Quarterly Progress and Performance Indicators Report:
Project Number and Title: 1.4 Electromagnetic Detection and Identification of Concrete Cracking in Highway Bridges
Research Area: Thrust 1: Transportation infrastructure monitoring and assessment for enhanced life
PI: Tzuyang Yu (UMass Lowell)
Co-PI(s): N/A
Reporting Period: 1/1/2022~3/30/2022
Submission Date: 3/30/2022

Overview:

The research problem we are trying to solve is the structural assessment of aging concrete bridges (reinforced and prestressed) in New England, targeting at concrete cracking and degradation. The overall research objective is to develop a remote radar sensor for the characterization of corroded reinforced concrete structures. In the reporting period of this project, we continue our field test activities by monitoring several intact and corroded bridge piers of an I-495 bridge in Chelmsford, MA (Task 3.2). The collected GPR B-scan images have also been added to the development of an electromagnetic (EM) database (Task 4).

Meeting the Overarching Goals of the Project:

- We have collected more GPR B-scan images of intact and corroded concrete bridge piers from I-495 bridge in Chelmsford, MA since last quarter to continue studying the detectability (signal-to-noise ratio) of corroded reinforced concrete.
- For field GPR B-scan images of **corroded** concrete bridge piers, we have been developing pattern recognition algorithms to study the pattern in GPR images and correlate it with the level of steel rebar corrosion.
- For field GPR B-scan images of **intact** concrete bridge piers, we have been studying the backscattering pattern of different concretes to understand the impact of background variation on corrosion detectability on concrete structures.

Accomplishments:

- We have expanded the EM database by adding GPR B-scan images of intact and corroded concrete bridge piers.
- We have developed pattern recognition algorithms for understanding radar images (GPR and SAR) of concrete structures.

Task, Milestone, and Budget Progress:

Table 1: Task Progress

Task Number: Title	Start Date	End Date	% Complete
Task 1: Design and manufacturing of laboratory reinforced concrete specimens at various corrosion levels	10/01/20	09/30/21	100%
Task 2: Laboratory SAR imaging of corroded RC specimens and development of a robust baseline SAR/GPR image of concrete	10/01/21	09/31/22	85%
Task 3.1: Development of a compact, self-powered, light-weight SAR imaging sensor	10/01/21	05/31/22	97%

Task 3.2: Field inspection of corroded RC structures (Preliminary)	06/01/21	09/30/22	85%
Task 4: Development of EM database and correlation between SAR and GPR images	08/01/21	03/31/23	65%
Task 5: Data analysis and image interpretation	10/01/20	09/30/23	65%

Table 2: Milestone Progress

Milestone #: Description	Corresponding Deliverable	Start Date	End Date
Milestone 1: Design of laboratory reinforced concrete (RC) specimens at various corrosion levels	Experimentation design matrix; manufactured RC specimens (10%); Quarterly report on 12/31/20	10/01/20	12/31/20
Milestone 2: Manufacturing of laboratory RC specimens at various corrosion levels / Laboratory SAR imaging of corroded RC specimens and development of a robust baseline SAR image of concrete / Development of a compact, self-powered, light-weight SAR imaging sensor	Manufactured RC specimens (20%); SAR images of RC specimens (5%); design of a compact SAR imaging sensor (10%); Quarterly report on 03/31/21	11/01/20	03/31/21
Milestone 3: Manufacturing of laboratory RC specimens at various corrosion levels / Laboratory SAR imaging of corroded RC specimens and development of a robust baseline SAR image of concrete / Field inspection of corroded RC structures (Preliminary)	Manufactured RC specimens (80%); SAR images of RC specimens (30%); Development of a compact SAR imaging sensor (100%); Preliminary SAR imaging of RC specimens in the field (5%); Quarterly report on 06/30/21	12/01/20	06/30/21
Milestone 4: Manufacturing of laboratory RC specimens at various corrosion levels / Laboratory SAR imaging of corroded RC specimens and development of a robust baseline SAR image of concrete / Field inspection of corroded RC structures (Preliminary)	Manufactured RC specimens (100%); SAR images of RC specimens (40%); Preliminary SAR imaging of RC specimens in the field (10%); Quarterly report on 09/30/21	12/01/20	09/30/21
Milestone 5: Laboratory SAR imaging of corroded RC specimens and development of a robust baseline SAR image of concrete / Field inspection of corroded RC structures (Preliminary)	SAR images of RC specimens (50%); Preliminary SAR imaging of RC specimens in the field (25%); Quarterly report on 12/31/21	12/01/20	12/31/21
Milestone 6: Laboratory SAR imaging of corroded RC specimens and development of a robust baseline SAR image of concrete / Field inspection of corroded RC structures (Preliminary)	SAR images of RC specimens (80%); Preliminary SAR imaging of RC specimens in the field (50%); Quarterly report on 03/31/22	12/01/20	03/31/22
Milestone 7: Laboratory SAR imaging of corroded RC specimens and development of a robust baseline SAR image of concrete / Field inspection of corroded RC structures (Preliminary)	SAR images of RC specimens (100%); Preliminary SAR imaging of RC specimens in the field (100%); Quarterly report on 09/30/22	12/01/20	09/30/22
Milestone 8: Field inspection of corroded RC structures	SAR imaging of RC specimens in the field (15%); Quarterly report on 12/31/22	10/01/22	12/31/22

Milestone 9: Field inspection of corroded RC structures	SAR imaging of RC specimens in the field (100%); Quarterly and Final reports on 09/30/23	10/01/22	09/30/23

Table 3: Budget Progress

Project Budget	Spend – Project to Date	% Project to Date (include the date)
$330,495 (federal)	$250,225.66 (federal)	$75.71 (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)**
Conference presentation	Interpretation of synthetic aperture radar images of concrete by combined uses of image parameters	Tzuyang Yu, Ahmed Alzeyadi, SPIE SS/NDE Symposium, Conference 12047 *Nondestructive Characterization and Monitoring of Advanced Materials, Aerospace, Civil Infrastructure, and Transportation XVI*	International conference & Academics, practitioners, government officials	Long Beach, CA	March 8, 2022
Conference presentation	Application of dual-frequency GPR for subsurface void detection in culverts	Koosha Raisi, Nimun Nak Khun, Tzuyang Yu, SPIE SS/NDE Symposium, Conference 12047 *Nondestructive Characterization and Monitoring of Advanced Materials, Aerospace, Civil Infrastructure, and Transportation XVI*	International conference & Academics, practitioners, government officials	Long Beach, CA	March 8, 2022

Table 5: Submitted/Accepted Publications, Technical Reports, Theses, Dissertations, Papers, and Reports				
Type	**Title**	**Citation**	**Date**	**Status**
Peer-reviewed journal	Electromagnetic detection of concrete cracking by using synthetic aperture radar and ground penetrating radar	NDT&E International	March 30, 2022	Under revision

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 applied an EM sensor (ground penetrating radar or GPR) on intact and corroded concrete bridge piers in the field on February 20, 2022.

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?

   Not yet. We need to collect more data in order to confirm our findings and to address the variation in concrete structures in our development.

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?

   Not yet. But we are moving toward the goal by conducting this applied research and by collaborating with industry partners like GSSI on this project.

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. The City of Lowell contributed to Project 1.4 by sending an inspection team assisting our field test in Lowell, MA. An invoice for their in-kind contributions is attached to this progress report. \

In Figure 1, change of GPR signals due to the presence of surface cracks is shown in the B-scan images. When there is a surface crack, a near-surface hyperbola is formed as expected. While the internal EM wave scattering may reduce the GPR amplitude in the subsurface region, it is still possible to detect subsurface steel rebars underneath a surface crack. Figure 1 shows three steel rebars being detected by GPR B-scan inspection. One center steel rebar is identified by the presence of a strong hyperbola, while two steel rebars are still identified by two relatively weak hyperbolas in Figure 1.

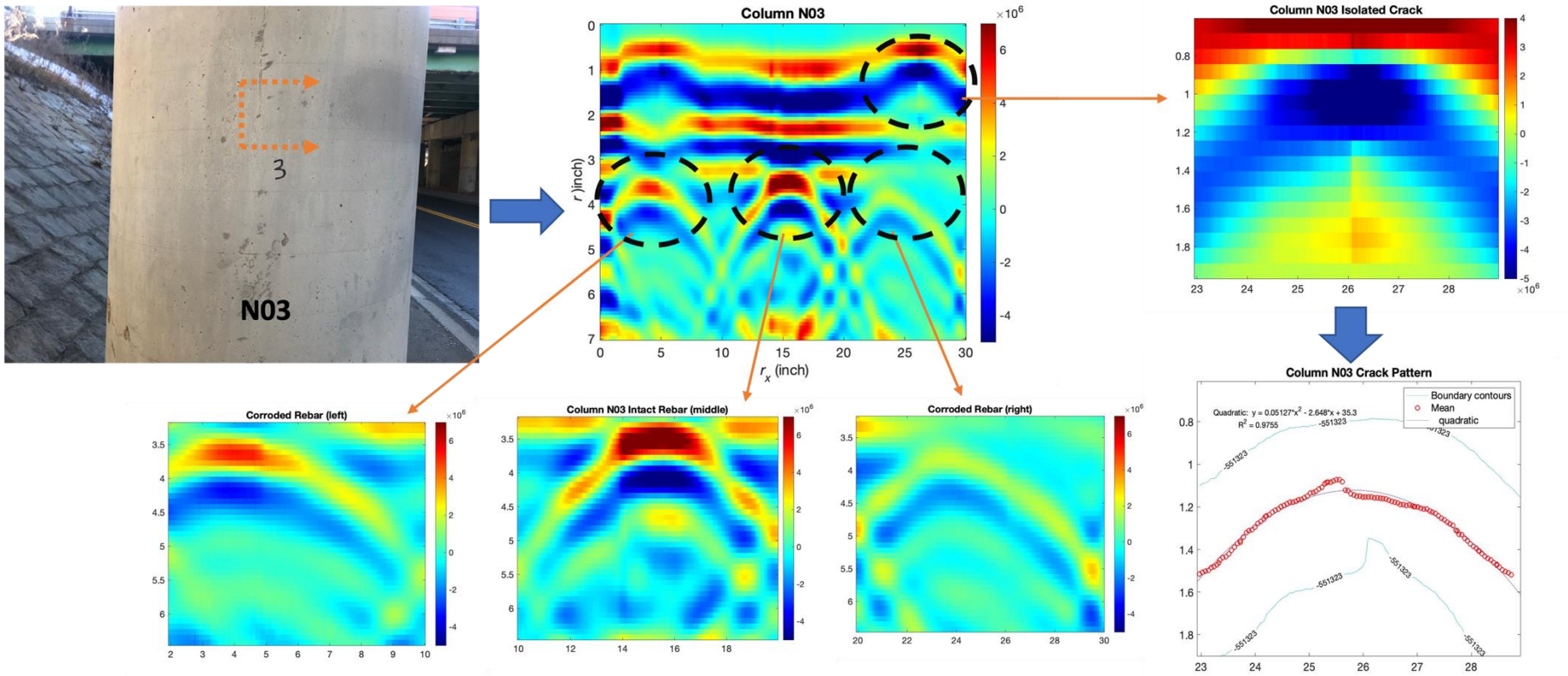

Fig. 1. I-495 Bridge pier N03 (Chelmsford, MA) and its GPR B-scan images with extracted pattern

Outputs:

- New GPR B-scan image datasets have been included to our EM database for the nondestructive inspection and structural health monitoring of a highway bridge in Massachusetts.
- New image processing algorithm (written in Matlab) has been developed (and will be further improved) with the GPR B-scan images collected during this period of the project.

Outcomes:

- We presented our radar imaging study at the 2022 SPIE Smart Structure/NDE Symposium (Long Beach, CA, March 6~10, 2022) to in-person and online attendees from around the world, through two conference presentations. We have received many questions regarding the use of GPR for concrete characterization.

Impacts:

- Through our conference presentation at the 2022 SPIE Smart Structure/NDE Symposium, we have promoted the use of EM sensors for concrete bridge inspection and monitoring to an audience comprising of faculty, undergraduate and graduate students, bridge engineers, and sensor vendors, and government officials.

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	10/01/2021~ 12/31/2021	Tzuyang_Yu@UML.EDU	Civil and Environmental Engineering	Project principle investigator and Institutional Lead at UML; overseeing all projects and working on radar imaging and interpretation

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
Yaneliz Garcis Ruiz	1/1/22	3/31/22	Prof. Yu		B.S.	Civil and Environmental Engineering		Assistance in the preparation for bridge field tests
Farel Adelson	1/1/22	3/31/22	Prof. Yu		B.S.	Civil and Environmental Engineering		Assistance in the preparation for bridge field tests

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**
MassDOT	Boston, MA				X	X
City of Lowell	Lowell, MA				X	X
Geophysical Survey Systems, Inc. (GSSI)	Nashua, NH				X	X
City of Lowell	Lowell, MA		$759.2		X	X

Table 11: Other Collaborators				
Collaborator Name and Title	**Contact Information**	**Organization and Department**	**Date(s) Involved**	**Contribution to Research**
David Cist		GSSI	3/16/22	Technical champion
Mark Jen		Michael Baker Engineering, Inc.	1/20/22	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:

- 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 left the UML research team, due to family reasons.

Planned Activities:

In the next reporting period, we plan to continue following research tasks with limited access to our laboratories.

- Task 3.2: Field inspection of corroded RC structures (Preliminary)
- Task 4: Development of EM database and correlation between SAR and GPR images
- Task 5: Data analysis and image interpretation