TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): ____IOWA DOT_____________________________________

INSTRUCTIONS:
Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Program Project # *TPF-5(449)*	**Transportation Pooled Fund Program - Report Period:** Quarter 1 (January 1 – March 31, 2021) Quarter 2 (April 1 – June 30, 2021) X Quarter 3 (July 1 – September 30, 2021) Quarter 4 (October 1 – December 31, 2021)	
Project Title: Robust wireless skin sensor networks for long-term fatigue crack monitoring of bridges		
Project Manager: Khyle Clute	**Phone:** 515-239-1646	**E-mail:** khyle.Clute@iowadot.us
Project Investigator: Simon LaFlamme	**Phone:** 294-3162	**E-mail:** laflamme@iastate.edu
Lead Agency Project ID:	**Other Project ID (i.e., contract #):** Addendum 736	**Project Start Date:** May 15, 2020
Original Project End Date: May 14, 2023	**Contract End Date:** May 14, 2023	**Number of Extensions:**

Project schedule status:

X On schedule ☐ On revised schedule ☐ Ahead of schedule ☐ Behind schedule

Overall Project Statistics:

Total Project Budget	Total Cost to Date for Project	Total Percentage of Work Completed
$ 540,000	$67,874.63	15%

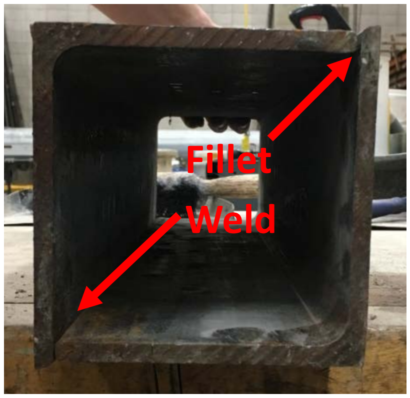
Quarterly Project Statistics:

Total Project Expenses This Quarter	Total Amount of Funds Expended This Quarter	Percentage of Work Completed This Quarter
$67,874.63		

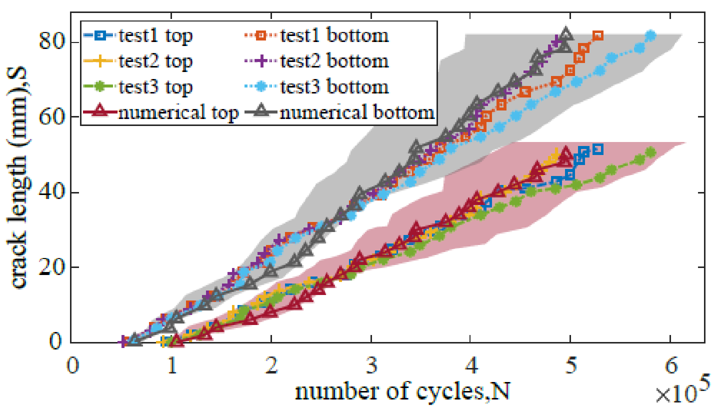
Project Description:

Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):

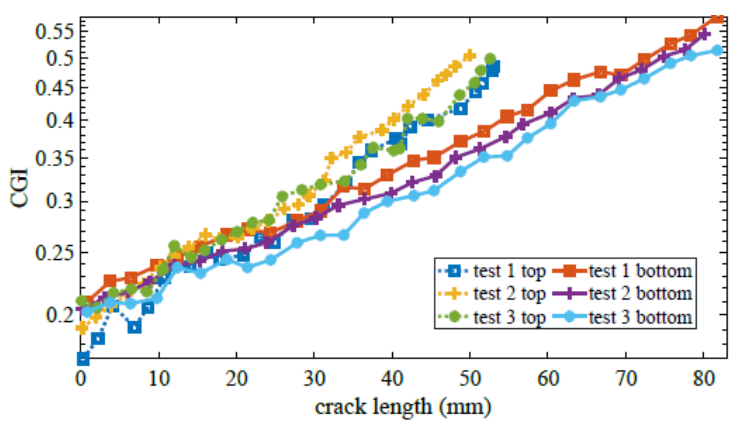
- TAC meeting on July 14th 2021.
- ISU conducted tests to investigate the capability of the SEC at detecting and quantifying fatigue cracks in weld. Tests were conducted on two L-shape steel beams welded using a fillet weld as shown below, and the sensors deployed over the weld.



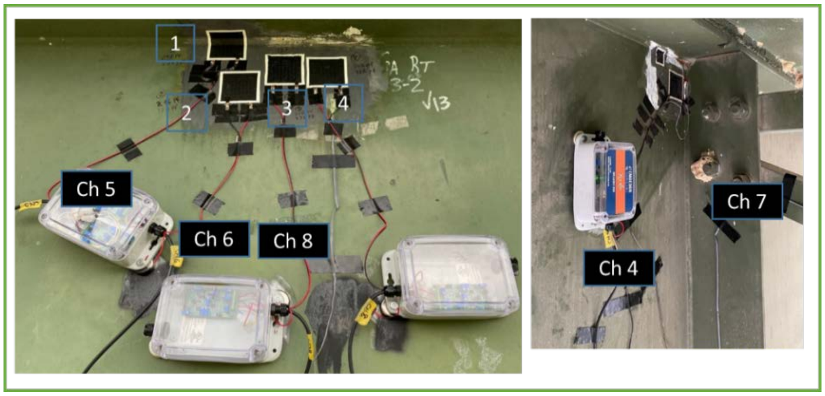
- ISU developed an electromechanical model and a data fusion algorithm (modified crack growth index (CGI)) to link SEC measurements to crack length.
- ISU created a numerical model to reproduce experimental results. The plot below show that experimental results fall within the numerical model



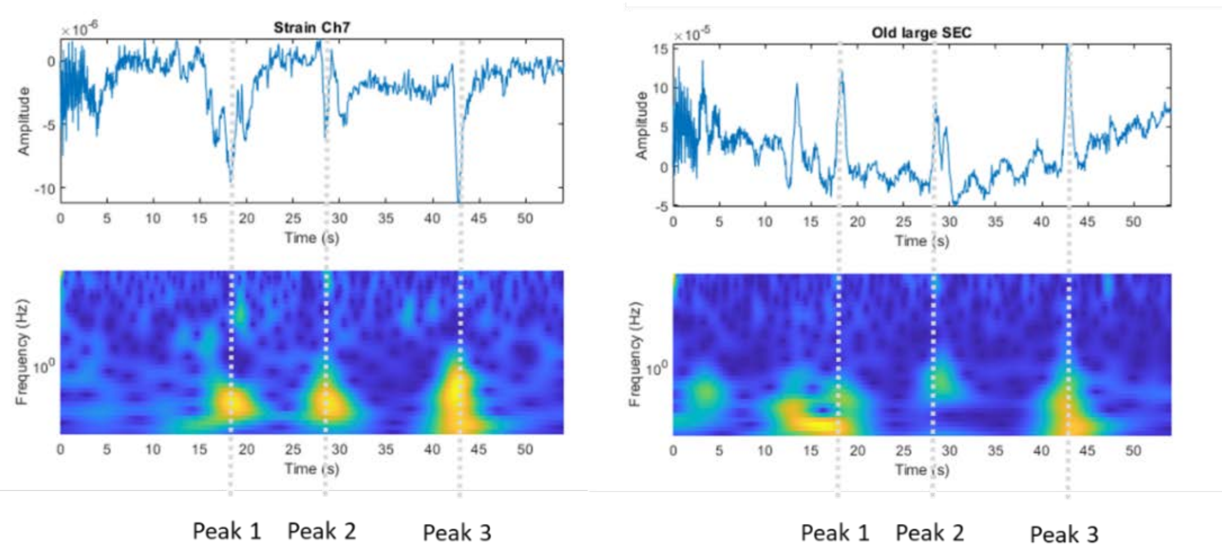
- Results showed that the CGI can relate linearly to the crack length, as shown in the plot below, thus verifying the sensor's capability to measure fatigue cracks in a folded configuration.



- KU prepared plans for the field deployment and data collection by integrating the new textured SEC developed at ISU and a wireless sensing and storage platform, Xnode, from Embedor Technologies. A field deployment to test the integrated system on a highway steel bridge was conducted by KU between August 4th and August 6th. The sensor network was deployed, shown in the figure below (new SECs on the left).



- KU processed and analyzes data to monitor fatigue crack growth. Specifically, they focused on developing an algorithm based on signal processing for monitoring fatigue cracks with bridge response induced by heavy traffic loading. The algorithm consists of a modified crack growth index (CGI) using peak-to-peak amplitudes achieved through the wavelet transform. The figure below compares the Wavelet transform from the strain gauge (left) and SEC (right) measurements. The four peaks in both figures indicate the accuracy of the proposed algorithm. The CGI was calculated based on the ratio between the peaks of the strain and SEC and remained mostly constant, indicating no crack growth.



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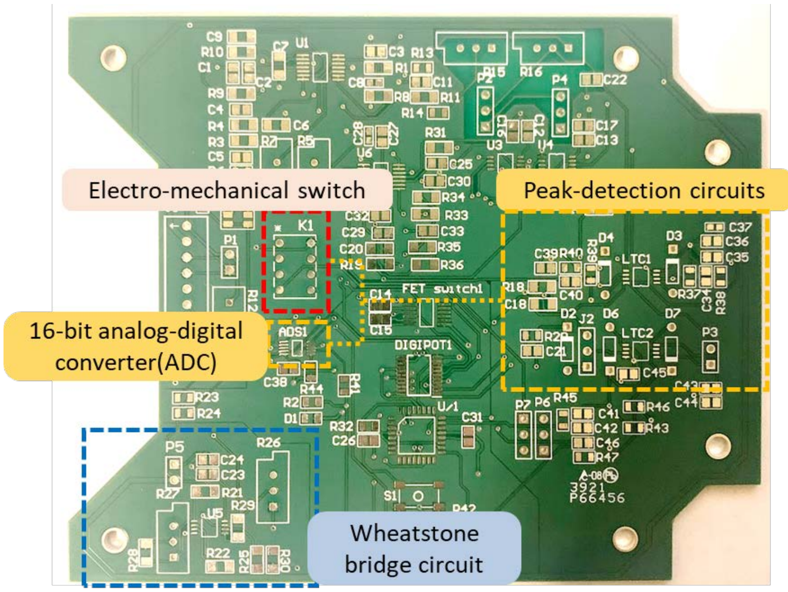
- UA redesigned the sensorboard to include a strain wheatstone bridge with a signal amplifier and an electromechanical switch to save power consumption. New wheatstone bridge circuit for high-sensitive strain sensing allows up to 1000x gain control using an instrumental amplifier. The electromechanical switch disconnects the power supply for the peak-detection circuit and analog-digital converter, once the Desauty bridge balancing and signal amplification are done. The figure beloe shows the newly updated PCB. The wheatstone bridge circuit is added as shown in blue colored box region. The power supply of peak detection circuit and ADC were connected to the main power source via the electro-mechanical switch. The electro-mechanical switch is software controlled by ATmega328 to turn it on and off.



- USC investigated the required isolation thickness for obtaining accurate strain measurement using the SEC on concrete. Rubber pads of different thicknesses were used as the isolation material. In terms of the sensor's recorded signal-to-noise ratio, a thickness between 0.015 and 0.025 inches was found to be near-optimum. The measured SEC strain was compared to that of commercial off-the-shelf strain gauges (ST350 Strain Transducer, BDI). Plots on the left and right of the figure below are measurements from using thicknesses of 0.025 and 0.030 in, respectively. The bottom plot shows the signal-to-noise ratio for a variety of tested rubber thicknesses.

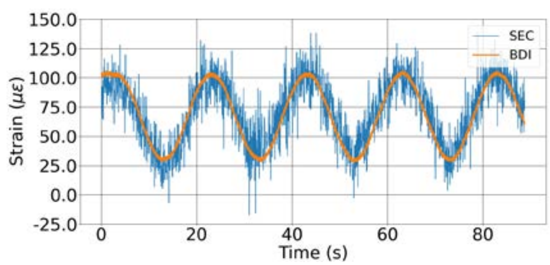


Figure 1 Strain data using 0.025" rubber

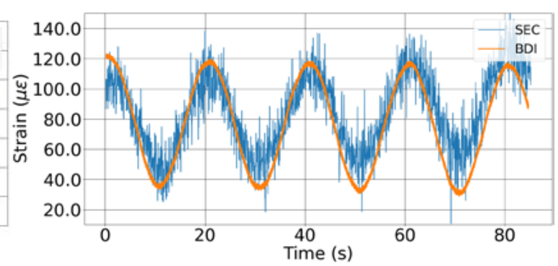


Figure 2 Strain data using 0.030" rubber

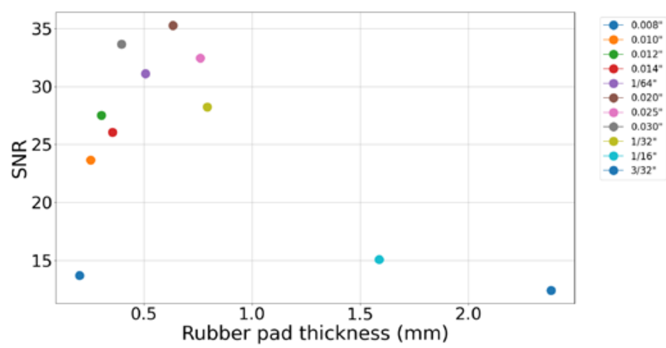


Figure 3 SNR of different rubber thicknesses

- USC conducted validation of the strain on the isolation material surface using DIC. The results show that the expected strain values are measured on the surface of the isolation material using DIC as shown in the figure below. These tests validated that the measured capacitance change in the SEC is caused by the strain transduced in the SEC. Therefore, concluding that the rubber pad isolates the SEC from concrete and reduces if not eliminates the complex electrical coupling experienced between the SEC and concrete.

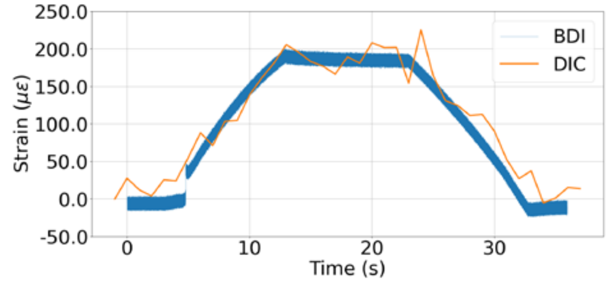
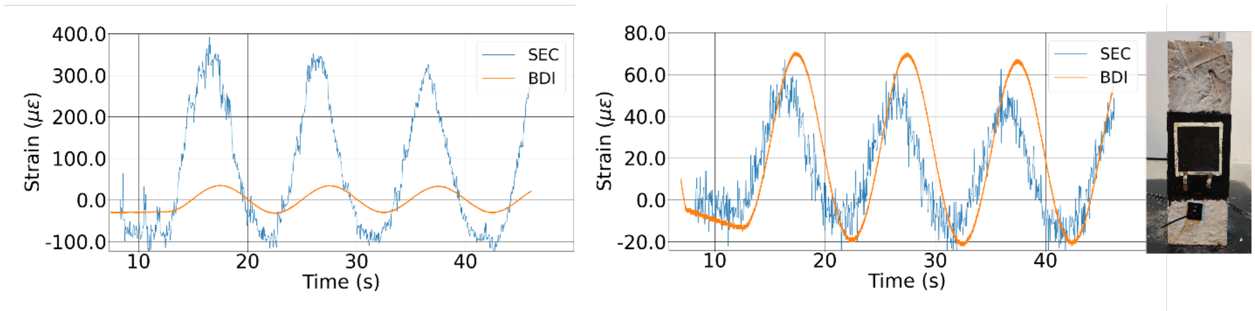


Figure 4 DIC on rubber pad surface against BDI



Anticipated work next quarter:

- ISU will wrap up work on the algorithm linking measuremetns to fatigue cracks in weld for folded configurations.
- ISU will work on archiving experimental results from the fillet-weld specimen.
- KU will continue collecting, processing, and analyzing data.
- KU will fix the issue of power supply from the leaf nodes by updating the breakout box such that it only supplies power to the sensor boards while the lead nodes are triggered by significant events, which will save power and allow long-term monitoring.
- UA will assemble and test the new PCB to ensure the performance of the strain wheatstone bridge circuit and power saving feature of new circuit design.
- USC will investigate the isolation of SEC on fullscale concrete specimens provided by the SCDOT.
- USC will conduct tests to ascertain the minimum strain values at which the SEC is suitable for use.
- USC will investigate crack detection in concrete.

Significant Results:

- Measurements demonstrate that the sensor can be used in folded configurations for crack detection in welds.
- An updated PCB to improve strain sensitivity and power consumption.
- New generation of SECs was successfully deployed onto the bridge, along with an event-trigerred sensing mode.
- Optimal installation methodology for concrete structures established.

Circumstance affecting project or budget (Describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope, and fiscal constraints set forth in the agreement, along with recommended solutions to those problems). N/A