Quarterly Report

Project Title:
Development of a Self-Sustained Wireless Integrated Structural Health Monitoring System for Highway Bridges

Cooperative Agreement # RITARS11HUMD

Eighth Quarterly Progress Report

Period:
April 14, 2013 through July 15, 2013

Submitted by:
The Research Team – University of Maryland with North Carolina State University and URS

Submitted to:
Mr. Caesar Singh, Program Manager, US DOT

Date: July 29, 2013

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EXECUTIVE SUMMARY

I — TECHNICAL STATUS

Accomplishments by Milestone

1.1. General

- Updated Project web site (http://www.ncrst.umd.edu/) (Task 1 and Deliverable 2)
- Delivered eighth quarterly financial and technical reports (Task 6 and Deliverable 11)
- Prepared and sent request for one-year no-cost extension by e-mail on May 10th, 2013
- Conducted meeting with Mr. Caesar Singh of RITA, USDOT on June 7th, 2013 for reviewing the request on no-cost extension for one year (Task 6 and Deliverable 11)
- Prepared presenting (2) at the ASCE/EMI Conference and published several journal papers (Task 6 and Deliverable 12).
- Collected and used the updated traffic data (2012) around the bridge of I-270 (Southbound) over Middlebrook Road near Germantown, Maryland, to simulate the traffic flow.
- Based on the Weight-in-Motion data from the nearby station -Hyattstown southbound station, three types of truck models (2-axle, 5-axle, and 6-axle trucks) have been proposed.
- Conducted the time history analysis using updated traffic and truck information, and tried to match the simulated data with the summer and winter field test results for the remaining life estimation.
- Configured Matlab fatigue program to count damage accumulations using Palmgren-Miner rule
- The revised work plan is shown below as Milestones/Deliverables. Dark Shading indicates Deliverable items and Tasks in which the Research Team has been engaged over the past quarters. Lighter shading indicates anticipated duration for Deliverables by quarters. Grid pattern shading means partially fulfilled.

Deliverables	Action	Quarter No.											
		1	2	3	4	5	6	7	8	9	10	11	12
1	Form TAC and conduct kick-off meeting. Determine baseline field test procedure (Task 1)												
2	Establish and update project web site (Tasks 1 & 6)												
3	Conduct baseline field test and finite element analysis on pre-selected bridges (Task 1)												
4	Design, fabricate and characterize AE sensor and measure the performance (Task 2)												
5	Develop and evaluate T-R method for passive damage interrogation (Task 3)												
6	Develop and experimentally evaluate wireless smart sensor and hybrid-mode energy harvester (Task 4)												
7	Implement passive damage interrogation T-R algorithm in the wireless smart sensor on bridges (Task 4)												
8	Integrate and validate AE sensors with wireless smart sensor and hybrid-mode energy harvester (Task 5)												
9	Develop and conduct field implementation/validation of commercial-ready ISHM system with remote sensing capability (Task 5)												
10	Recommend strategy to incorporate remote sensing and prognosis into BMS (Task 5)												
11	Prepare and submit quarterly status and progress reports and final project report (Task 6)												
12	Submit paper to conference presentations and publication to TRB meeting or other conferences (Task 6)												

Note: Deliverables items 7, 8, 9 and 10 for the 8th quarter are partially fulfilled. They are still tested and modified by the NCSU team. The explanation of the delay is described and highlighted later under Section 1.6 - Future Plan.

1.2. Remote Health Monitoring System

- Real time strain and AE data monitoring is continuously viewed (, except two occasions due to thunderstorms and accidently pulled the plug by maintenance workers.) The following web address should display the BDI strain and AE data, both the graph and the properties.
  1) Try entering this web address into your browser (either Internet Explorer or Firefox should work fine)
  Link 1 to Remote BDI strain monitoring (link to

http://166.143.163.215:8000/BDI.html)
Link 2 to Remote AE sensor monitoring (link to
http://166.143.163.215:8000/AE.html)
2) It will then ask you to download the Labview plug-in, and direct you to the webpage with the download.
3) After the plug-in is downloaded and installed, you should be able to view the file.

1.3 Pilot Bridge Fourth Test and following activities

- 1st and 2nd Pilot Bridge tests: MD Bridge No. 1504200 I-270 over Middlebrook Road, was first tested on March 19-21, 2012 and then second tested on June 28 &29, 2012. Here is the list of troubleshooting and configuring hardware in the field in this quarter to alleviate problems with noise and interference (Task 1 and Deliverables 1 & 3; Task 2 and Deliverables 4 & 9).
    - **October 18, 2012** – Checked the connections of Amplifiers, and the DC Power Supply. Reset connections and powered off/on all equipment.
    - **November 2, 2012** – Looked for sources of interference in the field. Brought the PXI system back to the lab. Connected PXI to the laboratory sensors and found the PXI is operating correctly.
    - **November 9, 2012** – Brought the PXI back to the field and attached test panels to compare the plots of sensor data.
    - **November 15/16, 2012** – Visited the field with North Carolina State University graduate students. Replaced one inoperable amplifier with a specialty made amplifier: coated with waterproof epoxy. Replaced all sensors and covered with plastic to guard the sensors from moisture. Found there is still interference and brought the PXI back to the lab for more testing.
    - **November 30, 2012** – Cut wires in 100ft lengths to test if interference was coming from the wires. Consulted with National Instruments (NI) for grounding solutions and for field wiring and noise considerations for analog signals.
    - **December 4, 2012** – Reconfigured the ground so all equipment was grounded to the bridge. This solved the interference problem that was disrupting the AE sensors.
- 3rd Pilot Bridge test: Reconfigured hardware in the field after power losses.
    - **March 13, 2013** – Reset connections and powered off/on all equipment. Reset the AE hardware. Collected all the data from the data acquisition system.
    - **April 19, 2013** – Revisit the bridge to reset the system.
- 4th Pilot Bridge test: Wireless sensor integration test on May 29-30, 2013. Details of the test are listed in the following sections.
    - **June 19, 2013** – Reset connections and powered off/on all equipment. Attached Universal Power Supply (UPS) for temporary loss of power.

1.4 AE Sensor

- Integrating wireless sensor node with piezo paint AE sensor was examined in the lab test using pencil break tests in May 2013. The wireless sensor node was brought by NCSU researcher and tested in UMD Structures lab before field test on the I-

270/Middlebrook Bridge. The AE signals were collected with wireless piezo film AE sensors of different sampling rate of 2 MHz. The AE signal due to pencil break (a standard AE event simulation technique) was found to be ok.

- Field test of the wireless acoustic emission sensor was carried out in late May 2013. The field test bridge is the I-270 Middlebrook Bridge near Germantown, Maryland. During this field tests, some aging issues (humidity and electrode peel off) were identified with several existing piezo film AE sensors and they were replaced with new sensors. In order to protect the new sensors from humidity, a layer of polyurethane coating was applied on top of the sensors for additional protection as shown in Figure 1.

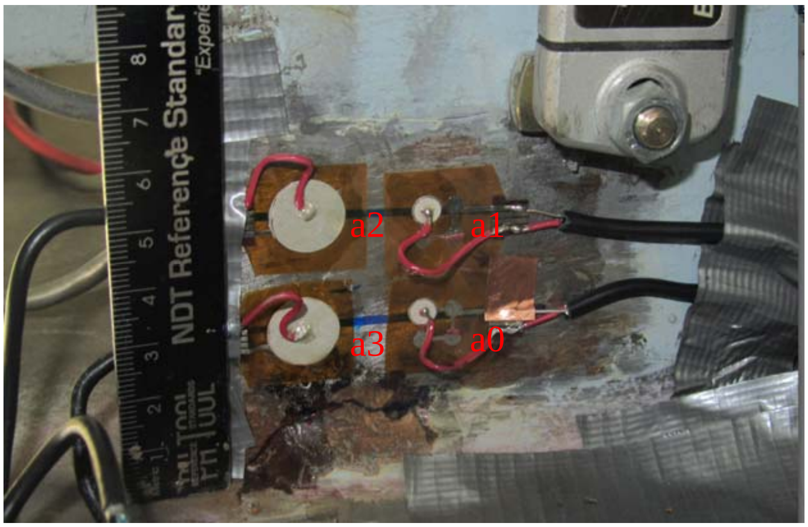

Figure 1. Newly installed sensor near the fatigue crack (a layer of polyurethane coating was applied on the sensors for extra protection of humidity).

- During the field test, the UMD team did pencil lead break tests for calibration purpose. The test set up is shown in Figure 2. Figure 3 shows the signals and their frequency spectra due to a pencil lead break event captured by all the five sensors including the guard sensor. It can be seen that the guard sensor has nearly no response since it’s far away from the simulated source.

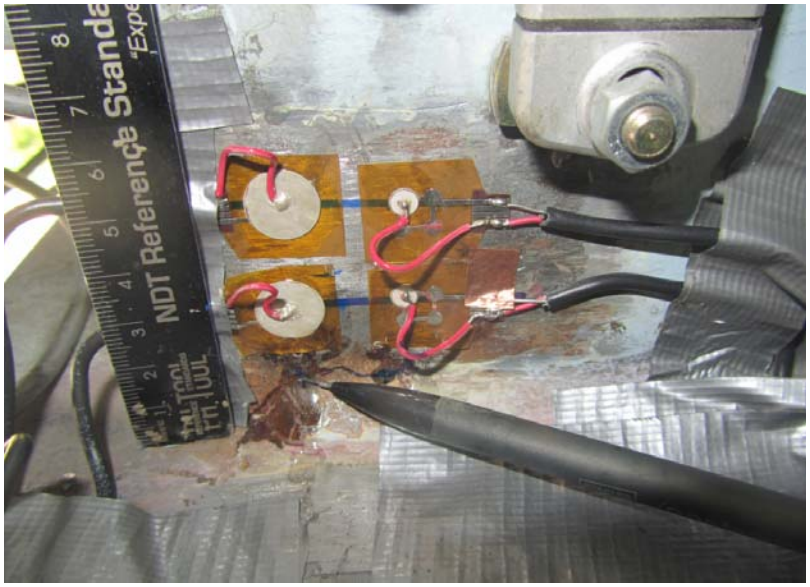

Figure 2. Pencil lead break test at the middle point of the fatigue crack

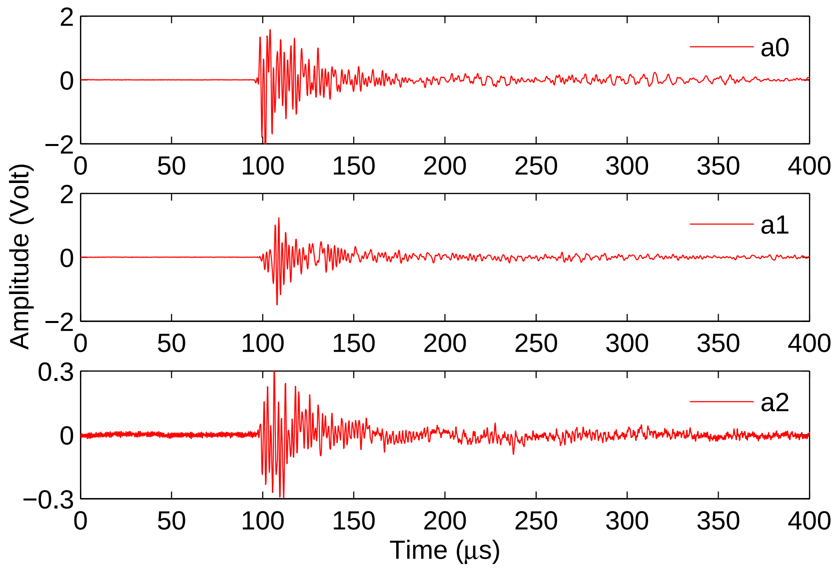

Figure 3a. Typical AE signals measured by the three piezoelectric film AE sensors due to pencil lead break

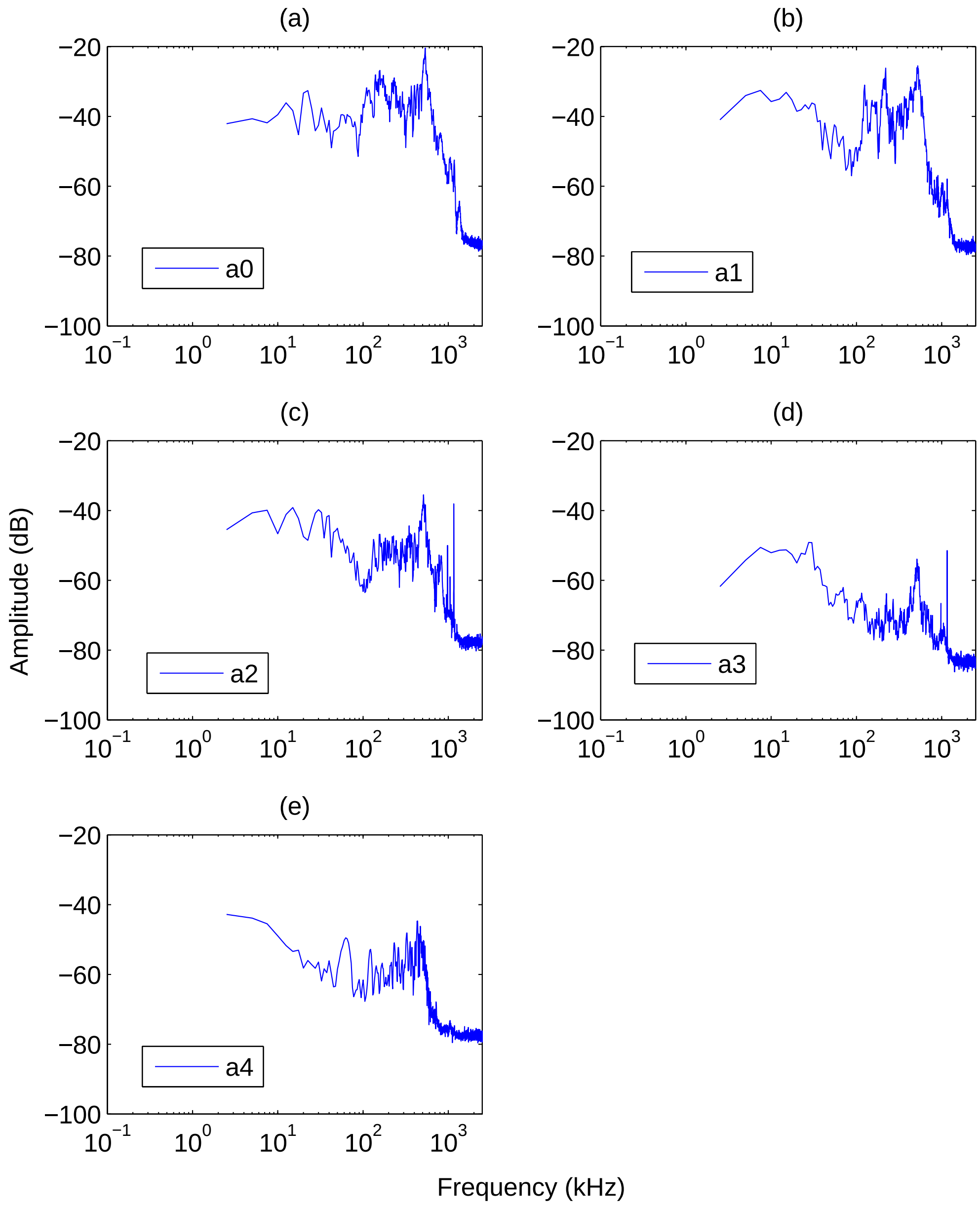

Figure 3b. Pencil lead break test conducted at the crack tip (averaged from 40 sets of data)

- Channel 0 sensor is connected to the wireless sensor node as shown below in Figure 4a. Pencil lead break tests were carried out and traffic induced signals were captured. Figure 4b shows the status of wireless sensor storing captured signal. Figure 4c shows the base station for receiving signals at the abutment. This base station was connected to PXI through USB.

- In the last quarter, unexpected power-down happened in the middle of June and a field trip was arranged on June 19, 2013 to bring the power back to the monitoring system at the bridge site. Continuous AE monitoring was done since then.

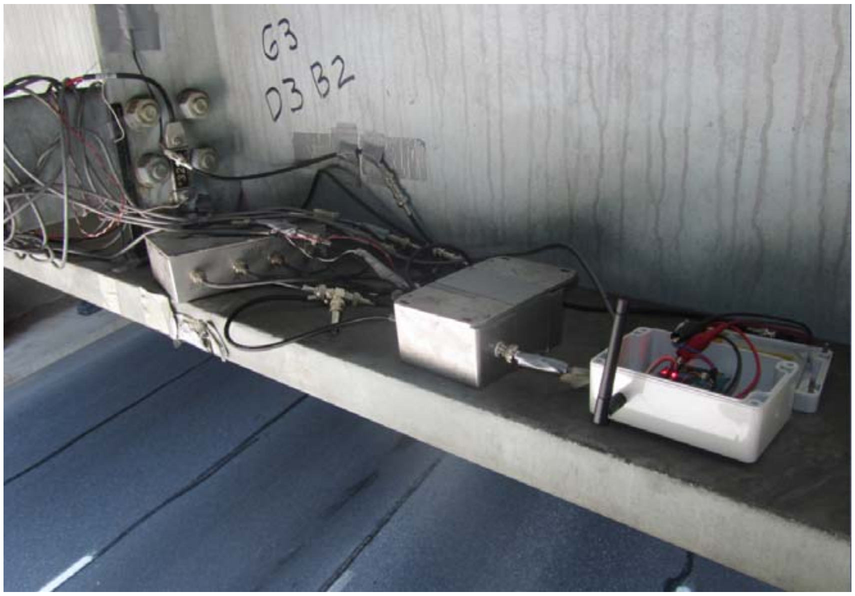

Figure 4a. System set up overview with the wireless sensor

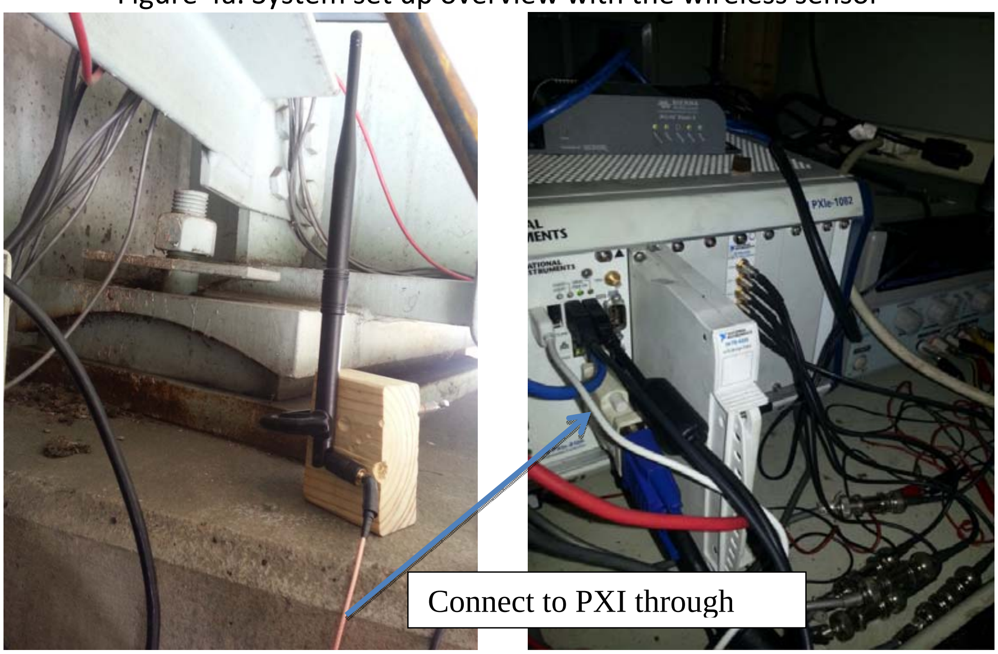

Figure 4b and 4c. Wireless sensor receiver at the abutment: (b) base station (c) connection to PXI with USB.

1.5 T-R Method, Energy Harvesting and Smart Sensor

Accomplishments of these tasks by NCSU team are summarized here:

* Solder the redesigned wireless piezoelectric sensor board and test it with power.

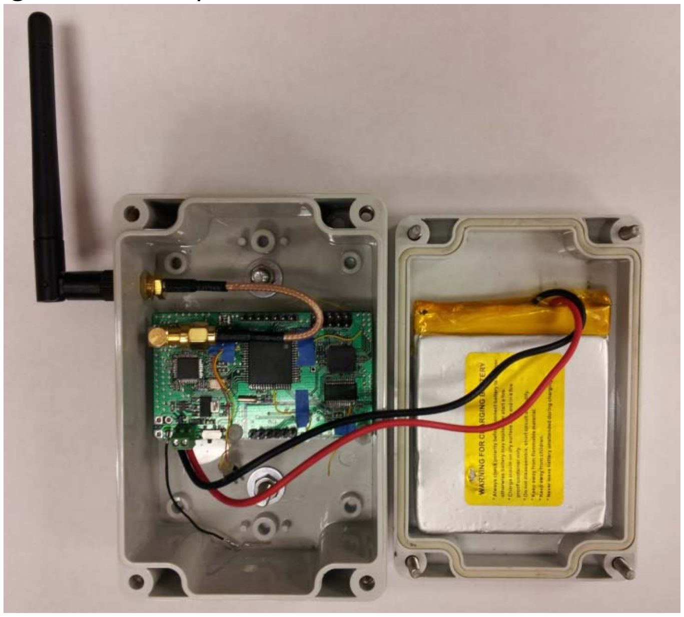

Figure 5. The Redesigned Wireless Piezoelectric Sensor

* Debug the piezoelectric acquisition program of the microcontroller and FPGA.
* Conduct pencil lead break experiments with new wireless piezoelectric sensor in the Lab.

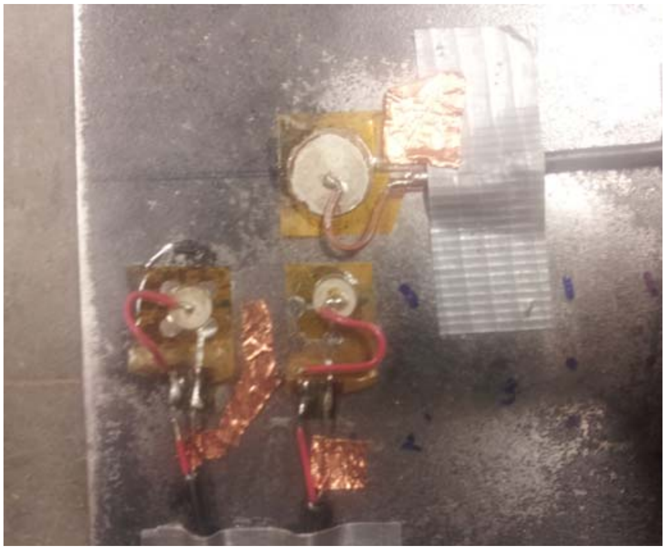

Figure 6. Piezo Sensors

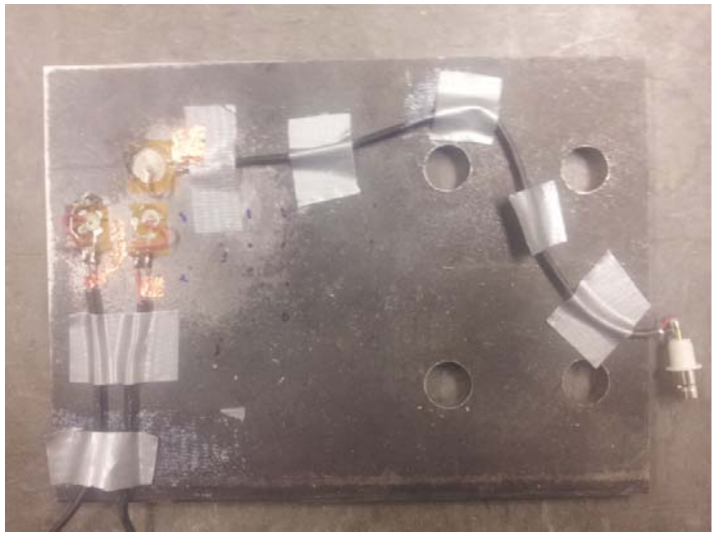

Figure 7. Test Platform

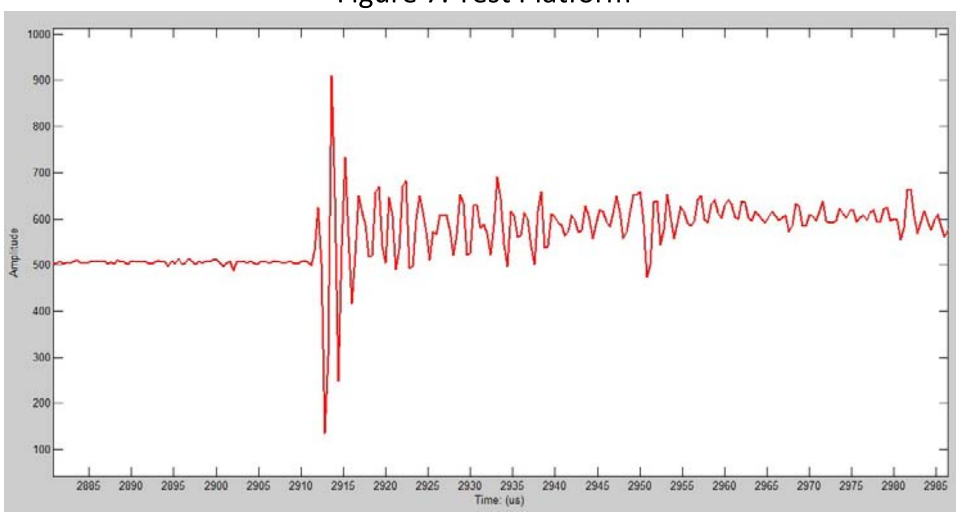

Figure 8. Pencil Lead Break Test 1

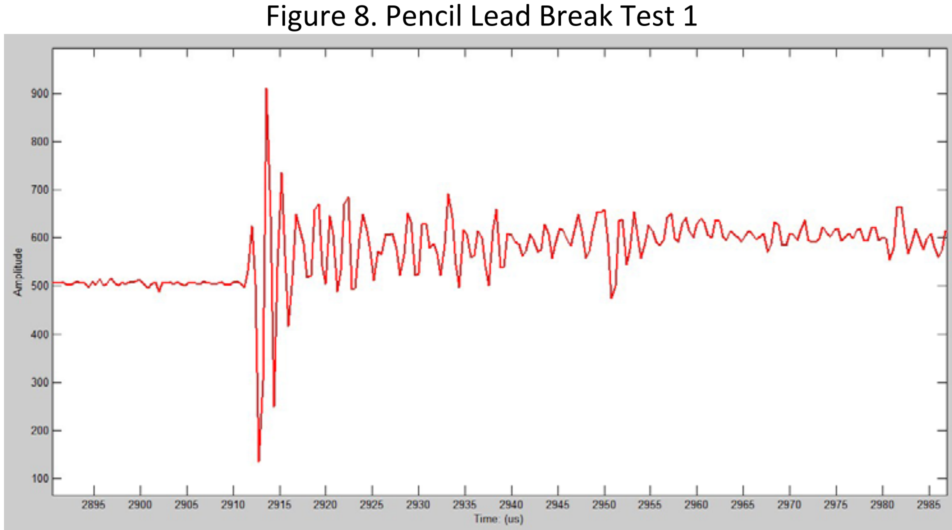

Figure 9. Pencil Lead Break Test 2

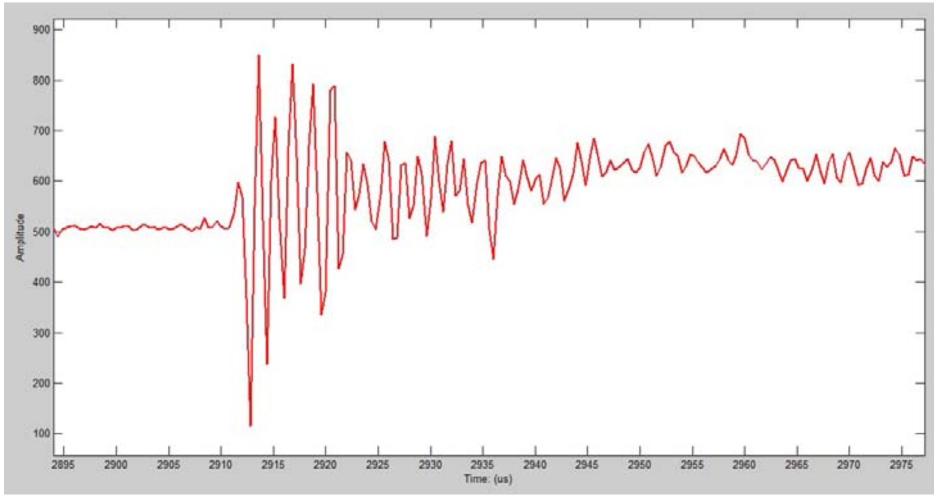

Figure 10. Pencil Lead Break Test 3

- Conduct field test on I-270 Middlebrook Bridge

  a. Wireless Signal Packet Loss Rate Test:
  Test Condition:
  Under the bridge, Test Distance: 42 meters (The width of the whole bridge)
  Send 147775 packets

Table 1. Packet Loss Rate Test 1

Base Station: 7 dBi Omnidirectional Antenna Sensor: 2 dBi Omnidirectional Antenna		**Base Station: 14 dBi Directional Antenna Sensor: 2 dBi Omnidirectional Antenna**	
Received Packets	**Packet Loss Rate**	**Received Packets**	**Packet Loss Rate**
36570	75.25%	147545	0.16%
142715	3.42%	145130	1.79%
93150	36.96%	147315	0.31%
106605	27.86%	147545	0.16%
81420	44.90%	147200	0.39%
102810	30.43%	147660	0.08%
118105	20.08%	146165	1.09%
37145	74.86%	147545	0.16%
49795	66.30%	147545	0.16%
122475	17.12%	147430	0.23%
Average	39.72%	**Average**	0.45%

Table 2. Packet Loss Rate Test 2

Base Station: 14 dBi Directional Antenna Sensor: 8 dBi Directional Antenna		**Base Station: 7 dBi Omnidirectional Antenna Sensor: 8 dBi Directional Antenna**	
Received Packets	**Packet Loss Rate**	**Received Packets**	**Packet Loss Rate**
145705	1.40%	146740	0.70%
147315	0.31%	147775	0.00%
147430	0.23%	147545	0.16%
145935	1.25%	146510	0.86%
147660	0.08%	123970	16.11%
147660	0.08%	130180	11.91%
147315	0.31%	133170	9.88%
144095	2.49%	146855	0.62%
142600	3.50%	135815	8.09%
146510	0.86%	145015	1.87%
Average	1.05%	**Average**	5.02%

b. Wireless Sensor Test on the Bridge:

Test Condition:

The distance between Base Station and wireless sensor is 21 meters. The base station and wireless sensor are close to the steel structure.

Base Station: 7 dBi Omnidirectional Antenna Wireless Sensor: 2 dBi Omnidirectional Antenna.

c. Remote Test from Lab

Test the wireless sensor packet loss rate in the lab through the 3g network

Table 3. Packet Loss Rate Test 3

Send 147775 packets		
Time	**Received Packets**	**Packet Loss Rate**
2013/5/29/21:00	144095	2.49%
2013/5/29/22:00	147315	0.31%
2013/5/29/23:00	147775	0.00%
2013/5/30/00:00	147775	0.00%
2013/5/30/01:00	147775	0.00%
2013/5/30/02:00	147775	0.00%
2013/5/30/03:00	147775	0.00%
2013/5/30/03:30	147775	0.00%
2013/5/30/08:00	147545	0.16%
2013/5/30/08:30	147315	0.31%

1.6 Future Plans

Pilot Bridge Testing (UMD team led by Dr. Fu) –

- Continue AE monitoring, evaluating and validating results on the pilot test bridge in Maryland (MD Bridge No. 1504200 I-270 over Middlebrook Road)
- Conduct the last field testing on the I-270 pilot bridge using the proto-type ISHM system and retrieve the system.
- Coordinate with MDSHA on the demo bridge (currently I-95 over Patuxent River was selected) and testing schedule.
- Collecting W-I-M data on I-95 Bridge to simulate traffic through FEM models for all pilot test bridge in Maryland and validating test data with FEM results.
- Establish the local finite element model of the crack location, do the same analysis with the global model, compare the results and discuss the necessarily of local model for our studies.
- Discuss which of the four possible crack configurations has the highest SIF at the crack tip and thus most likely to occur using finite element model.
- Estimate fatigue failure using Wohler Curve (S-N curve) where their results are currently undergoing analysis and comparisons with a probabilistic model for fatigue damage.

AE Sensor (UMD team led by Dr. Zhang) -

- Continue the long-term fatigue crack growth monitoring with piezo film AE sensor and remote sensing features on I-270 Bridge in Maryland. Focus will be placed on long term performance test of wireless sensor node with the piezo film AE sensor. Another field trip is planned for August 2013.
- Field test is planned to test the long-term fatigue crack growth monitoring with piezo film AE sensor and remote sensing features on another steel highway bridge along I-95 near Laurel in Maryland. This bridge is selected to implement full scale integrated structural health monitoring system.
- Higher sensitivity piezo film AE sensor will be sent to flexible circuit manufacturer for enhanced weathering and environmental impact protection and these sensors with new design will be tested first in the lab to characterize its performance for fatigue crack localization. The AE monitoring performance of wireless piezo film AE sensors will be tested on field test bridges.

T-R Method, Energy Harvesting and Smart Sensor (NCSU team led by Dr. Yuan) -

- Enhance the function with a new design of wireless piezoelectric sensor system to take care at least 3 remote sensor nodes.
- Improve the energy-harvesting circuits for remote sensor nodes.
- Enhance the compatibility between AE sensor and the wireless sensor node

II — BUSINESS STATUS

- Hours/Effort Expended – As the last reporting period, PI Dr. Fu worked one month paid by his cost sharing account for 167 man-hours. Three (3) UM and two (2) NCSU graduate assistants worked three months half-time (20 hours), the quarterly accounting deadline, for a total of 1,470 man-hours (one NCSU assistant is partially cost-shared by their University.)

- Total Budget - $1,151,169 & Invoiced (3/31/13) - $664,560 (57.7%)
- Cost sharing committed - $1,525,063 & Cost shared (3/31/13) - $813,025 (53.3%).