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: 4/1/2022~6/30/2022
Submission Date: 7/6/2022

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 continued processing 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 extracted the load vs. flexural rigidity ratio (*w/EI*) of the bridge.

Accomplishments:

- We have demonstrated the capability of our system-level sensing technique on extracting one global property (*w/EI*) of the bridge for long-term bridge health monitoring.
- Our paper submitted to journal of Optical Fiber Technology has been published in May 2022.
- We presented our research in MassDOT Transportation Innovation Conference on June 25, 2022.

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?
   No. But we presented our TIDC project C.11 in MassDOT's Transportation Innovation Conference in Worcester, MA on May 25, 2022. More than 50 participants from state DOTs, industry, and academia attended our talk. It was well-received by the audience.
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)
Conference presentation	Sensing Textiles for Bridge Health Monitoring	MassDOT Transportation Innovation Conference	MassDOT annual conference / state DOT engineers, contractors, researchers, students (>50)	Worcester, MA	May 25, 2022

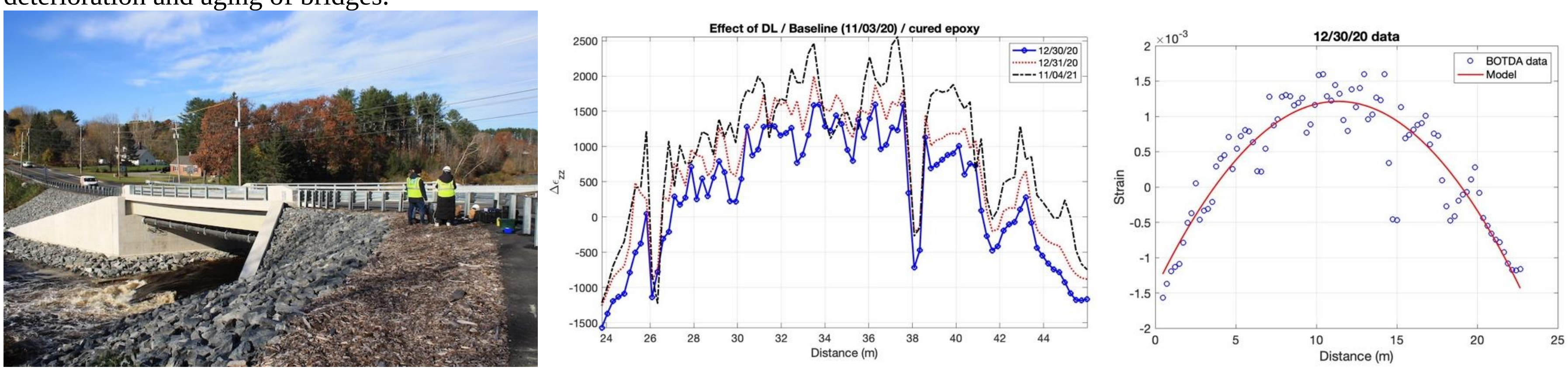
Table 5: Submitted/Accepted Publications, Technical Reports, Theses, Dissertations, Papers, and Reports

Type	Title	Citation	Date	Status
Peer-reviewed journal	Pipeline structural health monitoring using distributed fiber optic sensing textile	*Optical Fiber Technology*, Volume 70, May 2022, 102876 / doi: 10.1016/j.yofte.2022.102876	May 2022	Published
Peer-reviewed journal	Bridge monitoring using sensing textiles	BSCE Civil Engineering Practice	June 30, 2022	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?
   N/A
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?
   N/A
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?
   N/A
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).
   N/A

Figure 1 shows the comparison of BOTDA strain datasets collected on 12/30/20 and 11/03/21 at Grist Mill Bridge. We used a simply supported beam model with rotational end constraints (springs) under uniformly distributed loading (denoted by *w* or dead load) in the calculation of load vs. flexural rigidity (*EI*) ratio (*w/EI*). After performing curve-fitting between the beam model and the BOTDA strain data, we found the load vs. flexural rigidity ratio and converted to its inverse (*EI/w*). From the 12/30/20 dataset, the value of *EI/w* is 0.0293 m^3. Assuming constant dead load over time, the load vs. flexural rigidity ratio can be used for long-term bridge health monitoring. Reduction of this ratio indicates the deterioration and aging of bridges.



(a) Grist Mill Bridge data collection on 12/30/20. (b) Temperature-compensated BOTDA strain data. (c) Curve-fitting of BOTDA strain data.

Fig. 1. BOTDA strain datasets collected from the Grist Mill Bridge (Hampden, ME)

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.

Outcomes:

- Global property of the Grist Mill Bridge is extracted from curve-fitting result. The load vs. flexural rigidity ratio (*EI/w*) of the bridge can be used to indicate bridge health for long-term monitoring.

Impacts:

- Our research work has been disseminated in the annual conference held by MassDOT.

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	4/1/2022 ~ 6/30/2022	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	4/1/2022 ~ 6/30/2022	Xingwei_Wang@uml.edu	Civil and Environmental Eng.	Co-PI; working on optical fiber sensing
Susan Faraji	4/1/2022 ~ 6/30/2022	Susan_Faraji@uml.edu	Civil and Environmental Eng.	Co-PI; working on structural analysis
Ehsan Ghazanfari	4/1/2022 ~ 6/30/2022	Ehsan.Ghazanfari@uvm.edu	Civil and Environmental Eng.	Co-PI; working on data fusion and numerical modeling
Bill Davids	4/1/2022 ~ 6/30/2022	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	4/1/22	6/30/22	Prof. Yu		Ph.D.	Civil and Environmental Engineering	TIDC	Data processing and analysis

Nimun Nak Khun	4/1/22	5/23/22	Prof. Yu		M.S.	Civil and Environmental Engineering		Laboratory radar imaging and data processing
Andres Biondi Vaccarriello	4/1/22	6/30/22	Prof. Wang		Ph.D.	Civil and Environmental Engineering	TIDC	Optical fiber data collection and processing
Farel Adelson	4/1/22	6/30/22	Prof. Yu		B.S.	Civil and Environmental Engineering		Assistance in the preparation for bridge field tests
Rui Wu	4/1/22	6/30/22	Prof. Wang		Ph.D.	Electrical and Computer Eng.	TIDC	Optical fiber data collection and processing
Lidan Cao	4/1/22	6/30/22	Prof. Wang		Ph.D.	Electrical and Computer Eng.	TIDC	Optical fiber data collection and processing
Andrew Schanck	4/1/22	6/30/22	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?
Nimun Nak Khun	Masters degree	May 23, 2022	Yes

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?
Andres Biondi Vaccarriello			

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
David Cist		GSSI	5/19/22	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:

Planned Activities:

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