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) X Quarter 2 (April 1 – June 30, 2021) 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:** 239-1471	**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%

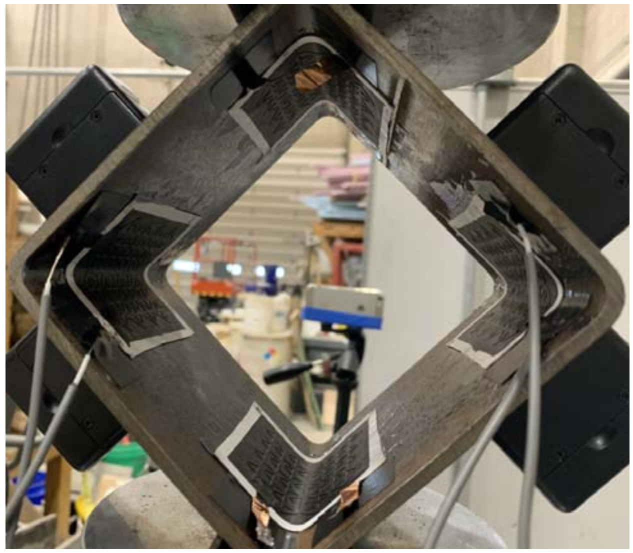
Quarterly Project Statistics:

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

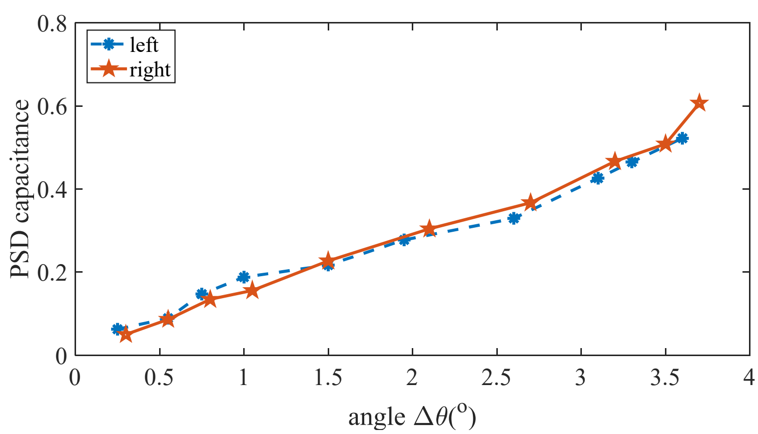
Project Description:

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

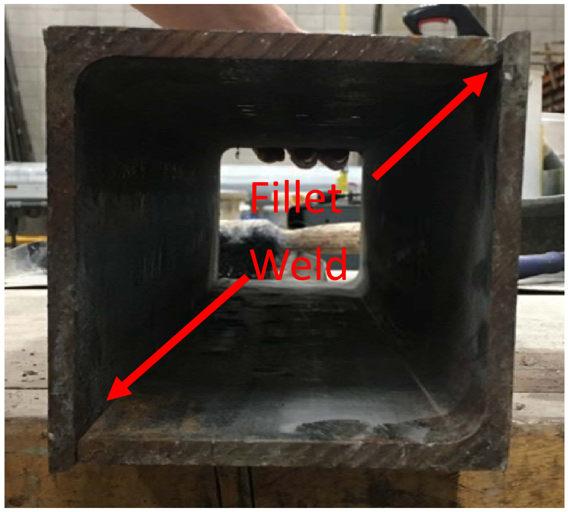
- TAC meeting on April 21st 2021 (TAC meeting on July 14th 2021 planned).
- ISU conducted tests to evaluate the performance of the SEC at measuring strain in a folded configuration. Tests were conducted on an HSS section equipped with SECs and tiltmeters, as shown below.



- Results from tests in folded configuration demonstrated that sensor data can be related to rotation angles, thus confirming that the SEC could be used in such configuration. The figure below plots the pseudo-spectral density (PSD) of capacitance data as a function of the rotation angle for the left and right SECs in the figure above. Results shows linearity and trackable angles.



- ISU designed tests to investigate the capability of the SEC at detecting and quantifying fatigue cracks in weld following the successful tests discussed above.Tests will be conducted on two L-shape steel beams welded using a fillet weld as shown below, and the sensors deployed over the weld.



- KU team visited the I-70 highway bridge in May, as shown Figure 1, to inspect the bridge girders and decide sensor deployment plan:
  - The locations, specifically in Span 3 shown below, and the number of girders to be monitored have been determined.
  - The number of SECs, sensor boards, strain gauges, Wheatstone bridge boards, breakout boxes, and Xnodes have been determined.
  - Table below summarizes items to be used in the field deployment (planned in July)

Figure . I-70 highway bridge (Eastbound)

Table: Items for upcoming field deployments

Diaphragm 3-2							
Girder	new SECs	Strain gauge	Board	enclosure	Wheatstone bridge	Breakout box	Xnode
A	4	1	4	3	1	1	1
B	4	1	4	2	1	1	1
H	4	1	4	2	1	1	1
Diaphragm 3-3							
Girder	new SECs	Strain gauge	Board	enclosure	Wheatstone bridge	Breakout box	Xnode
A	3	1	3	2	1	1	1
H	3	1	3	3	1	1	1
Total	18	5	18	12	5	5	5

- In the plan for field deployment, KU team will also include monitoring cracks under folded configuration. Therefore, KU prepared the fourth specimen with a new and an old SECs to investigate them under folded configuration. The new SEC using the UA board was successfully balanced. The results based on NI DAQ shown in the figure below indicated successful data collection from the new SECs under folded configuration.

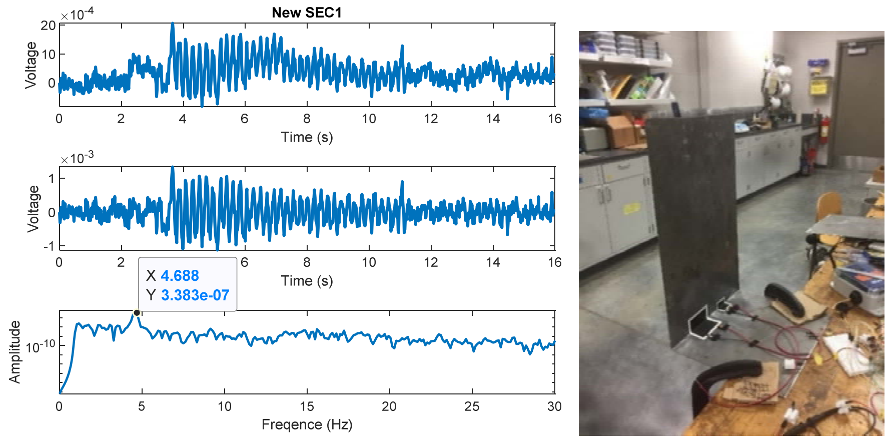


Figure . The SECs and data under folded configuration.

- KU team worked on the cellular-supported event-triggered sensing strategy to enable long-term field deployment. Specifically, the new gateway node with 4G cellular capability has been acquired, which will be used to collect data from other sensor nodes and send the data to the cloud server. This enables us to access data remotely without visiting the bridge. KU reprogramed the leaf nodes to be compatible with the new gateway node and solved several issues experienced including the issue of uploading data to the cloud, changing the threshold parameters remotely for the event-triggered sensing, etc.
- KU worked on analyzing old data recorded during 2018 to improve the algorithm for crack detection. Specifically, the ability of power spectral density to process the field data was investigated and new method for transient signal such as Wavelet analysis is being investigated for improved performance.
- KU team continued to evaluate data collection using multiple SEC sensors. As shown below, new SEC 1 and SEC 3 provided satisfactory data collections, while data collected from the SEC 2 had room for improvement on its sensitivity.

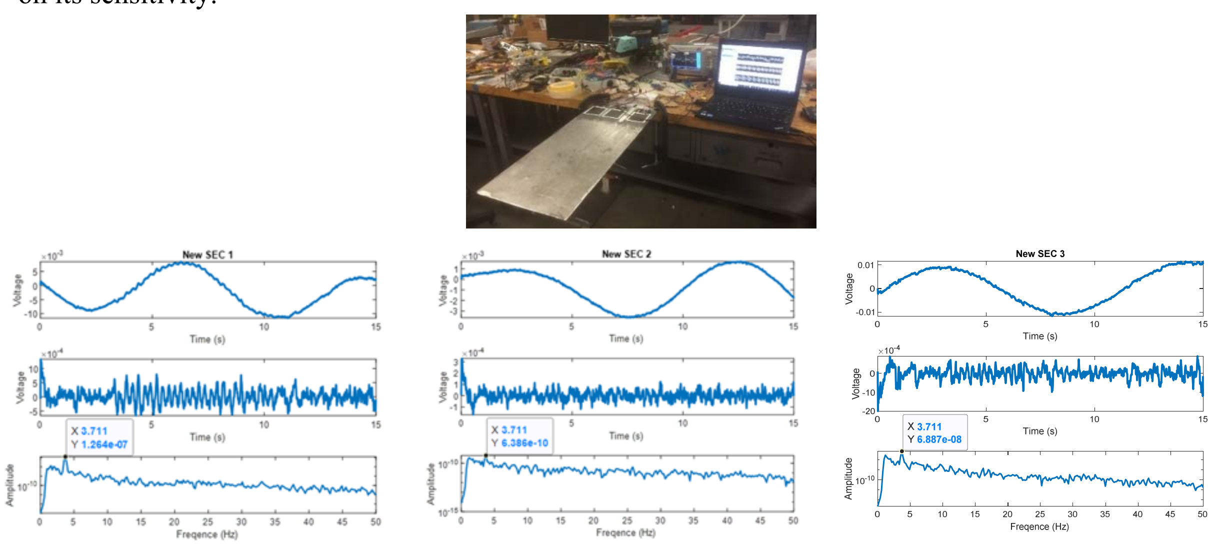
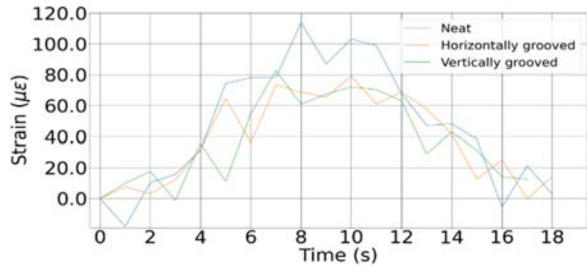
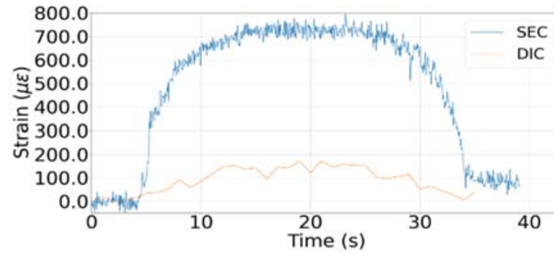


Figure. Data collected simultaneously using three new textured SEC sensors.

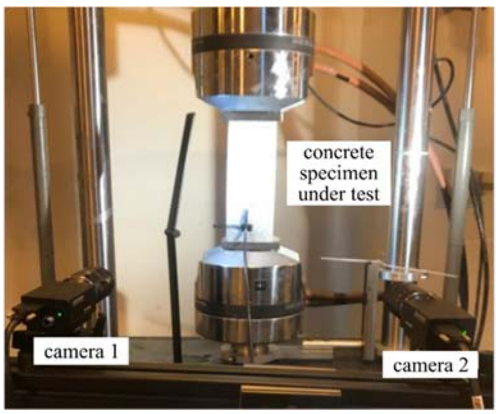
- UA assembled a new prototype sensorboard and verified the developed features that automate the De-sauty bridge balancing and shunt calibration
- UA conducted performance tests by comparing to the off-the-shelf capacitance data acquisition system PCAP02.
- USC used DIC to measure strain that propagates to the surface of the SEC sensor. The figure below (left) reports the average strain measured over the sensing area of the SEC using DIC for a neat, horizontally grooved, and vertically grooved sample. Results show that the strain

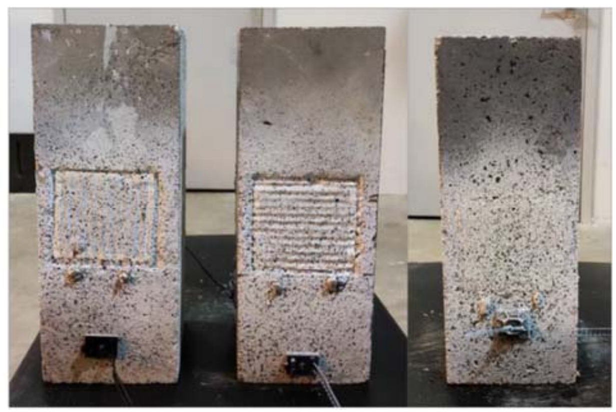
in the concrete propagates to the surface of the SEC. Figure (right) reports the strain measured by the SEC vs the strain measured by DIC. The tests found the strain values to be significantly higher than those measured through DIC.



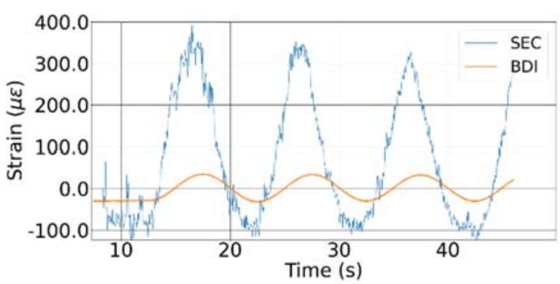


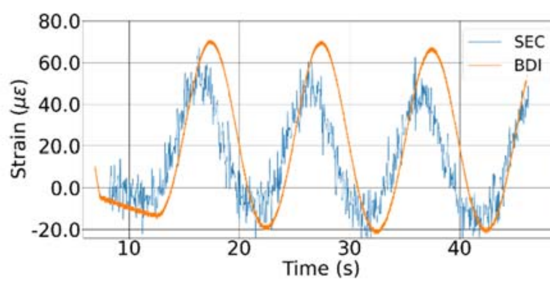
- The figure below shows USC’s experemenital test setup and the concrete specimens with SECs attached prepared for DIC.





- Results led the team to investigate the potential that the SEC sensors react electrically with the concrete material. To test this, the strain tests were repeated using DIC on metal substrates, and the SEC acted as expected and provided accurate results with +/- 25 με. The phenomena of the SEC reacting with concrete will need to be further studied.
- Figures below reports a preliminary investigation into the use of an isolating pad that electrically separates the conductive face of the SEC from the concrete. Results show that isolating the inner conductive face from the concrete allows the SEC to capture accurately the strain levels in the concrete.





Anticipated work next quarter:

- ISU will conduct an initial series of tests on angled folds on steel subjected to fatigue cracking.
- KU will complete the testing of the new cellular-enabled event-triggered sensing strategy for the field deployment.
- KU will finalize the deployment schedule with KDOT to install the new SECs and start collecting data from the I-70 highway bridge.
- UA will update the sensorboard design with additional Wheatstone bridge circuit to accommodate the resistive strain sensing using conventional foil-type strain gauges and improve the power consumption efficiency.
- USC will run tests on concrete assisted with digital image correlation (DIC) to further the understanding of the SEC on concrete.
- USC will investigate the effects of isolating the SEC from the concrete to obtain accurate strain measurements.
- USC will use DIC to validate the use of isolated SECS for strain measurement.
- USC will perform Finite Element Analysis (FEA) of the concrete-rubber-SEC interface.

Significant Results:

- Characterized SEC behavior in folded configuration (no fatigue crack)
- Tests on angled folds subjected to fatigue cracking designed
- Test bridge visited and a sensor installation plan established
- Data acquisition tested for multiple sensors and sensors in folded configuration
- The automation features (for bridge balancing & shunt calibration) worked well as expected
- New sensorboard showed better performances than off-the-shelf capacitance data acquisition PCAP02
- Discrepancies in SEC readings from concrete tests could be attributed to electromagnetic noise.

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