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Combining speed and acceleration to define car users' safe or unsafe driving behaviour

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ABSTRACT

Speed and acceleration describe the motion of a vehicle. Therefore, these parameters are fundamental to define the behaviour of a driver. To this aim, it is useful to analyse instantaneous and geo-referenced kinematic parameters of the vehicle recorded by real tests on the road.

Among all the available methods in the scientific literature, a way for characterizing driver behaviour is the g–g diagram, that shows the longitudinal and lateral accelerations on the *y* and *x*-axes, normalized with respect to gravity, recorded on a vehicle during a real test on the road. However, we retain that also speed has to be considered for characterizing drivers' behaviour, being acceleration and speed strictly interrelated. Starting from the g–g diagram, we propose a methodology which describes the relationship between lateral and longitudinal accelerations and speeds, and represents a tool to classify car drivers' behaviour as safe or unsafe. An app for smartphone allows the geo-referenced kinematic parameters of the vehicle to be detected. The experimental survey supporting the methodology was carried out on a rural two-lane road in Southern Italy.

1. Introduction

The motion of a vehicle is described by kinematic parameters like speed and acceleration, varying in time and space. Instantaneous and geo-referenced travelling kinematic parameters of the vehicle can be recorded by real tests on the road. The availability of this kind of data permits to track individual vehicles and to analyse the trajectories in order to verify drivers' behaviour, which includes all manoeuvres that a driver performs while driving, in safe or unsafe conditions. Different drivers have different driving behaviours: driver's personal characteristics and habits will affect their reaction when they face with a dangerous situation while driving (Chen et al., 2013). Traditionally, drivers were distinguished on the basis of their level of "aggressiveness" (e.g. Bonsall et al., 2005). An aggressive driver takes a driving behaviour characterized by high speed together with numerous and sudden changes of the instantaneous speed, which cause sudden accelerations and decelerations. The higher the speed variation, the greater the interactions among vehicles will be (Mehar et al., 2013). As a consequence, we can generally say that an aggressive driver has an "unsafe driving behaviour". On the contrary, some researchers have distinguished between two main categories of driver: "aggressive" or "cautious" (e.g. Wang et al., 2014). Cautious driver is often described also as "careful" (e.g. Taubman-Ben-Ari et al., 2004). A driver can be considered as cautious when he tries to maintain a constant moderate speed, avoiding sudden acceleration and braking, indicating that he has a "safe driving behaviour".

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Numerous studies have focused on driving behaviour. A summary of these works is reported in Zeeman and Booysen (2013), who highlighted that the main differences between these studies are in the specific application area and the sensing employed method. According to this literature review, research focus has recently shifted from visual monitoring to the use of vehicle-mounted motion sensors. Motion sensors, such as accelerometers and gyroscopes, allow vehicle's speed, lateral, longitudinal and vertical accelerations, and instantaneous vehicle positions to be measured and recorded. Motion sensors are becoming increasingly important due to their simplicity, robustness and low cost.

Among all the available methods in the scientific literature, a way for characterizing driver behaviour is the g–g diagram that shows the longitudinal and lateral accelerations on the *y* and *x*-axes, normalized with respect to gravity, recorded on a vehicle during a real test on the road (Hisaoka et al., 1999). As emphasized by Da Lio et al. (2005), this diagram represents a very effective way to characterize vehicle–driver performance, because longitudinal and lateral acceleration values can be seen as the synthesis between the vehicle dynamics and the driving behaviour selected according to driver's motion perception and the risk level he/she accepts. However, it is necessary to consider also that speed is important too to characterize drivers' behaviour, and speed and accelerations are strictly interrelated.

The aim of this paper is just to analyse the relationship between lateral and longitudinal acceleration and speed in order to have a tool to classify car drivers behaviour. We distinguish drivers' behaviour from safe to unsafe driving conditions, according to the instantaneous values of accelerations and speeds recorded by real tests on the road. The parameters were surveyed through smartphones with satellite-based Global Positioning System (GPS) device, and specifically by using an app for smartphone which allows the geo-referenced kinematic parameters of the vehicle to be detected. The experimental survey was carried out on a rural two-lane road in Southern Italy.

After this brief introduction, we propose a literature review of the studies that analysed the relationship between acceleration and speed, and between friction and speed, being these parameters the elements considered for the development of our proposed methodology for analysing driving behaviour. After literature review, the methodology is described, together with the experimental survey conducted for validating it. The paper ends with a brief conclusive section.

2. Literature review

2.1. Relationship between acceleration and speed

Speed and acceleration rates are primary parameters in the estimation of road safety conditions. Since 1930 some studies have focused their attention on the relationship between speed and accelerations during the vehicle motion. Specifically, a paper proposed by Goebelbecker and Uzgiris (1998) refers about a series of filed tests carried out in 1930s and 1940s to determine the safe speed on curves. Some relationships between lateral acceleration and speed were found, indicating that the lateral acceleration decreases when speed increases. The results established levels of lateral acceleration to which drivers of heavy trucks experienced some discomfort; it was found that drivers are more tolerant of lateral acceleration at slower speeds than at higher speed (AASHTO, 1984).

Also in recent years, several researchers have focused on the relationship between speed and accelerations. As an example, Reymond et al. (2001) proposed a driving behaviour model which takes into account the drivers' estimation of both maximal lateral acceleration and predictable steering corrections, based on their driving style and experience. They showed that in curves maximum lateral acceleration quadratically decreases with driving speed. Vehicle speed and lateral acceleration were recorded on a test truck by driving a real vehicle equipped with a set of high-precision accelerometers, gyrometers, and optical velocity sensors. A pattern of lateral accelerations was also tested by driving a simulator.

Wang et al. (2004) collected field data to analyse acceleration rates of different vehicles using GPS, and proposed two new polynomial models developed for driver acceleration behaviour for turning manoeuvres versus straight manoeuvre acceleration from a stopped condition. Specifically, the model formulations were quadratic relationship between acceleration and speed, proving that acceleration decreases with driving speed also at all way stop controlled intersections.

Da Lio et al. (2005) found relationships between longitudinal acceleration and speed, and lateral acceleration and speed. By using empirical data, they observed that longitudinal acceleration varies with speed by following two phases: in a first phase longitudinal acceleration is constant with speed, and in a second phase it linearly decreases with speed. Differently, lateral acceleration increases from low to medium speeds, and then linearly decreases with speed as well.

Brooks (2012) found that also during overtaking manoeuvres in rural roads vehicles decrease their acceleration when speed increases; the link deduced from experimental data is a linear relationship. Acceleration characteristics were manually observed.

Zeeman and Booysen (2013) proposed a model that combines speed and acceleration to detect reckless driving in public transport. This model considers only the lateral accelerations to create an erratic driving detection model. The authors consider a lateral threshold based on design standards and a longitudinal threshold as a rate of deceleration based on literature studies.

Mehar et al. (2013) measured maximum and average acceleration at different speeds for different types of vehicles, from a standstill condition to a higher speed. According to their analysis, the average acceleration is found to exponentially decrease when speed increases, whereas the maximum acceleration linearly decreases with speed.

Xu et al. (2015) showed that lateral acceleration depends on driving speed and trajectory curvatures. They analysed the change laws for the lateral acceleration over the speed based on experimental data measured on twelve highways with