MPC-378

January 1, 2012 – December 31, 2012

Project Title:
MEMS Sensors for Transportation Structures

University:
Colorado State University

Principal Investigator:
Paul Heyliger, Professor, prh@engr.colostate.edu, 970-491-6685

Research Needs:
Non-destructive infrastructure monitoring includes the capability to remotely determine local or global changes in the fundamental character of transportation structures (Abdel-Ghaffar 2001, Xu 2004, Engel 2004 . These changes are nearly always negative and usually occur because of 1) changes in geometry or material continuity from usage distress, and 2) degradation in material properties from corrosion or other environmental factors. Deploying micro-electromechanical systems (MEMS) devices at strategic points within the structure can provide real-time behavioral characteristics of variables including quasi-static deflection, vibration frequency, or wave propagation speed.

It has been rather common to accomplish indirect detection of structural character by measuring and interpreting induced motion or vibration of the structure as a result of outside forcing functions (Hill 2000). The most common method for doing so has been to use conventional piezoelectric accelerometers, which link mechanical motion to induced electric response, directly wired to data acquisition systems. The challenges of this sort of system are nearly all related to cost: 1) the initial installation and instrumentation, including the necessary wiring, 2) the cost to maintain the system over a reasonable period of time, and 3) the up-front costs of the required equipment.

There are alternatives. MEMS cantilevered devices at the micron scale, when optimized to detect these measure associated with structural response, will provide real-time information collected at remote hubs for analysis and synthesis with other health monitoring devices. This approach removes the need for frequent manual inspections and prioritizes decision-making for the most cost-effective remedy. Existing MEMS research focuses on combining these devices with radios and energy harvesting systems to form wireless mesh communications networks for uploading the sensor data, and removing the reliance on batteries. However, such wireless networks place a heavy burden on the integrated device cost and size due to the need for long communications distance and high energy harvesting rates.

Research Objectives:
This proposed effort removes most existing burdens by utilizing connected vehicles as a mobile gateway between the sensors and the remote processing units. Sensors need only communicate across several feet instead of hundreds of feet, which reduces their transmission power, antenna size, energy harvesting requirement, and overall cost. To reduce energy consumption even

further, sensors transmit available data only when the excitation from moving vehicles awakens the radio circuits.

Implanted MEMS devices monitor structural health factors but may not necessarily measure the impact of pavement roughness on moving vehicles. Therefore, vehicles equipped with GPS-vibration sensors to monitor pavement conditions may combine surface roughness measurements with the received MEMs data from their GPS-tagged location.

This effort develops the analytical framework and proof-of-concept for utilizing such a combined system of in-situ MEMS sensors and dynamic pavement condition monitoring within a connected vehicle environment. Assessing the effectiveness of this solution will lead to further MEMS design refinement, implementation, and field-testing.

Research Methods:

The main thrust of this work is to further develop MEMS cantilevered sensors so that they can successfully deployed for transportation structural health monitoring. A schematic of these devices is shown in Figure 1. These are built at the micro scale, usually out of two dissimilar materials, and possess inherent structural dynamic properties to detect the motion of the larger structure to which they are attached.

This is intended to be the first phase of a collaborative effort between researchers at Colorado State University and North Dakota State University. This work will initial develop the necessary mechanics for understanding the force-displacement relations and natural frequency behavior of the cantilever MEMES devices.

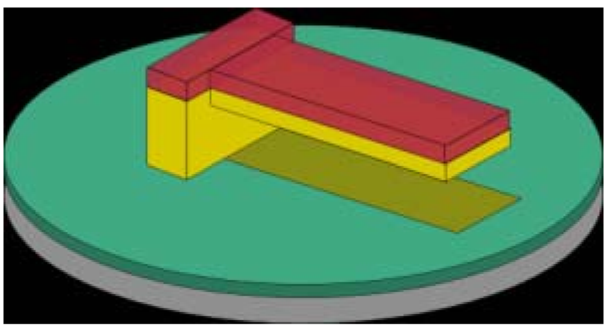

Figure 1. An example of a bi-material cantilever MEMSS sensor. The device is fixed at the left end and is free to vibrate on the right in all directions (http://matthieu.lagouge.free.fr).

Finite element models in three dimensions will be used to predict the flexural, torsional, and coupled natural frequencies, and parametric changes will be incorporated to determine the optimal geometry so that the sensor can be tuned to detect the ambient motion of the transportation structure and used within the larger health monitoring system.

Expected Outcomes:

The primary outcomes of this work are 1) a better understanding of MEMS cantilever characteristics, advantages, and disadvantages over existing systems, and 2) the necessary sensing and mechanics foundation for a new type of structural health monitoring system for not only transportation structures but other structures as well.

Relevance to Strategic Goals:
This project is related to the strategic goals of State of Good Repair (using MEMS system to continuously determine the health of existing structures) and Safety (these sensing systems are currently being deployed to avoid the sort of high-profile bridge and structural failures that have found their way into newspaper headlines during the past decade).

Educational Benefits
This project has strong ties to undergraduate class material because of the cantilever structure of the MEMS device and the vibrational nature of the sensors. These geometries will specifically be discussed in classes taught by the PI – namely CIVE 360 (Mechanics of Materials), CIVE 367 (Structural Analysis), and CIVE 562 (Fundamentals of Vibrations). Some undergraduate student labor will also be used during the course of the project.

Work Plan:
The project will follow the schedule below:
Task 1: Develop the three-dimensional finite element codes for frequency analysis, determine the prototype MEMS configurations, mesh these solids using 8-noded brick elements.
Task 2: Determine the natural frequencies and modal shapes for the proposed configurations, plot the resulting mode shapes, determine the level of motion that can be detected.
Task 3: Incorporate these sensors into the larger SHM rubric for transportation systems, assess limitations of motion, complete parametric studies to optimize performance both for the individual sensor and the entire sensing array.
Task 4: Complete final report and any journal articles that result from this project.

A time schedule is given below:

	Months					
Task	**1-2**	**3-4**	**5-6**	**7-8**	**9-10**	**11-12**
1						
2						
3						
4						

Project Cost:

Total Project Costs: $92,000
MPC Funds Requested: $46,000
Matching funds: $46,000

Source of Matching Funds**:**

- (Projects require a non-federal dollar-to-dollar match for MPC funds received)
- Colorado State University: 1/2 time GTA for Michael Lebsack (MS student working on project) plus tuition: $13,500.
- Department of Civil Engineering: $1000 travel funds.

- Colorado State University: 2.0 months research coverage for PRH $31,500.

TRB Keywords:
Sensors, Transportation Systems, Composites, Stiffness, Strength of Materials, Wireless Communication Systems

References:

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