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RESEARCH PAPER

Bayesian Network Method of Speed Estimation from Single-Loop Outputs

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Abstract: Real-time and accurate traffic speed is important for a successful traffic management system. However, the most common form of the single-loop detector is incapable of providing speed measurements. This paper presents a method of speed estimation from single-loop detector data using Bayesian network method. After analyzing the causal relationship between volume, occupancy, and speed, a Bayesian network model of speed estimation is proposed using volume and occupancy from single-loop outputs. The Gaussian mixture model (GMM) and the expectation-maximization (EM) algorithm are used to represent model and train model parameters, respectively. The proposed method is implemented and evaluated using the field data from urban expressways in Beijing. Estimated speeds are compared with the observed speed data and also with results from conventional algorithm. The results show that the proposed method is robust for every kind of sampling intervals, lanes, and traffic condition. The mean absolute error holds more than 2 km/h decrease. This method can be efficiently applied in traffic management system.

Key Words: intelligent transportation; speed estimation; single-loop detector; Bayesian network

1 Introduction

Traffic speed is one of the most basic and important parameters for traffic condition description. Along with the development of intelligent transportation systems, vehicle speed for traffic stream plays a crucial role in advanced traffic management systems and advanced traffic information systems (ATIS). Typically, data collection of ATIS is conducted by inductive loop vehicle detectors embedded in roadways, which are of stable and reliable performance. Unfortunately, single-loop detectors which are the most common form used in the highway for decades cannot provide traffic speed measurements efficiently. The expense that is used to upgrade single-loop detectors to dual-loop detectors is large, meanwhile the operation of traffic flow will be interrupted. Therefore, it is of considerable significance to study speed estimation from the single-loop detector data (traffic count and occupancy).

The first research on speed estimation from single-loop outputs can be dated back to 1965, in which Athol proposed a conversion factor g method[1]. On the basis of the assumption that occupancy is linearly proportional to density, the proposed method used the flow-speed-density relationship to estimate speed. Extended Kalman filter and unscented Kalman filter were, respectively, presented to estimate speed by Dailey *et al*.[2,3]. Coifman *et al*.[4,5] noted the effect of truck volumes on speed estimation and proposed using median vehicle length rather than the mean effective vehicle length (MEVL) to estimate the speed. Pushkar *et al*.[6] used a cusp catastrophe theory model to estimate speeds from single-loop freeway flow and occupancy data, whereas Sun *et al*.[7,8] used waveforms from loop detectors to anonymously identify vehicles between detectors and estimate speed. Several researchers in China have also proposed some methods to provide speed estimation and used field and simulated data to validate these methods[9–11]. However, all the above-mentioned methods were difficult to put into practice. Most traffic information systems use common g-factor method to estimate speed, such as the Washington State Department of Transportation (WSDOT) and Transportation Systems of Chicago (TSC). In this paper, a Bayesian network method was proposed to improve performance of speed estimation.

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2 Factors of speed estimation

Traffic flow speed is defined as the harmonic average value of all vehicles in one sampling interval. However, the outputs of single-loop detector can only provide traffic volume and occupancy. To estimate the traffic speed, some additional information should be used in theory. MEVLs and the relationship between speed and occupancy have significant influences on speed estimation.

On the basis of the detection principle of loop detector, the occupation in a given sampling interval T can be calculated as follows:

$$occ(k) = \frac{\sum_{i=1}^{n(k)} \frac{l_i(k)}{v_i(k)}}{T} \quad (1)$$

where $occ(k)$ is the occupancy during sample k, $l_i(k)$ is the vehicle i's effective vehicle length during sample k, $v_i(k)$ is the vehicle i's speed during sample k, $n(k)$ is the number of vehicles that pass the detector during sample k, and T is the sampling period.

Provided that vehicle lengths and vehicle velocities are uncorrelated, which also means $E(L/V)=E(L)E(1/V)$, Eq. (1) can be rewritten as

$$occ(k) = \frac{\sum_{i=1}^{n(k)} \frac{l_i(k)}{v_i(k)}}{T} \approx \frac{\frac{\sum_{i=1}^{n(k)} l_i(k)}{n(k)} \sum_{i=1}^{n(k)} \frac{1}{v_i(k)}}{T} = \frac{q(k)\bar{l}(k)}{v_s(k)} \quad (2)$$

where $q(k)$ is the flow during sample k, $q(k)=n(k)/T$, $\bar{l}(k)$ is the MEVLs during sample k, and $v_s(k)$ is the speed during sample k.

Thus, the estimation measurement of speed can be calculated using the equation

$$\hat{v}_s(k) = \frac{q(k)\bar{l}(k)}{occ(k)} \quad (3)$$

where $\hat{v}_s(k)$ is the estimation value of the speed during sample k.

Speed estimation with single-loop detectors using Eq. (3) should set a constant value of MEVL beforehand. But in every sample, the values of MEVL changes with the different component of vehicle types. Thus, there will be some errors in speed estimation using a constant value of MEVL in every sample. On the assumption that the MEVL is a random variable in every sample, $\hat{v}_s(k)$ and $q(k)/occ(k)$ can be described as a causal relationship (Eq. (3)) with a certain probability.

On the basis of the classical traffic flow theory, the three traffic flow parameters (flow, speed, and density) have a deterministic relationship. Greenshields model, Greenberg model, and Underwood model are three important speed-occupancy relationship models. Fig. 1 presents the speed-occupancy relationship curves using field data.

Figure 1 shows that there are some stable relationships between speed and occupancy. This relationship can be used to describe the causality and present a speed estimation model.

3 Bayesian network model

3.1 Bayesian network

A Bayesian network is a probabilistic graphical model that represents a set of random variables and their conditional independencies via a directed acyclic graph. Bayesian networks are becoming an increasingly important research field and application in the entire field of artificial intelligence. They are useful for both inferential exploration of previously undetermined relationships among variables and descriptions of these relationships upon discovery. Compared with other data mining methods, such as decision trees and artificial neural network, Bayesian networks have the ability to deal with incomplete data easily, to learn the causal relationship between variables, and to make full use of domain knowledge and sample data information. Thus, after analyzing the causal relationship between traffic flow parameters, a Bayesian network model is proposed for estimating speed from single-loop detector outputs.

3.2 Model

After the analysis in Section 2, $q(k)/occ(k)$ and $occ(k)$ have a close causal relationship with average speed in sample k. Taking time series relationship into account, the traffic condition in sample k–1 has an effect on that in sample k. Thus, $q(k–1)/occ(k–1)$ and $occ(k–1)$ are also selected as input variables in Bayesian network model. The structure of the proposed Bayesian network model is shown in Fig. 2.

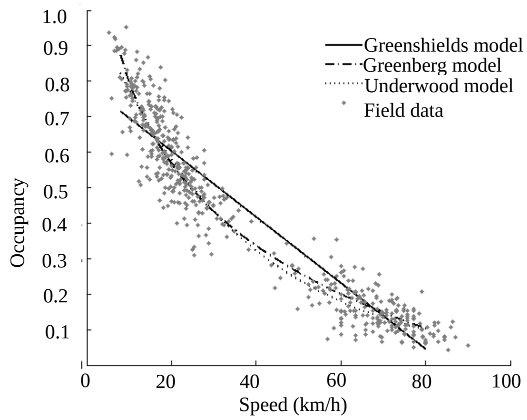

Fig. 1 Speed-occupancy relationship for different models

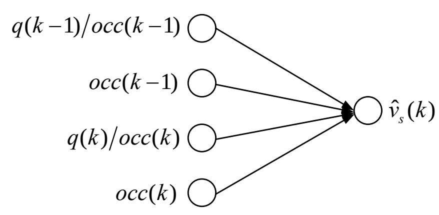

Fig. 2 Bayesian network model for speed estimation