Transportation Research Part C 69 (2016) 313–327

Contents lists available at ScienceDirect

Transportation Research Part C

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

An inference engine for smartphones to preprocess data and detect stationary and transportation modes

Hamid Reza Eftekhari [a], Mehdi Ghatee [a,b,*]

[a] Department of Computer Science, Amirkabir University of Technology, N. 424, Hafez Avenue, Tehran 15875-4413, Iran
[b] Intelligent Transportation Systems Research Institute, Amirkabir University of Technology, Tehran, Iran

ARTICLE INFO

Article history:
Received 27 July 2015
Received in revised form 4 May 2016
Accepted 7 June 2016
Available online 20 June 2016

Keywords:
Intelligent Transportation Systems
Mode detection
Smartphone sensors
Inference engine

ABSTRACT

A smartphone can be utilized as a cost-effective device for the purposes of intelligent transportation system. To detect the movement and the stationary statuses in the motorized and non-motorized modes, this study develops a new inference engine, including two sets of rules. The first sets of rules are defined by the related thresholds on the features of smartphone sensors while the second sets are extracted from the human knowledge to improve the results of the first rules. The experimental results reveal that by utilizing Inertial Measurement Unit (IMU) sensors in the proposed inference engine, it is possible to save 40% energy in comparison with the previous research. Moreover, this engine increases the accuracy of the motorized mode detection to 95.2% and determines the stationary states in motorized mode with 97.1% accuracy.

1. Introduction

The ability of smartphones to recognize driver behavior encourages researchers to analyze the data provided by smartphone sensors for Intelligent Transportation Systems (ITS). Zhang et al. (2010) used the data generated by smartphones to recognize driver behavior, Bhoraskar et al. (2012) and Eriksson et al. (2008) used it to detect road abnormalities, Mohan et al. (2008) to monitor traffic, and White et al. (2011) to detect accidents. A drawback to these approaches is that a great deal of smartphone data concerns time intervals for which the driver is outside of the vehicle. These parts are not useful for ITS applications and their storage and processing are expensive and may cause false detection. On the other hand, the use of smartphones in some ITS applications requires prepossessing to detect whether or not the smartphone is inside a vehicle. This prepossessing phase must be done continuously over the course of a day (Ghorpade et al., 2015). For example, for accident detection, road surface classification, and connection between on-board devices and drivers, such preprocessing is important.

To respond to this need, the present study developed a method of recognizing the motorized mode independent of motorized mode and traffic conditions. Good accuracy and low energy consumption are two important properties of this solution. Because other solutions based on GPS consume a large amount of energy and their accuracy is dependent on the environment, it is reasonable to search for better alternatives to GPS sensors. Previous techniques independent of GPS (or Wi-Fi) suffer from low accuracy. Major efforts in this area have been reviewed by Engelbrecht et al. (2015) and Hoseini-Tabatabaei et al. (2013).

* Corresponding author at: Department of Computer Science, Amirkabir University of Technology, N. 424, Hafez Avenue, Tehran 15875-4413, Iran.
E-mail address: ghatee@aut.ac.ir (M. Ghatee).

http://dx.doi.org/10.1016/j.trc.2016.06.005
0968-090X/

Table 1 compares recent literature on smartphone-based systems in transportation concepts. The determination of smartphone location and scientific gaps in the methods are presented based on application category. The similarity of sensor data for motorized and non-motorized modes, particularly under stop and continual stop-and-go conditions, and the use of the smartphones by users make it difficult to detect the motorized intervals accurately (Garg and Singh, 2014). Some drawbacks of published efforts are as follows:

- Use of sensors with high energy consumption or unavailability of continuous sensors (Reddy et al., 2010; Gong et al., 2012)
- Use of heavy processing methods (Hemminki et al., 2013)
- Inability to distinguish between stationary and moving states in motorized mode (Manzoni et al., 2010)
- Low accuracy (Miluzzo et al., 2008; Wang et al., 2010).

Zheng et al. (2010) determined the walking, biking, bus travel, and vehicle travel modes using GPS. The walking mode was detected with 83% accuracy compared with the vehicle mode. High energy consumption of GPS sensors and the inability to

Table 1
Contributions of the smartphone based intelligent transportation systems.

Name	Category	Contribution of the paper	Necessary comments
Aldunate et al. (2013)	Accident detection	They assumed that the smartphones are inside the vehicles without any contribution for finding its location	Accident detection with threshold velocity of 60 km/h to distinguish between motorized and non-motorized modes
White et al. (2011)	Accident detection and traffic monitoring		Usable only for high speed situations
Vaiana et al. (2014)	Driver behavior recognition		
Fazeen et al. (2012)			
Chaovalit et al. (2013)			
Paefgen et al. (2012)			
Chu et al. (2014)			
Eren et al. (2012)			
Eriksson et al. (2008)	Pavement monitoring		
Mednis et al. (2011)			
Bhoraskar et al. (2012)			
Perttunen et al. (2011)			
Astarita et al. (2012)			
Thiagarajan et al. (2010)	User tracking	Walking mode detection	Using high energy consuming GPS sensor and Wi-Fi to detect non-walking states including biking, all stationary states, working with smartphone in stationary states and in vehicle
Reddy et al. (2010)	Mode detection	Motorized mode detection	Detection with 94% accuracy by using high energy consuming sensor GPS
Gong et al. (2012)			Detection with 92% accuracy by using high energy consuming sensor GPS
Zheng et al. (2010)			Detection with 83% accuracy by using high energy consuming sensor GPS
Sohn et al. (2006)			Detection with 85% accuracy, however low accuracy for stationary mode detection (<60%)
Hemminki et al. (2013)			Detection with 85% accuracy, however low accuracy in sensitive application such as accident detection
Wang et al. (2010)			
Manzoni et al. (2010)			Detection with 82% accuracy, however low accuracy in sensitive application such as accident detection
Miluzzo et al. (2008)			Detection with 69% accuracy
Anderson and Muller (2006)			
Yang (2009)			Detection with 66% accuracy using simplified features and somewhat high energy consumption
Wang et al. (2009)			Detection with 74% accuracy
Mohan et al. (2008)	Pavement monitoring and Traffic condition		Using Accelerometer and GSM without any report for motorized mode detection
Hong et al. (2014)	Driver behavior Recognition	They are activated by users	Connection with OBD
Dai et al. (2010)			Manual activation and installation in each trip
Wahlstrom et al. (2015)			
Johnson and Trivedi (2011)			
Castignani et al. (2013)			