Do Vehicles Sense, Detect and Locate Speed Bumps?

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Abstract

The paper presents a data-driven framework and related field studies on the use of supervised machine learning and smartphone technology for the detection and georeferencing of speed bumps. The study proposes a low-cost and automated method to obtain up-to-date information about speed bumps, with the use of smartphones mounted on vehicles. The proposed methodology is based on readily available and accurate technologies, it can be utilized in crowd-sourced applications for pavement management systems (PMS) and geographical information system (GIS) implementations, and it has already been field-tested for the detection and classification of cracks, rutting, raveling, patches and potholes, exhibiting accuracy levels higher than 90%. The smartphone-based data collection and speed-bump detection algorithms discussed in this paper are complemented with robust regression analysis and Random Under Sampling (RUS) Boosted trees classification models. Ongoing work will further investigate the automated measurement of the geometric properties of the detected bumps and their compliance to regulatory requirements.

Keywords: Road anomaly detection; Smartphones technology; Robust Regression; Classification models

1. Main text

Informed drivers on infrastructure quality and getting back information from the same users, has become the new frontier on smartphone applications for driving assistance and navigation. Since speed bumps (if they are not constructed by regulations) can damage vehicles, cause unpleasant driving and, in many cases, be the reason for traffic accidents, injuries and/or fatalities, it is widely accepted that ride quality and safety are greatly impacted by the anomalies in the roadway pavement surface. Nowadays pavement monitoring agencies typically assess pavement quality approximately only once per year even though it is widely accepted that the continuous monitoring of roadway anomalies would improve the ride quality and the safety of travelers. The reason for this low frequency of inspections is the fact that current methods are expensive and laborious.

In current years smartphone technology has gained significant consideration within transportation, infrastructure and automotive industries. Standard-model smartphones come with a variety of built-in sensors such as accelerometer, gyroscope and GPS sensors. Further onboard diagnostic (OBD) Bluetooth devices coupled with specialized smartphones applications enable monitoring of, among others, GPS latitude and longitude, forward and lateral acceleration, vehicle roll and vehicle pitch. The study discussed herein examines the use of smartphone applications, in the interest of improving the condition evaluation of roadway pavements, and by extension it studies the possibility that smartphone-based data and tools could contribute to efficiently monitoring the condition of transport infrastructure.

The evaluation of roadways by current automated data collection methods is conducted periodically because of their high cost; the combined cost of pavement imaging and analysis range from $15 to $52 per kilometer McGhee (2004). In such an evaluation process, very important are the stages related to data collection, the classification of pavement anomalies and the spatial mapping of the pavement conditions. These stages have been at many researchers’ sight over recent decades, with the work on low-cost defect detection and classification methods gaining momentum in recent years. Sigh et al. (2017) presented a smartphone based sensing and crowdsourcing technique to detect road surface conditions. The in-built sensors of the smartphone like accelerometer and GPS have been used to observe the road conditions. The motivation of their work is to improve the classification accuracy of detecting road surface conditions using the Dynamic Time Warping (DTW) technique which can automatically cope with time deformations and different speeds associated with datetime data. Their technique shows a detection accuracy rate of 88.66% and 88.89% for potholes and speed bumps respectively. Varona et al. (2019) proposed a deep-learning approach that allowed the identification of different types of road surfaces and the distinction of potholes from destabilizations produced by speed bumps or driver actions. They analyzed and applied different deep learning models: convolutional neural networks, long short-term memory networks and reservoir computing models. Their experiments were carried out with real-world information and the results showed an accuracy above 95%. Kyriakou et al. (2018, 2019) proposed a low-cost automated pavement monitoring system to obtain up-
to-date information about roadway pavement surface anomalies with the use of typical smartphones mounted on vehicles. Robust regression analysis and bagged trees classification models were used to compliment smartphone-based data collection. The proposed methodology has been field-tested for the detection and classification of five types of pavement surface anomalies, (exhibiting accuracy levels higher than 90%) and it is currently expanded to include larger datasets and a bigger number of roadway pavement surface anomaly types (e.g. speed bumps).

This abstract focuses on the detection of speed bumps in two case-study roadways albeit being part of a larger effort on the detection of vibration-inducing pavement anomalies, as documented in Kyriakou et al. (2018, 2019). The data on speed bumps is collected in-situ by use of a car equipped with a smartphone (mounted on the car’s windshield) and with an OBD reader attached to it. Vehicle system data can be transmitted through the OBD reader to the smartphone device and then transferred, for either processing or storing, via a digital cellular connection or other means. Further, for visually verifying the existence of a pavement surface anomaly (as detected by the sensor data), the smartphone had also its video camera active for recording the routes travelled. The collected dataset is of high spatial resolution (at intervals of 0.1 seconds) and relates to both uni-dimensional (e.g. X, Y, Z accelerations, speed, etc.) and two-dimensional indicators (e.g. the vehicles’ roll and pitch values). Mathematically, the proposed method is based on rigid-body dynamics and the ability to express any three-dimensional rotation as a combination of yaw, pitch and roll rotations. Robust multiple regression was used in the analysis to investigate the statistical significance of the factors through the detection of outliers for both the dependent and independent variables ($R^2=1$), narrowing the most significant statistical variables (with p-values ≤0.05) to the forward and lateral acceleration, vehicle roll and the vehicle pitch. The datasets were then fed into classification models based on supervised machine learning algorithms. In order to classify and validate the data, supervised learning algorithms for multiclass problems were used and an evaluation comparison was conducted between the various classification algorithms to check their performance. Among the classification models investigated were decision trees using various classifiers, discriminant analysis, support vector machines (SVM), logistic regression, k-nearest neighbors (KNN), and ensemble classification. Supervised machine learning was performed by supplying a known set of input data (forward and lateral acceleration, vehicle roll and vehicle pitch) and known responses to the data (‘1’ for no defect, ‘2’ for speed bumps), and the data used for training the model was the basis for the generation of predictions in response to new data. The dataset in the study contained approximately 2124 points for training, 1453 points for validating and 1625 for predicting, of which 25 percent was held out for cross-validation purposes. Upon evaluating the various models against their performance on a given dataset and comparing the resulting cross-validation errors of each method, the best model for the studied problem and dataset was chosen to be the RUS Boosted trees, which rightly classifies speed bumps with approximately absolute accuracy (99.3%). The outcome of the RUS Boosted trees analysis can be mapped spatially pointing out the areas of concern and in need of rehabilitation activities. The method’s detection accuracy for the case-study dataset (of 5Km total distance, ~10 data points per geographical location, 5500 total data points, 85 data points of speed bumps) is approximately 95-98 % per run. Noted limitations of the method are the range of defects detected (only the ones causing a vibration of the vehicle) and the missing of defects not on the vehicle’s wheel path (to be solved by the use of participatory sensing).

The detection of speed bumps and their checking for compliance to national construction standards is key to road condition monitoring, which impacts transport safety and driving comfort. Transportation agencies can enrich the condition and operations of their transportation networks by putting into practice a PMS that operates on smartphone-based data collection. The abstract discusses a study on the use of smartphones for the detection of speed bumps by utilizing robust regression analysis and RUS Boosted trees classification model. Future work will develop threshold ranges for the height and width of speed bumps and will extend the proposed system to participatory sensing, by use of the fleet of vehicles of the Ministry of Transport. The proposed methodology, which is instantly obtainable, low-cost, accurate and can be utilized in crowd-sourced applications, is currently field-tested with larger datasets and a higher number of roadway defect types, and has generated interest by the Ministry of Transport, Communications and Works for possible implementation on Cyprus’s national roadway network.

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References


