Semi-Annual Progress Report

Project Number and Title: Thrust #1 Distributed Fiber Optic Sensing System for Bridge Monitoring
Research Area: Thrust #1
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Overview:

The problem we are trying to solve is how to monitor the aging bridges. The problem is important because managing aging civil infrastructure is a major challenge facing every country in the world, including the U.S. Deterioration and premature failures of civil infrastructure have a critical impact on the U.S. economy, impacting business productivity, gross domestic product (GDP), employment, personal income, and international competitiveness. It is estimated by the ASCE that the U.S. economy is expected to lose almost $4 trillion in GDP, resulting in a loss of 2.5 million jobs in 2025 if the infrastructure investment gap is not addressed (ASCE 2016). Fiber optic sensors are good candidates to monitor and inspect the aging status of the bridges; therefore, they can provide useful data for the asset owners to prioritize of the maintenance and repair. The optical fiber sensors can provide fast and accurate measurements on strain and temperature. With good packaging, they can function in harsh environments. Moreover, using the BOTDR (Brillouin Optical Time Domain Reflectometry) technology, along a length of the fiber, it can provide fully distributed sensing capabilities (e.g., spatial resolution of 1m over 60 km distance). The objective of this project is to develop fiber optic sensing cables using BOTDR (Brillouin Optical Time Domain Reflectometry) for monitoring of civil infrastructure systems such as highway bridges.

Accomplishment achieved:

We have developed a series of tests using the BOTDR and BOTDA mode to comprehend the functionality of the equipment as well as the performance of different fiber optic cable. The test was performed using 100m Corning fiber. One meter corresponding the fiber segment where the load is applied, and the rest correspond to two fiber spools of 69m and 32m. Figure 1 shows a sketch of the experiment set up. Weights were applied at one side of the fiber to simulate the change in the fiber tension. The changes in loading will correspond to a Brillouin frequency shift which will be related to a strain value. The difficulty of this approach is to be able to detect a small frequency shift. To overcome this problem different parameters such as Step Frequency, averages number, Window scan, and pulse rate must be chosen adequately to improve the resolution.

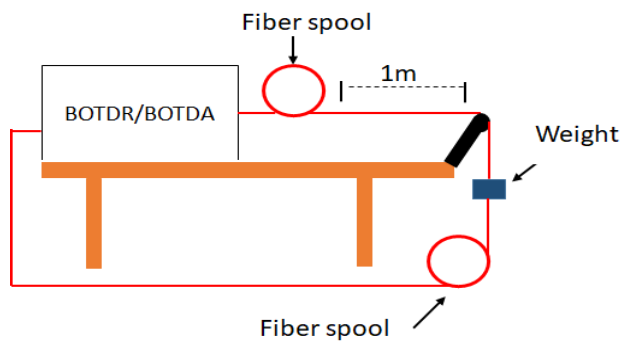


Figure 1. *Sketch of the test set up*

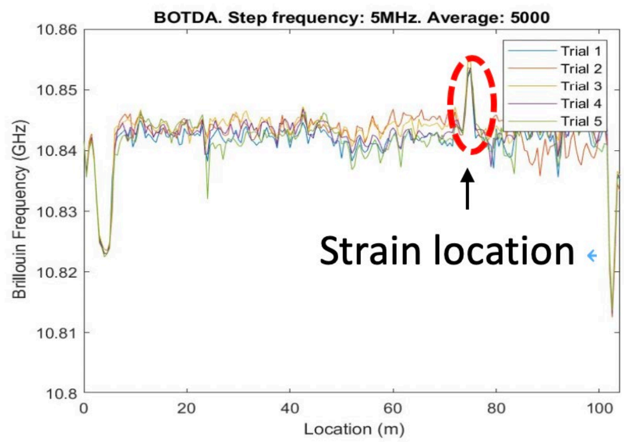
There are two possible modalities, one known as BOTDR (Brillouin Optical Time Domain Reflectometer) and the other as BOTDA (Brillouin Optical Time Domain Analysis). For each modality, we varied the parameters as shown in table 1. Form this test, the best combination was chosen from both modalities (Figure 2). The parameters will need to be changed to accommodate the needs of the test. Our findings from the tests are given below.

1. A low value for the step frequency will provide a more accurate measurement at the expense of the total scan time.
2. A high value for the averages number will provide a more accurate measurement at the expense of the total scan time.
3. Increasing the window scan will increase the total scan time and vice versa.

4. Increasing the pulse rate will decrease the total time scan and vice versa.
5. The total time of scan is subject the length of the fiber as well as the previous four points.

Table 1. *List of Parameter used and the experiment.*

Step Frequency (MHz)	*Averages*	*Scan Window (GHz)*	*Pulse rate (MHz)*
0.1	*2000* *5000*	*10.8 to 11*	*25*
0.5			
1			
5			



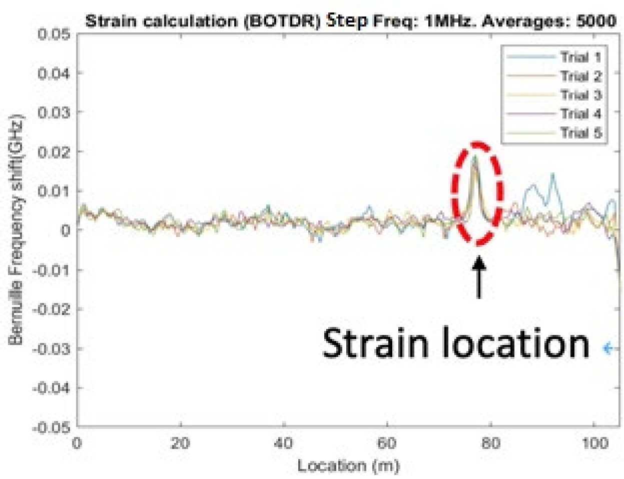


Figure 2. *BOTDA and BOTDR results.*

The result provided has allowed understanding better the mechanism in which the BOTDR/BOTDA machine works as well as the idea of using Brillouin scattering as a sensing system. These results also align with the overall goal of the project since a similar procedure will be implemented when the fiber is applied to infrastructure. For example, once the fiber is installed on a bridge the most appropriate parameters will have to be chosen depending on the level of sensitivity we would like to obtain. This decision will follow the guidelines provided at the beginning of the document, which was written by the performance of this experiment.

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We have developed a pedestrian bridge field test by using BOTDR technology to validate the sensing system. A pedestrian bridge connecting Ball Hall and Olsen Hall locates at UMass Lowell, as shown in Figure 3. The pedestrian bridge is a one-span steel truss bridge with a span of 92 ft and a width of 7 ft. An OZ optics fiber cable (28 m/ 92ft) was planned to be installed on the floor for strain measurement.

Figure 3. Pedestrian bridge at UMass Lowell.

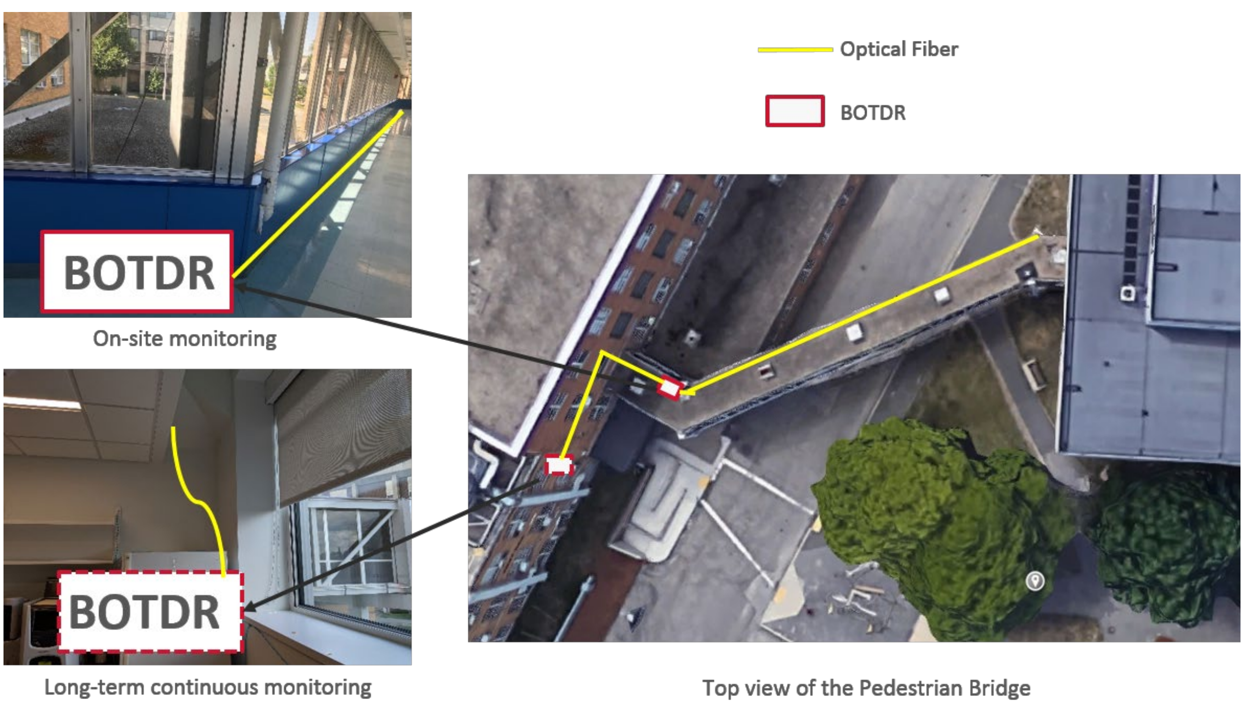


Figure 4. *Location of installation.*

BOTDR is placed on the pedestrian bridge for on-site monitoring. For long-term continuous monitoring, BOTDR will be placed inside a lab next to the pedestrian bridge. Optical fibers will be extended to BOTDR through the ceiling.

The sensing system was installed following the procedure listed below.

1. Check the integrity of the optical fibers using an OTDR.
2. Disconnect OTDR and set up BOTDR at 0 meter.
3. The interface Between the BOTDR machine and the sensing fiber is done by using multiple different fibers. A 2 meters fiber (Corning fiber SME-TB2-OFNR) with a LC connector is connected to 8- meter fiber (Corning fiber SMF-28e) with a FC connector. The two fibers are then connected to a 50-meter fiber (Nufern 1550B-HP) which is used as lunching cable to improve the BOTDR measurement. Finally, the lunching fiber is spliced with the sensing fiber.

Figure 5. *Extending sensing fiber cable to an optical fiber spool and connection fiber cable.*

4. Take the BOTDR measurement as the background signal.
5. Lift the 4-ft sensing fiber cable from the floor. Apply 3M Hi- Strength 90 spray adhesive both on the floor and on the bottom side of the sensing fiber cable. Put the sensing fiber cable back on the floor and remove air bubbles with hands and brush.
6. Repeat step 5 on every 4-ft of sensing fiber cable until the entire sensing fiber cable is glued to the floor.

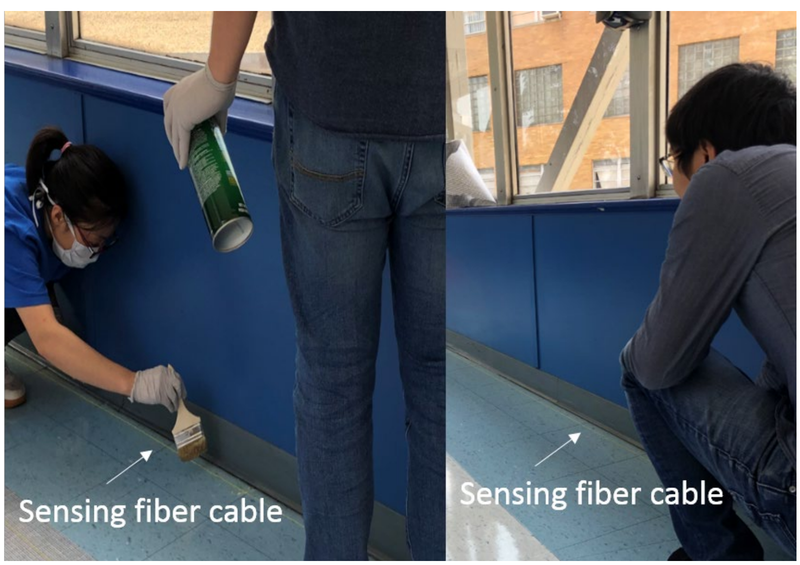


Figure 6: *Apply 3M Hi- Strength 90 spray adhesive between the floor and the sensing fiber cable.*

The pedestrian bridge was loaded with 707 kg weight at 19-m, as shown in Figure 7. (Note: This load is not precisely applied only at 19-m. Due to the size of the loading, the total weight was distributed around the loading area.) BOTDR measurements were obtained before and after the loading. Settings of BOTDR were considered, as listed in Table 2.

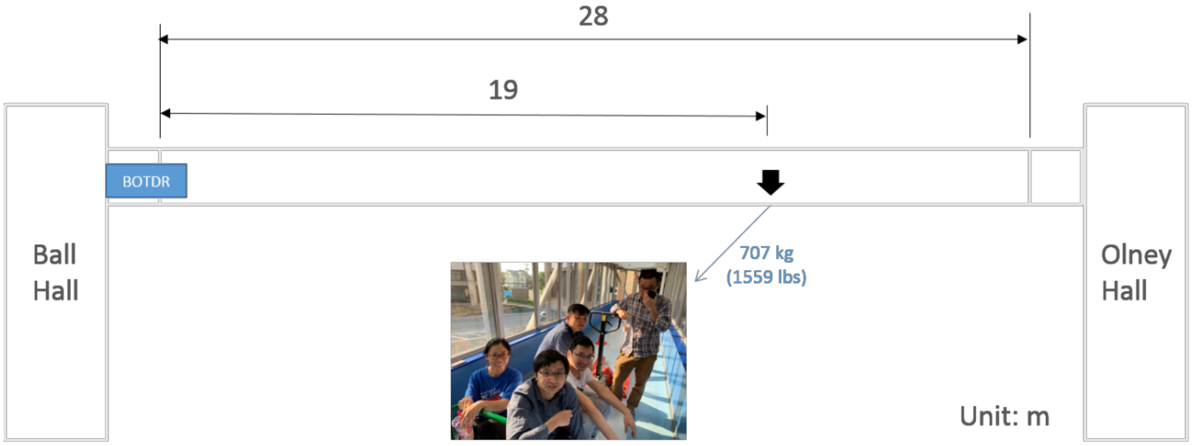


Figure 7: Considered loading.

Table 2. List of parameters used on the experiment.

Step Frequency (MHz)	*Average*	*Frequency Range (GHz)*	*Loading (kg)*	*Loading Location (m)*	*Measurement Duration (s)*
5	*5,000*	*10.7~11*	*707*	*19*	*13*

In Figure 8, the total distance observed is roughly 98m. This corresponds a 2-meter length connection fiber cable (Corning fiber SME-TB2-OFNR), an 8-meter length connection fiber cable (Corning fiber SMF-28e), a 50-meter length optical fiber cable spool (Nufern 1550B-HP), and a 28-meter length sensing fiber cable (OZ optics SMF-1300/1550-9/125-1TBYL-L). The 28-meter length OZ optics fiber cable is the actual length of the sensing cable. A total of ten BOTDR trials were taken for the unloaded and loaded pedestrian bridge. The loading area is at 89m location. The data are shown in figure 8, figure 9, and figure 10 is the average of 10 times data.

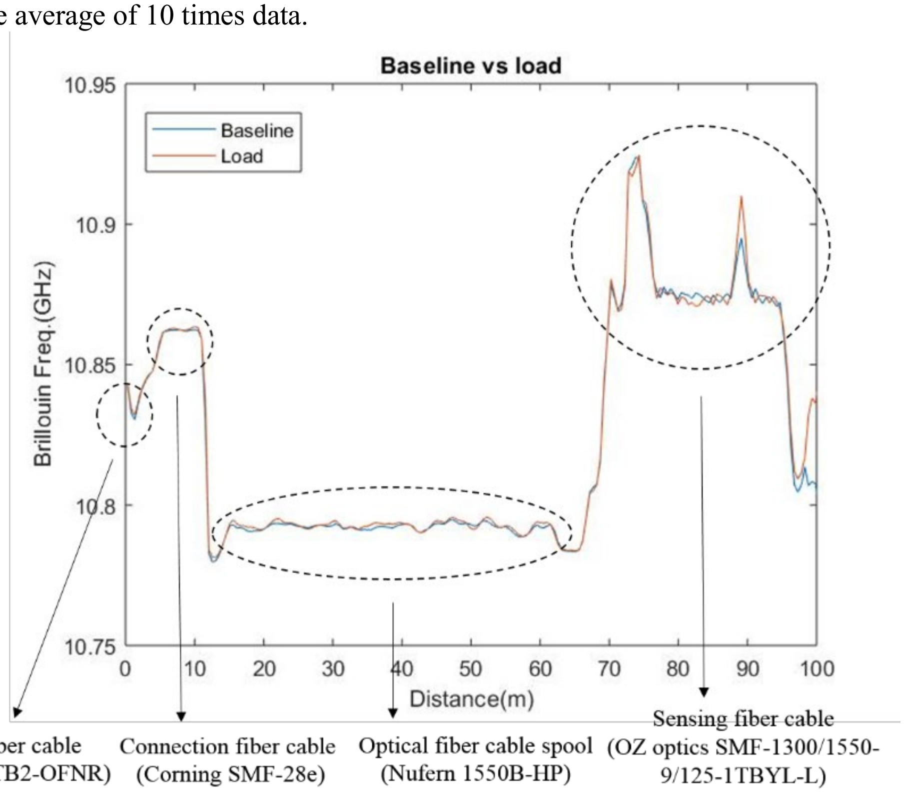
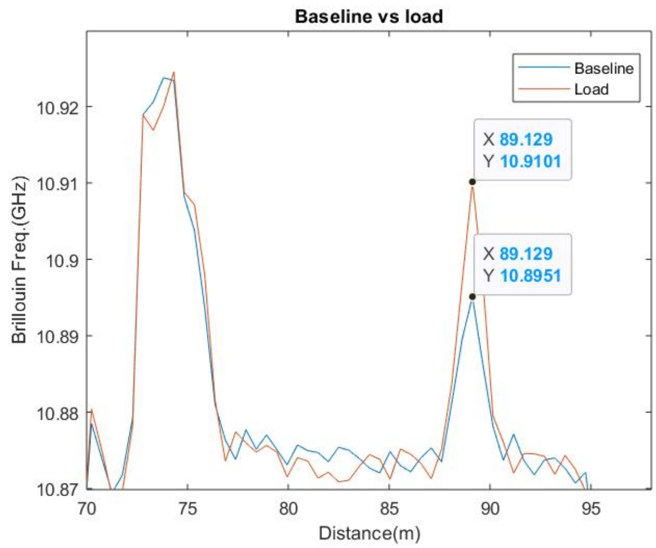
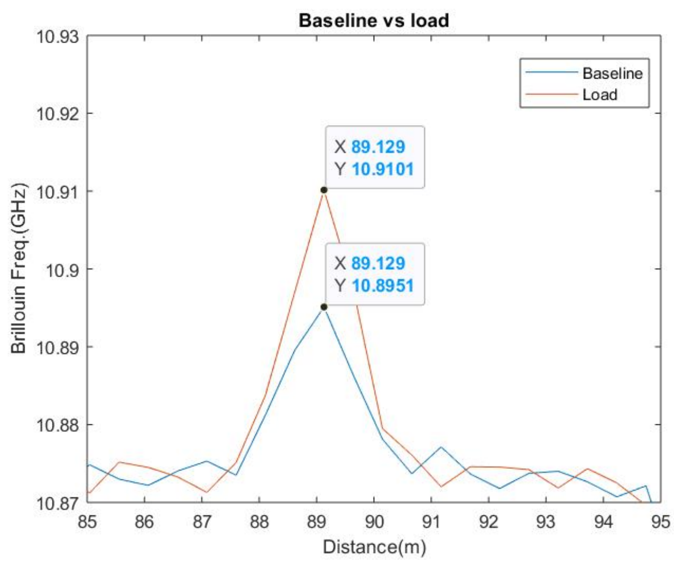


Figure 8. *BOTDR results for the entire connected fiber cable area.*



(a)



(b)

Figure 9. *BOTDR results for the sensing fiber cable area.*

The area where the sensing fiber is located is shown in Fig.9. The load was applied at 19-meters from the beginning of the fiber, which corresponds to 89.1-meter location from the total fiber combination. At that specific location we observed Brillouin frequency shift which correspond to 300 με, as shown in Figure 10. This strain is computed from the following relation $0.1MHz = 0.1℃ = 2\mu\varepsilon$. The BOTDR parameter chosen was 5Mhz step frequency, 5000 averages number, 1-meter spatial resolution and 0.5 sampling interval. The total time scan was 13.186 for each trial, Also, further test will be performed in order to understand the noise effect in the signal due to these parameters.

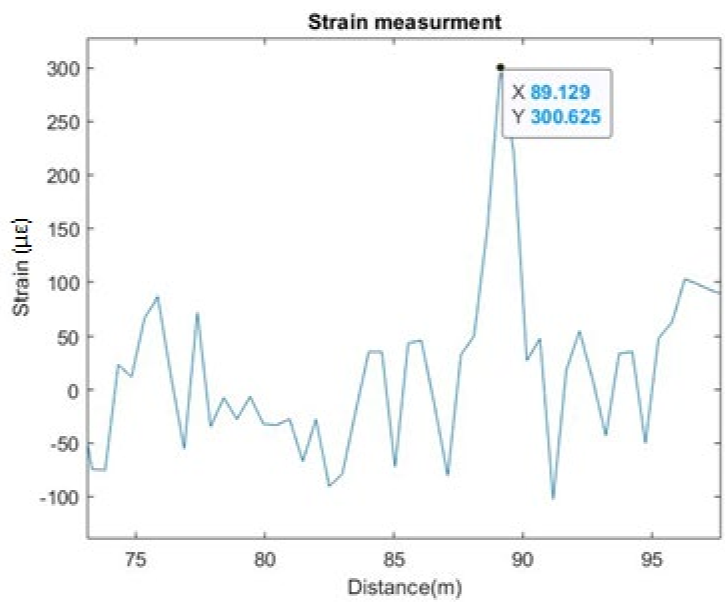


Figure 10. *BOTDR results for the sensing fiber cable area in strain information.*

At the 19-meters location, we observed a crack on the floor (Figure 11). We believe the strain observed in the plot may be due to either the internal defect of the bridge or surface crack of the tiles.

Figure 11. *Photo on 19m location.*

In summary, a pedestrian bridge field test by using BOTDR technology has been conducted, and it has validated the sensing system. We observe an obvious strain change during unloading and loading at the testing area. We believe the strain comes from either the internal defect or surface crack.

Opportunities for training:

Throughout these 6 months, a total of 3 PhD and one Master took part on this project. The students started from learning how to conduct literature review, prepare slides and oral presentations; prepare reports and papers; at the same time, they learned data analysis and research methodologies. In addition, by working closely with companies, like Omnisens, the students not only learned the use and handling of the hardware equipment as well as the software, but also learned how to coordinate with outside collaborators. A conference paper abstract was accepted by the Asia-Pacific Optical sensor conferences.

Participants and Collaborators:

Organizations: University of Massachusetts Lowell

Participants

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Changes:

None.

Planned Activities:

1. Test different fiber optic cables to determine which fiber is most suitable for the field test.
2. Further analysis of the data regarding the noise level, different type of fibers, packaging and temperate compensation techniques