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Innovative Applications of O.R.

Estimating freeway traffic measures from mobile phone location data

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ABSTRACT

The worldwide propagation of mobile phone and the rapid development of location technologies have provided the chance to monitor freeway traffic conditions without requiring extra infrastructure investment. Over the past decade, a number of research studies and operational tests have attempted to investigate the methods to estimate traffic measures using information from mobile phone. However, most of these works ignored the fact that each vehicle has more than one phone due to the rapid popularity of mobile phone. This paper considered the circumstance of multi-phones and proposed a relatively simplistic clustering technique to identify whether phones travel in the same vehicle. By using this technique, mobile phone data can be used to determine not only speed, but also vehicle counts by type, and therefore density. A complex simulation covering different traffic condition and location accuracy of mobile phone has been developed to evaluate the proposed approach. Simulation results indicate that location accuracy of mobile phone is a crucial factor to estimate accurate traffic measures in case of a given location frequency and the number of continuous location data. In addition, traffic demand and clustering method have a certain effect on the accuracy of traffic measures.

1. Introduction

Comprehensive and accurate traffic information is necessary to manage the freeway network and provide navigation services for the road users. Traditionally, freeway traffic measures have been obtained from the fixed sensors such as loop detectors and television cameras. Due to the high cost of the devices installation and maintenance, they are typically installed only on a relatively small portion of the freeway, thus providing limited coverage of the entire freeway network. In addition, these fixed sensors are vulnerable to extreme weather in certain areas. With the rapid development of wireless communication technologies, mobile sensors based on GPS (Global Positioning System) and mobile phones have been increasingly applied to collect traffic data in recent years. GPS-based sensors can provide better accuracy in terms of vehicle position compared with mobile-phone-based sensors, but traffic information which is acquired from a small group of vehicles equipped with GPS device is insufficient to represent general traffic flow and this may lead to a bias of real traffic information. Mobile phones become very popular at present. According to national telecommunications statistics, up to May 2012, the mobile phone penetration rate in China grows to 78.02%. So using mobile phones instead of GPS to estimate traffic measures has attracted a lot of attention. Compared with GPS-based sensors, mobile-phone-based sensors have the advantage of the ready-to-use infrastructure and the wide coverage. Moreover, mobile-phone-based sensors are less susceptible to multi-path fading from skyscrapers than GPS-based sensors (Jirapa et al., 2008). During the past years, a number of operational tests and simulated studies have attempted to investigate the feasibility of traffic measures acquisition from mobile-phone-based sensors. The first operational test was CAPITAL (Cellular Applied to ITS Tracking and Location) project, which was conducted by University of Maryland Transportation Studies Center (1997) over 27 month period in the Washington DC area and various state routes in the Virginia suburbs. The test demonstrated the location technique can provide geolocation data and vehicle speed under the proper circumstances, but the geolocation data do not appear to be accurate enough to adequately estimate speed. STRIP (System for TRaffic Information and Positioning) project conducted a field test on inter-city motorways and intra-urban motorways of Lyon (Ygnace et al., 2001). The objectives of the STRIP project were to estimate highway travel times by "Abis/A probing" location technology. Estimated travel time from mobile phones was compared with data from loop detectors both on inter-city motorways and intra-urban motorways, with a larger variation in the second case (Yim, 2003; John et al., 2011). In 2002, Finnish Road Administration and mobile phone operators conducted a study that used mobile phone data to estimate travel time. The travel time estimation from the mobile phone position was compared to License Plate

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Recognition estimation. Good results were obtained when vehicles leaving or merging with the link or stopping on the link are rare (Kummala, 2002; Virtanen, 2002). The TTECP (Travel Time Estimation Using Cell Phone) project was initiated by the Florida Department of Transportation in 2004, with an objective of investigation on mature and applicability of using mobile phones to estimate travel time. The TTECP team found by virtue of their investigations that travel time estimation in congested condition is less accurate than in free flow condition (Wunnava et al., 2007). During January–March of 2005, Hillel (2007) compared speed and travel time measurements from a cellular phone-based system with loop detector data on a 14 kilometer freeway. Good match between the two measurement methods indicated that the cellular phone-based system play a practical role for traffic information collection. From January to July of 2008, a project on traffic information acquisition from mobile phone location has been exhibited in China. Two mobile phone operators conducted experiments on several road segments of Beijing, Shanghai, Tianjin and Jinan city to obtain test values of average travel time. The accuracy of test values in the four cities is 71%, 77%, 68% and 61% respectively (Wang, 2009). Researchers from the University of California at Berkeley and Nokia Telecommunications Company performed a 7-hour field experiment to test the feasibility of using GPS-equipped cell phones as traffic probe. The travel time and velocity estimates proved to be accurate against video data (Saurabh et al., 2008). A project proposed by Transportation Development Centre of Canada showed that it is clearly feasible to use A-GPS-enabled cell phones to estimate speed. The testing on the highway was more successful than on the arterial roads (Kirk et al., 2005). Besides, simulation studies have shown the potential for the estimation of traffic measures using mobile phone location. Astarita et al. (2006) proposed a new method for estimation of vehicular flows and densities on motorways by fusing traffic counts with mobile phone counts. Numerical application on a test network showed that the precision of the estimate improves with an increase in the ratio between mobile phones on board and total vehicles on the network. Bolla and Davoli (2000) analyzed the possibility of collecting traffic parameters based on mobile phones in vehicles. The tests using traffic simulator showed a satisfactory result. Fontaine and Smith (2004) developed a test bed consisted of a microscopic traffic simulation model and an emulated WLT-based monitoring system to assess the quality of speed estimates. The researchers found that map matching, sample frequency, location error, geometric and traffic characteristics are major factors for speed estimation accuracy. David (2003) presented an invention to utilize cell phone position data for creating vehicles path profile and estimating travel time by vehicles clustering. Sohn and Hwang (2008) investigated main factors that affected the performance of the space-based mobile phones as traffic probes.

However, Most of these works including operational tests and simulated studies assumed that every vehicle has maximum one mobile phone. With the rapid popularity of mobile phone, it is necessary to consider the possibility that more than one phone locates in a vehicle. So this paper took into account the circumstance of multi-phones and proposed a clustering method to obtain individual vehicle counts and further to estimate traffic measures from mobile phone location data. The remainder of this paper is organized as follows: Section 2 describes the mobile-phone-based traffic information system. Section 3 elaborates the proposed method including path selection of mobile phone, location data preprocessing, the clustering method and traffic measures estimation. Section 4 presents a simulation experiment with the microscopic traffic simulation VISSIM which simulates the freeway network and records traffic data. Section 5 offers a conclusion along with future research topics.

2. The mobile-phone-based traffic information system

The mobile-phone-based traffic information system consists of three parts: mobile phone location, map-matching and traffic measures estimation system. Mobile phone location system generates geographical coordinates of mobile phone according to AOA (Angle of Arrival) or TDOA (Time Difference of Arrival) location technique. Map-matching techniques are in charge of integrating phone location data with digital road network data to place a phone on the correct path. Since a moving vehicle has similarity in traveling discipline with corresponding phones subscribed by drivers or passengers (called vehicle based phones), traffic measures estimation system identifies individual vehicle counts on an observed segment based on clustering algorithm so that traffic measures can be acquired.

3. Mobile-phone-based traffic measures estimation based on graph clustering

3.1. Path selection of mobile phone

Path selection of mobile phone depends on each phone consecutive positions provided by the phone network operator periodically. The position information including phone's unique ID number, geographical coordinates and signal receiving time are stored in the database. Based on the latest m (m is discussed in Section 4.1) recorded positions $(p'_{i1}, p'_{i2}, \ldots, p'_{im})$ for a special phone i, the map-matching algorithm presented below is used to select the correct phone path and determined the phone position on the selected path. Given a position p'_{ik} at time k and digital road network, the map-matching algorithm takes the roads crossing the circle centered at p'_{ik} and having radius R (maximum phone location error) as candidates for locating p'_{ik}. Assume that h^l_{ik} represents the vertical distance from p'_{ik} to candidate road l. We define the probability of a position p'_{ik} on the candidate road l as $\zeta^l_{ik} = \sqrt{1 - \left(h^l_{ik}\right)^2 / R^2}$ and the average probability of a series of positions $(p'_{i1}, p'_{i2}, \ldots, p'_{im})$ on the candidate road l as $\gamma_l = \frac{1}{m}\sum_{k=1}^{m}\zeta^l_{ik}$. The candidate road with the maximum γ_l is considered as phone path. Then the geographical positions $(p'_{i1}, p'_{i2}, \ldots, p'_{im})$ are assigned the corresponding positions $(p_{i1}, p_{i2}, \ldots, p_{im})$ on the selected path by vertical projection.

3.2. Data preprocessing of mobile phone location

As every mobile phone is a potential probe, location data collected from mobile phone do not completely originated from vehicles traveling on a freeway. For example, a number of information from mobile phones of pedestrian, of non-motorized vehicles or of stopping vehicles on a freeway can be located and interfere with the traffic measures estimation. So we should separate phones located in moving vehicles from all other phones. According to "Road Traffic Safety Law of the People's Republic of China" seventy-eighth clause, the speed for vehicle traveling on the freeway should not be less than 60 kilometers/hour and not exceed 120 kilometers/hour. Under normal circumstances, the speed ranges for pedestrian and non-motor vehicles are about 2–6 kilometers/hour and 8–16 kilometers/hour respectively. The average speed for these phones is quite different from that of moving vehicles. Consider a mobile phone i whose path profile contains m continuous position data: $(p_{i1}, p_{i2}, \ldots, p_{im})$, $p_{i1} = (x_{i1}, y_{i1})$ is the initial position, $p_{im} = (x_{im}, y_{im})$ is the current position. The average speed between p_{i1} and p_{im} is $\overline{vp}_i$. A mobile phone that travels with an average speed $\overline{vp}_i$ larger