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Real-Time Traffic Data Smoothing from GPS Sparse Measures Using Fuzzy Switching Linear Models

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Abstract

Traffic is one of the urban phenomena that have been attracting substantial interest in different scientific and industrial communities since many decades. Indeed, traffic congestions can have severe negative effects on people's safety, daily activities and quality of life, resulting into economical, environmental and health burden for both governments and organizations. Traffic monitoring has become a hot multi-disciplinary research topic that aims to minimize traffic's negative effects by developing intelligent techniques for accurate traffic states' estimation, control and prediction. In this paper, we propose a novel algorithm for traffic state estimation from GPS data and using fuzzy switching linear models. The use of fuzzy switches allows the representation of intermediate traffic states, which provides more accurate traffic estimation compared to the traditional hard switching models, and consequently enables making better proactive and in-time decisions. The proposed algorithm has been tested on open traffic datasets collected in England, 2014. The results of the experiments are promising, with a maximum absolute relative error equal to 9.04%.

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Keywords: Traffic state estimation, Gaussian linear models, fuzzy switching system.

1. Introduction

Traffic is one of the urban phenomena that have been attracting substantial interest in different scientific communities for many decades. Indeed, traffic congestions can have severe negative effects on people's safety, daily activities and quality of life, resulting into economical, environmental and health burden for both governments and organizations. Traffic monitoring has become a hot multi-disciplinary research topic that aims to minimize traffic's negative effects by developing intelligent techniques for accurate traffic states estimation, control and prediction. Moreover, recent progress in information and communication technologies has dramatically changed traffic data acquisition techniques, leading to a switch from the traditional so-called *Eulerian* perspective to the *Lagrangian* one[1]. In the former perspective, fixed sensing equipments (e.g., loop detectors, video and radar cameras) are installed in fixed and pre-selected road parcels (segments) and / or intersections, and are used to collect traffic data in those particular segments / intersections (e.g., traffic flow and traffic density). This perspective is infrastructure-intensive and allows for traffic estimation only at certain locations of the transportation network. In the *Lagrangian* perspective, traffic data are collected by mobile sensors that are moving within the transportation network, which

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allows for covering the whole transportation network. The *Lagrangian* perspective can be implemented either in controlled or uncontrolled mode. In the controlled mode, dedicated vehicle probes are equipped with GPS receivers and communication links, and are exclusively used to move within the transportation network and collect traffic data. Where and when traffic data is collected is somehow controlled by probes' trajectories, but accurate results require a minimum penetration rate[2]. On the other hand, uncontrolled mode is based on the use of mobile phones of road' users as sensors to collect traffic data. This mode takes benefit of the progress in the mobile communication technology to provide cheaper data collection solutions that do not need additional infrastructure's investment and maintenance costs, compared to the Eulerian and controlled Lagrangian approaches. However, relying on drivers' mobile phones to collect data raises one main challenge: the data collection process is opportunistic, in the sense that it is not possible to control where and when data will be collected in the transportation network. This depends both on the availability of the communication network (network coverage) and the presence of connected smart phones (switched-on) in space and time, leading to incomplete traffic data because of the gaps in the acquisition process. Moreover, due to the heterogeneity of measurement sources (in terms of accuracy, connectivity or redundant readings), the collected data are also noisy. Hence, a filtering pre-processing step is necessary to both remove noise and fill in the data gaps by estimating the missing traffic data.

In this paper, we address the problem of data incompleteness, and we propose a solution for real-time, short-term macroscopic traffic data estimation and prediction in the context of mobile sensor-based traffic data acquisition (Figure 1). In this solution, current traffic speed and density in every road parcel g_i - denoted by $d(g_i, t)$ and $s(g_i, t)$, respectively- are sensed by drivers' smartphones and sent to a central Intelligent Transportation System (ITS). The ITS stores the collected data in a Traffic Data Repository (TDR) and updates the parameters used for the estimation and prediction model. Then, the ITS calculates the predicted parcel's density and speed (respectively denoted by $d(g_i, t+1)$ and $s(g_i, t+1)$in Figure 1) and sends them back to end-users' smartphones, along with the file containing current updated estimation parameters (denoted by Θ_t). The ITS also uses the updated parameters to estimate the missing traffic data and to fill the gaps in the TDR. In case there is no internet connection, the prediction can be carried out on the end-users' mobile phones, but using the last estimation parameters received from the ITS for the corresponding road parcel (denoted by Θ_{t-1}). The main contribution of our solution is the use of a Fuzzy Switching Linear Model to implement a novel smoothing algorithm for traffic data estimation / prediction. Indeed, several filtering algorithms have been proposed in the literature, including Kalman filtering[3], ARIMA[4], SARIMA[5] and particle filtering[6] approaches. To the best of our knowledge, fuzzy switching linear models have not been used in the existing filtering approaches, which attribute two main advantages to our algorithm. In the one hand, the algorithm is linear and has an efficient computation time. Hence, it is suitable for real-time applications, and it can be run on end-users' smartphones if the internet connection is not available. On the other hand, the use of fuzzy switching techniques leads to more precise prediction results, given that it is possible to differentiate between more traffic states (e.g., slow, medium and heavy congestion), compared to the two common states in the classic switching models (congested vs. not congested).

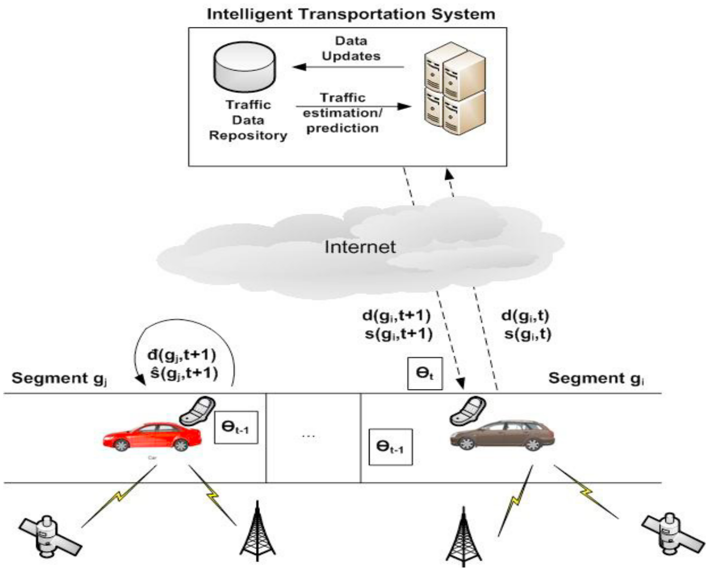

Figure 1: An architecture for smartphone-based real-time traffic data estimation and prediction.

In this paper we only present our proposed estimation algorithm, and the paper is structured as follows. In Section 2 we introduce macroscopic traffic flow modeling concepts. In Section 3 we outline the problem of traffic data acquisition using mobile probes. The estimation algorithm is detailed in Section 4, while an experimental study is presented in Section 5. Section 6 concludes the paper and outlines our future work.