Decision-Making Tool for Road Preventive Maintenance Using Vehicle Vibration Data

Developing and evaluating an automated road damage recognition method for road preventive maintenance through moving vehicles' vibration data

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Road pavement damage inspection is a critical yet challenging task. At present, road pavement damage inspection is usually done by DOTs using a manual process. Another emerging method of inspection is via the use of sensors, such as the use of LiDAR. This study proposes an automated road damage recognition method via the Sparse Coding analysis of vehicle vibrations. Sparse Coding is a class of unsupervised methods that learn data patterns based on extracted overcomplete bases. Unlike frequency domain-based analysis, e.g. Spectral Analysis, Sparse Coding analysis preserves the temporal information of the vehicle vibration that contains important patterns related to road pavement damage. A preliminary study was performed with vehicle vibration data collected in College Station, TX. Results confirm the feasibility of the proposed method in automated road pavement damage recognition. More data points should be collected in the future to further benchmark the effectiveness of the proposed method.

Background

At present, road surface inspection is heavily done with a manual process. DOTs have published standard procedures for manual inspection, such as the "Texas Pavement Management Information System Rater's Manual". The manual approach brings two potential problems: variation in inspection results due to inspectors' personal bias and the difficulty of high-frequent inspection and coverage area.

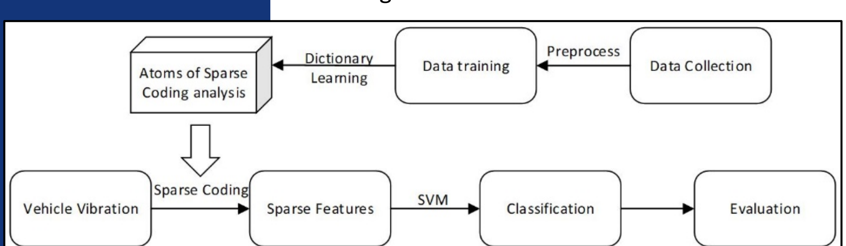

Figure 1. Proposed Research Framework

To overcome the limitations of manual inspection, a variety of automated road surface inspection methods have been proposed. Representative technologies include vision based method, laser scanning, ground penetration radar (GPR), natural lighting method and a combination of multiple sensors. However, these sensor-based technologies also have their own limitations. Despite the accuracy and effectiveness of these sensing methods, they are usually very expensive, and thus the coverage and collection frequency can remain insufficient for detecting the dynamically changing road conditions. This project proposes to adopt a Crowdsourcing approach in automated pavement inspection tasks. Crowdsourcing is an emerging paradigm in computing that employs the power of human workers' knowledge and expertise to help solve problems that machines cannot solve alone. Recently, there has been increasing interest among researchers in employing crowdsourcing to tackle a wide range of complex engineering problems.

Project Summary

To overcome the foreseeable challenges in system-level road pavement preventive maintenance decision-making, this study aims to test a framework that maps pavement surface conditions based on running vehicles' vibration data (via sensors built in most smartphones), and optimizes the preventive maintenance plans based on the deterioration modeling of the road system (urban level). As shown in Figure 1, in this project, we propose the use of vehicle vibration data to enable the automated recognition of road pavement damage. First, the moving vehicles' vibration data is collected using the built-in accelerometer of iPhone with a self-designed iOS app. In order to label the raw data appropriately, a DJI OSMO camera is set up to capture the imagery data of pavement conditions (Figure 2). The imagery data is then tagged by domain experts to establish the ground truth in the model training. After the training data is preprocessed and normalized, Sparse Coding will be applied to establish a dictionary of overcomplete bases, or atoms. In Sparse Coding, the atoms are the fundamental elements that can reconstruct the raw data with the minimum coefficient. They allow multiple representations of the raw signal but also provide an improvement in sparsity and flexibility of the representation. As a result, the dictionary of atoms can help extract the features of the original vibration data. Finally, the Support Vector Machines (SVMs) method will be used to classify the damage types.

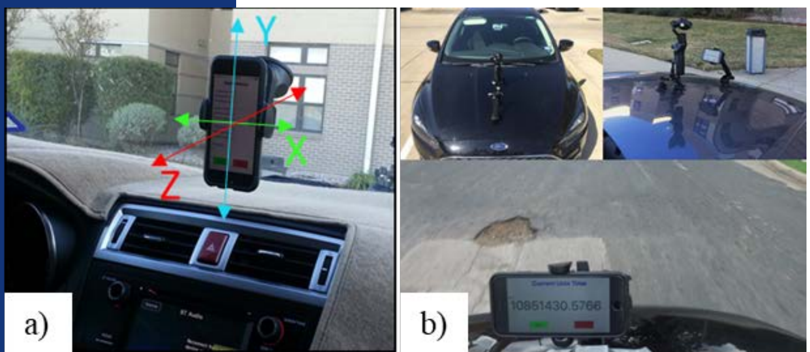

Figure 2. Data collection system. a) The Cartesian coordinate axes of accelerometer; b) The camera and the phone mounted on the hood of the car.

Status Update

In this study we used Sparse Coding to extract the vibration features of moving vehicles, and then performed the Sparse Dictionary Learning to find a dictionary that would adapt well to the raw data. The dictionary was applied with vibration data to solve the sparse representation of input signals, which would be utilized as sparse features for the further classification. Figure 3 illustrates five sample signals and their corresponding sparse representations. It indicates that sparsity was evident for each signal's features, and vibrations signals could be represented as a sparse linear combination of atoms.

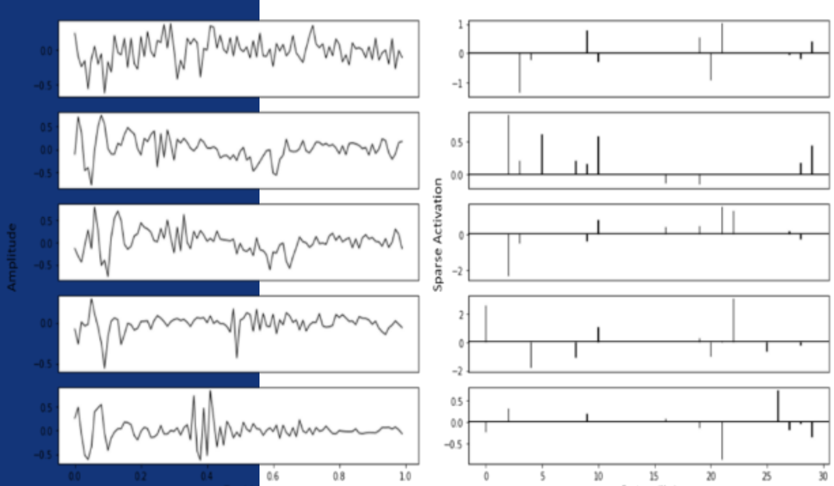

Figure 3. The original Y-axis signals and their corresponding sparse features.

A total of over 30 miles of roads in College Station, TX and Baton Rouge, LA were collected for field study. We labelled three types of pavement damage: pothole, raveling and cracking. A pothole is a bowl-shaped hole through one or more layers of the asphalt pavement structure, between about 150 mm (6 inches) and 900 mm (3 feet) in diameter. Raveling is progressive deterioration of pavement surface as a result of loss of aggregate particles from the surface downward. The start time of the damage was determined and we segmented 100-points (1 second) after start time as a sample. Cracking is a common type of distresses caused by repeated heavy wheels' load. There are 105 potholes, 38 raveling and 24 cracking samples in our current dataset.

Impacts

This study will advance knowledge about preserving existing road infrastructure through calculated preventive maintenance. The findings will enable the development of an automatic and economic road condition evaluation method by monitoring the vibration patterns of the running vehicles on the road. Decision makers will be able to develop precise road deterioration models to predict the temporal change of conditions. The set of deterioration models will ultimately help optimize the preventive maintenance activities to preserve the functional condition of the road system at the minimum cost. The large amount of empirical data collected in this study will help build the holistic view of road infrastructure system in the selected areas. The maintenance decision-making will be driven by the system science of all interdependent factors instead of local optimization.

Tran-SET

Tran-SET is Region 6's University Transportation Center. It is a collaborative partnership between 11 institutions (see below) across 5 states (AR, LA, NM, OK, and TX). Tran-SET is led by Louisiana State University. It was established in late November 2016 "to address the accelerated deterioration of transportation infrastructure through the development, evaluation, and implementation of cutting-edge technologies, novel materials, and innovative construction management processes".

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