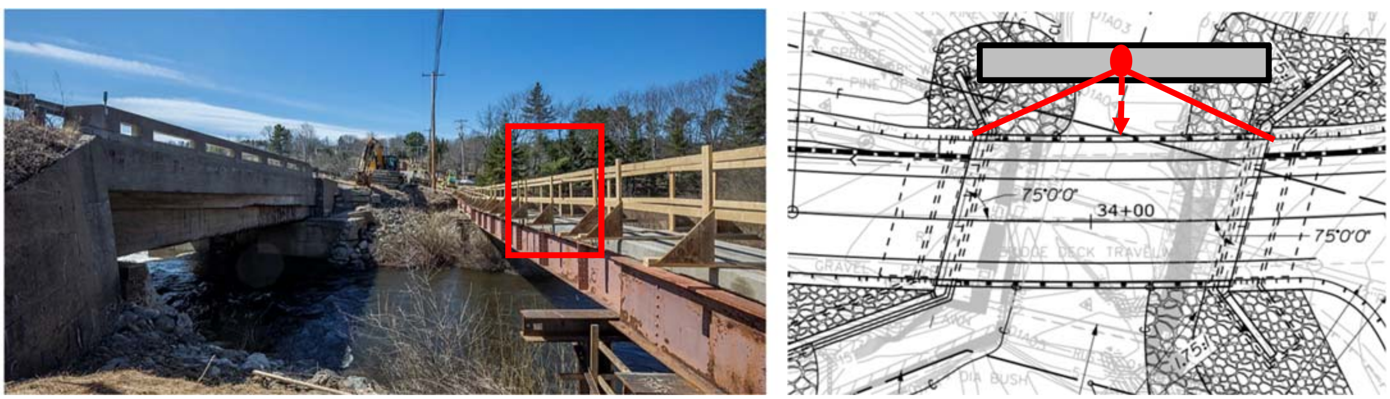
<u>Quarterly Progress Report</u>:
Project Number and Title: 3.8 Bridge Modal Identification via Video Processing and Quantification of Uncertainties
Research Area: Thrust 3 – New Systems for Longevity and Constructability
PI: *Zhu Mao, University of Massachusetts Lowell*
Co-PI(s): *Co-PIs and home institution(s)*
Reporting Period: *07/01/2020-09/30/2020*
Date: *09/30/2020*

Overview:

A brief contribution of the reporting period is:

- Keeping investigating the machine learning (CNN under Softmax environment) for damage identification
- Preparing for field testing to collect data for optical sensing and machine learning

This project has as objective investigate the capability of applying non-contact optical sensing and motion magnification to identify structural dynamics and damage in a truss bridge. Previously, it was applied a machine learning algorithm with convolutional neural networks in order to identify damage in the structure from its mode shape. During this period, since the opportunity for a test in a real bridge arose it were done the preparations needed for the test.



(a) (b)

Figure 1. (a) Hampden Bridge in Maine and the planned location for data acquisition, (b) sketch of the temporary pedestrian bridge to set up video camera.

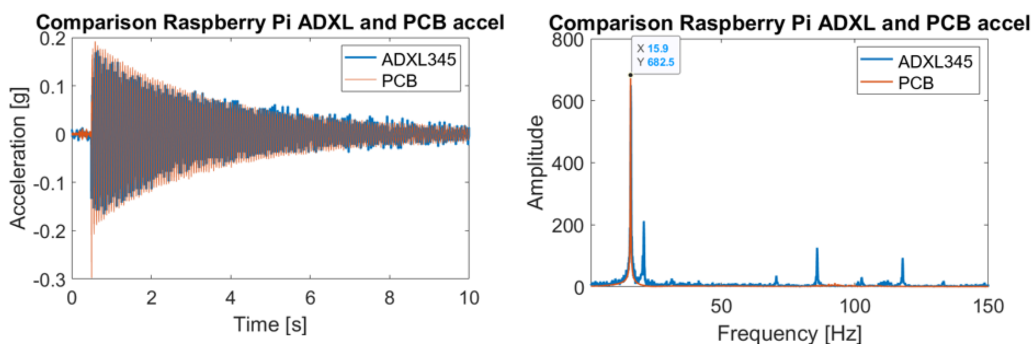
The test will occur in a new composite bridge that will be installed in Hampden, Maine. For camera-based sensing, one of the factors that must be taken in consideration is the recording location for data collection as the field of view of the camera needs to capture the maximum area of the structure possible. In this case, the best recording location is a temporary pedestrian bridge at the side of the existing one, as it can be seen highlighted in red in Figure 1. However, the temporary bridge has its own natural frequencies and also vibrates according to the ambient loadings. To avoid false readings from the ground vibration it was decided to acquire a new system that could be portable and be used for ground motion compensation at the camera.

The solution chosen was to create a low cost and portable data acquisition system using Raspberry Pi 4 system. Since it is a portable single-board computer which is able to be powered by batteries, it can be used at locations without power supply. It is also capable to be used with different programming languages and already has general-purpose input/output (GPIO) connections, which are capable to connect to accelerometers using either inter-integrated circuit (I^2C) or serial peripheral interface (SPI). For sensing an ADXL345 digital accelerometer was adopted, which has a good compatibility with Raspberry Pi, with a sampling rate of up to 3,200Hz and a maximum sensitivity of 0.0039g when set with a ± 2g range. Figure 2 shows the data acquisition system during a contrived testing to prove the concept.

(a) (b)

Figure 2. Setup of the lab-scale test of ground motion compensation (a) comparing ADXL345 with PCB accelerometer and (b) using two ADXL345 back-to-back

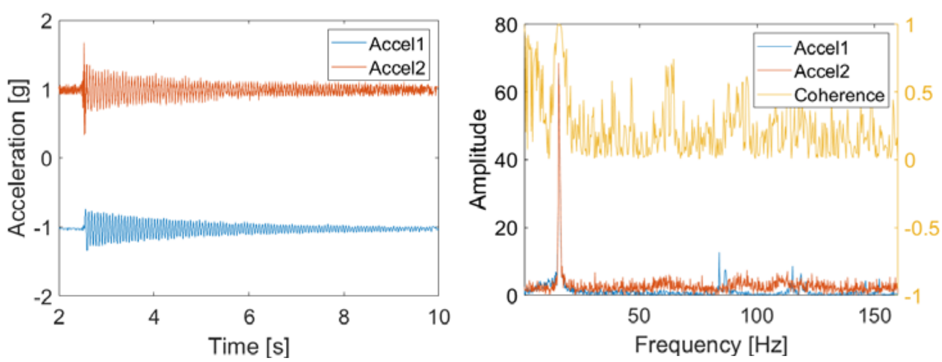
Tests comparing the accelerometer used in the Raspberry with traditional PCB accelerometers were performed using a cantilever beam in order to validate the accuracy of the new data acquisition system. Figure 2(a) shows the setup for the test, for this test, it was used a sampling rate of 400Hz and it was recorded 30 seconds of data. The signal response for the ADXL345 showed the same level of background noise as for the PCB accelerometer and had the same order of amplitude after an impulse excitation as available in the 10 seconds sample in Figure 3 (a). It had also a good accuracy on the frequency domain, extracting the same first natural frequency as the commercial accelerometer, however with other lower peaks caused by noise.



(a) (b)

Figure 3. Comparison of ADXL345 and PCB accelerometer in (a) time and (b) frequency domain.

To increase the reliability of the system it was added a second accelerometer to be used back-to-back with the first one as a redundant backup. Each accelerometer will be connected using a different communication protocol (I²C and SPI) in order to reduce failure due to any malfunction in either the accelerometer or in electrical connections. Figure 2-(b) shows the setup for the testing and the sampling rate and time are the same of the previous test. In Figure 4 it is possible to see the response of both accelerometers. Both accelerometers extracted the same natural frequency of the cantilever beam used in the test. In addition, the signals had the same amplitude. However, due to the noise level the coherence between the signals showed a low value for frequencies above the region of the signal.



(a) (b)

Figure 4. Comparison of signals of two ADXL345 assembled back-to-back in (a) time and (b) frequency domain.

For the next reporting period it is planned to perform a field test at Hampden, Maine. The test will contribute to increase the amount of video-based data for the damage detection algorithm as well as to enhance the use of optical-sensing and motion magnification under different conditions. In addition, it will be resumed the study on how to improve the convolutional neural network that is being developed during the previous period report. For this aim, more tests are planned on a cantilever beam as the early trial, which can be seen in Figure 5, just to take advantage of the simple geometry and dynamics before applying the full artificial neural network model to a much sophisticated bridge.

Figure 5. Cantilever beam setup.

The activities in this period resulted in a data acquisition system that is portable and can be used for ground motion compensation for cameras during testing. Also, the use of Raspberry Pi with the ADXL345 accelerometer showed an acceptable noise level and good testing results compared to commercial PCB accelerometers.

The activities in this period led to a better understanding of the convolutional neural network algorithm studying other techniques it is possible to enhance the current software to obtain a better result. Furthermore, the algorithm also showed an improvement on the accuracy of the model.

Table 1: Task Progress

Task Number	Start Date	End Date	% Complete
Task 1: video motion magnification	1/1/2019	12/31/2020	80%
Task 2: non-contact modal analysis	1/1/2019	9/1/2019	100%
Task 3: machine learning	9/1/2019	12/31/2020	40%
Task 4: nonlinear modal analysis	1/1/2020	8/31/2021	10%
Overall Project:	1/1/2019	8/31/2021	

Table 2: Budget Progress

Project Budget	Spend – Project to Date	% Project to Date*
$55219.5	$ 28379.77	60.85% as of 09/30/2020

Include the date the budget is current to.

Table 3: Presentations at Conferences, Workshops, Seminars, and Other Events

Title	Event	Type	Location	Date(s)
Bridge Modal Identification via Video Processing and Quantification of Uncertainties	TIDC 1st Annual Conference	Conference meeting	UMaine	June 6-7, 2019
Bridge Modal Identification via Video Processing Motion Magnification	Northeastern Society for Experimental Mechanics Conference	Conference	UMass Dartmouth	June 22nd, 2020

Bridge Modal Identification via Video Processing and Quantification of Uncertainties	TIDC 2nd Annual Conference	Conference meeting	UML	August 12, 2020
Optical-Based Structural Health Monitoring of Truss Bridges	2020 TIDC Annual Student Poster Contest	Competition	Online	TBD

Table 4: Publications and Submitted Papers and Reports

Type	Title	Citation	Date	Status
Conference Proceedings	Motion magnification for optical-based structural health monitoring	https://www.spie.org/SS20/conferencedetails/health-monitoring-structural-biological-systems	04/27/2020-04/30/2020	In press
Conference Abstract	An Optical Mode Shape-Based Damage Detection using Convolutional Neural Networks		08/15/2020	Abstract submitted

Participants and Collaborators:

Table 5: Active Principal Investigators, faculty, administrators, and Management Team Members

Individual Name	Email Address	Department	Role in Research
Zhu Mao	Zhu_Mao@uml.edu	Mechanical Engineering	PI
Tzuyang Yu	Tzuyang_Yu@uml.edu	Civil Engineering	Collaborating on bridge testing and sensor placement; providing lab-scale testbed for algorithm validation

Table 6: Student Participants during the reporting period

Student Name	Email Address	Class	Major	Role in research
	Email is not included in the external report and is only used for internal purposes.	(i.e. Junior, Master's Ph.D)		
Celso do Cabo		Ph.D.	Mechanical Engineering	Key personnel to conduct the theoretical investigation
Nicholas Valente		Ph.D.	Mechanical Engineering	Idea discussion, and helping on tests
Matthew Southwick		Master's	Mechanical Engineering	Idea discussion, and helping on tests

Table 7: Student Graduates

Student Name	Role in Research	Degree	Graduation Date
Aral Sarrafi	Key personnel to conduct the theoretical investigation	Ph.D.	Spring 2019

Table 8: 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		Mark the appropriate contribution with an "x"				

Table 9: Other Collaborators			
Collaborator Name and Title	Contact Information	Organization and Department	Contribution to Research
N/A			(i.e. Technical Champion)

Who is the Technical Champion for this project?
Name: John (Jack) Moran
Title: Deputy Chief of Performance and Asset Management and Director of Asset Management
Organization: MassDOT
Location (City & State): Boston, MA

Changes:

In addition to the planned modal identification approaches that will be applied, machine learning and nonlinear modal analysis will be adopted too. Review of literatures has been deployed in the past reporting period, and these new techniques will be a successful complement to the bridge assessment.

Planned Activities:

In the next reporting period, we will focus on the following challenges.

- Study the possible methods of nonlinear modal analysis and choose the best approach to the truss-bridge structure
- Compare non-contact sensing with traditional sensing modalities in a metallic structure
- Perform tests with a cantilever beam to apply in the damage detection algorithm
- Perform field tests in the new composite bridge in Hampden, ME, in order to collect realistic bridge data for further analytics
- The lab-scale truss bridge will be kept utilized for testing new models of data extraction to provide realistic data.
- Non-contact sensing will be adopted and more in-depth investigation of selecting pixels, especially a big number of pixels to take advantage of the averages. By doing this, a better estimation of the modal information will be expected, but this is contingent on the data quality at the selected pixels. Trimming and cropping the videos prior to calculating the expected resonance frequencies may also help enhance the performance.

- Applying other sensing modalities, and maybe collaborating with other projects, in identifying frequencies using conventional data acquisition method. This will help design a better band-pass filter in getting mode shapes and motion magnification results. This effort will be cohered with other UMass Lowell faculty.
- Machine learning algorithms will be studied in the next reporting period to provide an improvement of the results of this period and an option in classifying different damaged types and possibilities for damage localization.