<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: *09/01/2020-12/31/2020*
Date: *12/31/2020*

Overview:

A brief contribution of the reporting period is:

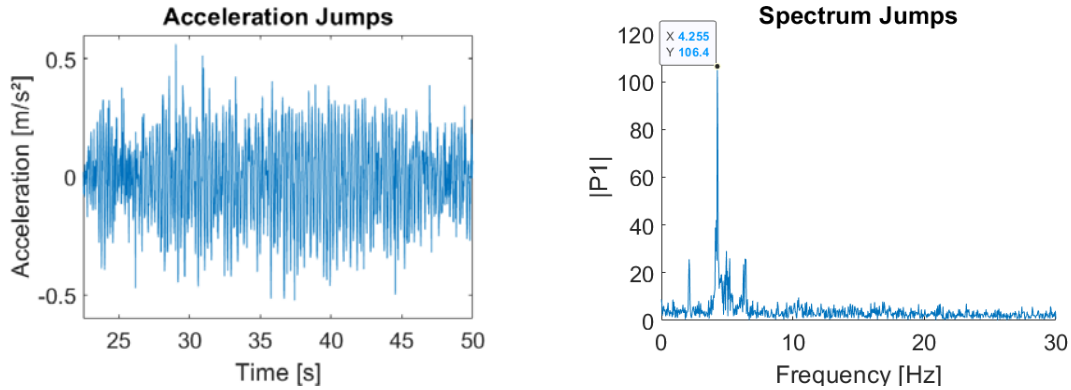
- Carry out vibration testing on a UML campus pedestrian bridge and data analytics
- Keeping investigating the machine learning (CNN under Softmax environment)
- Preparing for field testing to collect data at Hampden ME for optical sensing and machine learning

This project aims to investigate the capability of applying non-contact optical sensing and motion magnification to identify structural dynamics and damage on truss bridges. During this reporting period, a pedestrian bridge on UMass Lowell campus was tested and by collaborating with other UML faculty members, data from multiple sensing modalities were acquired. Figure 1 below shows the bridge and a portable ground motion sensor on RaspberryPi platform that was adopted in the test.

(a) (b)

Figure 1. (a) Olney Hall bridge at UMass Lowell; (b) RaspberryPi data acquisition system.

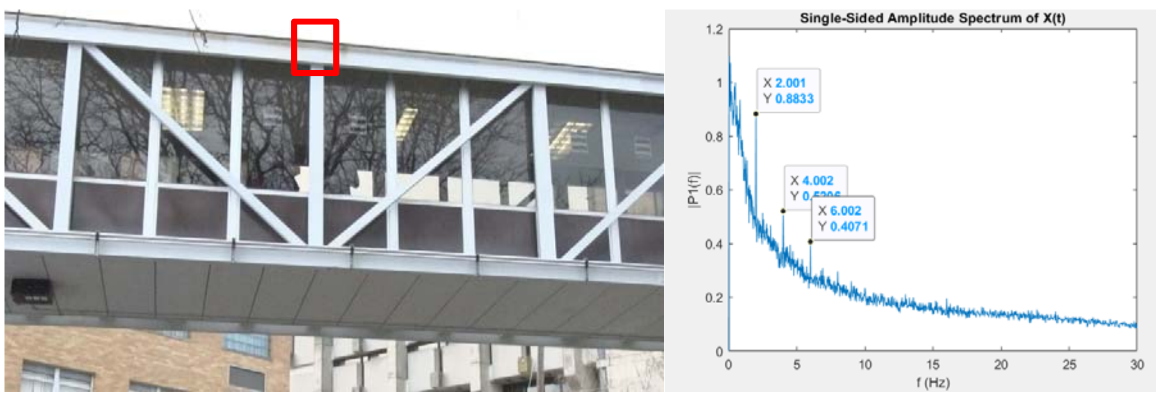
In addition to assess the feasibility of the Raspberry Pi as a data acquisition system, the test is valuable to acquire more information from real bridge structures, which can be used to enhance the Convolutional Neural Network algorithm presented in previous reports. As abovementioned, the test was performed using two primary types of sensing techniques, namely the video camera and accelerometer. As a benchmark, laser Doppler vibrometer was also applied by Professor Yu's team. The data of both video-based motion extraction and the acceleration from the RaspberryPi are compared. The sampling rate applied to the accelerometer was 60Hz with a range of ±2g, achieving a resolution of 0.0039g, while the camera was set with 60FPS and 1920x1080 pixels per frame. Considering the distance to the bridge, the spatial resolution calculated was around 0.45 inches/pixel. Considering that the phase-domain motion extraction can obtain subpixel information, the video can collect up to 0.04 inches movement without much distortions.



(a) (b)

Figure 2. Acceleration response from Raspberry Pi (a) in time domain and (b) in frequency domain.

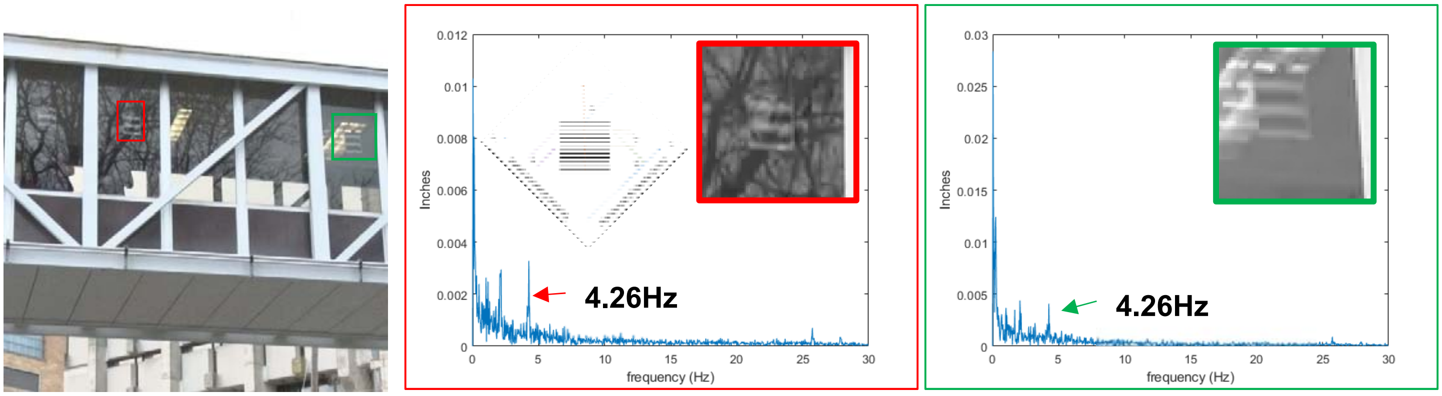
As a form of excitation, 3 people jumped in synchrony during different periods of time generating an input at approximately 2Hz to the structure. In Figure 2 (a), a sampled time history of the collected acceleration response is plotted in time domain, and the frequency spectrum of the response is demonstrated in Figure 2 (b). The input excitation gives a peak at 2Hz and the first bending mode shape of the bridge is shown at 4.2Hz. To collect the data from the camera, phase-based motion extraction is applied in different locations. In Figure 3 (a), the region in the red box is selected for motion extraction. In Figure 3 (b), similar peaks are observed close to the frequency lines consistent to the accelerometer spectrum in Figure 2.



(a) (b)

Figure 3. (a) Location selected for phase-based motion extraction and (b) response in the frequency domain.

In addition to the motion directly extracted from the video frames, patterned optical targets are attached at different locations on the bridge. In Figure 4 (a) the targets are highlighted in red and green boxes. The peaks presented in the red target also match the excitation and first bending mode frequencies in Figure 4 (b). Also, the target in green placed far from the middle of the bridge, where the deformation is smaller, and it has consistent power spectrum with the target in the middle. However, as the amplitude of the movement is smaller, the peak also had a smaller amplitude if compared to the center of the bridge. The results obtained from both the accelerometer and video-based sensing were then compared to the results obtained by the team led by Prof. Yu using laser Doppler vibrometer.



(a) (b) (c)

Figure 4. (a) Location of the targets, (b) frequency response of the target in the middle of the bridge (red) and (c) frequency response of the target in the side of the bridge (green).

As shown in Figure 5, the frequency response obtained by the laser Doppler vibrometer also has the peak at the excitation frequency and bending mode around 2 and 4Hz respectively, proving the accuracy of the data acquisition system developed during the past reporting period. In addition, the data acquired will be useful for training the machine learning algorithms for damage detection.

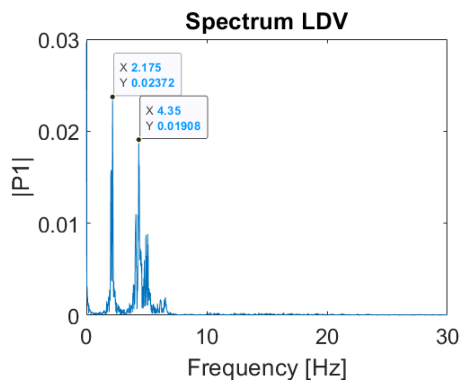
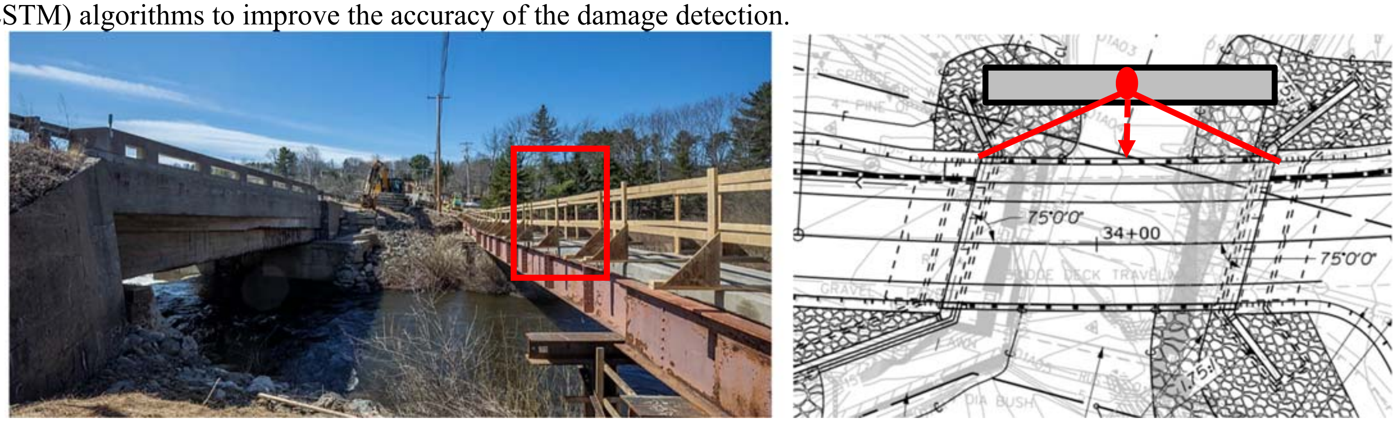


Figure 5. Frequency response obtained by a laser Doppler vibrometer.

For the next reporting period it is planned to be performed the test at Hampden, Maine as Figure 6 illustrated. The test will contribute to increase the data available for the damage detection algorithm as well as to enhance the use of optical sensing and motion extraction and magnification in different conditions and to different structures. In addition, the algorithm for damage detection, Convolutional Neural Network will be keeping investigated along with Long-Short Term Memory (LSTM) algorithms to improve the accuracy of the damage detection.



(a) (b)

Figure 6. (a) Hampden Bridge in Maine and the planned location for data acquisition, (b) sketch of the temporary pedestrian bridge to set up video camera.

Table 1: Task Progress			
Task Number	**Start Date**	**End Date**	**% Complete**
Task 1: video motion magnification	9/1/2019	5/30/2021	80%
Task 2: non-contact modal analysis	9/1/2019	9/1/2020	100%
Task 3: machine learning	9/1/2019	8/31/2021	60%
Task 4: nonlinear modal analysis	1/1/2020	12/31/2021	10%
Overall Project:	9/1/2019	12/31/2021	

Table 2: Budget Progress		
Project Budget	**Spend – Project to Date**	**% Project to Date***
$55219.5	$ 34957.2	63.3% as of 12/31/2020

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	October 21,2020
Infrastructure State Awareness and Dynamics Identification via Advanced Sensing	NEC Laboratories America, Inc.	Seminar	Online	January 4, 2021

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	Full paper published
Conference Paper	An Optical Mode Shape-Based Damage Detection		12/1/2020	Full paper submitted

	using Convolutional Neural Networks			

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
Xingwei Wang	Xingwei_Wang@uml.edu	Electrical 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. No cost extension has been requested due to the impact from COVID.

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. This event has been postponed from the Fall to the end of 2020, and will conduct test if it is further delayed.
- 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.