo et al., 2008), as well as the popular fixed

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position devices plugged into the on-board diagnostics (OBD-II) port of vehicle (Amarasinghe et al., 2015; Tselentis et al., 2016). While OBD-II solutions have been pointed as the most accurate market solution for collecting vehicle's characteristics data, smartphones are gaining ground due to several advantages over OBD-II devices. First, they are a low-cost solution when compared to OBD systems that cost more than 100$ each, plus cloud or other services to transmit, analyze and maintain data. Second, smartphones are quite transparent data collection mechanisms; the users may resort to their data to check their behavior or even interact with them through the proper software, usually developed to work in a smartphone. Evidently, smartphones entail several disadvantages, such as the battery drain, the arbitrary position in vehicle, the noisy data encompassing various trips with various means of transportation and so on (Handel et al., 2014). These shortcomings may significantly affect the accuracy and reliability of smartphone based data collection systems.

Interestingly, there is little information on how accurate and reliable are smartphone-based collected data compared to other sources of information e.g. fixed GPS devices or Inertial Measurement Units (IMUs) with a combination of accelerometers, gyroscopes, and less often magnetometers. In (Paefgen et al., 2012) a study of driving event detection based on smartphones and OBDs is conducted in order to compare the performance of smartphones against an OBD in-car unit. Results revealed correlation between the events detected by smartphones and ODB devices. Smartphones were found to overestimate critical events when compared to OBDs, whereas roadway conditions and smartphone's position significantly affect the performance of smartphones. In (Saiprasert and Pattara-Atikom, 2013) it is shown that speed data from Smartphone are as accurate as the values from car's speedometer with a speed offset of approximately 4 km/h. In (Bergasa et al., 2014) experiments are conducted to detect driver's behavior and compared different approaches, but for fixed smartphone positions. Data fusion algorithms were developed in (Chowdhury et al., 2014; Ghose et al., 2016) based on GPS and inertial collected data to infer the speed of a vehicle and concluded that the estimated speed is comparable to the OBD based tachometer readings.

The above approaches converge to a single idea: to detect driving patterns one has to analyze the accelerometer and/or GPS data and trace - with some method - the outlying behavior. Literature has emphasized that GPS speeds are reliable and accurate, but need significant processing in order to be leveraged for extracting driver's analytics (Chowdhury et al., 2014; Ghose et al., 2016). On the other hand, the accelerometer data suffer from extreme levels of noise and are sensitive to device repositioning.

The present work proposes an algorithmic toolbox based on machine learning in order to leverage the data collection capabilities of smartphones and generate information on the driver's behavior. Two distinct research questions are treated:

- How to account for the noise induced in the sensor's signals due to the arbitrary positioning of a smartphone inside a moving vehicle or the differences between sensors and devices?
- What is considered an event and how to set the thresholds between regular and irregular (extreme) driving?

The proposed approach entails three processing steps: first, a simple and flexible device repositioning algorithm is implemented in order to continuously detect the true position of the smartphone inside a vehicle and correct the recorded data, so as to match its orientation to the one of the vehicle. Second, a flexible peak detection algorithm is developed to pick up irregularities in the rotated accelerometer data and tag them as possible harsh driving events. Third, a parameter free model based on rough set theory is developed to find the optimum accelerometer threshold values and extract critical driving events, specifically, harsh acceleration, harsh braking, and harsh left and right cornering. The accuracy of the proposed approach is compared to a fixed position device, which encompasses a threshold-based approach to detect critical events based on accelerometer data. The evaluation is based on two distinct experiments: a "free driving" experiment, where the subject driver conducts his daily driving habits with no intervention (naturalistic driving experiment) and a controlled experiment, where an observer monitors and annotates the behavior of drivers during the driving task.

2. Smartphone-based driving analytics and modeling

2.1. Critical driving patterns from smartphone data

Smartphones are equipped with a variety of sensors, such as motion sensors (e.g. accelerometer and gyroscope), position sensors (e.g. magnetometer), global navigation satellite system (GNSS) receivers, environmental sensors (barometers, photometers, and thermometers), microphone, cameras, etc. Although, theoretically each sensor may add knowledge to the driver's behavior and conditions during driving, literature has systematically addressed the problem of harsh driving events detection using GNSS, as well as 3-axis accelerometer, gyroscope and magnetometer data (Wahlstrom et al., 2015).

Based on the above sensors various driving patterns may be detected. A concise review of the indicators and metrics extracted from smartphones and may characterize driving behavior is provided in Handel et al. (2014). The most popular of these, often met in usage based insurance schemes, include acceleration/braking, speeding, as an absolute value or in relation to a specific limit, right/left cornering and swerving (including lane changing). The frequency of these metrics in relation to the distance traveled, the time of day, etc. may be used to quantify risky driving, to rate driver's behavior, to explore aggressiveness during driving and so on (Chakravarty et al., 2013; Johnson and Trivedi, 2011; Musicant et al., 2014).