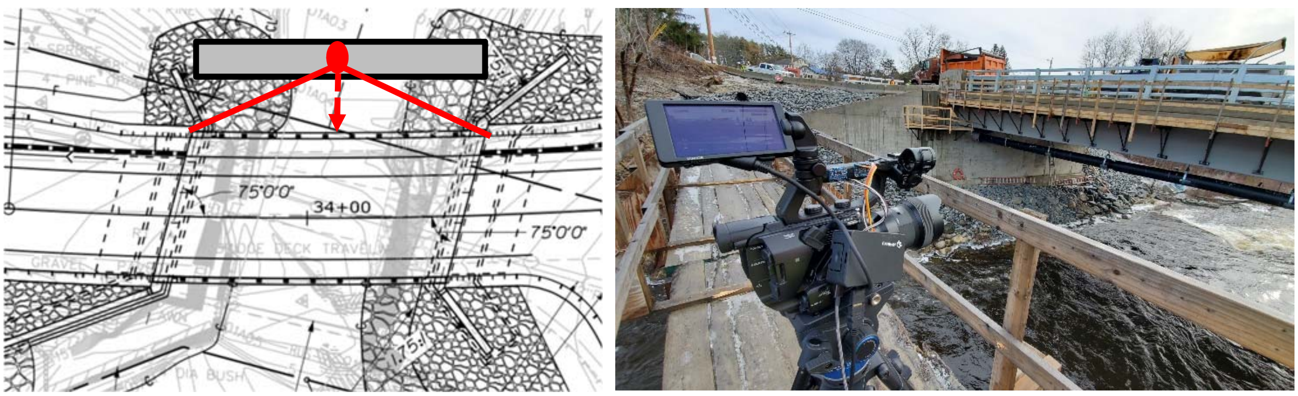
TIDC Transportation Infrastructure Durability Center AT THE UNIVERSITY OF MAINE

Quarterly Progress Report

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: *01/01/2021-03/31/2021*
Date: *03/31/2021*

Overview: **(Please answer each question individually)**

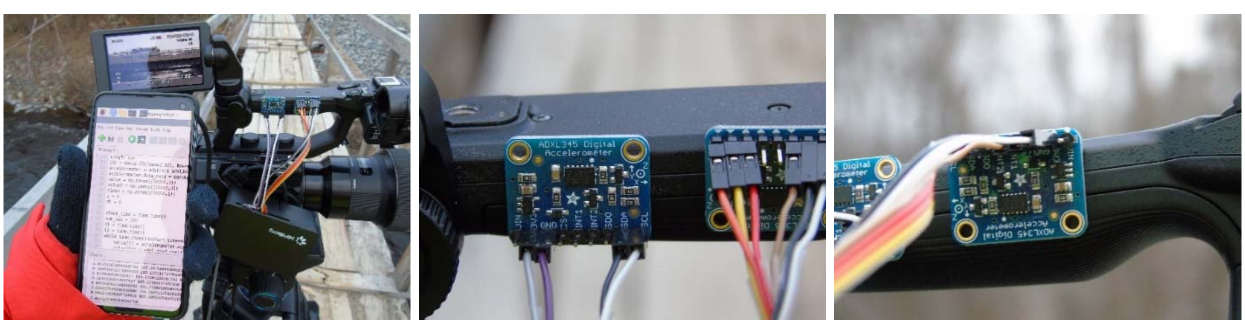
This project has as objective investigate the capability of applying non-contact optical sensing and motion magnification to identify structural dynamics and damage in a truss bridge. Previously, experiments on the equipment were performed in the Olney Hall Bridge, on the campus of UMass Lowell, and then an in-situ test of the new Grist Mill Bridge, located at Hampden, Maine was conducted as part of Project C11. During this reporting period, the test was performed and the data collected were processed in order to obtain dynamic information of the bridge. In addition, a $10,000 in-kind donation from NEC Labs was received in this reporting period, and a collaborative investigation of the transportation infrastructure durability and testing is initiated.



(a) (b)

Figure 1. (a) Scheme of bridge and temporary pedestrian bridge, (b) camera setup for the test.

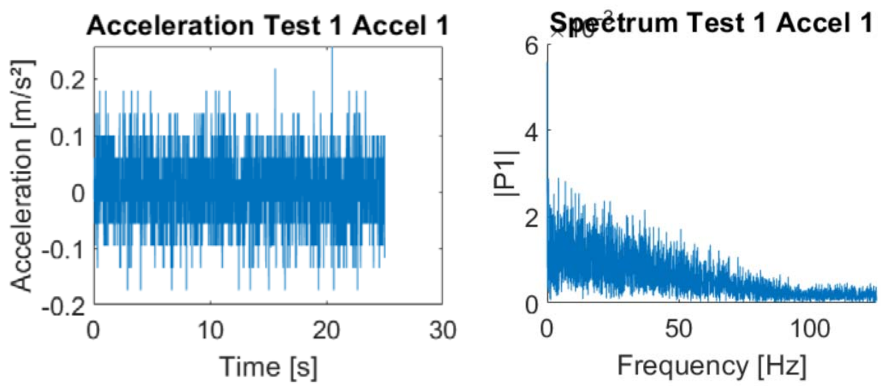
Considering the requisites for camera-based data collection, in order to achieve a field of view to observe the whole span of the bridge, the recording location selected was in a temporary pedestrian bridge built on the north side of the Grist Mill Bridge. Its location can be seen as a gray rectangle in figure 1a) as well as the camera position can be seen as a red circle in the same image. In figure 1b) a picture of the setup with the object of interest for the test can be seen. As discussed in previous reports, the camera would be placed in another bridge which is also subjected to vibration, thus, a portable system was developed based on Raspberry pi in order to detect ground motion. In figure 2 it is possible to verify the Raspberry Pi based system placed in the camera.



(a) (b) (c)

Figure 2. (a) Raspberry Pi setup in the camera, (b) accelerometer 1 using I^2C communication protocol and (c) accelerometer 2 using SPI communication protocol.

A Python-based data acquisition system measures structural response from two different accelerometers using different communication protocol in order to increase the reliability. Both accelerometers were attached in the camera, for the purpose of camera motion compensation, using its Y-axis as the vertical motion. To operate the accelerometers, the operational system was remoted accessed from a smartphone. The system was able to extract data at a sampling rate of 250Hz and with a maximum range of ±2g, generating a resolution of 0.004g or approximately 0.04m/s^2. Regarding the camera setup, the videos of the bridge were recorded at a 60FPS rate using a full HD resolution (1920X1080 pixels), which considering the distance between the camera and the object, and the lens used can be converted to approximately 12mm/pixel. Allowing the extraction of movements up to 1.2mm of displacement and 30Hz. The testing was divided into a static load test and a dynamic load test. For this project, the focus was on the dynamic load test, which had a loaded truck with 27,000kg weight passing through the bridge at 20 and 30mphs to generate its excitation.



(a) (b)

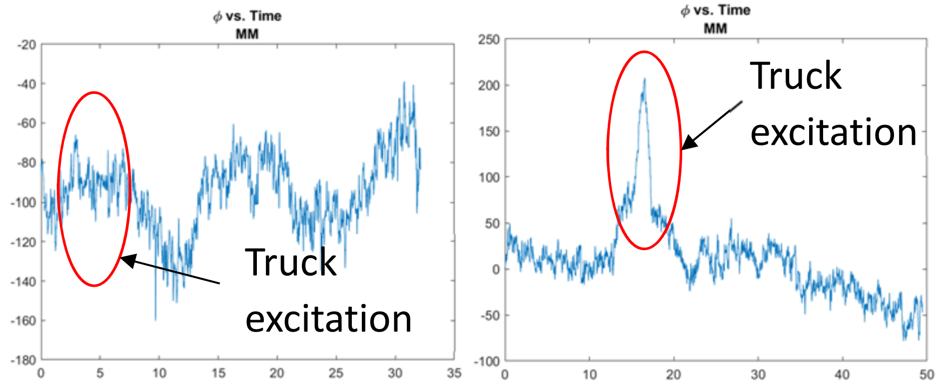
Figure 3. (a) Response in time domain and (b) in the frequency domain from accelerometer 1.

Before processing the data collected by the camera it was needed to know any possible vibrations coming from the ground which could interfere with the results, generating false natural frequencies peaks. Several measurements were taken by the accelerometers during the test, a sample of the accelerometer data can be seen in figure 3. As it can be seen in figure 3a), the vibration extracted from the pedestrian bridge has an amplitude of the same level of the resolution of the accelerometer. Since experiments were performed with the accelerometer prior to the field test, to prove its accuracy and sensitivity for vibration extraction, it was considered that the vibration on the pedestrian bridge was low enough to not be captured by the system. In addition, the frequency spectrum, in figure 3b) also shows only white noise as response. Therefore, for the data extraction from the video camera it was supposed that there was no ground vibration.

Figure 4. Region of interest for phase-based motion extraction.

Regarding the video camera data, different sections from the bridge were used in order to extract its dynamic information. In figure 4 it is possible to see one of the regions selected. The data then was processed for both 20 and 30mph tests. In figure 5 it is available the time domain response for both tests. Although the excitation from the truck cannot be clearly seen in the first test, it is evident in the second test at 30mph, allowing a clear separation between the forced and free vibration to extract the frequency spectrum. In addition, the exact time for the excitation can be checked with the video, resulting in a precision of frames to distinguish the truck position.

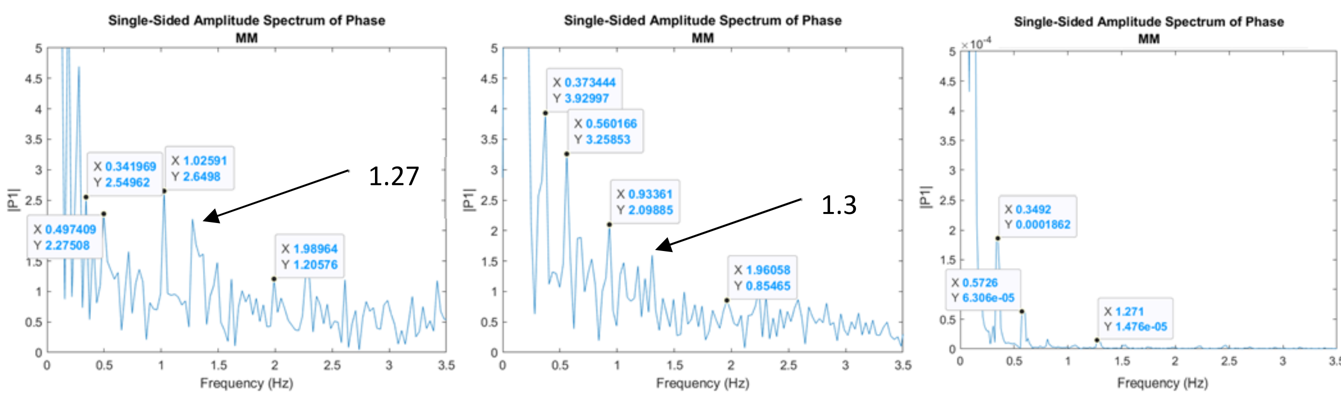
Afterwards, the spectrum for the free vibration for both tests were extracted as available in figure 6a) for 20mph and figure 6b) for 30mph. In addition, the frequency response was compared with strain gauges measurement from figure 6c) in order to prove the feasibility of using camera measurements for in-situ tests. It can be noticed that all graphs have peaks on the same frequencies, such as, 0.34Hz, 0.5Hz, 1Hz and 1.3Hz. Showing consistence on the free vibration for both camera recordings and good accuracy if compared with traditional sensing techniques.



(a) (b)

Figure 5. (a) Time response for 20mph and (b) for 30mph test.

For the next reporting period, further investigation will be done on the natural frequencies displayed in figure 6. Using phase-based motion magnification it is possible to extract particular mode shapes of the bridge, matching with its natural frequency, it can be used for damage detection in case of sudden changes of the frequency and for the mode shapes. The activities in this reporting period demonstrated the challenges faced in an in-situ test for camera-based sensing techniques. Such as, the difficulties and restrictions of the available places for data collection, interference of light and background change during the data extraction. However, even with its challenges, it was proven to still be a portable option for dynamic information extraction, having a setup time considerably shorter than traditional sensors. Moreover, even with its difficulties having provided frequency spectrums with results as accurate as the ones obtained by a strain gauge.



(a) (b) (c)

Figure 6. (a) Frequency response for 20mph and (b) for 30mph test. (c) Strain gauge frequency response from 20mph test.

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	70%
Task 4: nonlinear modal analysis	1/1/2020	12/31/2021	20%
Overall Project:	9/1/2019	12/31/2021	

Table 2: Budget Progress		
Project Budget	**Spend – Project to Date**	**% Project to Date***
$55219.5	$ 39353.8	71.3% as of 3/31/2021

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
An Optical Mode Shape-Based Damage Detection Using Convolutional Neural Networks	International Modal Analysis Conference	Conference	Online	February 11, 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 using Convolutional Neural Networks		0/11/2021	Full paper in press

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 and data processing

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
Matthew Southwick	Idea discussion, and helping on tests	M.S.	December 2020

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
NEC Laboratories America, Inc.	Princeton, NJ	x		x	x	

Table 9: Other Collaborators

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

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.

As abovementioned, an industry collaboration is initiated and we will fine-tune the research emphasis with our better understanding of the industry needs.

Planned Activities:

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

- Identify and isolate the mode shapes of the Grist Mill bridge based on the data collected
- 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
- 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.
- Collaborate with NEC Labs America.
- Comparison of Grist Mill Bridge results obtained from multiple sensing modalities
- Improvement of current model, by changing the type of materials, elements and excitation to obtain a more realistic model