National Concrete Pavement Technology Center

CP Tech Center

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RESEARCH PROJECT TITLE

Embedded Micro-Electromechanical Sensors and Systems (MEMS) for Monitoring Highway Structures and for Infrastructure Management

SPONSORS

Iowa Highway Research Board (IHRB Project TR-575)
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The mission of the National Concrete Pavement Technology Center is to unite key transportation stakeholders around the central goal of advancing concrete pavement technology through research, tech transfer, and technology implementation.

IOWA STATE UNIVERSITY
Institute for Transportation

A Feasibility Study on Embedded Micro-Electromechanical Sensors and Systems (MEMS) for Monitoring Highway Structures

tech transfer summary

MEMS provide vast improvements over existing sensing methods in the context of structural health monitoring (SHM) of highway infrastructure systems.

Objective

The primary objective of this research was to investigate the feasibility of using micro-electromechanical sensors and systems (MEMS) in highway pavement infrastructure for structural health monitoring (SHM).

Background

The development of novel "smart" structures by embedding MEMS capabilities directly into the construction material during the manufacturing and deployment process has attracted significant attention in the context of autonomous SHM.

Research Description and Methods

This feasibility study focused on investigating the use of MEMS-type devices and their potential applications in portland cement concrete (PCC) through a comprehensive literature review, a vendor survey, and a laboratory study, as well as a small-scale field study.

The WAKE Inc. radio-frequency identification (RFID) wireless HardTrack Concrete Monitoring System, the Sensirion Inc. USA Digital Humidity Sensor, and the Maxim Integrated Products Thermochron iButtons were selected for the laboratory and field studies.

A concrete slab form was fabricated to install the selected sensors. The mixed fresh concrete was carefully placed in the instrumented concrete form. The experimental test program consisted of four test phases (including a field test phase) based on different test conditions.

Summary of Key Findings

- The test results validated the ability of the RFID wireless concrete monitoring system in accurately measuring the temperature both inside the laboratory and in the field under severe weather conditions.
- Because the micro-sized MEMS devices are intended to be used in harsh environments, reliability is one of their most important properties. However, the reliability of MEMS products is still not well established given that their failure mechanisms are much more complex than those of simple integrated circuits (ICs).
- A number of factors, including, but not limited to, whether or not they are embedded and how they are embedded into structures, the environment in which they operate, and the casing or packaging, will determine the reliability of these devices. The lack of adequate knowledge in this area is also contributed to by the hesitancy of MEMS manufacturing and packaging companies to share such valuable data.

- In this research study, the wireless RFID sensors were the ones that survived the severe freeze-thaw conditions imposed during the field experiments. All of the wired sensors failed or didn't function properly after a few freeze-thaw cycles in the field environment. This could be partly attributed to the malfunctioning of the wired systems connecting to the data acquisition box.
- The wireless concrete monitoring system appears promising due to a number of benefits, including wireless transmission of temperature data to construction staff directly to alert them of freezing or elevated curing temperatures; development of future concrete strength forecasting models; monitoring of cold or hot weather effects on mix designs using certain materials; strength gain in concrete bridges, etc.; and characterization of early-age PCC curling behavior, etc.

Future Research Recommendations

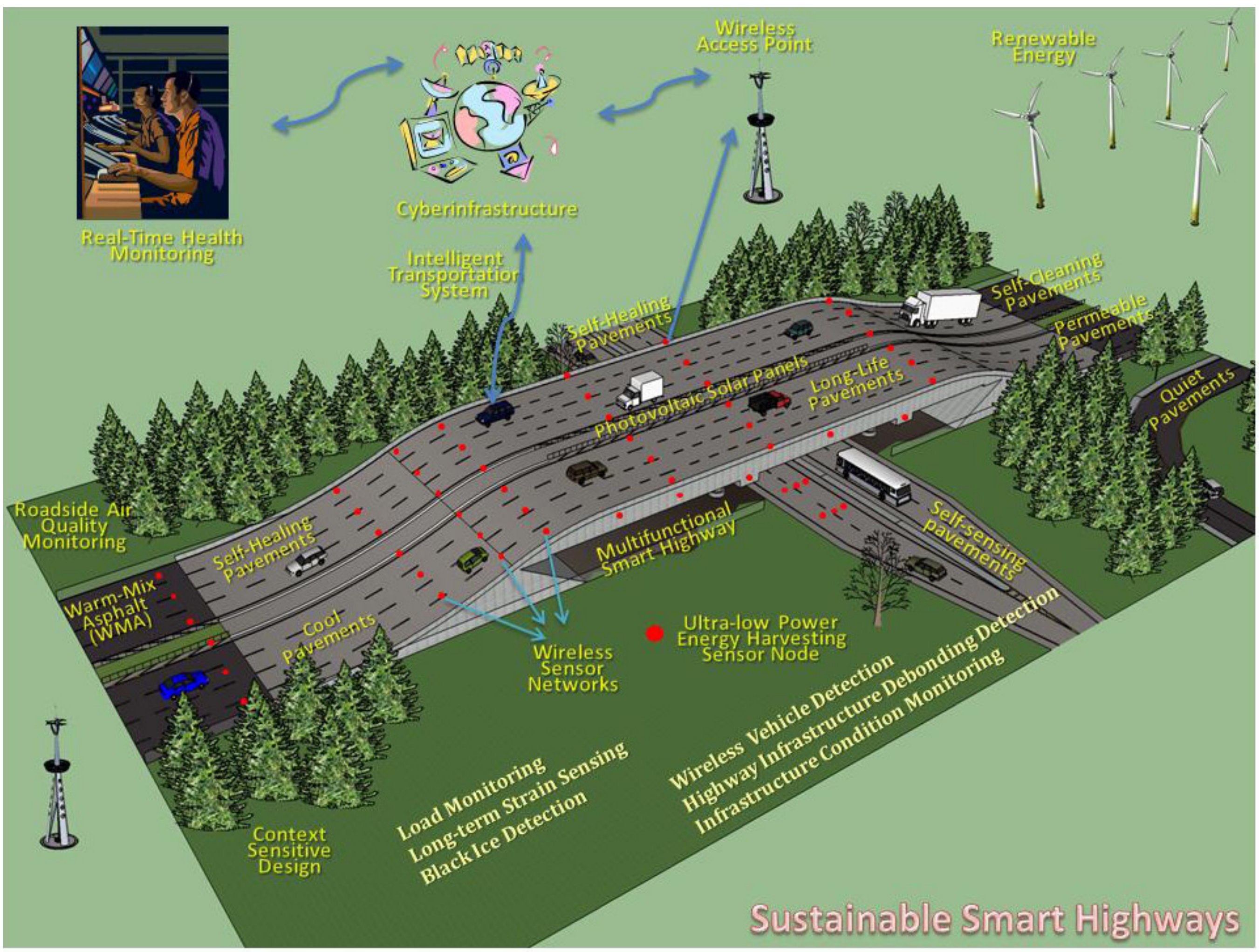
In consultation with the project technical advisory committee (TAC), the most relevant MEMS-based transportation infrastructure research applications to explore in the future were highlighted and summarized.

The top five applications to explore in the future are development of a pavement strain monitoring system, an overweight/heavy vehicle pre-alert and detection system, a critical stop sign tracking/monitoring system, a traffic flow detection and wrong-way vehicle control and warning system, and a black ice detection and warning system. (Five other research projects were also recommended.)

Implementation Benefits

MEMS provide vast improvements over existing sensing methods in the context of SHM of highway infrastructure systems, including improved system reliability, improved longevity and enhanced system performance, improved safety against natural hazards and vibrations, and a reduction in life-cycle cost in both operating and maintaining the infrastructure.

Advancements in MEMS technology and wireless sensor networks provide opportunities for long-term, continuous, real-time structural health monitoring of pavements and bridges at low cost within the context of sustainable infrastructure systems.



Research team's vision of sustainable smart highways for the future