Three Novel Methods to Predict Traffic Time Series in Reconstructed State Spaces

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ABSTRACT

This article proposes three novel methods—temporal confined (TC), spatiotemporal confined (STC) and spatial confined (SC)—to forecast the temporal evolution of traffic parameters. The fundamental rationales are to embed one-dimensional traffic time series into reconstructed state spaces and then to perform fuzzy reasoning to infer the future changes in traffic series. The TC, STC and SC methods respectively employ different fuzzy reasoning logics to select similar historical traffic trajectories. Theil inequality coefficient and its decomposed components are used to evaluate the predicting power and source of errors. Field observed one-minute traffic counts are used to test the predicting power. The results show that overall prediction accuracies for the three methods are satisfactorily high with small systematic errors and little deviation from the observed data. It suggests that the proposed three methods can be used to capture and forecast the short-term (e.g., one-minute) temporal evolution of traffic parameters.

Keywords: Fuzzy Reasoning, Traffic Time Series Data, Forecasting

INTRODUCTION

Traffic time series is referred to as temporal evolution of traffic parameters (e.g., flow, speed, and occupancy) measured in a chronological order with identical time interval. Accurately capturing and predicting the temporal evolution of traffic parameters is prerequisite for developing and implementing many intelligent transportation systems (Stephanedes et al., 1981; Chang & Miaou, 1999; Lam et al., 2005). A smart adaptive signal control, for instance, is oftentimes established on the basis of instantaneous or predicted short-term (e.g., 5-minute) traffic data. Advanced incident detection may require even shorter-term (e.g., 1-minute) traffic data as inputs (Lan & Huang, 2006).

Techniques for predicting traffic time series can be categorized in different ways, including parametric (e.g., historical mean value algorithm, regression method, neural network algorithm, time series method, Kalman filter-
ing, compound forecasting algorithm) versus nonparametric (e.g., nonparametric regression method, wavelet filtering method), linear (e.g., autoregressive moving average or ARMA model, autoregressive integrated moving average or ARIMA models) versus nonlinear (e.g., nonlinear ARIMA, fuzzy local reconstruction method, fuzzy neighborhood method, state-space local approximation method), among others. To save space, the present article has no intention to exhaust all the relevant works on traffic prediction. A state-of-the-art review on the traffic predicting techniques has been done by Van Arem et al. (1997) and Vlahogianni et al. (2004). However, the literature on traffic prediction is full of differing conclusions and it is never easy to make a general statement.

For example, Smith and Demetsky (1997) compared historical average, time-series, neural network, and nonparametric regression models and concluded that the nonparametric regression model significantly outperformed the other models and was also easier to implement. Durbin (2000) claimed that the state space approach has advantages over the ARMA models or ARIMA models. Smith et al. (2002) compared parametric and nonparametric models and concluded that using nonparametric regression coupled with heuristic forecast generation methods would perform better than a naïve forecasting approach, which also outperformed over a classic parametric modeling approach (e.g., seasonal ARIMA models). Taking the superior capability of neural networks to approximate a nonlinear system, however, the nonlinear ARMA (NARMA) model has been claimed satisfactorily in nonlinear prediction (Bonnet, 1997).

A considerable number of literature adopted time series analysis for traffic prediction purposes (e.g., Head, 1995; Lee & Fambro, 1999; Lingras et al., 2000; Lam et al., 2006). Many literature showed that neural networks are one of the best alternatives for modeling and predicting traffic parameters because they can approximate almost any function, regardless of its degree of nonlinearity and without prior knowledge of its functional form (e.g., Clark, et al., 1993; Kirby et al., 1997; Ishak et al., 2003; Vlahogianni et al., 2005; Sheu et al., 2009). Other literature also elaborated the traffic predicting techniques with Kalman filtering (e.g., Okutani & Stephanedes, 1984; Sun et al., 2003; Wang & Papageorgiou, 2005), wavelet analysis (He & Ma, 2002; Li, 2002; Soltani, 2002), and multivariate state space approach (Stathopoulos and Karlaftis, 2003; Lan et al., 2007).

The aforementioned predicting techniques mainly examined the traffic series in one-dimensional state space. It has been shown that if one could scrutinize the traffic series in multidimensional state spaces, one could perhaps gain more information to better elucidate and/or to more accurately predict the real-world traffic evolutions (Lan et al., 2008a, 2008b). In view of this, the present article aims to develop three novel methods, which embed the one-dimensional traffic series into multidimensional spaces and then perform various fuzzy reasoning logics to predict the traffic evolutions.

The remaining parts are organized as follows. The use of a single time series to generate a reconstruction space to characterize the traffic evolution is described. Three novel methods adopting different fuzzy reasoning logics in temporal, spatiotemporal, and spatial confined domains, respectively, are then detailed. The criteria used for evaluating prediction performance are also explained. An empirical study is carried out, wherein one-minute traffic time series data directly extracted from freeway detectors are used to establish and validate the proposed prediction methods. The discussion of applicability of our proposed methods and concluding remarks are finally addressed.

**STATE SPACE RECONSTRUCTION**

Building the state space prediction models from a time series mainly involves two parts: reconstruction of the state space from data by time delay embedding and development of the methods for state-space prediction. Reconstruction of state space is to embed the one-dimensional
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