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Urban traffic congestion estimation and prediction based on floating car trajectory data

Xiangjie Kong [a], Zhenzhen Xu [a,*], Guojiang Shen [b], Jinzhong Wang [a], Qiuyuan Yang [a], Benshi Zhang [a]

[a] School of Software, Dalian University of Technology, Dalian 116620, China

[b] College of Computer Science and Technology, Zhejiang University of Technology, Hangzhou 310023, China

HIGHLIGHTS

- Floating car trajectory data can be used to predict traffic congestion effectively.
- A Fuzzy Comprehensive Evaluation method with dynamic adaptive weight is introduced.
- A Traffic Flow Prediction method utilizing particle swarm optimization is proposed.
- Experiments verify methods' performances in accuracy, instantaneity and stability.

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ABSTRACT

Traffic flow prediction is an important precondition to alleviate traffic congestion in large-scale urban areas. Recently, some estimation and prediction methods have been proposed to predict the traffic congestion with respect to different metrics such as accuracy, instantaneity and stability. Nevertheless, there is a lack of unified method to address the three performance aspects systematically. In this paper, we propose a novel approach to estimate and predict the urban traffic congestion using floating car trajectory data efficiently. In this method, floating cars are regarded as mobile sensors, which can probe a large scale of urban traffic flows in real time. In order to estimate the traffic congestion, we make use of a new fuzzy comprehensive evaluation method in which the weights of multi-indexes are assigned according to the traffic flows. To predict the traffic congestion, an innovative traffic flow prediction method using particle swarm optimization algorithm is responsible for calculating the traffic flow parameters. Then, a congestion state fuzzy division module is applied to convert the predicted flow parameters to citizens' cognitive congestion state. Experimental results show that our proposed method has advantage in terms of accuracy, instantaneity and stability.

1. Introduction

Urban traffic congestion has become a critical problem that not only affects the people's daily lives, but also restricts the stable development of society and economy [1,2]. Hence, it is urgent to ease the traffic congestion, especially the recurrent congestion. Nevertheless, urban traffic flow is complex and constantly changing, and then it is difficult for travelers to acquire the current and the future traffic condition at road sections.

There are two major challenging problems that should be answered to perform urban traffic congestion estimation and prediction. Firstly, how to estimate and predict the traffic congestion in large-scale urban areas? Floating car, namely Global Position System (GPS)-equipped taxi, is an effective way to collect the real-time traffic flow data in a large-scale road network, which can be regarded as ubiquitous mobile sensors probing a city's rhythm and pulse [3]. In addition, floating car has more acceptable cost than the traditional methods with fixed sensors collecting data at fixed trunks or major intersections. Secondly, how to improve the accuracy, instantaneity and stability of traffic congestion estimation and prediction? The existing methods have not addressed the three performance aspects systematically.

We propose a novel method using floating car trajectory data to improve the overall performance of traffic congestion estimation and prediction. The paper is based on our previous work [4]. The

* Corresponding author.
E-mail address: xzz@dlut.edu.cn (Z. Xu).

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major difference between this work and the prior one lies on the proposal of new traffic congestion estimation method and the improvement of traffic congestion prediction combined with the new estimation module.

In the matter of traffic congestion estimation, we propose a Fuzzy Comprehensive Evaluation (FCE) method in which the weights and the fuzzy matrix of multi-indexes can be adapted according to the traffic flows. Assigning the multi-indexes weights in accordance with the congested traffic flow dynamically improves the estimation accuracy and instantaneity performance in comparison to the fixed weighting method.

For traffic congestion prediction, we propose a novel method including Traffic Flow Prediction (TFP) and Congestion State Fuzzy Division (CSFD) modules. The former predicts traffic flow parameters by using Particle Swarm Optimization (PSO) algorithm. The latter converts the predicted traffic flow parameters to citizens' cognitive congestion state using the proposed FCE method. TFP module is composed by three sub modules: Traffic Volume Prediction (TVP), Traffic Speed Prediction (TSP) and PSO. TVP sub module predicts the traffic volume, while TSP sub module is for predicting average speed. Furthermore, PSO sub module optimizes the punish coefficients and the multi-kernel functions' parameters of Support Vector Machine (SVM) in TVP and TSP sub modules. The reason for choosing PSO algorithm is that it can get the optimum solution in a short time with a low computing complexity which meets the performance requirements of congestion prediction in terms of accuracy, instantaneity and stability.

The rest of this paper is organized as follows. In Section 2, we present related works about urban traffic congestion estimation and prediction. Then, our proposed congestion estimation and prediction method is introduced in Sections 3 and 4 respectively. In Section 5, experiment results are described. Finally, the paper is concluded in Section 6.

2. Related work

In this section, we present an overview of urban traffic congestion estimation and prediction methods based on the recent literature.

Pattara-Atikom et al. [5] estimated the traffic congestion using weighted exponential moving averages of measured GPS speed. Yoon et al. [6] proposed a simple yet effective method using the spatial and temporal speed information in order to estimate traffic status on surface streets with GPS location data. The authors in [7] estimated the traffic state by calculating the average velocities along GPS-equipped vehicles' tracks. Similarly, an improved method was presented in [8] that makes use of both time-varying and space-varying information to predict the urban traffic state based on an adaptive cubic surface traffic flow model.

Kong et al. [9] presented a systematic solution to efficiently predict traffic state by extracting the spatio-temporal average velocity from a large number of GPS probe vehicles. The method was based on a curve-fitting and vehicle-tracking mechanism. In order to improve the estimation accuracy, the same authors in [10] calculated mean speed at road section from multi-source traffic data to estimate the traffic states. Zhang et al. [11] proposed a weighted approach to estimate traffic state using GPS data by increasing the weights of recent velocity information. Li et al. [12] presented a hybrid learning framework to appropriately combine estimation results of freeway traffic density state from multiple macroscopic traffic flow models. Feng et al. [13] proposed a cooperative approach to estimate arterial travel time states including Bayesian and Expectation Maximization algorithms using GPS probe data.

The above-mentioned methods estimated the traffic state using one specific parameter such as average velocity, travel time or traffic density. However, the uncertainty and complexity of traffic state have not been studied in these methods sufficiently. To address these shortcomings, Lu et al. [14] evaluated traffic congestion state using an adaptive neuro-fuzzy inference system in which a series of fuzzy logic rules was extracted. Pongpaibool et al. [15] presented a traffic congestion estimation system from video data using manually tuned fuzzy logic. However, vehicle volume and velocity were used in this method without considering the road space information. Chen et al. [16] rendered a tracking-based method using Pareto optimal decision theory and fuzzy comprehensive judgment in order to estimate the traffic state. Shankar et al. [17] explored advantages of fuzzy inference systems to evaluate the level of road traffic congestion using traffic density and speed information.

Related to traffic flow and congestion prediction, Su et al. [18] proposed a hybrid traffic flow prediction model using Genetic algorithm (GA) to optimize the input parameters. Then, the SVM method was used to update the prediction function through an online learning process. Similarly, Cao et al. [19] used an improved PSO algorithm to preprocess the input parameters of the SVM method. Xu et al. [20] presented a spatio-temporal variable selection method based on Support Vector Regression (SVR) model to predict traffic volume. In this method, the spatial and temporal information of all available road segments was utilized.

Hong et al. [21] presented a SVR traffic flow forecasting model using Gaussian Radial Basis Function (RBF) kernel. In this method, a hybrid Genetic Algorithm with Simulated Annealing is used to forecast the RBF suitable parameters accurately. Li et al. [22] applied SVR model with Gauss loss function (Gauss-SVR) to forecast urban traffic flow and proposed a Chaotic Cloud Particle Swarm Optimization algorithm to optimize the parameters of Gauss-SVR model. Wang et al. [23] proposed a traffic speed forecasting model using chaos–wavelet analysis and SVM to choose the appropriate kernel function. Wang et al. [24] proved that selecting the appropriate SVR parameters improves the prediction of traffic flow in terms of the instantaneity and accuracy performance metrics. Gong et al. [25] proposed a traffic volume forecasting model based on SVR and analyzed the nature of the RBF kernel function.

The discussed methods above only considered one kernel function of the SVM method to improve the accuracy of urban traffic state prediction, while the road traffic congestion cannot be predicted by these methods accurately. The reason is that various SVM kernel functions have different prediction accuracy and adaptability. In addition, the predicted traffic flow cannot intuitively forecast the future traffic congestion for the travelers and the traffic administrators. To tackle these shortcomings, Hen et al. [26] proposed an accurate particle filter method to predict multi-step traffic state using the speed measurements. Similarly, Dunne et al. [27] proposed a regime-based multivariate traffic condition prediction method using an Artificial Neural Network (ANN) structure with adaptive learning strategies. Min et al. [28] presented a scalable multivariate spatial–temporal autoregressive model to predict the traffic volume and speed jointly. Zhang et al. [29] proposed a robust traffic congestion prediction method based on hierarchical fuzzy rule-based systems and GA, which combines the variable selection, ranking and lateral tuning of the membership functions with optimization of the rule base.

Closely related to traffic congestion estimation and prediction, Herring et al. [30] proposed two statistical learning algorithms which use data from GPS-equipped smart phones. In this method, logistic regression and spatio-temporal autoregressive moving average models are employed to estimate and forecast the arterial traffic conditions. Castro et al. [31] proposed a method to construct a model of traffic density based on large scale taxi traces, and used the model to predict future traffic conditions according to