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: *04/01/2020-06/30/2020*
Date: *06/30/2020*

Overview:

A brief contribution of the reporting period is:

- Keeping investigating the machine learning (CNN under Softmax environment) for damage identification
- Augmentation of imagery data to enhance the training quality

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, the effort was to improve the accuracy and applicability of this algorithm.

(a) (b)

Figure 1. Subtraction of frames (a), subtraction of frames with contrast increased (b).

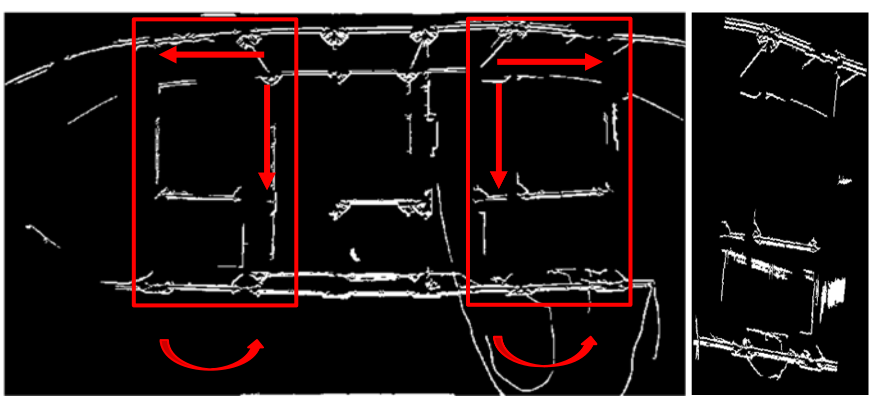
From the previous period report, it was used a convolutional neural network with a severe damage case in order to differentiate the healthy to the damaged structure. Applying motion magnification at the first natural frequency of the bridge will amplify the mode shape, becoming easier to the algorithm to differ from healthy and damaged. As the frames are similar and the background of the video is not a solid color and has details, which could lead to a lower accuracy. Therefore, it was decided to subtract the frames from the static view and then increase the contrast to highlight the pattern of the movement. In Figure 1 it is possible to verify the subtraction of the frames with a static reference (a) and the subtraction with a higher contrast (b).

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

Figure 2. Section with damage visible for a healthy (a) and a damaged case (b), section selected without visible damage for a healthy (c) and a damaged case (d)

During this reporting period, the effort was on increasing the accuracy and applicability of the algorithm, for that, two aspects were considered. Initially, as it can be seen in Figure 1, the frame contains information of the entire structure, and since the damage applied was the removal of one truss element, it is easy to identify the damages just via computer vision. In Figure 2, the healthy (a) and damaged case (b) is easily identifiable as expected, highlighted in red. Therefore, aiming to hide the damage to the algorithm, it was selected a region of the frame to be the new input for the algorithm and it can be seen in Figure 2 for a healthy scenario (c) and damaged scenario (d). Which would force it to classify the difference of the cases from the deflection shapes.

Since the complexity of the problem was increased as the damage was not visible in the frame, the accuracy of the first tests also decreased. The algorithm was able to identify just 43% of the damaged frames correctly and 41% of the healthy frames. Since the accuracy for both damaged and undamaged predictions was lower than 50%, the second aspect considered during this period was increasing the amount of data for the algorithm. As it was available just one video for each scenario, in total there was only around 2,000 frames available for training and testing. In order to increase both accuracy and robustness of the model, it was applied techniques of data augmentation to the original frames. The three most common techniques for data augmentation are adding random noise, rotating and translating the images.



(a) (b)

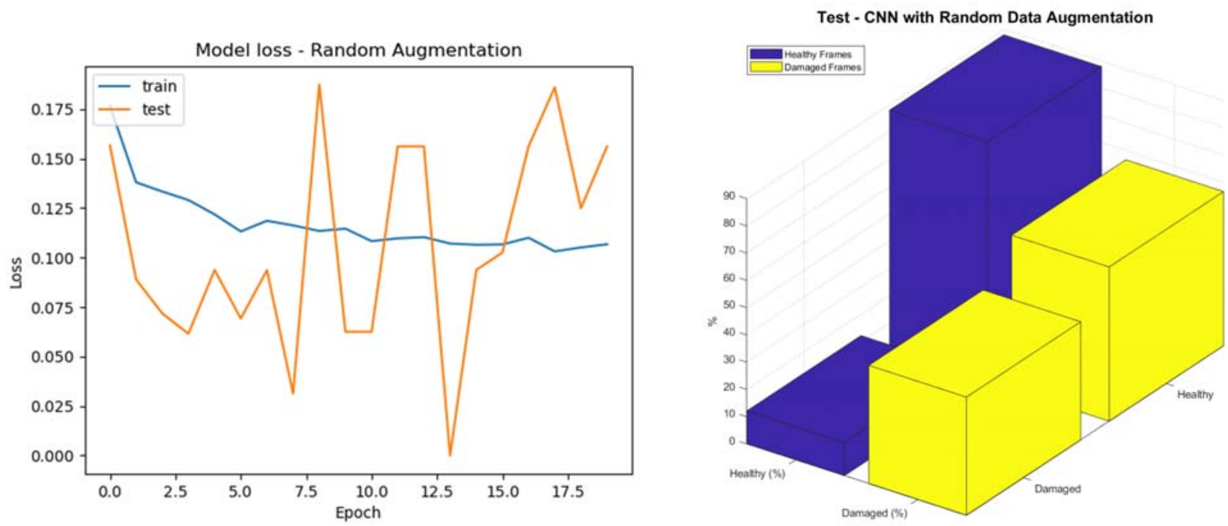
Figure 3. Highlight of the selected sections and explanation on the data augmentation (a) and a sample of one of the selections (b).

All the frames were saved as a binary matrix to increase contrast, therefore it was decided to apply just rotation and translation for the data augmentation. It was selected a section on both left and right side of the bridge, shown by the red boxes in Figure 3 (a). For the data augmentation this box was translated in the vertical and horizontal as shown by the arrows in the figure, at a random number of pixels and rotated at a random angle as well. Repeating this procedure, it was possible to generate 20,000 frames for each case tested, thus leading to 28,000 frames for training and 12,000 frames for testing. Figure 3 (b) shows an example of the section with a random translation and rotation.

Table 0: Parameters of the Convolutional Neural Network

	LAYER 1	LAYER 2	LAYER 3
CONVOLUTIONAL LAYER	k(3*3)/c(32)	k(3*3)/c(32)	k(3*3)/c(64)
MAX POOLING LAYER	k(4*4)	k(4*4)	k(4*4)
ACTIVATION FUNCTION	ReLU	ReLU	Sigmoid
EPOCHS	20		
BATCH SIZE	32		

The parameters of the convolutional neural network algorithm are presented in Table 0 above. The loss function was calculated using the Mean Absolute Error (MAE) and can be seen in Figure 4 (a). As it can be seen the error during the training was around 0.1, which is still considered high for a machine learning algorithm. However, after the data augmentation, it can be seen that the error for the testing sample is also of the same magnitude. While for previous tests the loss function for testing reached values 10 times higher than in the testing. This model predicted 87% of the healthy frames and 43% of the damaged for validation correctly, a graphic form of the results can be seen in Figure 4 (b).



(a) (b)

Figure 4. Loss function of the convolutional neural network model (a) and the results from the validation test (b).

For the next reporting period it is planned to keep studying on how to improve the algorithm. With this aim, there are tests planned with a simple cantilever beam, which the setup can be seen in Figure 5, since its mode shapes are simpler than the mode shapes of a truss bridge. For this test it is planned to be added weights in the structure in order to change its dynamic behavior, as well as changing the boundary conditions to simulate damage. Also multiple types of excitations are being considered, such as impact tests and wind excitation. There are also planned tests with the metallic truss structure and the real truss bridge inside the campus of the University of Massachusetts, Lowell, which could not be performed during this reporting period.

Figure 5. Cantilever beam setup.

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	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	30%
Task 4: nonlinear modal analysis	1/1/2020	12/31/2020	10%
Overall Project:	1/1/2019	12/31/2020	

Table 2: Budget Progress		
Project Budget	**Spend – Project to Date**	**% Project to Date***
$55219.5	$ 28379.77	51.4% as of 06/30/2020

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	September 2020

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

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		Ph.D.	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 and in an on-campus truss bridge
- Perform tests with a cantilever beam to apply in the damage detection algorithm
- 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.