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Project Title

Studying the Use of Low-Cost Sensing Devices to Report Roadway Pavement Conditions

University

University of Colorado Denver

Principal Investigators

Moatassem Abdallah
Assistant Professor
University of Colorado Denver
Phone: (303) 315-7566
Email: moatassem.abdallah@ucdenver.edu
ORCID: 0000-0002-3077-6518

Caroline M. Clevenger
Associate Professor
University of Colorado Denver
Phone: (303) 315-7567
Email: caroline.clevenger@ucdenver.edu
ORCID: 0000-0003-2265-8447

Research Needs

Road networks require regular inspection and repair to maintain their performance and function. Several techniques are currently in practice for inspecting roadway performance for presence of cracks, potholes, and other distress such as: inspectors that visually judge the road conditions, specialized vehicles that measure distress with laser devices and camera, and citizens that report their observations. These techniques, however, are inefficient, labor intensive, and expensive. The goal of this research work is to study the use of currently available low-cost sensors such as GPS, gyroscopes, accelerometer, noise recorders, and cellphones to automate inspection of roadway pavement conditions. The outcome of this research work is expected to reduce inspection cost and enable the capability of generating more frequent maps of roadway pavement conditions. Furthermore, authorities will be able to allocate available funds more efficiently to improve existing road performance and function based on more up-to-date conditions of existing transportation networks.

Several studies focused on developing road surface monitoring systems using standalone accelerometers and accelerometers that come with smartphones to detect speed bumps and anomalies. For example, Das et al. focused on the use of mobile devices for detection of road bumps called Platform for Remote Sensing using Smartphones (PRISM). The developed system uses three-axial accelerometer and the GPS receiver to collect motion-related data of vehicle passing over road bumps. The information recorded by the accelerometer were locally processed (on the device) for a real-time localization of the bumps before transferring data to a central server. To secure the privacy of users and avoid misuse/ steal of information over network, they developed a mechanism of forced amnesia where the application was stopped every 60 seconds and then restarted immediately (in about 5 seconds). Results showed that the percentage of detected bumps was about 70% (without phone amnesia) and of about 45% in the other case (*1*). In another study, Bhoraskar et al. developed a system of road and traffic state monitoring that is capable of recording braking events, to collect information on traffic congestion, and vertical acceleration peaks for identifying the speed bumps. The system was developed based on a K-mean algorithm for identification of the class labels (bumpy or smooth road). The results showed that the standard deviation of the acceleration along the vertical direction seemed to be the most significant parameter through which a correct localization of bumps could be done (*2*). Several other similar studies have also focused on identifying the location of potholes. For example, (*3*) and (*4*) used an Android smartphone device with accelerometer to detect location of potholes. Their developed system uses several simple algorithms to identify changes in acceleration vibration to detect the location of potholes. In another similar study, Sense developed a road anomaly identification system using sensing devices from mobile phone such as accelerometer, microphone, GSM radio, and GPS (*5*).

Most of the studies discussed above only focused on identifying the locations of anomalies in order to plan for their repair and maintenance. However, several other studies focused on estimating the road surface or pavement condition in terms of roughness. Two popular methods to classify the road roughness are the International Roughness Index (*6*) and the International Standards Organization (ISO) classification (*7*). Road roughness is defined by American Society of Testing and Materials (ASTM) (*8*) as: “The deviations of a pavement surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic loads, and drainage, for example, longitudinal profile, transverse profile, and cross slope”. Gonzalez et al. used an accelerometer to fit in a simulation car to assess road surface condition by measuring and quantifying road roughness according to ISO definition. Their simulations results showed that the roughness of road can be estimated from acceleration data obtained from the sensor (*9*). In another study, Douangphachanh and Oneyama developed a system of road surface monitoring by using smartphones motion sensing sensors. The developed system was designed based on a simple algorithm that uses several if-conditions to detect changes in recorded accelerations due to potholes and speed bumps. Additionally, the developed model was designed to be capable of estimating the road roughness based on the International Roughness Index (IRI). Based on the results from testing their developed model, it was shown that there is a strong linear relationship between the IRI and magnitude of acceleration vibrations (*10*).

Although, most studies in the literature focused on the use of accelerometer sensing as the main indicator for road anomalies, it might not be sufficient indicator, especially when there is a sudden stop or change in motion acceleration. To this end, several other studies focused on the use of other motion sensing data such as gyroscope around gravity rotation to improve the accuracy of pothole detection. For example, Mohamed et al. proposed a road condition monitoring framework that detects the road anomalies such as speed bumps, based on sensors built in Smartphones. In addition to the accelerometer, data from gyroscope around gravity rotation was utilized as a cross-validation method to confirm the detection results based on accelerometer data (*11*). In another similar study, Douangphachanh & Oneyama extended their previously road surface roughness analysis model using data from accelerometers and gyroscopes on smartphones. They could verify that there is a linear relationship between the road roughness and the magnitudes of vibration calculated from each axis of the accelerometers and gyroscopes. They could identify a linear function that can be used to estimate the road roughness and demonstrated the use of gyroscope data to improve the accuracy of their earlier models (*12*).

Most of the studies discussed above, use sensing technology devices mounted on vehicles to record and collect data such as acceleration, and gyroscope. However, vehicles are equipped with suspension and dampers to attenuate certain vibrations caused by road anomalies. When the vehicle drives slowly, less vibration can be detected and accordingly inaccurate road conditions can be reported. Accordingly, several studies have focused on developing models that are independent from vehicle speed. For example, Seraj et al. developed a road surface monitoring system, RoADS, that uses smartphones sensors including accelerometer and gyroscope. They used a method to reduce the effects of speed, slopes and drifts from sensor signals. The developed system uses an audiovisual data labeling where the labeler uses microphone and camera of the phone to manually identify different types of road conditions such as potholes, speed bumps, road and bridge joints, and railroad crossings. The system was developed based on wavelet decomposition analysis for signal processing of acceleration and gyroscope data, and Support Vector Machine (SVM) for anomaly detection and classification. The system could identify real-time road conditions at an accuracy of nearly 90% regardless of vehicle type, and road location (*13*). In another similar study, Perttunen et al. proposed a method of linear regression to remove the linear dependency of the speed from the feature vector. They used a Nokia N95 mounted on the wind-shield, with accelerometer sampling at 38Hz and GPS to collect the data. Their developed system could classify different road surface anomalies into two classes: mild and severe. Although their developed system could not lead to highly satisfactory accuracy, the obtained results showed that the use of such method to remove the reliance of detection models on vehicle speed can improve the accuracy road conditions (*14*).

Despite the significant contribution of the existing research studies in identifying road pavement conditions using low-cost sensors, there limited research that compared the accuracy and reliability of using such sensors in reporting roadway conditions. Furthermore, limited studies exist that used a combined set of sensors to analyze roadway conditions, including GPS; gyroscope; accelerometer; voice/noise; camera; cellphone; and vehicle year, make and model with various mounting conditions. Finally, limited research exists that used artificial intelligence such as Artificial Neural Networks (ANN) in analyzing and identifying pavement conditions.

Research Objectives

The objectives of this research work are listed as follows:

1. Develop new models that are capable of evaluating performance of roadway pavement conditions using low-cost sensors
2. Identify needs and challenges to develop reliable maps that show road pavement conditions more frequently and efficiently
3. Study the feasibility of wide spread application of low-cost sensors and their use to prioritize roadway maintenance based on limited budgets.

Research Methods

The primary goal of this research work is to evaluate the use of low-cost sensors to report performance of transportation networks in terms of roughness conditions, cracks, bumps and pothole locations. The research team will use low-cost sensors to collect data from road patrol vehicle, including acceleration; voice/noise; speed; vehicle year, make, and model; location; and visual conditions. Standalone devices and smartphones will be used to collect the aforementioned factors, as shown in Figure 1. New models will be developed to identify roadway pavement conditions based on the abovementioned factors. The research team will explore the use of regression models and Artificial Inelegance (AI) such as Artificial Neural Networks (ANN) to correlate the above factors with roadway pavement conditions. Roads with predefined pavement conditions will be used to build and test the regression or ANN models. Finally, the developed models will predict roadway pavement conditions as the sensors are used in road patrol vehicles as shown in Figure 1.

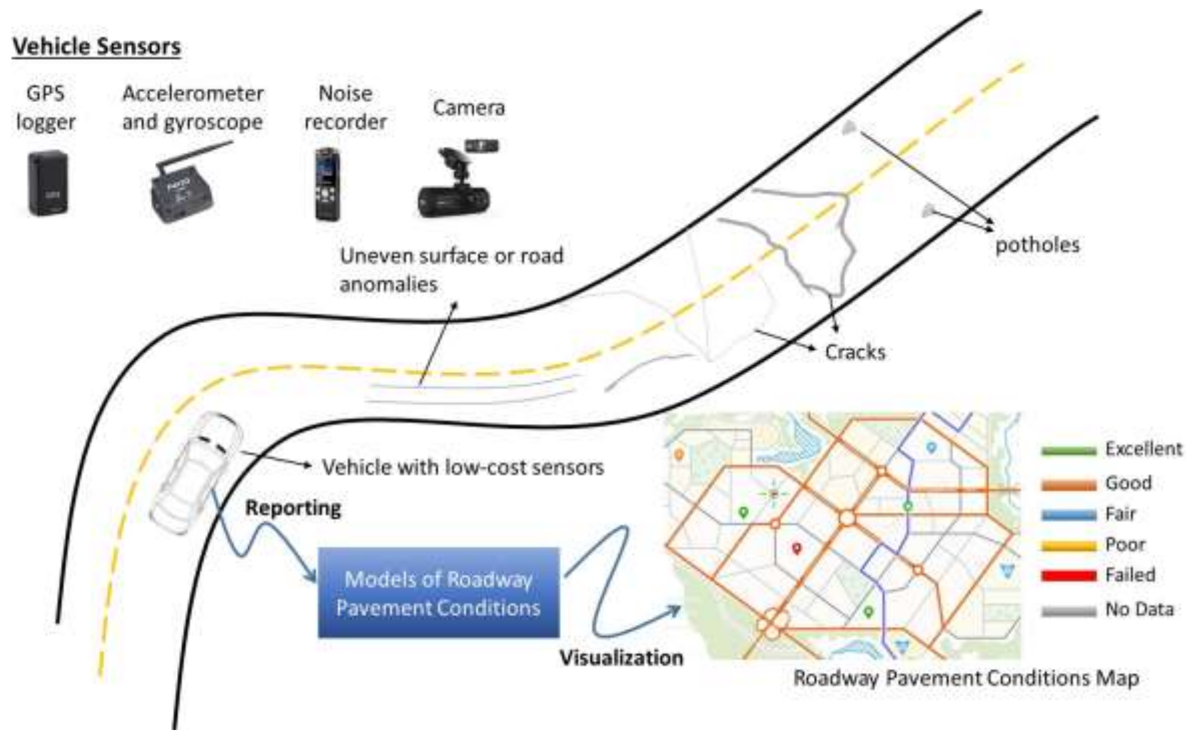

Figure 1. Proposed System for Reporting Roadway Pavement Conditions

Based on the collected data, the team will study the feasibility of wide spread application of the models to report roadway pavement conditions frequently using police patrol vehicles or taxi services. Furthermore, the researchers will explore the development of decision support system to prioritize maintenance of roadways to improve their performance within limited budgets.

Expected Outcomes

The present research will focus on evaluating the use of low-cost sensors to report pavement conditions of roadways. This research work is expected to lead to: (1) document the use of low-cost sensors to evaluate roadway pavement conditions; (2) develop new models that are capable of identifying roadway pavement conditions using low-cost sensors, (3) study feasibility of widespread application of the technology and prioritizing maintenance based on limited budgets. The outcome of this research work will support the development of an automated system for inspecting and prioritizing maintenance of roadways. Successful completion of this research work and its widespread application are expected to significantly reduce cost for inspecting and evaluating roadway pavement conditions; and efficiently use available budgets to improve roadway conditions.

Relevance to Strategic Goals

The outcome of this research work will contribute to two important USDOT strategic goals, including State of Good Repair, and Economic Competiveness. The proposed models will allow roadway pavement to be inspected and evaluated with lower cost and higher efficiency. Furthermore, new models will enable the capability to generate maps that report roadway pavement conditions more frequently. The availability of such data will allow new decision support systems to be developed to prioritize maintenance based on limited budgets. These decision support systems will improve efficiency of budget allocation to improve roadway conditions and improve overall quality of the transportation network.

Educational Benefits

To perform this research work, a team consisting of two professors and a graduate student at University of Colorado Denver is formed. Over the past five years, the faculty members have successfully advised and mentored hundreds of undergraduate and graduate students. The majority of these students are currently active and advancing in various industries today including transportation, planning, construction, engineering and consulting. This project will provide the research team with sustained support to train one graduate student for one year. In addition, the faculty members will seek involvement from undergraduate and other graduate students in the Construction Engineering and Management program.

The proposed research and outcomes will serve as the foundation for new educational modules and materials to be integrated into graduate courses. Modules will be carefully designed and implemented to enable students to (1) understand efficient roadway inspection and maintenance and (2) develop new decision support systems to prioritize maintenance with limited budgets.

Technology Transfer

The research team will disseminate and transfer the knowledge generated from the proposed research using publications in scientific journals and/or presentations in national conferences to disseminate the research findings to the broad research and industrial community. Additionally, the research team will explore opportunities to facilitate the transfer of new technologies to the industry by reaching out to agencies that can directly benefit from the outcomes of this research work. Finally, educational material will be generated to train graduate and undergraduate students and prepare them for the construction and transportation workforces.

Work Plan

In order to accomplish the objectives of this research work, the following research tasks will be conducted:

Task 1: Conduct comprehensive literature review of the latest research on reporting roadway pavement conditions. The research team will study and summarize the latest development and findings of the existing research work to report pavement conditions, including standards of roadway pavement conditions, traditional methods for reporting pavement conditions, type and installation of low-cost sensors, and available models for analyzing data from sensors. The outcome of this task will (1) document available models and system for evaluating roadway conditions, and (2) establish a baseline to conduct the proposed research work.

Task 2: Identify low-cost sensors and their setup to report roadway conditions. This task will focus on exploring available technologies and sensors for recording a number of factors, including acceleration in three-dimensions, speed, location, noise, and visual road conditions. The collection of these factors will require the use of standalone sensors such as accelerometer, gyroscope, GPS, noise recorder, and camera or cellphone. The team will document the accuracy of existing standalone devices and cellphone to record the above factors. Furthermore, this task will explore various alternatives for mounting the above sensors to accurately record the above factors. The outcome of this task will support identifying a set of sensors and/or cellphone as well as their installation to report factors of roadway pavement conditions.

Task 3: Develop new model to identify roadway conditions. The research team will record factors listed in Task 2 for a number of roads with predetermined pavement conditions. The recorded data will be used to build and test regression models and/or Artificial Neural Network (ANN) models to identify roadway pavement conditions.

Task 4: Collect data using low-cost sensors. The research team will coordinate with few local taxi drivers to install the low-cost sensors and collect data for a predefined period. Monetary incentives will be used to motivate drivers to participate in the study.

Task 5: Generate map of pavement conditions. The collected data in Task 4 along with the models developed in Task 3 will be used to generate a map that report pavement conditions in Denver metro area.

Task 6: Study practicality of wide-spread application of the technology. The research team will explore the feasibility of installing low-cost sensors at police patrol vehicles and/or taxi vehicles to generate maps of roadway pavement conditions. This task will study cost and efficiency of the new technology as compared to traditional methods for reporting roadway pavement conditions.

Task 7: Explore the feasibility of prioritizing roadway maintenance based on limited budgets. This task will explore the development of a decision support system to prioritize maintenance of roadways to improve their performance based on limited budgets.

Task 8: Prepare and submit final report. The research team will prepare and submit final report to document the research developments and findings.

Project Plan

The proposed research tasks will be carried out according to the schedule shown in Figure 2.

Project Tasks	Start (M)	Dur. (M)
Exploring the Use of Low-Cost Sensing Devices to Report Roadway Pavement Conditions		
Task 1: Conduct comprehensive literature review of the latest research on reporting roadway pavement conditions	1	3
Task 2: Identify low-cost sensors and their setup to report roadway conditions	3	2
Task 3: Develop new model to identify roadway conditions	5	5
Task 4: Collect data using low-cost sensors	10	8
Task 5: Generate map of pavement conditions	17	3
Task 6: Study practicality of wide-spread application of the technology	18	3
Task 7: Explore the feasibility of prioritizing roadway maintenance based on limited budgets	21	3
Task 8: Prepare and submit final report.	22	3

Figure 2. Schedule of the Project Tasks

Project Cost

Total Project Costs: $83,448.38
MPC Funds Requested: $39,999.99
Matching Funds: $43,448.39
Source of Matching Funds: Faculty academic salary

References

1. Das, T., P. Mohan, V. N. Padmanabhan, R. Ramjee, and A. Sharma. PRISM: Platform for Remote Sensing Using Smartphones. 2010.

2. Bhoraskar, R., N. Vankadhara, B. Raman, and P. Kulkarni. Wolverine: Traffic and Road Condition Estimation Using Smartphone Sensors. 2012.

3. Mednis, A., G. Strazdins, R. Zviedris, G. Kanonirs, and L. Selavo. Real Time Pothole Detection Using Android Smartphones with Accelerometers. 2011.

4. Strazdins, G., A. Mednis, G. Kanonirs, R. Zviedris, and L. Selavo. Towards Vehicular Sensor Networks with Android Smartphones for Road Surface Monitoring. No. 11, 2011, pp. 2015.

5. Sense, T. *Rich Monitoring of Road And Traffic Conditions Using Mobile Smartphones*. Microsoft Research, Tech. Rep. MSR-TR-2008-59, 2008.

6. Sayers, M. W. Guidelines for Conducting and Calibrating Road Roughness Measurements. 1986.

7. Standardization, I. O. for, T. C. ISO/TC, M. Vibration, S. S. S. Measurement, E. of M. Vibration, and S. as A. to Machines. *Mechanical Vibration--Road Surface Profiles--Reporting of Measured Data*. International Organization for Standardization, 1995.

8. ASTM International. *ASTM Standard E867, Standard Terminology Relating to Vehicle-Pavement Systems*. West Conshohocken, PA, 2012.

9. González, A., E. J. O'brien, Y.-Y. Li, and K. Cashell. The Use of Vehicle Acceleration

Measurements to Estimate Road Roughness. *Vehicle System Dynamics*, Vol. 46, No. 6, 2008, pp. 483–499.

10. Douangphachanh, V., and H. Oneyama. A Study on the Use of Smartphones for Road Roughness Condition Estimation. *Journal of the Eastern Asia Society for Transportation Studies*, Vol. 10, 2013, pp. 1551–1564.

11. Mohamed, A., M. M. M. Fouad, E. Elhariri, N. El-Bendary, H. M. Zawbaa, M. Tahoun, and A. E. Hassanien. RoadMonitor: An Intelligent Road Surface Condition Monitoring System. In *Intelligent Systems' 2014*, Springer, pp. 377–387.

12. Douangphachanh, V., and H. Oneyama. Exploring the Use of Smartphone Accelerometer and Gyroscope to Study on the Estimation of Road Surface Roughness Condition. No. 1, 2014, pp. 783–787.

13. Seraj, F., B. J. van der Zwaag, A. Dilo, T. Luarasi, and P. Havinga. RoADS: A Road Pavement Monitoring System for Anomaly Detection Using Smart Phones. In *Big data analytics in the social and ubiquitous context*, Springer, pp. 128–146.

14. Perttunen, M., O. Mazhelis, F. Cong, M. Kauppila, T. Leppänen, J. Kantola, J. Collin, S. Pirttikangas, J. Haverinen, and T. Ristaniemi. Distributed Road Surface Condition Monitoring Using Mobile Phones. 2011.