MPC-374

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Proposal Title: An integrated real-time health monitoring and impact/collision detection system for bridges in cold remote regions

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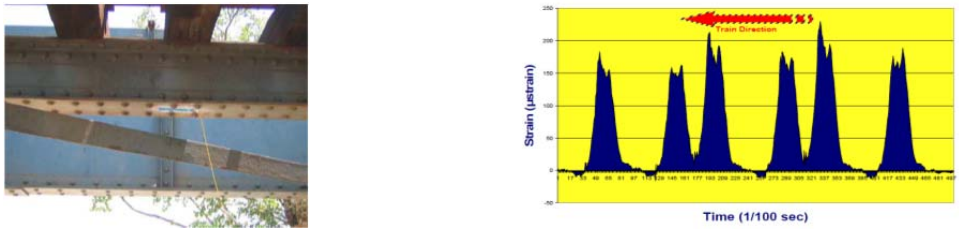
A. Research Needs: With about one-third of the nation's 600,000 highway bridges in need of repair or replacement, there is a great demand to prioritize the needs for different maintenances and utilize the budget efficiently to maintain a sustainable infrastructure for economic development. Common concerns in effectively maintaining existing highway bridges are what status of each inventory bridge is and where the particular/emergent needs are located. Particularly in the northern states, such as Colorado and Dakotas, the damage induced by impact/collision of trucks, which either exceeds the allowable height clearance of the bridges or due to careless driving, are commonly seen. It is important to detect these events and assess whether the impact/collision induced damage is critical to bridge safety for timely correction and repair. For example, the AKDOT/PF has invested considerably in developing an over-height detection system for truck impact of bridges (Qiao and Yang, 2008). However, this system uses conventional techniques of audible alarms and laser detectors, which are not effective in detecting small to middle force but detrimental impact incidents, and the developed system does not connect with bridge management information systems and its subsequent maintenance procedures. Another issue with the maintenance of northern region bridges, especially due to recent oil booming, heavy oil trucks has caused much deterioration over the existing bridges. A real-time assessment of bridge health status is critical in avoiding similar tragedies of I-35 happened again. Integrated health monitoring and impact/collision system through optical sensors will provide a viable solution to the above problems and maintain a sustainable infrastructure system for future economic development.

Optical sensors have shown to provide efficient applications in structural assessment and maintenance (Tsamasphyros et al. 2008), and exhibit excellent merits in easy installation and stable signal collection. Besides these advantages, bridges instrumented with optical sensors can trigger the detection system and remotely monitor the impact incidents or any extreme events such as earthquake or blasting. Moreover, the instrumented bridges can self-monitor conventional deterioration due to daily usage such as overweight trucks or long-term de-icing chemical corrosions. Due to the unique challenges faced in Northern remote regions, such as large distances between communities, adverse cold climate, and high transportation costs, such a system can provide an efficient guidance to improve maintenance and operation of cold regions transportation infrastructures.

B. Research Objectives: The goal of the proposed project is to stimulate the innovation of *an integrated real-time health monitoring, impact/collision detection system through optical sensors* for bridges in cold remote regions. The objectives of the proposed research are four-fold: (1) To develop a general design for the integrated structural health monitoring and impact/collision detection system, (2) To construct a data post-processing frame for bridge condition assessment and impact/collision events recording and inventory, (3) To field-implement the developed health monitoring and detection system in identified bridges in partnership with NDDOT(assistance from NDDOT is in discussion at the current stage), and (4) To monitor the short- and long-term performance of the instrumented bridges using the developed health monitoring and impact/collision detection system. The cornerstone of this proposed project is to develop a viable structural health monitoring and impact/collision detection system using smart optical sensing/wireless technology and field-implement the proposed systems in cold region bridges in partnership with NDDOT.

C. Research Methods: The proposed project will be using optical sensors as the structural monitoring and impact detection component for bridge systems. The innovative system will act as a condition assessment tool and an impact/collision inventory tool, which includes optical sensors and a PZT triggering circuit box. The integrated system could passively and actively interrogate the bridge regularly, or trigged by special events, or remotely controlled by maintenance personnel. The signals will be generated from the optical sensors during the impact or through the ambient traveling vehicles and transmitted over telephone lines (or through a wireless device) to a central monitoring station where the signal data are interpreted, thus extremely suitable for cold region infrastructure maintenance and automatic detection and monitoring of impact incidents. The integrated structural health monitoring and impact/collision detection system using advanced optical sensors is a new and promising technique in structural conditional assessment in cold regions, and is expected to be widely accepted after its validation.

The integrated optical sensing system and its field implementation: Using optical sensors for structural health monitoring has been research in the past decade. Tsamasphyros et al. (2008) has implemented the optical sensors for safety monitoring of a railway bridge in Greece. The whole system is designed as shown in Figure 1.



(a) The instrumented bridge (b) Measured strain history when train crossing

Figure 1. The instrumented optical structural health monitoring system in a railway bridge in Greece (Tsamasphyros, et al. 2008)

The derived strain profile and its history will be used to determine the outliers from the normal status of health bridges with respect to damage locations and sizes. A similar approach researched at Iowa State University (Wipf et al. 2011) is shown in Figure 2.

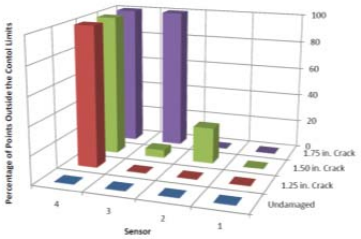


Figure 2. Percentage of outliers at different sensor locations (Wipf et al. 2011)

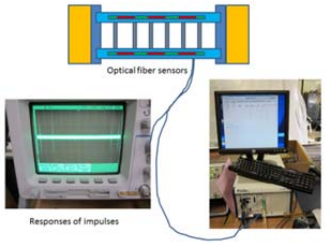


Figure 3. Schematic plot and the identified forces in the suggested health monitoring system

Impact/collision detection has been researched for more than 2 years by the PIs in two projects. One of the projects is for collision detection of over-height truck impact with bridge girders. The other project is looking at detecting impact events happened on aerospace structures due to flying debris, hails, or flying birds. The detection system is consisted of a PZT trigger box and a clustering algorithm to locate the position of impact/collision. The system diagram is shown in Figure 3.

Conditional assessment and impact identification through signal processing: After the prototype of the system is developed, algorithms for sensed signal processing will be developed. Two algorithms need to be created for fulfilling the anticipated functions of the structural condition assessment and impact detection, which are the algorithm for identification of damaged state, damage locations, and their extensions of an instrumented bridge, and the algorithm for recording impact/collision events, impact/collision levels, and their happened locations in bridges. Preliminary work has been conducted in the PI's group. A laboratory study of identifying impact forces on a model bridge is shown in Figure 3.

D. **Expected Outcomes:** The project, if accomplished, will have great impact and significance on improving bridge assessment and safety. The proposed concept will be designed, tested, and field-implemented/evaluated during the project period. The PIs also anticipated a final ready-for-market product through this project will be developed. In particular, design and field implementation manuals and acceptance test report for the integrated system will be produced as one of the outcomes of this project. After the completion of the proposed project, the PIs anticipate that the market for installing the integrated structural health monitoring and impact/collision system in northern cold regions will be open and follow-up implementation opportunities will be enormous.

   The outcomes of this study will greatly promote research and invention of new condition assessment tools in transportation infrastructure in cold regions and benefit the safety and security of transportation systems in the northern mountainous area. The adoption of the system is also anticipated to be cost-effective. The simplicity and easy installation of the integrated health monitoring and damage/collision detection system will make effective on-time condition assessment and promote timely correction of critical safety problems in bridges, thus leads to effective allocation of maintenance forces and resources. The proposed concept can also be implemented to a broad range of highway structures including road barriers, sign structures, and retaining structures, which are also susceptible to vehicle impact.

E. **Relevance to Strategic Goals:** The proposed integrated structural health monitoring and impact/collision detection meet the MPC theme of "**State of good Repair and safety**", by exploring the novel use of optical sensors in cold region, developing integrated condition assessment and monitoring technology in difficultly-accessible areas during cold weather, Guiding rapid and pin-pointed/focused repair and maintenance in cold climates, and more

important, enhancing safety and security through early warning and remote monitoring. The impact of the proposed project on local and national economic prosperity is directed to two areas of pressing concern: (1) Provide sustainable infrastructures for oil development in North Dakota, and (2) Reduce maintenance cost/improve repair efficiency in infrastructure rehabilitation.

F. Educational Benefits: Two graduate students will participate in the project, including designing, installation, monitoring the instrumented bridges, and calibrated the invented system. The developing, installation, and monitoring process will give the graduate students a great opportunity to enhance their learning experience and apply their knowledge in practice. The project will also benefit undergraduate and graduate students at large through a series courses currently offered in Civil Engineering, which includes CE 425/625: Bridge Evaluation and Rehabilitation and CE 447/647: Structural Stability. The research results will be used as course materials.

G. Work Plan: The following tasks are proposed to accomplish the objectives defined in this project:

(1) Task A: Design of the integrated structure health monitoring and impact/collision detection System (Month 1-6). The structural health monitoring and impact/collision detection system will be designed and pilot-tested in the laboratory;

(2) Task B: Development of data recording, data processing, and bridge condition/damage index extraction algorithms (Month 7-12);

(3) Task C: Field Implementation (Month 13-18). The developed system and algorithm will be field-implemented in the identified bridges in partnership with NDDOT;

(4) Task D: Integrate the sensing information with the existing bridge information system of NDDOT for real-time condition monitoring, safety warning, and impact/collision event recording (Month 19-22);

(5) Task E: Final report (Month 23-24). A final draft and final report after addressing reviewers' comments will be provided. Technology transfer will be discussed with interested companies, and a research seminar to distribute the research findings will be coordinated through LTAP.

H. Project Cost:

Requested Funding from MPC: $100,000 Match Funding amount: $100,000

Matching Source: Department of Civil Engineering, NDSU (two graduate student tuition ($70,276), faculty research during academic year ($4,954/PI x 3 PIs/yr x 2 yr = $29,724))

TRB Keywords: bridge, condition assessment, impact/collision detection, information guided maintenance

References (details are available upon request): Qiao et al. (2008). Research report to Ohio DOT (134142); Tsamasphyros et al. (2008), Journal of Micron-Optics; Wipf et al. (2011). Research report to Iowa DOT (08-336)