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Asphalt pavement classification using smartphone accelerometer and Complexity Invariant Distance

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ABSTRACT

Most modern smartphones have a variety of built-in sensors, as an accelerometer, gyroscope, GPS, proximity and a magnetic sensor. The large variety of sensors makes these devices powerful measurement tools, allowing the emergence of new systems and applications. In this paper, is presented a real data stream application related to asphalt pavement evaluation using acceleration data gathered by the accelerometer sensor of smartphones. The quality of the pavement has a significant influence on the final price of goods and services, the safety of drivers, pedestrians and passengers, and driver's comfort. Thus, it is essential the use of tools, as proposed in this work, that allows the constant monitoring of pavement conditions by the Government authorities or private entities for more precise interventions in the maintenance planning with fewer expenses. This task is mainly important in developing countries where there is a lack of technology and a reduced budget for maintenance. Due to the popularity of smartphones, this tool can make possible that different users help to monitor the pavement quality ubiquitously during driving periods without effort. The application of asphalt evaluation is modeled in this work as a multi-dimensional time series classification problem, where the time series are the data from the three-axis accelerometer sensor. Given the characteristics of the data, we discuss and propose the combination of some classical distance measure for time series as Dynamic Time Warping or Longest Common Subsequence Similarity with the Complexity Invariant Distance. A comprehensive experimental evaluation was performed on three datasets that represent different scenarios of asphalt pavement classification. The proposed approach reaches a classification accuracy of 80% to 98% in the three evaluated problems and we experimentally show that the complexity invariance substantially improves the results achieved by classical distance measures given our classification tasks.

1. Introduction

In the last years, the number of smartphone users has rapidly increased. In 2007, the number of users worldwide was 400 million.[1] In 2016, smartphone sales to end users totaled nearly 1.5 billion units, an increase of 5 percent from 2015, according to Gartner, Inc.[2] It is expected that this number to pass the 5 billion mark by 2019.[3]

Most modern smartphones have a variety of embedded sensors, as an accelerometer, gyroscope, Global Positioning System (GPS), proximity and a magnetic sensor. These sensors allow smartphones to be used as useful measurement tools to collect a large amount of data from users and environmental. Consequently, emerge different sensing applications by portable devices as handwriting, gesture, and activity recognition (Kim et al., 2014; Liu et al., 2009; Ronao and Cho, 2016), road traffic detection (Predic and Stojanovic, 2015), among others.

In this direction, the industries of vehicles and navigation systems has gained new ways to collect data, which in turn has come to benefit drivers, vehicle owners, and society as a whole. According to Engelbrecht et al. (2015), the existing literature on vehicle sensing based on smartphones can be categorized according to the four types of

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[1] http://www.smartinsights.com/mobile-marketing/mobile-marketing-analytics/mobile-marketing-statistics/.

[2] http://www.gartner.com/newsroom/id/3609817.

[3] https://www.statista.com/statistics/330695/number-of-smartphone-users-worldwide/.

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information that are captured: (*i*) traffic; (*ii*) vehicle; (*iii*) environmental; and (*iv*) driver behavior. This information is then disseminated in various ways for different applications.

In this paper, we have a particular interest to collect the environmental information using portable devices. Specifically, information about asphalt pavement of roads and streets given by the accelerometer sensor while the user driving a vehicle.

In most of the countries, streets and roads play a key role in the transportation of cargo, products, and passengers by means of vehicles. The quality of the pavement has significant influence on the final price of goods and services, the safety of drivers, pedestrians and passengers, and driver's comfort. Thus, it is essential the use of tools that allow the constant monitoring of pavement conditions by the Government authorities or private entities for more precise interventions in the maintenance planning with fewer expenses. This task is mainly important in developing countries where there is a lack of technology and reduced budget for maintenance.

In order to reduce the effort and time cost of manual inspections made by experts or the need of use of high-cost equipment as laser profilometer, smartphones can be used to evaluate the pavement of roads and streets. Due to the popularity of smartphones, this tool can make possible that different users help to monitor the pavement quality ubiquitously during driving periods without effort.

In this paper, the task of asphalt pavement evaluation is divided into three different classification problems. In the first scenario, the goal of the classification is the identification of regular or deteriorated pavement asphalt. In the second scenario, the classification task is the identification of pavement type as cobblestone or dirt road. In the last scenario, the classification task is the identification of different obstacles in the road, as the speed bumps and raised markers.

Our problem is modeled in this paper as a time series classification task, where the time series are the data from the accelerometer sensor. As suggested by the literature, a simple One-Nearest Neighbor algorithm (1NN), with a proper distance function, presents very good results, frequently outperforming more complex classification algorithms (Ding et al., 2008). However, the choice of an adequate distance measure is essential and depends on the problem domain. Given the characteristics of the data, we discuss and propose the combination of some classical distance measure with the Complexity Invariant Distance (CID) (Batista et al., 2014).

As most of the smartphones have sensors that can measure the acceleration force on three axes (x, y, z), we have a multi-dimensional time series classification problem. We propose enrich our classifier combining the information of each acceleration axis by means of confidence levels provided by Conformal Prediction (Vovk et al., 2005) and different strategies to combine the data from different axes as majority vote and sum rule. To the best of our knowledge, the use of Conformal Prediction to combine classifiers has never been used in the literature for multi-dimensional time series classification.

Four popular distance measures for time series was evaluated alone and combined with CID: (*i*) Dynamic Time Warping (DTW), (*ii*) Longest Common Subsequence Similarity (LCSS), (*iii*) Derivative Dynamic Time Warping (DD_{DTW}), and (*iv*) Derivative Transform Distance (DTD_{DTW}). Although CID allows their use with any distance measure, the works from literature never used distance measures as LCSS, DD_{DTW}, and DTD_{DTW} with a complexity distance.

In summary, among different configurations to perform the classification task of asphalt pavement using data gathered by an accelerometer, we can suggest the use of a 1NN classifier with the distance measure CID-LCSS or CID-DD_{DTW}. With these configurations, it is possible to achieve a classification accuracy of 80% to 98% in the three classification problems evaluated in this paper.

The main contributions of this paper are the proposal of a simple and low-cost system to perform the evaluation of asphalt pavement, the collection and built of three different datasets, the proposal of Conformal Prediction for multi-dimensional time series classification, the evaluation of different distance measures for time series to choose the most adequate for the problem, and the confirmation of the importance of a complexity invariant distance to improve the results of classical distance measures.

The remainder of this paper is organized as follows. In Section 2, related works that use data from smartphones to evaluate the asphalt pavement are presented. In Section 3 is presented the data discussed and evaluated in this paper, as well as the procedures of data collection and preprocessing. Section 4 provides a background related to time series classification and distance measures. In Section 5 is presented a precise way to determine confidence levels in classification problems called Conformal Prediction. The proposed approach is presented in Section 6. The experimental evaluation is presented in Section 7. Lastly, our conclusions and future works are presented in Section 8.

2. Related work

Most of works has been devoted only to detect and report potholes. In general, these papers are based on the use of thresholds or simple analysis of the series, as the distance between two peaks. In this sense, we can consider that this work is the first one to deal with the problem of pavement evaluation as time series classification and it shows a more comprehensive experimental evaluation, never considered by other works. The works closest to our are: Pothole Patrol (Eriksson et al., 2008), Nericell (Mohan et al., 2008), the system proposed by Mednis et al. (2011), and Street Bump (Brisimi et al., 2016).

In Pothole Patrol (Eriksson et al., 2008), the three-axis acceleration data is gathered at high frequency (380 times per second) and the main goal of the system is to detect potholes. Signal processing filters are applied to reject one or more non-pothole event types as a manhole, expansion joint, and railroad crossing. The filters are based on the analysis of speed (to reject door slams and curb ramps), peaks of acceleration in the z-axis, and peaks of acceleration in the z-axis when the acceleration in the x-axis is below a threshold value. The authors report an accuracy of 92% for pothole identification

Nericell (Mohan et al., 2008) is a system to monitor road and traffic conditions. It detects potholes, braking, speed bumps, and honks using an accelerometer, microphone, GSM radio and GPS sensors of smartphones. For potholes, the detection is based on the analysis of z-values of the accelerometer. It also provides two heuristics based upon the speed of the vehicle. If speed is greater than 25 km/h, it uses z-peak heuristic where a spike along z-value above a specific threshold is classified as a pothole. At low speed, the z-sus heuristic is used which detects a sustained dip in z-value for at least 20 ms. The false negative rate for both detectors is high (20%–30%) for speed bump detection.

The system proposed by Mednis et al. (2011) uses four algorithms to detect potholes: Z-THRESH, Z-DIFF, STDEV(Z) and G-ZERO. Z-THRESH identifies the type of pothole (small pothole, a cluster of potholes, large potholes) based on the values of acceleration observed in the z-axis above a specific threshold level. In Z-DIFF, is performed a search in the acceleration values of z-axis for two consecutive measurements with a difference between their values above a specific threshold level. STDEV(Z) algorithm calculates the standard deviation of accelerometer data in the vertical direction over a specified window size. G-ZERO searches for the case where all the three-axis data values are near to 0g. This measure indicates that the vehicle it is in a temporary free fall. The best result is achieved by Z-DIFF algorithm, with 92% of true positives to the identification of pothole type.

Street Bump (Brisimi et al., 2016) is a system capable of classifying roadway obstacles into predefined categories using machine learning algorithms. They use the term "bump" in a generic sense to describe various obstacles which include potholes, sunk castings (manhole covers), utility patches, catch basins (drains), train tracks and speed bumps. In Brisimi et al. (2016) is presented an evaluation of supervised learning algorithms as SVM, AdaBoost, logistic regression, and random forests and unsupervised learning inspired by anomaly detection problems. The system extracts two main features of the acceleration data, the first