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Toward a mobile crowdsensing system for road surface assessment

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ABSTRACT

Road surface roughness assessment plays an important role in transportation infrastructure management. Many approaches have been proposed to assess road surface conditions, however, most of these are either labor-intensive tasks or make use of specialized and expensive instruments. The concept of "citizen sensing", which takes advantages of the sensor-rich smartphones, has been employed by scientists because of its low-cost and high-efficiency. This paper presents a novel crowdsensing-based system for road surface assessment using smartphones. The built-in GPS receiver and an accelerometer in smartphones are utilized to capture a spatial series of the geo-referenced *Z*-axis accelerations of the road surface, which are used to compute two assessment indexes that aid in determining the road quality. Field tests of the proposed system demonstrate that the condition of the road surface can be effectively identified and the transient events can be properly detected and located by mining the crowd sensed data.

1. Introduction

Road surface roughness has been assessed as a significant factor in road maintenance, management, and construction. Road surface transient events, such as potholes and bumps, not only impact road quality but also affect driver safety, fuel consumption and road maintenance (Beuving, De Jonghe, Goos, Lindahl, & Stawiarski, 2004; Vittorio et al., 2014). The World Bank has identified road roughness as a primary factor in the analysis of road quality vs. user cost. Many studies have demonstrated that the improvement of road surface conditions could directly promote fuel efficiency as well as driving safety (Beuving et al., 2004; Vittorio et al., 2014).

Studies have been carried out on the road surface roughness assessment since the 1950s. Several approaches, which require the use of costly and sophisticated vehicular instruments have been proposed and widely accepted, such as using laser profilometers to calculate the international roughness index (Paterson & Attoh-Okine, 1992; Watanatada, 1987), computing deflection basin parameters by deflectometers (Kim, 2001; Xu, Ranji Ranjithan, & Richard Kim, 2002) or using ground penetrating radar to determine the conditions of the roads (Cao, Labuz, & Guzina, 2011). However, these traditional assessment methods are labor-intensive and time-consuming requiring professional knowledge and high-end instrumentation (Harrison & Park, 2008). Most local governments and small municipalities cannot afford the high cost of these methods with a limited budget.

New detection methods have been proposed over the past few years, which can achieve a higher road revisiting rate and lower equipment cost (Allouch, Koubaa, Abbes, & Ammar, 2017; Astarita et al., 2012; Bhoraskar, Vankadhara, Raman, & Kulkarni, 2012; Eriksson et al., 2008; Macias, Suarez, & Lloret, 2013). These methods are used to monitor the ever-changing road surfaces by extracting the road surface anomalies and their corresponding locations. With various sensor technologies and the powerful computing capabilities, the use of smartphone sensing in research is proliferating. Smartphones equipped with a number of built-in sensors can be used to support various customized applications, which have been identified as promising platforms and can be used for mobile geospatial computing (Chen & Guinness, 2014). Built-in smartphone accelerometers have been utilized to detect ground vehicle jitters caused by the non-flatness of the road surface (Bhoraskar et al., 2012; Chen & Guinness, 2014). More importantly, by combining the accelerometer and GPS data obtained from a smartphone, the road roughness can be automatically geo-referenced (Aleadelat & Ksaibati, 2017; Astarita et al., 2012; Das, Mohan, Padmanabhan, Ramjee, & Sharma, 2010; Eriksson et al., 2008; Perttunen et al., 2011).

1.1. Related work

Threshold techniques have been broadly used to extract road surface transient events. A real-time pothole detection system was designed by Mednis, Strazdins, Zviedris, Kanonirs, and Selavo (2011). Four different transient events detection techniques were compared in this study. The system is designed mainly based on threshold technique. The overall accuracy can reach 90%. Harikrishnan and Gopi (2017)

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applied Gaussian Model on the *Z*-axis readings of built-in smartphone accelerometer for detecting and classifying bumps and potholes. The research hypothesis is that the *Z*-axis acceleration should fit on a Gaussian distribution. In this study, the vehicle vibration data was collected from a horizontally fixed smartphone and segmented into groups. A newly designed Max-Abs filter was applied on the segmented data for minimizing the small acceleration spikes and highlighting the abnormal events. Threshold technique was applied to classify the abnormal events as potholes and bumps. The accuracy of detection and classification of this method can up to be 100%.

Several studies investigated the relationship between road surface roughness and accelerometer readings. Amador-Jiménez and Matout (2014) have proposed a low-cost solution for road surface evaluation using tablets' built-in accelerometer. In this study, the Root Mean Square (RMS) of the *Z*-axis acceleration normalized by vehicle speed was confirmed as a proxy for the International Roughness Index (IRI), which can be used to examine the road quality. Aleadelat and Ksaibati (2017) tested the relationship between the *Z*-axis acceleration and the present serviceability index (PSI). PSI is a widely-used index for assessing pavement condition. In this study, two smartphones were horizontally fixed on the vehicle's dashboard. An Android app "*AndroSensor*" was used for data collection at two driving speeds: 40 mph and 50 mph. The result demonstrates that the *Z*-axis acceleration has a strong linear relationship with PSI.

Many different machine learning methods have also been employed for assessing road surface condition. Eriksson et al. (2008) proposed a signal processing and machine learning based approach to extract potholes from the readings of external GPS and accelerometer. 7 taxis were used in the test for data collection. Sensors were fixed at different positions inside the vehicle. The result demonstrated the pothole and other transient events can be effectively identified by the proposed method. Perttunen et al. (2011) proposed a solution to extract road surface anomalies (e.g. pothole, bumps) from acceleration data and GPS readings. Kalman filter was implemented to reduce the noise of GPS signal. A spectral analysis was performed on the acceleration signal to extract road features. Support Vector Machine (SVM) was used to predict three categories of transient events (i.e., speed bump, bump, and large pothole). Bhoraskar et al. (2012) designed a traffic monitoring system, which uses the detected braking events and vertical acceleration peaks to estimate the traffic congestion and examine potholes. To translate the acceleration from the frame of the portable device to the frame of the vehicle, a 3-axis accelerometers re-orientation was carried out in the system. SVM and K-means Clustering were implemented to predict road surface condition (identified as "bumpy road" or "smooth road") and optimize the assessment result of each road segment. Singh, Bansal, Sofat, and Aggarwal (2017) proposed a new method to detect bumps and potholes using smartphone sensors. An Android app "Smart-Patrolling" was created and employed for data collection. Five filters (Speed, Virtual Re-Orientation, Filtering Z-axis, SMA and Band-Pass filter) and Dynamic Time Warping (DTM) techniques are applied. In this study, smartphones were fixed inside the vehicle at different places including front dashboard pilot, font dashboard co-pilot, and back seat. The ground truth (unique patterns of accelerometer readings corresponding to these bumps and potholes) was collected during training phase and used as the template references. The accuracy of this method for detecting potholes and bumps is 88.66% and 88.89%. Allouch et al. (2017) implemented a machine learning method to estimate road surface condition. An Android app "Road Data Collector" is created for data. In the training phase, the real road quality was manually labeled as "Smooth" or "Potholed" using designed smartphone app. Different road segments' features were extracted from the readings of accelerometer and gyroscope. Correlation-based Feature Selection (CFS) approach was applied to the training dataset to optimize the feature selection. Three different machine learning methods (C4.5 Decision Tree, Support Vector Machines, and Naïve Bayes) were tested in this study. The result demonstrated that C4.5 classifier has the best performance with an overall accuracy of 98.6%.

Utilizing a crowdsensing method to obtain road surface roughness data would be exceptionally beneficial, as it would allow the data to be frequently updated, resulting in more accurate result, and would involve a minimal cost for local governments. Some researchers have tried to design a crowdsensing system, which can continuously monitor the changes of road surface condition. Chen, Lu, Tan, and Wu (2013) designed a system called CRSM, which has the potential to detect the potholes and assess the road surface quality effectively. This approach takes advantages of the crowd sensed data by utilizing specialized hardware modules (low-cost GPS receiver and accelerometer) mounted on the vehicles. A lightweight data mining approach was employed in this system with 100 taxis recruited for data collection. The accuracy of this system is about 90%. Lima, Amorim, Pereira, Ribeiro, and Oliveira (2016) proposed a simple lightweight smartphone-based approach, which can recognize road quality as "Good", "Normal", "Bad", and "Terrible". This study makes use of threshold technique with a bunch of thresholds are set through the empirical tests to recognize road quality. This study performed a crowdsourcing solution. Crowd sensed results were simply averaged and then mapped using GoogleMaps API.

A comparison of existing methods is detailed in Table 1, which reflects the following problems that need to be addressed: 1) the repeatability of threshold-based methods is limited. Thresholds need to be adjusted and retested when applied under different conditions; 2) machine learning methods require an extensive training phase, which is time-consuming and not suitable for the crowdsensing system; 3) most studies just focus on the transient events detection. A comprehensive road surface assessment is lacking; 4) very few studies utilize crowdsensing approaches, which just simply averages the crowd sensed data. An improved crowdsensing solution for assessing road surface condition need to be further explored.

1.2. Key contributions

This study presents a preliminary mobile crowdsensing system for road surface roughness detection, which includes a mobile data-collecting component and a web-based data server component. It takes advantages of previous studies but differs in following three aspects: 1) **a detailed crowdsensing solution:** An iOS app *Crowdsense* and an Android app *AndroSensor* are utilized in this study for data collection. This paper provides a detailed result optimization by integrating crowd sensed data; 2) **with comprehensive road condition assessment:** Instead of just focusing on the pothole or bump detection, a more comprehensive assessment of road conditions is introduced including an overall road condition estimation, IRI-proxy calculation, and transient events (bumps/potholes) detection; 3) **a cloud-based data server:** A low-cost, lightweight, cloud-based system framework, which takes advantages of free Google services, is developed in the study. Google Fusion Table is tested and innovatively applied in the model for data visualization.

To verify the proposed solution, a preliminary model for crowdsensing road surface roughness is created, and a detailed experiment is designed and conducted in the city of College Station, Texas.

2. Methodology

This section discusses the research methodologies. First, the system architecture is introduced. The strategy of the proposed road surface assessment is elaborated upon. A detailed explanation of the mathematical algorithm, which is used for evaluating road surface conditions and computing two assessment indexes, is also given in this section. The rest of this chapter covers the result optimization, visualization, and publication.