Transportation Research Part C xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Supporting large-scale travel surveys with smartphones – A practical approach

Philippe Nitsche *, Peter Widhalm, Simon Breuss, Norbert Brändle, Peter Maurer

Austrian Institute of Technology, Giefinggasse 2, 1210 Vienna, Austria

ARTICLE INFO

Article history:
Received 15 December 2012
Received in revised form 2 September 2013
Accepted 5 November 2013
Available online xxxx

Keywords:
Smartphones
Mobility data
Travel survey
Accelerometer
GPS
Transport modes
Mode detection

ABSTRACT

Collection of travel data is a key task of transportation modeling. Data collection is currently based on costly and time-intensive questionnaires, and can thus only provide limited cross-sectional coverage and inadequate updates. There is an urgent need for technologically supported travel data acquisition tools. We present a novel approach for supporting travel surveys using data collected with smartphones. Individual trips of the person carrying the phone are automatically reconstructed and trip legs are classified into one of eight different modes of transport. This task is performed by an ensemble of probabilistic classifiers combined with a Discrete Hidden Markov Model (DHMM). Classification is based on features extracted from the motion trajectory recorded by the smartphone's positioning system and signals of the embedded accelerometer. Our approach can cope with GPS signal losses by including positioning data obtained from the mobile phone cell network, and relies solely on accelerometer features when the trajectory cannot be reconstructed with sufficient accuracy. To train and evaluate the models, 355 h of probe travel data were collected in the metropolitan area of Vienna, Austria by 15 volunteers over a period of 2 months. Distinguishing eight different transportation modes, the classification results range from 65% (train, subway) to 95% (bicycle). The increasing popularity of smartphones gives the proposed method the potential to be used on a wide-spread basis and can complement existing travel survey methods.

1. Introduction

Data collected with travel surveys provide essential information for traffic planners, public transport providers, infrastructure authorities and transportation scientists. Travel data are the basis for transportation modeling and optimization of transportation services and routing. Conventional methods for collecting data for travel surveys comprise computer-assisted telephone interviews and personal interviews, computer-assisted self-interviews, mail-back questionnaires, web-based questionnaires, traffic counting at cross sections or intersections and analyses of transport schedule inquires. Most of the above conventional methods are costly and time-intensive. Hence large-scale travel surveys have been often conducted only once in a decade. Continuous data collection has already been discussed by Edmonston and Schultze (1995) for the US census. According to Stopher and Greaves (2007), a continuous survey collects data of a certain sample of households on a continuous basis. Acquired data is then averaged over a pre-defined period and provides up-to-date information about travel behavior in the region of interest.

* Corresponding author. Tel.: +43 50550 6517; fax: +43 50550 6599.
E-mail addresses: philippe.nitsche@ait.ac.at (P. Nitsche), peter.widhalm@ait.ac.at (P. Widhalm), simon.breuss@ait.ac.at (S. Breuss), norbert.braendle@ait.ac.at (N. Brändle), peter.maurer@ait.ac.at (P. Maurer).

0968-090X/$ - see front matter
http://dx.doi.org/10.1016/j.trc.2013.11.005

In addition to the cost factor, conventional surveys are also affected by non-response issues and underreported trips, see Abraham et al. (2006), Brög et al. (1982), Groves and Couper (1998), Groves (2006), Richardson et al. (1996) or Zmud and Arce (2000). Since the late 1990s, technologies such as Global Positioning System (GPS) devices have been utilized as a supplement to measure people travel. One of the first household surveys with a GPS subcomponent was conducted in 1997 in Austin, Texas, followed by many studies to examine the application of GPS for inferring travel behavior (Bohte and Maat, 2009; Gong et al., 2012; Marchal et al., 2011; Murakami and Wagner, 1999; Pearson, 2001; Stenneth et al., 2011; Stopher et al., 2008; Wolf et al., 2001a, 2001b). The results of these studies indicate the potential of GPS devices (portable or mounted in household vehicles) to replace or supplement traditional methods – often combined with Geographic Information Systems (GIS). Nevertheless, the most common problems of GPS devices for travel surveys are still signal losses in shadowed areas such as urban canyons (Gong et al., 2012) or underground transportation systems, high energy consumption and the acceptance of users carrying the device during daily travel.

The increasing popularity of smartphones opens novel opportunities for collecting data for travel surveys. Asakura and Hato (2004) studied the use of the location positioning function of cellular phone systems for tracking individual travel behavior and demonstrated the feasibility of mobile phone sensing for travel surveys. Bierlaire et al. (2010) proposes a method for estimating route choice models from smartphone GPS data and achieved satisfactory results, although the sample size was limited. A typical smartphone contains several internal MEMS (micro-electro-mechanical systems) sensors (e.g. accelerometer, magnetometer, gyroscope) and two different positioning services. They offer precise self-positioning via Assisted-GPS and approximate network positioning using GSM Cell IDs and WIFI SSIDs. This means a rich set of data sources, which can be exploited for classifying mobility behavior.

Existing approaches for utilizing smartphones can be summarized as follows: (1) they require an uninterrupted GPS lock to guarantee high quality positioning and speed information available throughout the data collection (Reddy et al., 2010; Stenneth et al., 2011), and (2) they can distinguish only a very small number of transportation modes such as "still", "walk" and "motorized" (Anderson and Muller, 2006; Ayu et al., 2011; Gonzalez et al., 2008; Liao et al., 2007; Sohn et al., 2006; Zheng et al., 2008). However, a practical approach with true potential to replace conventional surveys must cope with imperfect GPS data: during normal daily activities, the integrated GPS receiver of cell phones is often severely shielded, e.g. when the phone is carried in a bag or covered by clothing. Furthermore, a practical approach should infer the modes of all trip legs of a trip chain. Fig. 1 illustrates the concept of trip legs, which are defined as segments of a trip separated by transport mode changes or intervening activities with a short dwell time (cf. McGuckin and Nakamoto, 2004).

We present a novel practical approach for supporting travel survey that (1) alleviates the problems of GPS satellite losses by including positioning data obtained from the cellular network and accelerometer readings and (2) infers a richer set of transport mode categories. Accelerometers provide rotational and translational movement information. Based on this data, our approach can reconstruct trips even with weak or no satellite coverage. GPS and accelerometer features are extracted to train a classifier, similar to the work by Kwapisz et al. (2011), Sun et al. (2010), Wang et al. (2010) or Yang (2009). In contrast to previous research, we distinguish between eight different, fine-grained transport mode categories and deal with real-world smartphone data without requiring the respondent to wait for a GPS lock or removing trips with GPS signal losses in a pre-filtering step. Recognizing specific patterns in the frequency and time domain of the accelerometer signals allows

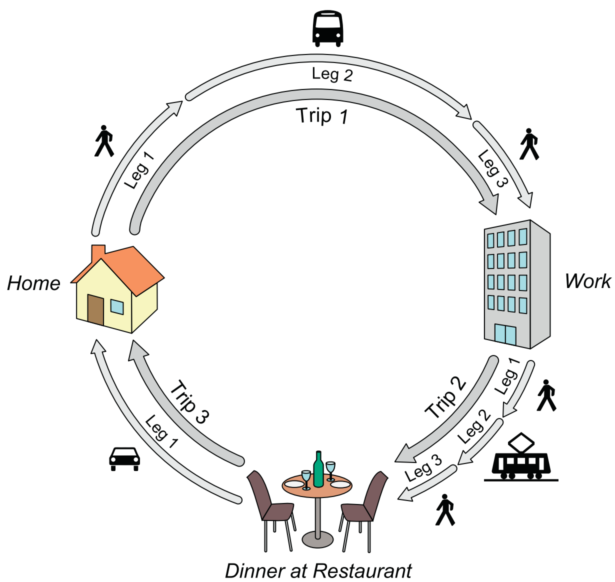

Fig. 1. Illustration of an exemplary trip chain with trips and trip legs.