

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: 10/1/21 – 12/31/21

Submission Date: December 31, 2021

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.
- Development of piezoelectric sensor ball - A steel ball serving as a potential acoustic transducer with embedded piezoelectric sensor element was assembled and tested, Figure 2.
- Continued testing of integrated air acoustic tapper on test slabs – Air acoustic sensor with manual wooden tapper, Figure 3, was evaluated on concrete slabs with various forms of damage in the laboratory, Figure 4.
- Met with TIDC administrative staff on December 14, 2021 to discuss project planning and progress.

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
- Development of piezoelectric sensor ball - Aligned with 1) develop an acoustic sensor capable of actively interrogating concrete delamination of bridge decks from underneath
- Continued testing of integrated air acoustic tapper on test slabs – Aligned with 1) develop an acoustic sensor capable of actively interrogating concrete delamination of bridge decks from underneath

- Met with TIDC administrative staff on December 14, 2021 to discuss project planning and progress – Aligned with all 5 project activities.

Accomplishments:

- Built a second-generation acoustic tapper mechanism for testing on concrete slab phantoms.
- Built and tested a steel acoustic sensor ball with embedded piezoelectric sensor element.

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	55
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	30
Task 3.2 (Phase 1.A): Development of radar signal and image conditioning algorithms through laboratory tests	4/1/21	3/31/22	30
Task 7.1 (Phase 1.A): Documentation	4/1/21	3/31/22	75
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
Milestone 3: Select and configure Acoustic Sensors	Report describing selection and operation of acoustic sensors	4/1/21	3/31/22
Milestone 4: Calibration of baseline interference on radar signals	Report describing calibration of baseline interference on radar signals	4/1/21	3/31/22
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

Milestone 6: Documentation	Quarterly reports for Phase 1-A	4/1/21	3/31/22
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 \$91,262.55 (Federal + Cost Share)	Phase 1.A 63.38 % 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? (i.e. The research team provided an in the field training for the SAR technology for 3 maintenance crew members of the MassDOT on 3/31/2021. The members learned how to use the technology and interrupt the data.) 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? Met with TIDC administrative staff on December 14, 2021 to discuss project planning and progress, approximately 8 attendees total (TIDC staff and project senior personnel).
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)
NA					

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

Type	Title	Citation	Date	Status
NA				

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 it 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

Insert figures here



Figure 1. Rack and sector gear pinion steel ball tapper mechanism



Figure 2 Piezoelectric sensor ball and embedded sensor disk

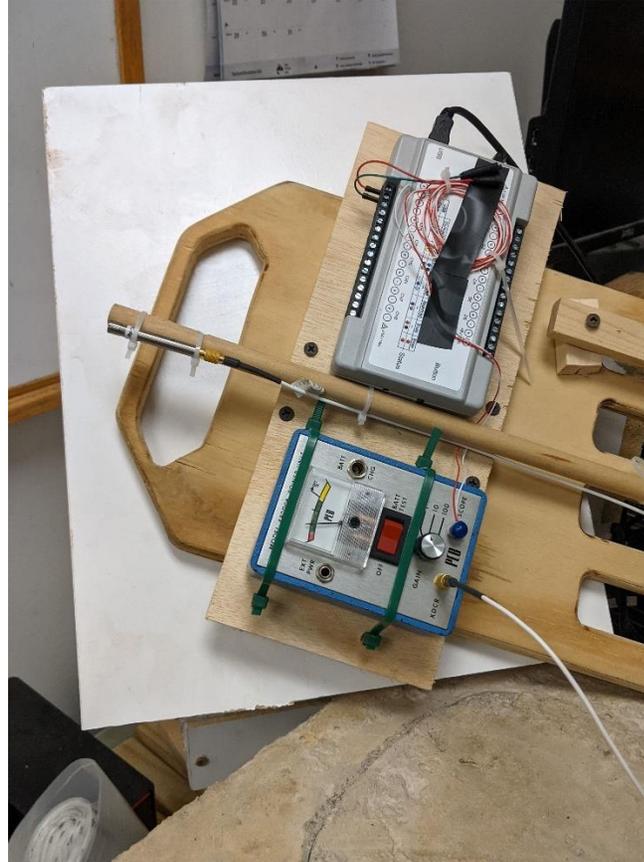


Figure 3 Air acoustic sensor system



Figure 4. Concrete slabs with various forms of cast in place damage for laboratory testing.

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:

- Prototype acoustic sensor arm for UAV bridge deck underside testing.

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.) **ALL FIELDS ARE REQUIRED.***

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	12/31/2021	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
Joshua Allen	10/1/2021	12/31/2021	D. Huston		Junior	Mech Eng	TIDC	Research on UAV sensing

Zahra Ameli	10/1/2021	12/31/2021	E. Landis		PhD	Civil Eng	TIDC	Research on UAV sensing
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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 (i.e. the student is now working at MaineDOT) or if they are continuing their students through an advanced degree (list the degree and where they are attending).

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?
NA			

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?
NA			

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
NA						

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	rblunt@vhb.com	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
NA						

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 – Attempt to conduct field tests in autumn before winter.