Identifying Number MPC-341

Project Title:

Off-grid MEMS Sensor Configurations for Transportation Structures

University:

Colorado State University

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Description of Research Problem:

The entire infrastructure of the Unites States is aging, often at a rate faster than economic resources can be allocated for repair or replacement. This is especially true for transportation structures and can be applied to structures composed of metal, concrete, wood, or composite. The ability to assess local damage or changes to the constituent materials of the structures is a critical feature of engineering management, and the need for this ability grows at a rapid rate. There have been numerous attempts (Maaskant 1997, Lynch 2006, Boujamaa 2009) to design sensing systems that (a) are inexpensive, (2) require limited maintenance or placement cost, (3) deliver continuous data, and (4) can be used to detect structural system response at either the local (damage) scale or the global (frequency, deflection) scale as input to additional inspection or possible repair, retrofit, or replacement.

Micro-electro-mechanical systems (MEMS) refer to the combination of sensors and actuators combined with mechanical elements on a single substrate, usually composed of silicon, that can be used for a variety of purposes. Use of these novel elements could provide vast improvements over existing sensing methods and have a number of key advantages that could revolutionize non-destructive evaluation methods. Combined with basic information on the global response of typical transportation structure response (for example, the dominant frequencies of a bridge) and a means of powering and linking the sensors into a cohesive sensing unit in off-grid sites far removed from municipal power sources (Weimer 2006), comprehensive sensing systems could provide a huge leap forward in monitoring the health of aging transportation structures.

Research Objectives:

The goal of this project is to design a preliminary sensing platform for a network of MEMS sensors for transportation structures, primarily but not limited to bridges, using new acoustic sensing technology. A collaborative agreement will be established with researchers at the National Institute of Standards and Technology for potential fabrication and testing of these devices. Of specific interest in this platform is new knowledge about the level of sensing required, the numbers and placement of sensors, potential sources of energy to power the system, challenges for wireless access, and overall sensitivity of the MEMS system.

Research Approach / Methods:

There are three linked topics that will be explored as during this research: 1) technical development of the actual MEMS acoustic sensor, using Ritz-based computational models of the basic acoustic properties and performance, 2) limits on the scale of the motion likely to be detected from typical structures during high usage or severe events using displacement-based finite element models, and 3) estimates on power requirements for off-grid sensing networks along with preliminary designs of a connected sensing system. These three topics will be linked into a cohesive preliminary sensing platform that can provide levels of determination (scaled by levels of Hz) of local or global structure response (Whelan 2007) that can track, for example, environmental degradation, loss of local stiffness, or changes in existing damaged regions.

MPC Critical Issues Addressed by the Research:

1. Rural transportation operations.
2. Low-cost safety improvements.
3. Traffic operations and management.
4. Infrastructure longevity.
5. Environmental impacts on infrastructure.

Contributions / Potential Applications of Research:

This work could provide the necessary technology to (a) develop a new generation of MEMS sensors for structural health monitoring, along with (b) guidance regarding power requirements and the limitations of this sort of system. This is very likely a long-term project that will rely on the ability to manufacture and power the complete sensing platform. It is expected that the complete structure of this effort will be completed in phases that include: 1) theoretical development of the sensors, including design and operating

limits, 2) manufacture of sensing prototypes including testing, 3) integration of sensors into a complete sensing platform, 4) powering of the sensors and instrumentation for off-grid applications, particularly in rural areas, 5) a demonstration site for a powered sensing platform on the CSU campus, 6) a demonstration site for a powered sensing platform on a bridge or rail structure in Colorado, and 7) an off-grid site with renewable power sources. Clearly, this will not all be accomplished given the small budget for this work, but a significant amount of feasibility and theoretical development work will be completed to provide a foundation for this use. We will be relying on the collaboration with researchers at NIST, who have manufacturing capability (and potential funding to create the necessary prototypes) for any acceleration in this schedule.

Potential Technology Transfer Benefits:

Few state or local entities have the resources necessary to computationally explore feasible sensing systems, especially for new-generation MEMS sensors. Development of the proposed technology, combined with the metrics of sensitivity, can be used to develop additional capability at potentially low cost for thousands of transportation structures across the nation. Additional work published in the science and engineering open literature will allow other investigators to expand the work developed in this proposal.

Time Duration:

July 1, 2010 – June 30, 2011

Total Project Cost:

$141,413

MPC Funds Requested:

$52,000

Source of Matching Funds:

- OE FAA ADM1000021, Colorado Department of Public Health and Environment: $89,413

TRB Keywords: Safety, Sensors, Bridges, Engineering, Environmental Effects, Concrete, Steel, Wood, Composites, Strength of Materials, Elastic Properties.

References

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