Quarterly Progress Report:
Project Number and Title: Thrust #1 Distributed Fiber Optic Sensing System for Bridge Monitoring
Research Area: Thrust #1
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Co-PI(s): Tzuyang Yu, Civil and Environmental Engineering Department, University of Massachusetts Lowell
Reporting Period: *10/01/2020-12/31/2020*
Submission Date: *12/31/2020*

Overview:
The overall objective of this project is to develop a fully distributed optical system to monitor bridge infrastructure. This monitoring process will help bridge engineers maintain structural integrity and track damage development that may occur to bridges. To develop a reliable bridge monitoring system, sensors have to collect data in different environmental conditions. In the last reporting period, our main project activities are in the field data collection of bridge response; one rail bridge (Salmon Falls River Bridge, NH) and one pedestrian bridge (Lowell, MA). This quarterly progress report documents our activities on these two bridges.

- **Salmon Fall River Bridge (New Hampshire)**

During the current quarter, our research work was focused on studying the response of the textile sensors installed at the Salmon Falls River (SFR) Bridge in New Hampshire. This sensor was installed in October 2019. Since then, a total of five tests were performed using a combination of BOTDA and BOTDR methods. Three tests were conducted in 2019 and the other two during the current quarter. The objective of the last two tests was to understand the fiber sensor performance during different weather conditions: 1) test the survivability of the sensor's installation during the winter period; 2) test the effect of different ambient temperatures on the sensor output: Brillouin frequency. As mentioned previously, the Brillouin spectrum is linearly related to strain and temperature. This means that under different weather conditions, the final signal will be affected differently depending on the environmental temperature. Figure 2 shows the sensors after approximately one year of the fiber installation. As observe in Figure 2, the textile has survived the previous winter season. No visible damage has been observed to either the textile or the launching fiber. However, after collecting data during the current winter, we observed that the fiber jacket will freeze during low temperature, making it more susceptible to be damaged. Nevertheless, this issue can be overcome, by adding fiber storage to protect it from environmental conditions.


Fig. 1. Aerial image of Salmon Falls River Bridge, NH


Fig. 2. Installed optical sensor on the bridge

Figure 3 shows the data taken from two different days using the BOTDA method. This approach will increase the signal to noise ratio and provide better data resolution. The temperature from each test day was different which induced changes in the base signal. The Brillouin Frequency in the results shows a shift due to the temperature difference. The general pattern remains the same which indicates the sensor is working properly. Further data processing will have to be performed to remove the temperature effect and show only the strain response.

With the information collected during this quarter the following conclusion were made. The installation of distributed fiber sensors have survived different weather seasons proving the possibility of the sensor to be used for long-term monitoring. From the second objective, it is concluded that the base signal is affected due to temperature. This effect is observed in Figure 3 with the frequency shift between both signals. Further data processing to remove this effect from the signal will be the scope of future investigation.

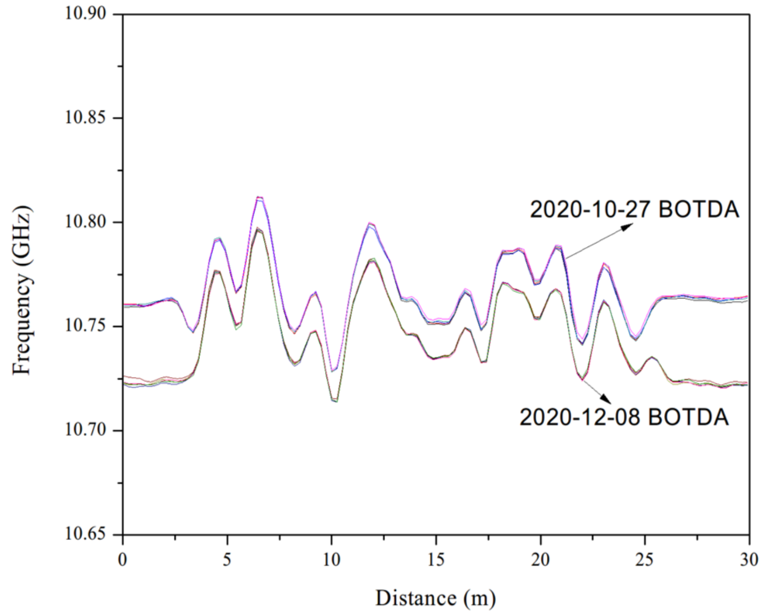

Fig. 3. BOTDA data comparison from two different field

<u>Pedestrian Bridge (UMass Lowell) dynamic test</u>

The purpose of this test was to first to verify that the sensors remained intact after more than one year of installation (Installed on 07/26/2019). Secondly, it was to investigate the possibility to measure dynamic loading on the bridge. The test was carried by three students simultaneously jumping at the middle location of the bridge. This force will introduce vibration on which we hoped to detect with the BOTDA/BOTDR machine. BOTDA was decided to be the method to collect data since it provides better signal-to-noise ratio data.

Fig. 4. Instrumented pedestrian bridge at UML.

The total length of the bridge is 15 m and the length of the fiber embedded in the textile is 30m. As shown in Figure 4, after more than one year of being installed, the sensor is still functioning. This result proves the durability of the sensor and the ability to collect data for long period. Regarding the second objective, the dynamic loading did not generate any meaningful strain in the fiber to be acquired by the BOTDA. The reason for this is the limitation of the equipment to perform faster measurements scan. BOTDA/BOTDR methods are most effective when used in static loading since it will allow the required time to get the event captured by the scan. However, there are other methods that will work during dynamic testing and can be in the future such as the Distributed Acoustic System (DAS) and the Optical Frequency Domain reflectometry.

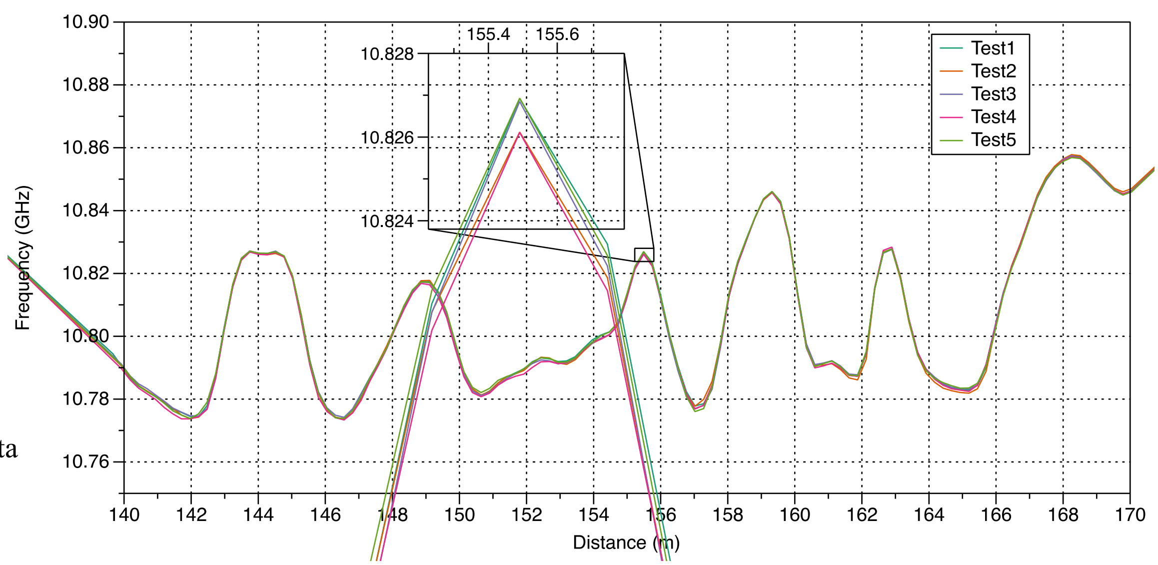

Fig. 5. BTODA data of the pedestrian bridge at UML.

Table 1: Task Progress			
Task Number	**Start Date**	**End Date**	**% Complete**
Task 1: Sensor development	1/1/2019	6/30/2019	100%
Task 2: Signal processing and sensor characterization	1/1/2019	12/30/2019	100%
Task 3: Preliminary field test on the bridge	6/1/2029	09/30/2021	90%
Overall Project:	1/1/2019	09/30/2021	90%

Table 2: Budget Progress		
Project Budget	**Spend – Project to Date**	**% Project to Date***
$102.1k	$87k	85%

Include the date the budget is current to.

We maintained constant communication with the technical team form OMNISENS and LUNA Innovation. They are continuously providing insights on how to use the BOTDA/BOTDA and OFDR controllers. Additionally, we have attended demos provide by OFS and NKT photonics. These demos were centered in providing information for a Distributed Acoustic System (DAS) which is another method that is implemented for SHM.

Table 3: Presentations at Conferences, Workshops, Seminars, and Other Events				
Title	**Event**	**Type**	**Location**	**Date(s)**

Table 4: Publications and Submitted Papers and Reports				
Type	**Title**	**Citation**	**Date**	**Status**
Journal	Pipeline monitoring using fiber optic textile for Structural Health Monitoring	Full citation		In review from other coauthors
Journal	Structural Health Monitoring of a bridge using optic sensing textile			In review from other coauthors
Letter	Embedded Optical fiber in textile techniques for Optical Distributed Sensors			In review from other coauthors

Participants and Collaborators:

Table 5: Active Principal Investigators, faculty, administrators, and Management Team Members			
Individual Name	**Email Address**	**Department**	**Role in Research**
Xingwei Wang	Xingwei_wang@uml.edu	Electrical and Computer Engineering	PI
Tzuyang Yu	Tzuyang_yu@uml.edu	Civil and Environmental Engineering	Co-PI

Table 6: Student Participants during the reporting period				
Student Name	**Email Address**	**Class**	**Major**	**Role in research**
Andres Biondi	Ph.D.		ECE	Signal analysis
Rui Wu	Ph.D.		ECE	Signal analysis
Lidan Cao	PhD.		ECE	Signal analysis

Table 7: Student Graduates			
Student Name	**Role in Research**	**Degree**	**Graduation Date**

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**
Luna Innovation	Virginia		X ($5K)		X	X
Omnisens	Switzerland		x			X
Saint-Gobain North America	Northborough, MA			X	X	X

Table 9: Other Collaborators			
Collaborator Name and Title	**Contact Information**	**Organization and Department**	**Contribution to Research**
Balaji Goplan		Saint-Gobain North America	Manufacturing and supply of textiles, technical support
Dongsheng Li, Ph.D.		Advanced Manufacturing LLC	Technical support

Changes: A no-cost extension to 09/30/2021 was submitted in December 2020 and has been approved.

Planned Activities:

We will continue to collect data every month as weather allows and study the response of the sensor to different weather. Additionally, we will work on the data compensation procedure.