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 #	**Transportation Pooled Fund Program - Report Perio**
TPF-5(449)	Quarter 1 (January 1 – March 31, 2021) Quarter 2 (April 1 – June 30, 2021) Quarter 3 (July 1 – September 30, 2021) X Quarter 4 (October 1 – December 31, 2021)

Project Title:
Robust wireless skin sensor networks for long-term fatigue crack monitoring of bridges

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Lead Agency Project ID:	**Other Project ID (i.e., contract #**	**Project Start Date:**
	Addendum 736	May 15, 2020
Original Project End Date:	**Contract End Date:**	**Number of Extensions:**
May 14, 2023	May 14, 2023	

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 Projec	Total Percentage of Work Completed
$ 540,000	$187,825.07	15%

Quarterly Project Statistics:

Total Project Expenses This Quarter	Total Amount of Funds Expended This Quarter	Percentage of Work Completed This Quarter
$120,050.44		

Project Description:

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

- TAC meeting planned on January 25th 2022.
- ISU archived results on fillet weld tests.
- ISU investigated techniques to coat the sensor to reduce EMI noise on concrete. After inconclusive results, ISU started the investigation on a new sensor deployment process to reduce EMI noise on concrete. The process is illustrated below. It consists of painting the concrete surface with a conductive ink, adhering the dielectric, and brushing the electrode onto the top of the dielectric. The resulting signal is stable and can detect hammer hits.

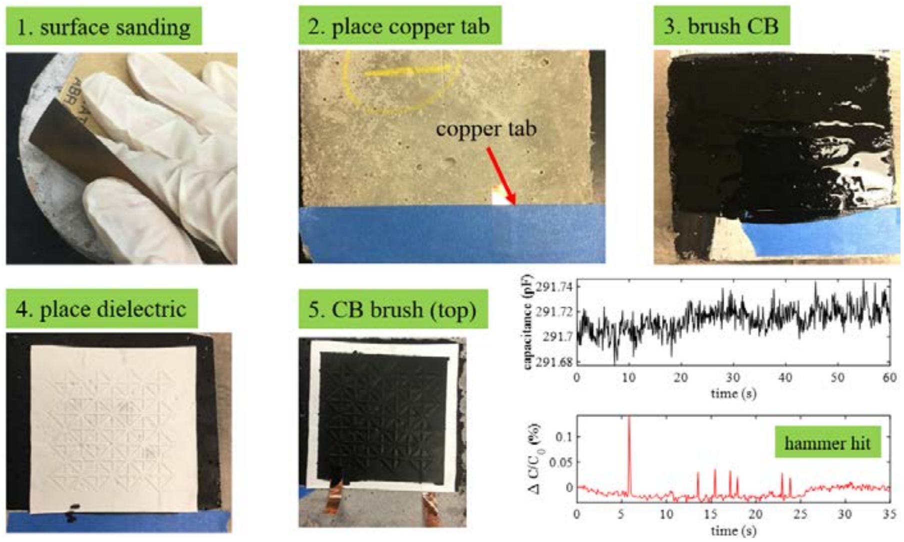
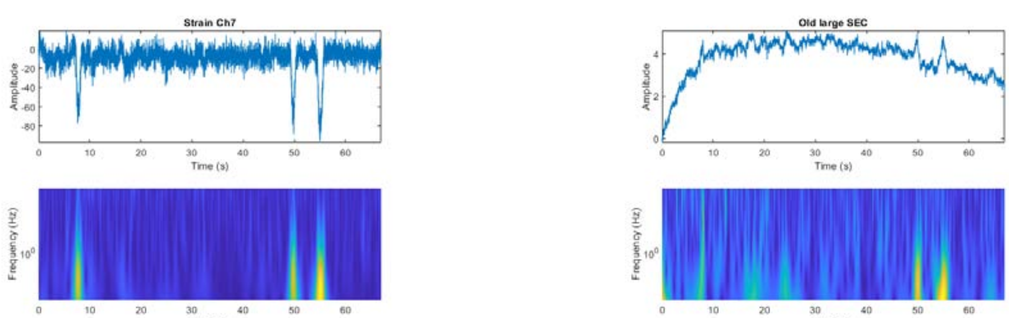
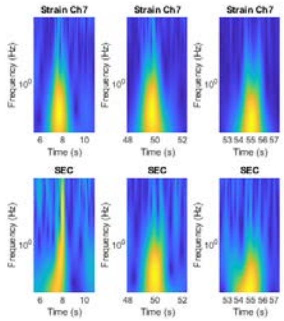


Figure: direct deployment method

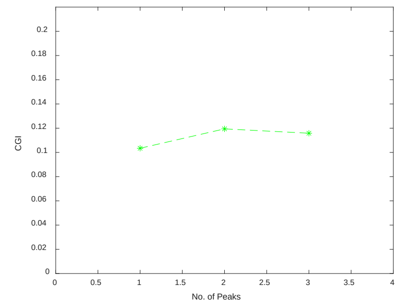
- KU fixed the power issue on the bridge and deployed the updated breakout boxes. The data acquisition has been functioning as designed ever since.
- KU continued to update the crack detection algorithm (CGI) to work on more noisy field data. A method based on wavelet analysis has been developed to filter the signal. The performance of the proposed method was examined. The figure below shows the results. The proposed method was able to separate the signal components corresponding to the peak events (see Figure c) for both the strain gauge and the SEC. As shown in Figure d, the CGIs were obtained using the proposed method and they remain relatively constant indicating that there is not crack growth.



a b



c



d

Figure: the proposed method based on Morse wavelet for: a) strain gauge data; b) SEC data; c) highlighted peak events for strain gauge and SEC data; and d) the obtained CGIs for crack monitoring

- UA assembled and tested the new PCB board. The high-sensitive strain sensing capability of the newly included DC wheatstone bridge circuit was validated. The figure below shows the DC wheatstone bridge.

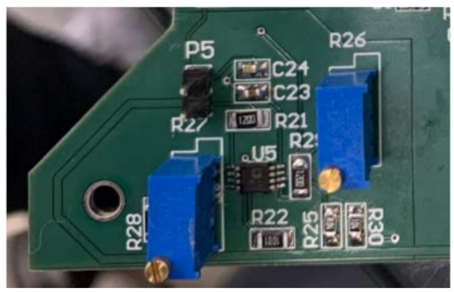


Figure: Newly added DC wheatstone bridge circuit

A cantilever free vibration test was conducted to validate the performance of the wheatstone bridge circuit and the results are shown in the figure below. The wheatstone bridge measured strain is about two times higher in amplitude levels than the expected as shown in Figure (a). The reason for this discrepancy will be investigated further. Half-scaling down shows good match with reference measurement by NIDAQ module by measuring low level strain response shown in Figure b, c and d.

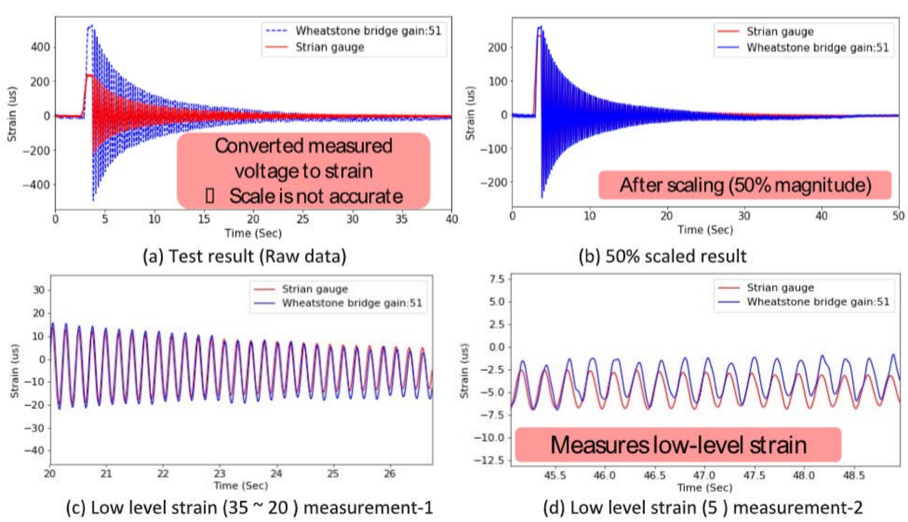


Figure: free vibration test results measurement

- KU tested the performance of the rearranged fully automated capacitive strain sensing circuit on new PCB board. The figure below shows the fully assembled new PCB prototype. The fully automated bridge balancing and amplification and shunt calibration procedure is shown in the subsequent figure.

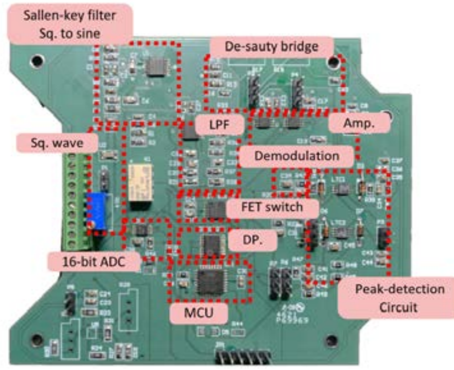


Figure: new PCB prototype

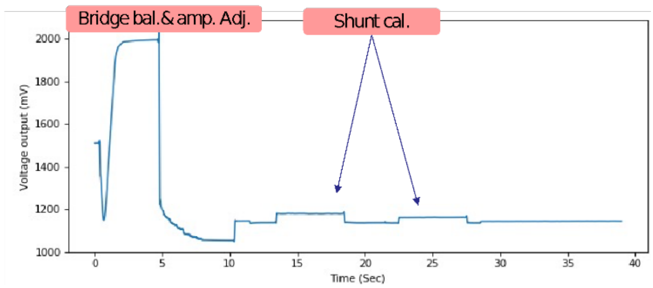
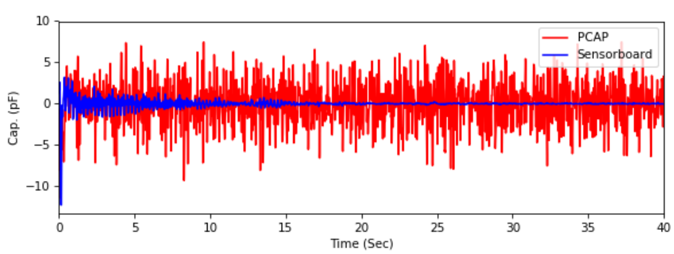
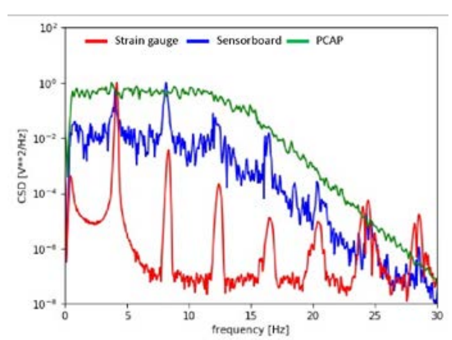


Figure: output measurement during fully automated bridge balancing & amplification and shunt calibration

The performance of the circuit was validated by cantilever free vibration test and compared to the off-the-shelf capacitance measurement toolkit PCAP02. The results are shown in the figure below. While PCAP shows noisy measurement in Figure (a), the sensorboard measurement shows clear vibration trend. It is evident from the frequency response comparison in Figure (b) that the new sensorboard shows much better sensitivity comparing to PCAP by showing clear peaks in frequency domain.



(a) time domain measurement



(b) Frequency domain analysis

Figure: free vibration test result compared with PCAP

- USC validated Concrete-SEC isolation with rubber pads on large, reinforced concrete bridge deck specimens provided by the SCDOT. To validate that the SEC behavior on the concrete bridge deck specimens is similar to their behavior on the small concrete specimens tested last quarter, two rubber pads, 0.016 mm and 0.031 mm, were tested. These results are shown in the Figures below. As expected, the rubber pads allow the SEC to measure strain correctly. Moreover, the SEC overestimates the real strain value without the rubber pad, as expected.

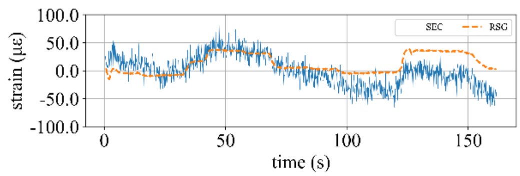


Figure 1: isolation test on large RC using 0.016 mm rubber pad.

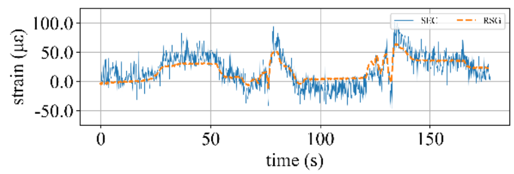


Figure: isolation test on large RC using 0.031 mm rubber pad.

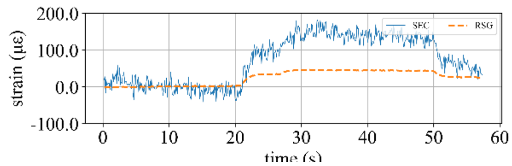


Figure: test on large RC without rubber pad.

- USC deployed an SEC with a 0.016 mm rubber pad on the reinforced concrete bridge deck specimen. The Figure on the right reports the measured percentage error on SEC compared to the RSG for a series of tests sinusoidal loading tests. It was observed that strain above 20 με could be reliably sensed by the SEC; while strain below 20 με is highly susceptible to noise.

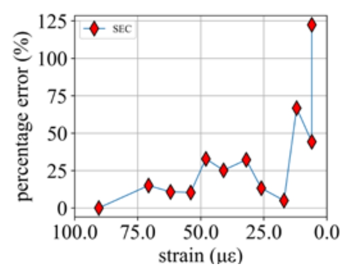


Figure error on measured SEC strain compared to the RSG.

Anticipated work next quarter:

- ISU will refine and validate the algorithm for angular rotation detection.
- ISU will work with USC to characterize the novel sensor deployment method.
- KU will continue monitoring and collecting data for the bridge through the web interface and cloud servers.
- KU will further evaluate the developed algorithm using more data collected from the bridge.
- KU will work on extending the proposed method to be more robust under non-zero mean and non-stationary signals with time-varying frequencies and amplitudes.
- UA will evaluate the power saving feature of new PCB prototype.
- UA will downclock buld (50 EA) micropressors ATmega328.
- USC will conduct testing of a newly designed SEC developed at ISU with multiple layers of SEBS, thereby eliminating the need for the rubber pads.
- USC will begin investigations on crack on concrete using SEC strain values

Significant Results:

- A method to deploy sensors directly onto concrete has been developed.
- Power issues are fixed on the bridge, and data is being acquired successfully.
- Better performance and sensitivity of the new sensorboard.

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