<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): *N/A*
Reporting Period: *10/01/2019-12/31/2019*
Submission Date: *12/31/2019*

<u>**Overview:**</u>
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. During this reporting period, we kept investigating new possibilities to simulate the behavior using the lab-scale model. In the previous period the noncontact sensing through a customized kernel-based optical target was compared with a LVDT sensor for validation, and currently the effort was to focus on different ways of excitation to the structure and the motion extraction.

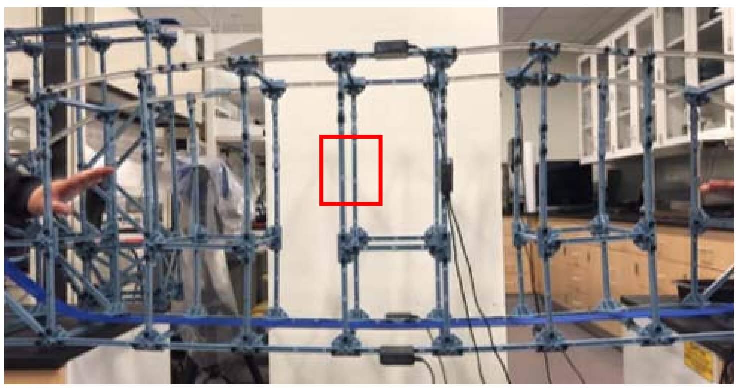
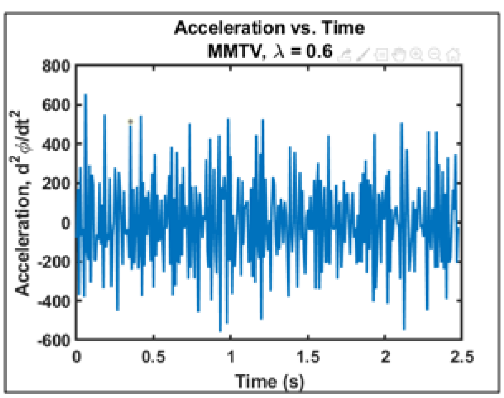
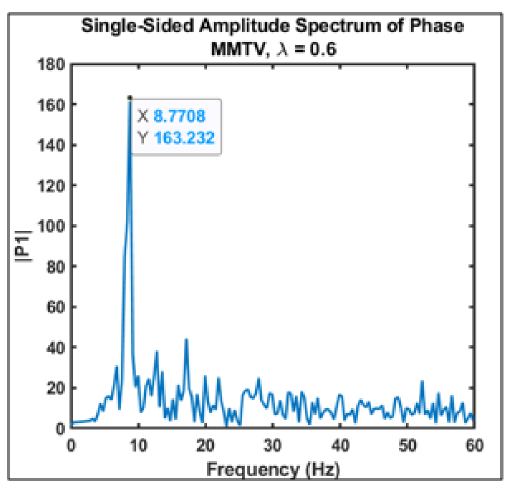


Figure 1. Bridge model testing with random impact excitation

As in real bridges there are many different inputs simultaneously, such as change of mass distribution by the movement of vehicles and external excitations caused by wind, scour, temperature loadings. The aim of the last test was obtaining a coherent frequency spectrum applying a random non-stationary excitation during a period of time in the model, far from the region which the motion magnification was applied, in other words, around the ends of the model. Applying the excitation during a long period of time would allow to extract many time samples, as shown in Figure 2-(a) for averaging and extraction of a frequency spectrum as shown in Figure 2-(b).





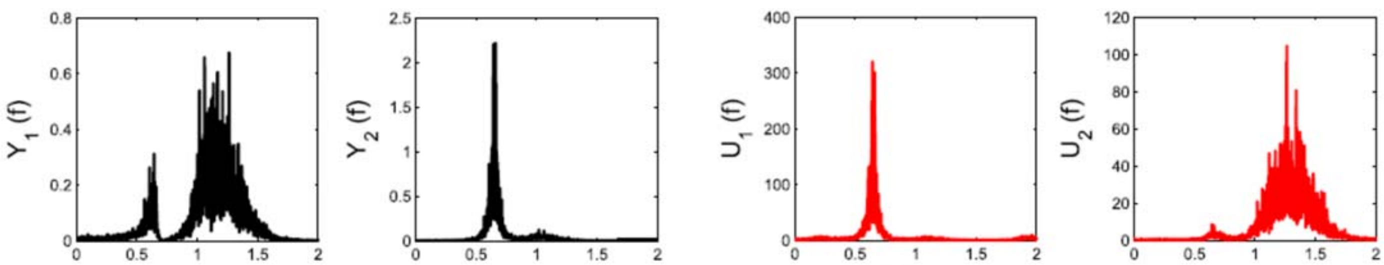
(a) (b)

Figure 2. Dynamic data extracted from the random input using motion magnification. (a) acceleration in time domain obtained and; (b) frequency spectrum acquired from the time domain

The resonance frequency obtained for this excitation is similar from previous tests, with a shift smaller than 1Hz. The area analyzed in this last test is also different from the results presented. Contrasting to the other tests the region analyzed this time was on a vertical truss as shown by the red square in Figure 1, this could cause shift of the frequency, even being a slight change.

After evaluating all data obtained in the lab-scale truss bridge and considering that the change of excitation and location of analysis had an impact in the frequency with the same magnitude of the damaged tests. It was needed to review which theoretical approach would be able to extract the information desired. Two methods are considered as paths to differentiate damage, and literature review and some preliminary research has started.

The first approach is applying nonlinear modal analysis on the extracted vibrational motion, as the bridge has a complex geometry and the joints cause a severe nonlinear dynamic behavior. Those systems may present different modal shapes in different frequencies according to the load applied. As shown in a two degree of freedom example in Figure 3-(a) and (b) the first modal shape appears in different frequencies and its frequencies correspond with the frequency at the second mode. The aim is to isolate the modal shapes into a specific frequency as shown by Figure 3-(c) and (d) changing the displacements for each mode into a function of one displacement and velocity.



(a) (b) (c) (d)

Figure 3. Examples of nonlinear modes shapes. (a) first modal shape; (b) second modal shape; (c) change of variables of the displacement to isolate the first mode; (d) change of variables of the displacement to isolate the second mode. [1]

A few options to extract the modal shapes in a nonlinear analysis can be used. One of them is analytically solving the system equations. However, as those governing equations may be impossible to be obtained and solved by mathematical derivation, currently, only numerical methods may help achieving useful results. Applying machine learning, especially unsupervised learning, would be a perfect candidate to decouple the vibration responses, which would be regarded as nonlinear modal shapes extraction under sophisticated excitation situation as well as geometric and material nonlinearities. Both approaches may be integrated and applied to the previously investigated motion magnification techniques, for a full field analysis aiming to obtain a visual mode shape of the structure in a desired frequency and verify any abnormality on its behavior. Moreover, instead of using motion magnification for a region of the structure, i.e. subvideo, applying it to the entire scope would allow curvature analysis which is more sensitive to the localization of damages, as shown in Figure 4. In a damaged condition, it is expected that the shape would have any abnormality and thus allow to check for maintenance just at the region desired.

Figure 4. Motion Magnification of a beam [2]

Table 1: Task Progress			
Task Number	**Start Date**	**End Date**	**Percent Complete**
Task 1: video motion magnification	1/1/2019	5/31/2019	100%
Task 2: non-contact modal analysis	1/1/2019	9/1/2019	100%
Task 3: machine learning	9/1/2019	12/31/2020	10%
Task 4: nonlinear modal analysis	1/1/2020	12/31/2020	0%

Table 2: Budget Progress		
Entire Project Budget	**Spend Amount**	**Spend Percentage to Date**
$109,834	$33,420.96	30.4%

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

Table 4: Publications and Submitted Papers and Reports				
Type	**Title**	**Citation**	**Date**	**Status**
N/A				

Participants and Collaborators:

The effort is leaded by Professor Zhu Mao, Department of Mechanical Engineering at University of Massachusetts Lowell, and there are a number of mechanical engineering graduate/undergraduate students participated/involved in this reporting period.

Table 5: Student Participants during the reporting period			
Individual Name	**Email Address**	**Department**	**Role in Research**
Celso do Cabo		Mechanical Engineering	Key personnel to conduct the theoretical investigation
Nicholas Valente		Mechanical Engineering	Idea discussion, and helping on tests
Matthew Southwick		Mechanical Engineering	Idea discussion, and helping on tests

Major collaborator is Professor Tzuyang Yu, Civil Engineering at UMass Lowell

Table 6: Active Principal Investigators, faculty, administrators, and Management Team Members			
Individual Name	**Email Address**	**Department**	**Role in Research**
Tzuyang Yu	Tzuyang_Yu@uml.edu	Civil Engineering	Collaborating on bridge testing and sensor placement; providing lab-scale testbed for algorithm validation

There is one student graduated late in the Spring of 2019 with his Ph.D., whose dissertation was partially supported by this TIDC core funding.

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

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 an on-campus truss bridge – the pedestrian overpass bridge between Ball and Olney Hall on UMass Lowell campus will be applied.
- 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 preliminarily studied in the next reporting period to provide an option in classifying different damaged types.

References:

[1]. K. Worden, P.L. Green, A machine learning approach to nonlinear modal analysis, Mechanical Systems and Signal Processing, Volume 84, Part B, 2017, Pages 34-53.
[2]. Yongchao Yang, Charles Dorn, Tyler Mancini, Zachary Talken, Garrett Kenyon, Charles Farrar, David Mascareñas, Blind identification of full-field vibration modes from video measurements with phase-based video motion magnification,