Quarterly Progress Report:
Project Number and Title: C20.2020: Advanced Sensing Technologies for Practical UAV-Based Condition Assessment
Research Area: Transportation Infrastructure Monitoring and Assessment for Enhanced Life
PI: Dryver Huston, University of Vermont
Co-PI(s): Tian Xia, University of Vermont; Eric Landis, University of Maine; Tzuyang Yu, University of Massachusetts Lowell
Reporting Period: 1/1/22 – 3/31/22
Submission Date: March 31, 2022

Overview:

This is a collaborative research project with the University of Vermont, University of Maine, and University of Massachusetts Lowell. This quarter was the third quarter of activity on the project. Some of the highlights are:

- Assembly of an acoustic sensor arm for use on a UAV – An upgraded prototype tapper mechanism with rack and sector gear pinion that launches spring-loaded steel ball into a concrete slab, has been designed and assembled, Figure 1 and Figure 2.
- Used improved acoustic sensor arm to test concrete slabs with different levels of damage in the laboratory.
- Signal processing of acoustic signals indicated that the different slabs were clearly distinguishable.

Meeting the Overarching Goals of the Project:

The overarching goals of this project center on the synergistic application of unmanned aerial vehicles (UAVs) with active acoustic sensing (AAS) and synthetic aperture radar (SAR) for the underside inspection of bridge decks. Employing such UAV-AAS-SAR systems may i) reduce inspection cost by more than 50%, ii) improve inspectors' safety, and iii) mitigate traffic interference with little or no traffic control measures needed. The plan is 1) develop an acoustic sensor capable of actively interrogating concrete delamination of bridge decks from underneath, 2) develop a compact radar sensor capable of remotely scanning concrete surface for delamination detection, 3) develop a UAV platform capable of housing the acoustic and the radar sensors for bridge inspection, 4) develop image processing and interpretation algorithms for condition assessment, and 5) work with partners in the bridge inspection industry to guide design decisions to produce a practical and useful system.

Progress in this past quarter advanced the goals of the project with efforts at evaluating two different acoustic sensing techniques, and microwave sensing and signal processing for the specialized case of detecting damage on the underside of bridge decks.

- Assembly of an acoustic sensor arm for use on a UAV – Aligned with 1) develop an acoustic sensor capable of actively interrogating concrete delamination of bridge decks from underneath
- Used improved acoustic sensor arm to test concrete slabs - Aligned with 1) develop an acoustic sensor capable of actively interrogating concrete delamination of bridge decks from underneath
- Signal processing of acoustic signals indicated that the different slabs – Aligned with 1) develop an acoustic sensor capable of actively interrogating concrete delamination of bridge decks from underneath

Accomplishments:

- Tested and refined the design of a second-generation acoustic tapper mechanism for testing on concrete slab phantoms.
- Tested laboratory specimens with different levels and types of damage.
- Evaluated and down selected different types of signal processing algorithms for acoustic signals, with Empirical Mode Decomposition combined with the Hilbert-Huang Transform method being perhaps most effective.
- Graduate student (Damien Garland) completed M.S. thesis on the acoustic sensor arm aspect of this project.

Task, Milestone, and Budget Progress:

Table 1: Task Progress

Task Number: Title	Start Date	End Date	% Complete
Task 1.1 (Phase 1.A): Survey of Commercial UAVs	4/1/21	6/30/21	100
Task 2.1 (Phase 1.A): Design and build acoustic sensor arm (ASA)	4/1/21	3/31/22	85
Task 2.2 (Phase 1.A): Select and configure acoustic sensors	4/1/21	3/31/22	55
Task 3.1 (Phase 1.A): Calibration of baseline interference on radar signals	4/1/21	3/31/22	35
Task 3.2 (Phase 1.A): Development of radar signal and image conditioning algorithms through laboratory tests	4/1/21	3/31/22	35
Task 7.1 (Phase 1.A): Documentation	4/1/21	3/31/22	85
Task 2.3 (Phase 1.B): Select and configure acoustic signal processing system	4/1/22	9/30/22	0
Task 2.4 (Phase 1.B): Assemble ASA system and test performance in laboratory	4/1/22	3/31/23	0
Task 4 (Phase 1.B): Laboratory validation and correlation of AAS and radar sensors	4/1/22	3/31/23	0
Task 5 (Phase 1.B): Laboratory integration of UAV, AAS, and radar sensors	4/1/22	3/31/23	0

Task 6.1 (Phase 1.B): Field modification of UAV-AAS-radar system, data collection, and data analysis	7/1/22	3/31/23	0
Task 7.2 (Phase 1.B): Documentation, dissemination, and reporting	4/1/22	3/31/23	0
Task 2.5 (Phase 2): Integrate ASA system into UAV	4/1/23	3/31/24	0
Task 2.6 (Phase 2): Laboratory and field testing of UAV with integrated ASA	4/1/23	3/31/24	0
Task 2.7 (Phase 2): Data analysis, reporting and dissemination	4/1/23	3/31/24	0
Task 3.3 (Phase 2): Modification of onboard SAR imaging sensor through field tests	4/1/23	3/31/24	0
Task 6.2 (Phase 2): Field modification of UAV-AAS-radar system, data collection, and data analysis	4/1/23	3/31/24	0
Task 7.3 (Phase 2): Documentation, dissemination, and reporting	4/1/23	3/31/24	0
Phase 1.A Overall	4/1/21	3/31/22	55%
Phase 1.B Overall	4/1/22	3/31/23	0
Phase 2 Overall	4/1/23	3/31/24	0

Table 2: Milestone Progress

Milestone #: Description	Corresponding Deliverable	Start Date	End Date
Milestone 1: Survey of Commercial UAVs	Report summarizing results of survey	4/1/21	12/31/20 - Delivered
Milestone 2: Design and build Acoustic Sensor Arm (ASA)	Report describing design and fabrication of ASA	4/1/21	3/31/22 - Pending
Milestone 3: Select and configure Acoustic Sensors	Report describing selection and operation of acoustic sensors	4/1/21	3/31/22 - Pending
Milestone 4: Calibration of baseline interference on radar signals	Report describing calibration of baseline interference on radar signals	4/1/21	3/31/22 - Pending

Milestone 5: Development of radar signal and image conditioning algorithms through laboratory tests	Report describing development of radar signal and image conditioning algorithms	5/1/21	3/31/22 - Pending
Milestone 6: Documentation	Quarterly reports for Phase 1-A	4/1/21	3/31/22 - Delivered
Milestone 7: Select and configure acoustic signal processing system	Report describing acoustic signal processing system	4/1/22	12/31/22
Milestone 8: Assemble ASA system and test performance in laboratory	Report describing ASA performance in laboratory	4/1/22	3/31/23
Milestone 9: Laboratory validation and correlation of AAS and radar sensors	Report describing laboratory validation and correlation of AAS and radar sensors	4/1/22	3/31/23
Milestone 10: Laboratory integration of UAV, AAS, and radar sensors	Report describing laboratory integration of UAV, AAS, and radar sensors	4/1/22	3/31/23
Milestone 11: Field modification of UAV-AAS-radar system, data collection, and data analysis	Report describing field modification of UAV-AAS-radar system, data collection, and data analysis	12/1/22	3/31/23
Milestone 12: Documentation, dissemination, and reporting	Quarterly reports for Phase 1-B	4/1/22	3/31/23
Milestone 13: Integrate ASA system into UAV	Report describing	4/1/23	3/31/24
Milestone 14: Laboratory and field testing of UAV with integrated ASA	Report describing	4/1/23	3/31/24
Milestone 15: Data analysis, reporting and dissemination	Report describing	4/1/23	3/31/24
Milestone 16: Modification of onboard SAR imaging sensor through field tests	Report describing	4/1/23	3/31/24
Milestone 17: Field modification of UAV-AAS-radar system, data collection, and data analysis	Report describing	4/1/23	3/31/24

Milestone 18: Documentation, dissemination, and reporting	Quarterly and final project report	4/1/23	3/31/24

Table 3: Budget Progress		
Project Budget	**Spend – Project to Date**	**% Project to Date (12/31/2021)**
Phase 1.A Full Budget $144,000	Phase 1.A 119,451.46 (Federal + Cost Share)	Phase 1.A 82.95% Spent
Phase 1.B Full Budget $120,000	Phase 1.B $0 (Federal + Cost Share)	0%
Phase 2 Full Budget $120,000	Phase 2 $0 (Federal + Cost Share)	0%

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:

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

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?

   NA

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?

   NA

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?

   NA

Technology Transfer:

Table 4: Presentations at Conferences, Workshops, Seminars, and Other Events					
Type	**Title**	**Citation**	**Event & Intended Audience**	**Location**	**Date(s)**
Masters Thesis Defense	**Active Acoustic Sensing Technologies for Practical UAV-Based Condition Assessment of Underside Bridge Decks**	M.S. Thesis, University of Vermont, Mechanical Engineering, 2022	Open to the public with online access	University of Vermont	3/25/22

Table 5: Submitted/Accepted Publications, Technical Reports, Theses, Dissertations, Papers, and Reports				
Type	**Title**	**Citation**	**Date**	**Status**
Masters Thesis	**Active Acoustic Sensing Technologies for Practical UAV-Based Condition Assessment of Underside Bridge Decks**	M.S. Thesis, University of Vermont, Mechanical Engineering, 2022	3/25/22	Complete

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?

   NA

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?

   NA

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?

   NA

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

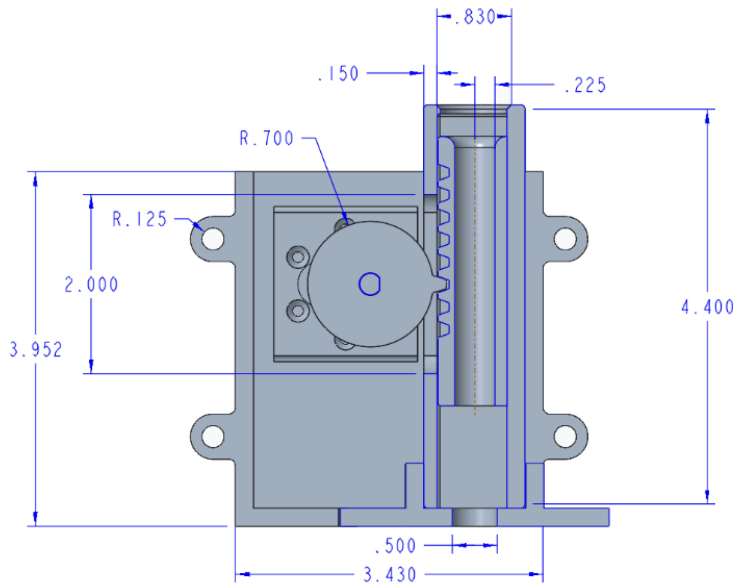
   NA

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.

   NA

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).

   NA



a.


b.

Figure 1. Acoustic sensor arm short version prototype, a. side view drawing, and b. tapper arm

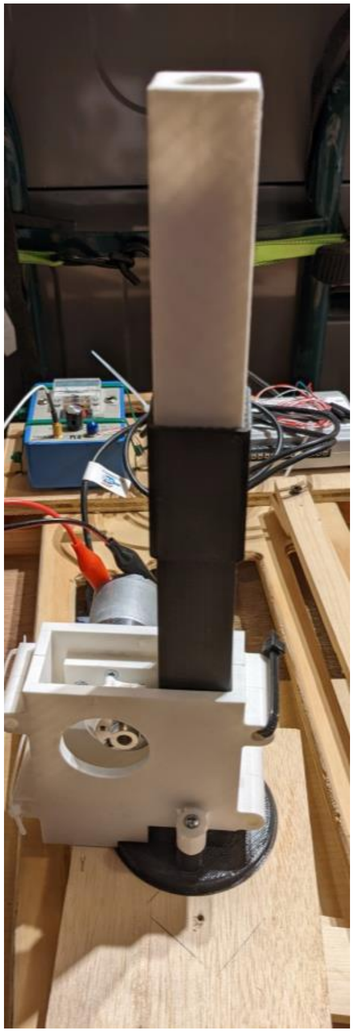


Figure 2 Extended version of acoustic sensor arm

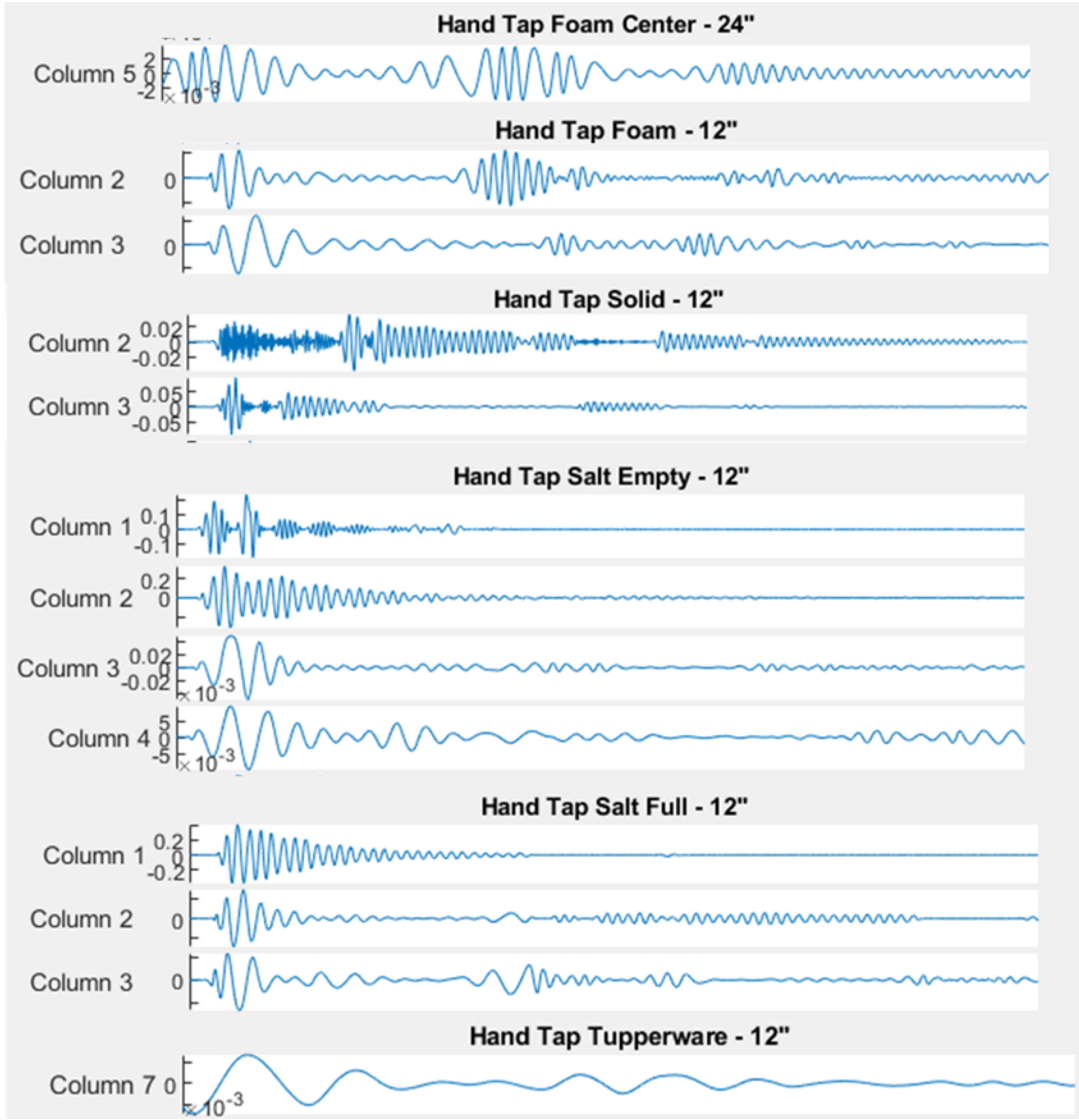


Figure 3 Empirical mode decomposition of acoustic data for concrete slabs with different damage conditions, indicating ability to distinguish different conditions.

Describe any additional activities involving the dissemination of research results not listed above under the following headings:

Outputs:

Definition: Any new or improved process, practice, technology, software, training aid, or other tangible product resulting from research and development activities. They are used to improve the efficiency, effectiveness, and safety of transportation systems. List any outputs accomplished during this reporting period:

- Improved prototype acoustic sensor arm for UAV bridge deck underside testing equipped with signal processing algorithms

Outcomes:

Definition: The application of outputs; any changes made to the transportation system, or its regulatory, legislative, or policy framework resulting from research and development activities. List any outcomes accomplished during this reporting period:

- NA

Impacts:

Definition: The effects of the outcomes on the transportation system such as reduced fatalities, decreased capital or operating costs, community impacts, or environmental benefits. The reported impacts from UTCs are used for the assessment of each UTC and to make a case for Federal funding of research and education by demonstrating the impacts that UTC funding has had on technology and education. NOTE: The U.S. DOT uses this information to assess how the research and education programs (a) improve the operation and safety of the transportation system; (b) increase the body of knowledge and technologies; (c) enlarge the pool of people trained to develop knowledge and utilize technologies; and (d) improves the physical, institutional, and information resources that enable people to have access to training and new technologies. List any outcomes accomplished during this reporting period:

- NA

Participants and Collaborators:

Use the table below to list individuals (compensated or not) who have worked on the project other than students.

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

Individual Name & Title	Dates involved	Email Address	Department	Role in Research
Dryver Huston	dryver.huston@uvm.edu	UVM	Mech Eng	PI
Tian Xia	txia@uvm.edu	UVM	Elec Eng	Co-PI
Eric Landis	landis@maine.edu	UM	Civil Eng	Co-PI
Tzuyang Yu	tzuyang_yu@uml.edu	UML	Civil Eng	Co-PI

*Use the table below to list **all** students who have participated in the project during the reporting period. (This includes all paid, unpaid, intern, independent study, or any other student that participated in this project.)*

Table 7: Student Participants during the reporting period								
Student Name	**Start Date**	**End Date**	**Advisor**	**Email Address**	**Level**	**Major**	**Funding Source**	**Role in research**
Damien Garland	10/1/2021	3/31/2022	D. Huston		MS	Mech Eng	Self-funded	Research on UAV sensing, self-funded
Yi Liu	10/1/2021	12/31/2021	D. Huston		MS	Mech Eng	TIDC	Research on UAV sensing
Zahra Ameli	10/1/2021	3/31/2022	E. Landis		PhD	Civil Eng	TIDC	Research on UAV sensing

Use the table below to list any students who worked on this project and graduated or received a certificate during this reporting period. Include information about the student's accepted employment during the reporting period

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

Use the table below to list any students that participated in Industrial Internships during the reporting period:

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

*Use the table below to list **organizations** that have been involved as partners on this project and their contribution to the project during the reporting period.*

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**
N/A	N/A	N/A	N/A	N/A	N/A	N/A

*Use the table below to list **individuals** that have been involved as partners on this project and their contribution to the project during the reporting period. (**List your technical champion(s) in this table.** This also includes collaborations within the lead or partner universities who are not already listed as PIs; especially interdepartmental or interdisciplinary collaborations.)*

Table 11: Other Collaborators				
Collaborator Name and Title	**Contact Information**	**Organization and Department**	**Date(s) Involved**	**Contribution to Research**
Robert Blunt		VHB	10/1/2021 – 12/31/2021	Technical Champion

Use the following table to list any transportation related course that were taught or led by researchers associated with this research project during the reporting period:

Table 12: Course List						
Course Code	**Course Title**	**Level**	**University**	**Professor**	**Semester**	**# of Students**
N/A	N/A	N/A	N/A	N/A	N/A	N/A

Changes:

No changes from previous quarter.

Planned Activities:

The planned activities for the next quarter generally follow those laid out in the original proposal. These include:

1. Acoustic sensing – Continue with laboratory testing on more realistic delaminated concrete samples. Develop customized signal processing methods.

2. Microwave sensing – Configure the microwave sensor to fit on UAV and evaluate background noise. Develop customized signal processing methods.

3. UAV system – Continue with custom UAV system development.

4. Field testing – Begin with UAV testing in large bay laboratories at U Maine and University of Vermont