MPC-445

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Project Title:
A Sensor Fusion Approach to Assess Pavement Condition and Maintenance Effectiveness

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Research Needs:

Transportation agencies in rural and cold regions face enormous challenges keeping up with demands to repair roads quickly. They must assure consistent repair quality assessment during the short construction season, particularly for roads that must support intense industrial activities in oilfields and rural freight corridors. Maintaining a state-of-good repair in these regions requires continuous performance measures, without disrupting traffic flows. To evaluate repair and maintenance effectiveness, infrastructure sensors such as electrical strain gauges and magnetic capacity sensors are widely deployed. Unfortunately, they provide performance measures only in the longitudinal direction. Furthermore, their installation requires waterproofing and even so, they are susceptible to electromagnetic interference and have relatively short lifecycles. To mitigate these and other performance issues, the Co-PI's research team developed more rugged and reliable devices in 2012 by packaging optical fiber sensors in three dimensions using fiber-reinforced polymer (FRP) to withstand the harsh environments within pavements. Testing shows that these devices operate robustly within pavements, and provides reliable and real-time road performance assessment (Zhou, et al. 2012). The Minnesota Department of Transportation (MnDOT) is using the new sensor system to evaluate the feasibility of installing thin (3 inches) concrete overlay with fiber reinforced concrete materials at the MnROAD facility as shown in Fig. 1.



Fig. 1 Three-dimensional FRP packaged fiber optic sensors and its field installation at MnROAD, MnDOT

To provide accurate and uniform repair assessment across all installation types, material variances, and different environmental conditions, optical sensors require calibration. Therefore, this proposal aims to develop an automatic sensor calibration approach that utilizes ride-quality performance measures. The Federal Highway Administration (FHWA) requires annual reporting of the International Roughness Index (IRI), which is the most common ride quality measure for the National Highway System (HPMS 2012). However, transportation agencies do not regularly monitor the ride quality of repaired and local roads because of the high complexity and cost of measuring and reporting the IRI. To provide continuous, network-wide, and lower-cost ride quality measures, the PI developed and validated a new approach using micro-electro-mechanical system (MEMS) inertial sensors (Bridgelall 2013). The emerging dominance of smartphone apps, social media, and connected vehicles presents significant opportunities for the ubiquitous deployment of wireless inertial sensors to monitor and report ride quality through data mining techniques and cloud computing. The fusion of dynamic ride-quality and static in-pavement performance measures, therefore, will enable rapid scalability of a low-cost solution for continuous, network-wide assessment of repair and maintenance practices, especially for cold, rural regions.

Research Objectives:

This goal of this study is to develop a sensor fusion approach to improve road repair and maintenance effectiveness assessment using embedded road sensors. To achieve this goal, the team will execute the following four specific objectives:

1) Optimize the design of the optical sensor network and its data acquisition to assess the performance of repaired roads.
2) Develop a theoretical understanding of the correlation between ride-quality measures and the output from embedded optical fiber sensors.
3) Characterize the ride quality accuracy and precision with respect to traversal volume, MEMS output quality, and GPS performance.
4) Synthesize a model that is capable of automatically calibrating the sensors using ride quality data.
5) Evaluate the effectiveness of the developed sensor fusion approach.

Research Methods:

To achieve the above objectives, this research will build upon rudimentary software that NDSU has developed to prove the concept of utilizing smartphones to collect inertial data for network-wide ride quality measures. The PI will design new algorithms to augment the app for repaired road quality assessment. These algorithms will align and combine the ride quality data from multiple vehicle traversals to produce an average ride quality for correlation with the average road performance reported by the embedded sensors. The complexity of this problem stems from the fact that the GPS position estimate of inertial data samples for each traversal will vary stochastically, and furthermore, the GPS update rate will differ from that of the on-board MEMS accelerometer and the embedded sensors. Minimizing the sample rates of the GPS and the inertial sensors will prolong battery life but will also reduce the assessment quality. The PI will develop a theoretical framework to quantify the trade-off between sample rate, GPS variance, and the number of vehicle traversals needed for statistical convergence of ride-quality measures.

The team will develop a database and software tools to facilitate the automatic model calibration. To conserve battery life and simplify its use, the new smart app will include a feature to log sensor data only when the vehicle moves within a specified geospatial region containing the infrastructure sensors. Once the new algorithm and associated software is developed, implemented, and tested, the PI and Co-PI will evaluate and validate the effectiveness of the sensor fusion approach to provide uniform and accurate performance measures.

Expected Outcomes:

Transportation agencies will be able to integrate the new ride quality measures and the calibrated sensor output into decision support platforms. The new situational understanding will lead to optimized asset management and maintenance practices, and significant cost reduction. The method will be applicable to all types of infrastructure sensors that are applied for pavement performance measures. Agencies will also be able to utilize the new low-cost ride-quality measures as a standalone solution to compare with IRI data, and to extend continuous condition monitoring to all roads. As part of the technology transfer, the research team will provide adequate documentation of the models and the software developed. The team will collaborate with the

Transportation Learning Network (TLN) to present the results and to demonstrate best practices for utilizing the solution.

Relevance to Strategic Goals:

This study relates to the following strategic goals:

State-of-good-repair – the research product provides a reliable, continuous, and long-term assessment of road repair quality throughout the asset lifecycle. The decision support platforms enabled will provide continuous ride-quality monitoring, improved deterioration forecasts, and a regular assessment of maintenance practices for all roads.

Safety – the ability to monitor ride quality continuously will improve the timeliness of locating distress symptoms before they contribute to property damage, injuries, or fatalities.

Economic competitiveness – a lower cost and scalable approach to monitor network-wide road condition and maintenance effectiveness will augment the quality of maintenance decisions, lower costs, and ultimately improve the performance of the nation's transportation network. An automated and continuous performance measurement system will reduce the burden of assessing the quality of road repairs in cold, remote regions where pavements deteriorate in a non-predictable manner and expert resources are scarce and expensive.

Educational Benefits:

This project will employ several undergraduate and graduate students whom the PI and Co-PI will mentor on the implementation of software for safety and quality assurance, data analysis methods, laboratory simulations, and field data collection. The level of practical training students will acquire, and their emersion in the development of real world, practical solutions will prepare them for employment in the transportation field. The Co-PI will also integrate this project into a graduate course titled "CE796 – Introduction to Intelligent Infrastructure" to provide students with hand-on experience in the practical implementation of intelligent transportation systems, and to encourage students to pursue transportation related occupations.

Work Plan:

The main tasks include the development of theory, models, software applications, infrastructure sensor deployment, data acquisition, data analytics, in-field experimental validation, student mentorship, outreach, and technology transfer. The detailed work plans are as follows:

TASK 1: LITERATURE SEARCH & STATE OF CURRENT PRACTICE (Months 1 – 3)

1) Identify present scope of intelligent pavement condition monitoring approaches.
2) Identify and review road quality assessment approaches using in-pavement and on-board inertial sensors.
3) Compare existing approaches with the proposed sensor fusion approach.
4) Prepare a memorandum of the present state-of-the-art.

TASK 2: APPLICATION DEVELOPMENT (Months 4 – 8)

1) Prepare software specifications to refine the smartphone app for practical field use.
2) Invent an algorithm to merge multi-resolution ride quality data from the deployed apps.
3) Develop a model for utilizing ride quality data to calibrate infrastructure sensors.
4) Document the models and algorithms developed.

TASK 3: APPLICATION IMPLEMENTATION & DATA COLLECTION (Months 9 – 14)

1) Collect infrastructure sensor data from select pavement sections (using both fiber optic and electrical sensors deployed at the MnDOT, MnROAD facility).
2) Identify and schedule suitable vehicles to collect ride-quality data at the MnROAD facility.

3) Deploy the smartphone apps to monitor the selected pavement sections.
4) Format, clean, and process the inertial data for merging and model estimation.

TASK 4: MODEL VALIDATION & ASSESSMENT (Months 15 – 21)

1) Assess the correlation between the infrastructure sensor parameters and the ride quality data, including the effects of sample rate on accuracy, sensitivity, and effectiveness.
2) Optimize the model for various environments and sensor types.
3) Update the CE796 course syllabus to include the project lessons learned.

TASK 5: FINAL REPORT & TECHNOLOGY TRANSFER (Months 22 – 24)

1) Prepare a draft final report and allow at least two weeks for a review cycle.
2) Draft papers for publication and submit the final project report with feedbacks incorporated.
3) Utilize the TLN or other outreach methods to present technology transfer options and future refinements.

Project Cost:

Total Project Costs: $305,252.25
Requested MPC Funds: $150,000
Matching Funds: $155,252.25 (Dept. of CE – Student Stipend & Tuition Waiver; UGPTI – General Funds)

TRB Keywords: Connected vehicles, ride quality, pavement, optical, inertial, sensors

References:

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