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A Fuzzy set-based method to identify the car position in a road lane at intersections by smartphone GPS data

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Abstract

Intelligent transportation systems (ITS) work by collections of data in real time. Average speed, travel time and delay at intersections are some of the most important measures, often used for monitoring the performance of transportation systems, and useful for system management and planning. In urban transportation planning, intersections are usually considered critical points, acting as bottlenecks and clog points for urban traffic. Thus, detecting the travel time at intersections in different turning directions is an activity useful to improve the urban transport efficiency. Smartphones represent a low-cost technology, with which is possible to obtain information about traffic state. However, smartphone GPS data suffer for low precision, mainly in urban areas. In this paper, we present a fuzzy set-based method for car positioning identification within road lanes near intersections using GPS data coming from smartphones. We have introduced the fuzzy sets to take into account uncertainty embedded in GPS data when trying to identify the position of cars within the road lanes. Moreover, we introduced a Genetic Algorithm to calibrate the fuzzy parameters in order to obtain a novel supervised clustering technique. We applied the proposed method to one intersection in the urban road network of Bari (Italy). First results reveal the effectiveness of the proposed methodology when comparing the outcomes of the proposed method with two well-known clustering techniques (Fuzzy C-means, K-means).

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Keywords: Intelligent transportation systems; Global positioning system; Positioning Accuracy; Supervised custering

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1. Introduction

The analysis of issues related to the urban movement of cars has assumed an increasingly important role in recent years. The urban traffic conditions greatly slowed down and have become congested; in fact, not only create inconveniences to car drivers for the increase in the average travel time but also make a less secure circulation on the road and increase air and noise pollution.

The development of Intelligent Transport Systems and info-mobility represent an opportunities to reduce costs and road congestion, with sustainable timing. In the era of multimedia convergence, communication, and sensing platforms, GPS-enabled smartphones are becoming an essential contributor to location-based services. These devices combine the advantages of mobile sensors mentioned earlier: low investment costs, high penetration, and high accuracy achieved by GPS receivers. In addition, GPS-enabled smartphones are able to provide accurately not only position but also speed and direction of the travel. Note that phones not only can send but also receive information. Therefore, traffic information can be delivered through this channel. Given the market penetration of mobile phones, this new sensing technology can potentially provide an exhaustive spatial and temporal coverage of the transportation network. In the mobile computing era, smartphones have become instrumental tools to develop innovative mobile context-aware systems because of their numerous sensors such as GPS, accelerometers, gyroscopes. This makes them suitable enablers to capture a wide range of contextual features, like weather and traffic conditions (Miranda-Moreno, 2015).

Real-time traffic reports are usually based on statistical methods. These methods have been also a common practice in studies that use cell phones as traffic sensors, in which the main goal has been to find the link speed or travel time estimation (Bar-Gera, 2007). Note that the aforementioned study uses cell phone antennas to obtain a cell phone position (i.e. vehicle), which is less accurate than GPS positioning. Krause et al. (2008) have investigated the use of machine learning techniques to reconstruct travel times on a graph based on sparse measurements collected from GPS devices embedded in cell phones and automobiles.

An overview of the GPS techniques is given in Skog and Handel (2009). For mapping the vehicle position in the road, sophisticated algorithms have been developed (Zhao, 2015; Fouque and Bonnifait, 2012). The usual problem in GPS positioning is that the accuracy is not within a lane-width. Therefore, solutions have to be found to get the accuracy to a lane level. Liu et al. (2017) present a recognition system for dangerous vehicle steering based on the low-cost sensors found in a smartphone, i.e. the gyroscope and the accelerometer. To identify vehicle steering maneuvers, we focus on the vehicle's angular velocity, which is characterized by gyroscope data from a smartphone mounted in the vehicle. Recently, there has been much related research on lane determination involving the use of the camera (Wang et al., 2009), Differential GPS (Moon et al., 2010), vehicle to vehicle communication (Basnayake et al., 2011), or Global Navigation Satellite System (Obst et al., 2011) as fully active sensors. All of these methods require a considerable amount of equipment to be placed in the car. Other works considered the creation of lane-level maps (Zhang and Taliwal, 2003; Chen and Krumm, 2010) and methods where the smartphone itself is fully active (Mohan et al., 2008; Biagioni et al., 2011).

Sekimoto et al. (2012) proposed a simple method for using the separation distance (offset) between a smartphone GPS and the center line on a digital road map to determine the lane position of a car.

Knopp et al. (2017) presented a methodology to map the lanes on a motorway using data collected. The methodology exploits the high accuracy and the fact that the most driving is within a lane.

Astarita et al. (2017) proposed the use of information coming from connected mobile devices (on vehicles) to regulate traffic light systems.

In this work, we present a methodology for the determination and identification of a vehicle on a road lane in proximity to a signalized road intersection, using GPS-enabled smartphones. The proposed method is based on the Fuzzy set theory (Zadeh, 1965) as it is useful in dealing with uncertainty embedded in the observed data. We have used fuzzy sets to represent the membership degree of a vehicle position to a lane. Moreover, a road reference system has been defined to process GPS track data obtained by a smartphone GPS. To find the optimal distributions, we have defined a *supervised* clustering technique to efficiently evaluate the lane positioning of a vehicle through a Genetic Algorithm.