Quarterly Progress and Performance Indicators Report:
Project Number and Title: C.11 Development of a system-level distributed sensing technique for long-term monitoring of concrete and composite bridges
Research Area: Thrust 1: Transportation infrastructure monitoring and assessment for enhanced life
PI: Tzuyang Yu (UMass Lowell)
Co-PI(s): Xingwei Wang (UML), Susan Faraji (UML), Ehsan Ghazanfari (UVM), Bill Davids (UMaine)
Reporting Period: 1/1/2022~3/31/2022
Submission Date: 3/31/2022

Overview:

The research problem we are trying to solve is the long-term monitoring problem of bridges (e.g., concrete and composite bridges), using multiple modes of sensing technology including fiber optic (BOTDA), optical, and electromagnetic (GPR) sensors. In the reporting quarter of this project, we processed the baseline data collected from Grist Mill Bridge (Hampden, ME) during November 3~4, 2021. Our processed data are presented in this quarterly progress report.

Meeting the Overarching Goals of the Project:

- With the collected sensor data, we have the one-year sensor data to study the long-term performance problem of a newly constructed composite bridge.

Accomplishments:

- We have preliminarily processed the sensor data (BOTDA, strain gauges, accelerometer, thermometer) collected on 11/03/21 and compared with the last baseline on 12/30/20. From the comparison between two BOTDA datasets on girder 1, the composite bridge does not demonstrate much change in the past year.
- We have developed bridge models for extracting the flexural rigidity (EI) of the bridge. We will use it as one of the indicators for long-term health monitoring.

Task, Milestone, and Budget Progress:

Table 1: Task Progress

Task Number: Title	Start Date	End Date	% Complete
Task 1 (Y1): Development of a finite element model of a composite/concrete bridge for strain range and distribution	01/01/20	02/28/20	100%
Task 2 (Y1): Design of a distributed sensing system using strain and temperature	01/01/20	03/31/20	100%
Task 3 (Y1): Establishment and modal calibration of baseline measurements using fiber optic, video motion, and electromagnetic sensors	01/01/20	07/31/20	100%
Task 4 (Y1): Installation of distributed fiber optic cables on a composite/concrete bridge	07/31/20	08/15/20	100%
Task 5 (Y1): Structural loading test and data collection	08/15/20	08/20/20	100%

Task 6 (Y1): Monitoring of structural performance under service and environmental loads	08/20/20	12/31/21	100%
Task 7 (Y1): Data fusion, visualization, and interpretation	01/01/20	12/31/21	100%
Task 8 (Y1): Documentation, reporting, and dissemination	01/01/20	12/31/21	100%
Task 9 (Y2): Design of a distributed sensing system using strain and temperature	06/01/22	12/31/22	0%
Task 10 (Y2): Establishment and modal calibration of baseline measurements using fiber optic, laser Doppler vibrometry, and electromagnetic sensors	06/01/22	07/31/22	0%
Task 11 (Y2): Installation of distributed fiber optic cables on a composite/concrete bridge	06/01/22	09/31/22	0%
Task 12 (Y2): Structural loading test and data collection	06/01/22	08/31/22	0%
Task 13 (Y2): Monitoring of structural performance under service and environmental loads	06/01/22	09/31/23	0%
Task 14 (Y2): Data fusion, visualization, and interpretation	06/01/22	12/31/23	0%
Task 15 (Y2): Documentation, reporting, and dissemination	06/01/22	12/31/23	0%

Table 2: Milestone Progress

Milestone #: Description	Corresponding Deliverable	Start Date	End Date
Milestone 1: Design and manufacturing of distributed sensing system	Experimentation design of distributed sensors for selected bridges; Quarterly report on 09/31/22	06/01/22	07/31/22
Milestone 2: Installation of distributed sensing system	Installed distributed sensors on selected bridges; Quarterly report on 09/31/22	06/01/22	08/31/22
Milestone 3: Development of baseline model for each new bridge	Baseline data for selected bridges; Quarterly reports during 09/31/22~06/30/23	06/01/22	09/01/22~05/01/23
Milestone 4: Development of graphic user interface (GUI) tool for each bridge	GUI and sensor database; Quarterly reports on 09/31/22 and 12/31/22	06/01/22	12/31/22
Milestone 5: Development of annual monitoring dataset	Sensor datasets; Quarterly reports on 09/31/23	06/01/22	08/31/23
Milestone 6: Development of structural performance curve for each bridge	Bridge performance datasets; Quarterly report on 12/31/23	06/01/22	11/31/23

Table 3: Budget Progress

Project Budget	Spend – Project to Date	% Project to Date (include the date)
$44,663.63 (Y1) (federal)	$44,663.63 (Y1) (federal)	$100 (Y1) (federal)

Is your Research Project Applied or Advanced?

☒ **Applied** (*The systematic study to gain knowledge or understanding necessary for determining the means by which a recognized and specific need may be met.)*

☐ **Advanced** *(An intermediate research effort between basic research and applied research. This study bridges basic (study to understand fundamental aspects of phenomena without specific applications in mind) and applied research and includes transformative change rather than incremental advances. The investigation into the use of basic research results to an area of application without a specific problem to resolve.)*

Education and Workforce Development:

1. Did you provide any workforce development or training opportunities to transportation professionals (already in the field)? If so, what was the training? When was it offered? How many people attended?
   N/A

2. Did you hold meetings with any transportation industry organizations or DOTs? If so, what was the meeting's purpose? When was it offered? How many people attended?

   N/A

3. Did you host/participant in any K-12 education outreach activities? If so, what was the activity? What was the target age/grade level of the participants? How many students/teachers attended? When was the activity held?

   N/A

Technology Transfer:

Table 4: Presentations at Conferences, Workshops, Seminars, and Other Events

Type	Title	Citation	Event & Intended Audience	Location	Date(s)
N/A	N/A	N/A	N/A	N/A	N/A

Table 5: Submitted/Accepted Publications, Technical Reports, Theses, Dissertations, Papers, and Reports

Type	Title	Citation	Date	Status
Peer-reviewed journal	Pipeline structural health monitoring using distributed fiber optic sensing textile	Optical Fiber Technology	December 20, 2021	Under revision
Peer-reviewed journal	Bridge monitoring using sensing textiles	BSCE Civil Engineering Practice	December 31, 2021	Under preparation

Answer the following questions (N/A if there is nothing to report):

1. Did you deploy any technology during the reporting period through pilot or demonstration studies as a result of this work? If so, what was the technology? When was it deployed?

   Yes, we collected another baseline dataset from the installed optical sensors and applied an optical sensor (LDV) and an EM sensor (GPR) on Grist Mill Bridge during November 3~4, 2021.

2. Was any technology adopted by industry or transportation agencies as a result of this work? If so, what was the technology? When was is adopted? Who adopted the technology?

   Yes. The distributed sensing textile was installed on Grist Mill Bridge (built by AIT Bridges and MaineDOT) in Hampden, ME. Commercially available GPR and LDV sensors were also applied on Grist Mill Bridge during November 3~4, 2021.

3. Did findings from this research project result in changing industry or transportation agency practices, decision making, or policies? If so, what was the change? When was the change implemented? Who adopted the change?

   Yes. MaineDOT has started constructing composite bridges to replace traditional prestressed concrete bridges.

4. Were any licenses granted to industry as a result of findings from this work? If so, when? To whom was the license granted?

   N/A

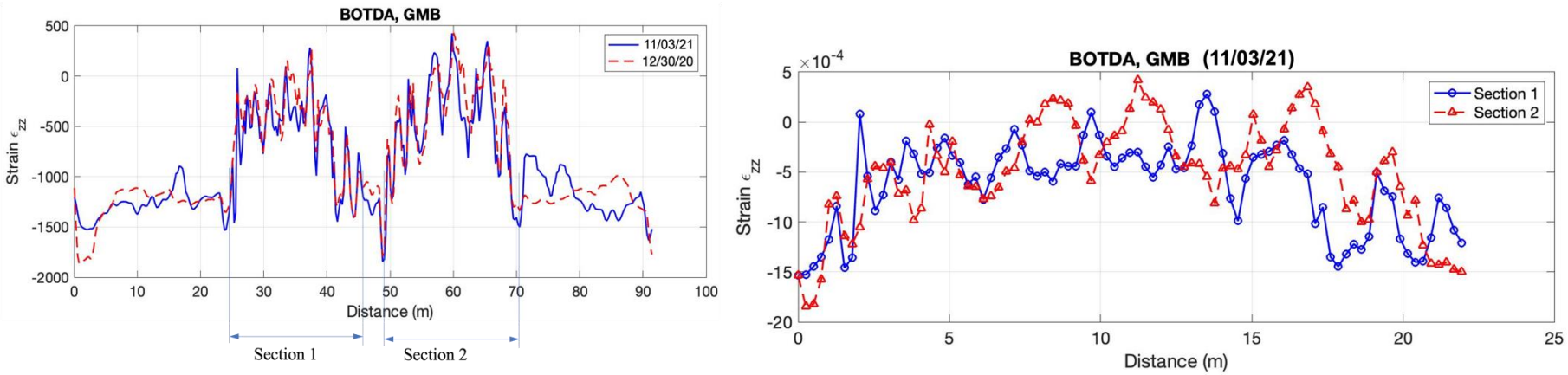
5. Were any patent applications submitted as a result of findings from this research? If so, please provide a copy of the patent application with your report.

   N/A

6. Did industry organizations or DOTs provide cost-share (cash or in-kind) to your research during the reporting period? Who was the organization? Please provide an in-kind support invoice from the organization with your report (this is kept confidential and used for record keeping purposes only).

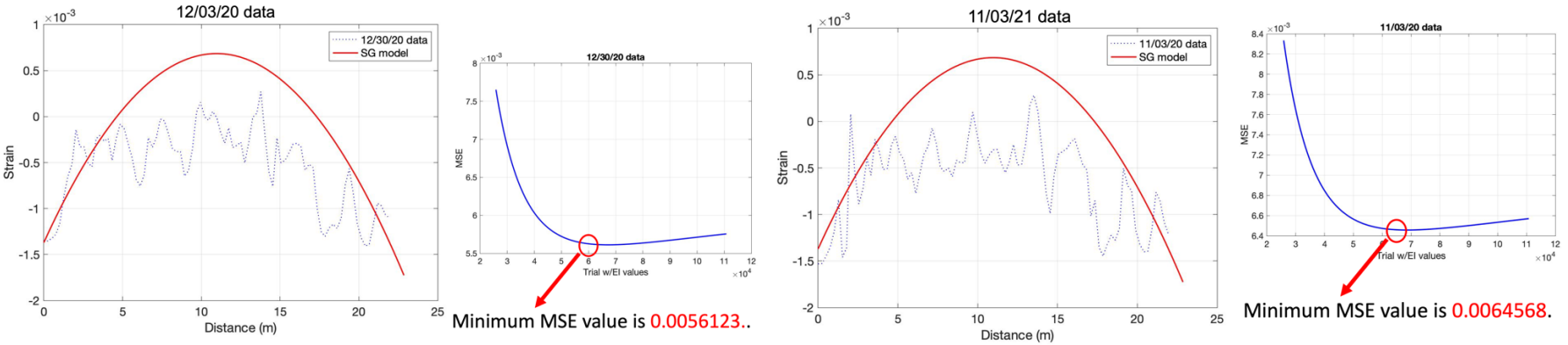
   Yes. MaineDOT (Dale Peabody) provided logistic supports to the UML research team during November 3~4, 2021. We will send an invoice to MaineDOT for their support.

Figure 1 shows the comparison of BOTDA datasets collected on 12/30/20 and 11/03/21 at Grist Mill Bridge. From the range of variation in the raw BOTDA data (after temperature compensation), we can see that the 12/30/20 dataset is in good congruence with the 11/03/21 dataset.



(a) BOTDA data of Grist Mill Bridge collected on 12/30/20 and 11/03/21. (b) BOTDA data of Grist Mill Bridge collected on 11/03/21

Fig. 1. BOTDA datasets collected on 12/30/20 and 11/03/21 at Grist Mill Bridge, Hampden, ME.



(a) Curve fitting of the 12/30/20 dataset. (b) Curve fitting of the 11/03/21 dataset.

Fig. 2. Curve fitting between BOTDA and a bridge model

Our preliminary modeling result is shown in Figure 2. From the optimization of mean square error (MSE) between the BODTA data and a bridge model, the load-flexural rigidity ratio (w/EI) of the bridge can be determined.

Outputs:

- Distributed strain measurements using BOTDA of bridge girders are fitted with a numerical model.
- We are preparing another journal paper manuscript for our experimental result on Grist Mill Bridge.

Outcomes:

- Our journal paper manuscript submitted to Journal of Optical Fiber Technology in last quarter has been accepted and published.

Impacts:

- With the distributed BOTDA strain data and the use of bridge models, we can extract structural health related parameters such as flexural rigidity (EI) for long term monitoring.

Participants and Collaborators:

Table 6: Active Principal Investigators, faculty, administrators, and Management Team Members

Individual Name & Title	Dates involved	Email Address	Department	Role in Research
Tzuyang Yu	01/01/2022~ 03/31/2022	Tzuyang_Yu@uml.edu	Civil and Environmental Eng.	Project principle investigator and Institutional Lead at UML; overseeing all project activities and working on GPR imaging and LDV sensing
Xingwei Wang	01/01/2022~ 03/31/2022	Xingwei_Wang@uml.edu	Civil and Environmental Eng.	Co-PI; working on optical fiber sensing
Susan Faraji	01/01/2022~ 03/31/2022	Susan_Faraji@uml.edu	Civil and Environmental Eng.	Co-PI; working on structural analysis
Ehsan Ghazanfari	01/01/2022~ 03/31/2022	Ehsan.Ghazanfari@ uvm.edu	Civil and Environmental Eng.	Co-PI; working on data fusion and numerical modeling
Bill Davids	01/01/2022~ 03/31/2022	William.Davids@maine.edu	Civil and Environmental Eng.	Co-PI; working on structural design and finite element modeling and strain sensing

Table 7: Student Participants during the reporting period

Student Name	Start Date	End Date	Advisor	Email Address	Level	Major	Funding Source	Role in research
Koosha Raisi	1/1/22	3/31/22	Prof. Yu		Ph.D.	Civil and Environmental Engineering	TIDC	Data processing and analysis

Aiyad Alshimaysawee	1/1/22	3/11/22	Prof. Yu		Ph.D.	Civil and Environmental Engineering	TIDC	Laboratory radar imaging and data processing
Nimun Nak Khun	1/1/22	3/31/22	Prof. Yu		M.S.	Civil and Environmental Engineering		Laboratory radar imaging and data processing
Andres Biondi Vaccarriello	1/1/22	3/31/22	Prof. Wang		Ph.D.	Civil and Environmental Engineering	TIDC	Optical fiber data collection and processing
Farel Adelson	1/1/22	3/31/22	Prof. Yu		B.S.	Civil and Environmental Engineering		Assistance in the preparation for bridge field tests
Rui Wu	1/1/22	3/31/22	Prof. Wang		Ph.D.	Electrical and Computer Eng.	TIDC	Optical fiber data collection and processing
Lidan Cao	1/1/22	3/31/22	Prof. Wang		Ph.D.	Electrical and Computer Eng.	TIDC	Optical fiber data collection and processing
Harsh Gandhi	1/1/22	3/31/22	Prof. Faraji		Ph.D.	Civil and Environmental Engineering	TIDC	Structural analysis and field test
Andrew Schanck	1/1/22	3/31/22	Prof. Davids		Ph.D.	Civil and Environmental Engineering	TIDC	Structural analysis and numerical modeling

Table 8: Students who Graduated During the Reporting Period

Student Name	Degree/Certificate Earned	Graduation/Certification Date	Did the student enter the transportation field or continue another degree at your university?
N/A	N/A	N/A	N/A

Table 9: Industrial Internships

Student Name	Degree/Certificate Earned	Graduation/Certification Date	Did the student enter the transportation field or continue another degree at your university?
N/A	N/A	N/A	N/A

Table 10: Research Project Collaborators during the reporting period						
Organization	**Location**	**Contribution to the Project**				
		Financial Support	**In-Kind Support**	**Facilities**	**Collaborative Research**	**Personnel Exchanges**
AIT bridges	Brewer, ME				X	X
Saint-Gobain North America	Northborough, MA			X	X	X
MaineDOT	Augusta, ME			X	X	X
Geophysical Survey Systems Inc. (GSSI)	Nashua, NH				X	X
MassDOT	Boston. MA		X	X	X	X

Table 11: Other Collaborators				
Collaborator Name and Title	**Contact Information**	**Organization and Department**	**Date(s) Involved**	**Contribution to Research**
Dale Peabody		MaineDOT	11/9/21	Technical champion
David Cist		GSSI	10/20/21	Technical champion

Table 12: Course List						
Course Code	**Course Title**	**Level**	**University**	**Professor**	**Semester**	**# of Students**
CIVE 5110	Inspection and Monitoring of Civil Infrastructure	Grad	UMass Lowell	Tzuyang Yu	Spring	17
ENGN 2070	Dynamics	Undergrad	UMass Lowell	Tzuyang Yu	Spring	37

Changes:

- Mr. Koosha Raisi (M.S., Univ. Birmingham, UK) has joined the UML research team in Spring 2022 as a doctoral research assistant.
- Mr. Farel Adelson has joined the UML research team since Spring 2022 as an undergraduate research assistant.
- Doctoral research assistant Aiyad Alshimaysawee has left the UML research team, due to family reasons.

Planned Activities:

In the next reporting period, we plan to continue research tasks (Task 9~Task 15) in Year 2.