Employing LEWIS1 Accelerometers on the Rail Runner for Strain Estimation

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ABSTRACT:

Structural Health Monitoring (SHM) plays a vital role in ensuring the safety of railroad infrastructure by enabling the detection of damage, fatigue, and potential failure. While strain is a direct indicator of structural stress and deformation, measuring it reliably across large-scale railroad systems presents significant challenges due to environmental exposure, logistical difficulties in sensor placement, and the limitations of traditional strain gauges. This paper presents an alternative SHM methodology that leverages acceleration data collected from Lightweight Efficient Wireless Intelligent Sensor (LEWIS1) accelerometers, which are low-cost, rapidly deployable, and highly adaptable sensors. The LEWIS1 sensors were deployed aboard the Rail runner train in New Mexico to capture acceleration data during various events such as deceleration, acceleration, steady-state movement, and bridge crossings. By analyzing both time-domain and frequency-domain characteristics, researchers were able to identify distinct time-domain event trends and modal resonances, which form the foundation for future strain estimation using modal decomposition and expansion techniques. This approach addresses the scalability, cost, and robustness issues faced by traditional strain measurement methods and offers a pathway to strain estimation using acceleration-based SHM. Future work will involve integrating these acceleration measurements with a finite element model of the train to estimate global strain distributions throughout train structures and bridge components.

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INTRODUCTION

Structural Health Monitoring (SHM) is critical to deploy on trains to detect damage and reduce the risk of failures in train cars, railroad bridges, and the track itself. Deploying SHM on these components is a challenging task as there is an incentive to always keep the trains moving across the close to 140,000 miles of tracks across the United States [1]. Researchers have been creating innovative ways to combat these issues that involve using advance sensor networks that combine time and distance-based data sources to detect and locate track irregularities [2]. The shear length of the railways and the number of sensors required to properly observe the tracks results in an immense amount of data.

The Lightweight Efficient Wireless Intelligent Sensor (LEWIS) accelerometer offers a data efficient, cost-effective alternative to the current accelerometers used in these sensor networks, as they only cost about 70$ each and they can be run from a laptop with no need for an advanced Data Acquisition (DAQ) system. The LEWIS accelerometer is a thoroughly researched sensor with many different applications such as sonar sensing, rain detection, and more [3-5]. This paper tests the efficacy of deploying the LAWIS accelerometer sensors on the Rail runner train of New Mexico.

SENSOR DESCRIPTION

The LEWIS sensors were first designed with the idea tha the sensors must be quickly deployable and reliable, low-cost to fabricate, wirelessly interconnected, self powered. The LEWIS1 accelerometer sensor is composed of various elements including an Arduino Board, a USB type A cable, an accelerometer, a protective case, and STEMMA QT wires. The integration of these components results in the assembly of the LEWIS1 accelerometer. The accelerometer is programmed using the open source Arduino software, and data collection is facilitated through the open source software Putty, which gathers the information in text format. The researchers show the LEWIS1 accelerometer's components and assembly (see Figure 1).

Figure 1. LEWIS1 Accelerometer components and assembly.

SENSOR DEPLOYMENT

The Advanced Dynamics class at UNM, consisting of 7 students and 1 associate professor, Dr. Fernando Moreu, deployed the LEWIS1 accelerometers on the Rail runner train during a class in the Spring 2025 semester. The researchers divided into 3 separate groups to record various cars and locations within those cars. A depiction of the 3 groups sensor placements is given (see Figure 2). The researchers then coordinated to record numerous events as the train headed from the KEWA station near Santa Fe, New Mexico to the Downtown Station in Albuquerque, New Mexico. The events that were recorded were as follows: train decelerating to a stop, train accelerating to steady-state, train at steady-state, and train crossing a bridge. An overview of the tests conducted including which group gathered the data, the times the data were collected, and a description of the event can be seen in table 1.

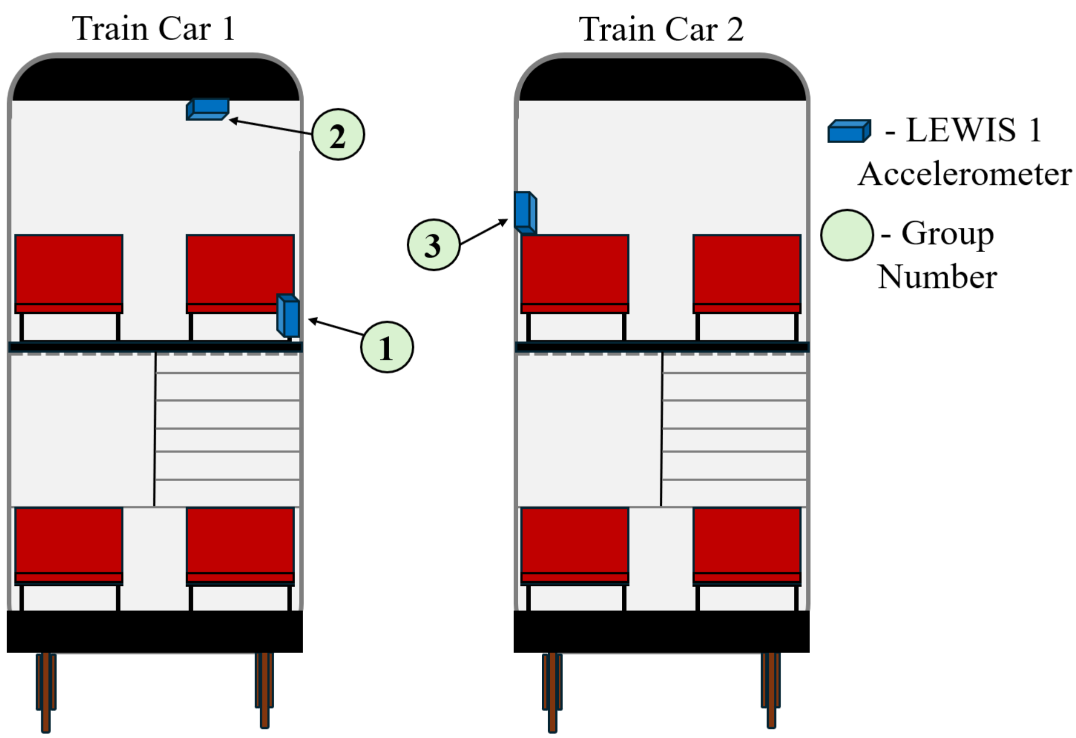

Figure 2. Sensor deployment diagram.

TABLE I. DESCRIPTION OF EXPERIMENTS.

Test Number	Engineer	Sensor Location (Floor #)	Time of Experiment	Test Description
1	Group 1	Bottom of cart (Floor 1)	15:48	Steady-State
2	Group 1	Bottom of cart (Floor 1)	15:50	Decelerating
3	Group 1	Bottom of cart (Floor 2)	15:56	Accelerating
4	Group 1	Bottom of cart (Floor 2)	16:00	Steady-state
5	Group 1	Bottom of cart (Floor 2)	16:03	Decelerating
6	Group 1	Bottom of cart (Floor 2)	16:07	Crossing bridge
7	Group 1	Bottom of cart (Floor 2)	16:09	Crossing bridge
8	Group 2	Top of cart (Floor 2)	15:56	Accelerating
9	Group 2	Top of cart (Floor 2)	16:00	Steady-state
10	Group 2	Top of cart (Floor 2)	16:03	Decelerating
11	Group 2	Top of cart (Floor 2)	16:07	Crossing bridge
12	Group 2	Top of cart (Floor 2)	16:09	Crossing bridge
13	Group 3	Middle of cart (Floor 2)	15:56	Decelerating
14	Group 3	Middle of cart (Floor 2)	15:57	Accelerating
15	Group 3	Middle of cart (Floor 2)	15:59	Steady-state
16	Group 3	Middle of cart (Floor 2)	16:04	Decelerating
17	Group 3	Middle of cart (Floor 2)	16:06	Accelerating
18	Group 3	Middle of cart (Floor 2)	16:08	Steady-state
19	Group 3	Middle of cart (Floor 2)	16:09	Crossing bridge
20	Group 3	Middle of cart (Floor 2)	16:12	Accelerating
21	Group 3	Middle of cart (Floor 2)	16:14	Steady-state

RESULTS AND ANALYSIS

The researchers analyzed all the time domain data in MATLAB. The experimental results were grouped into 4 different types of events: decelerating, accelerating, bridge crossing, and steady-state. The researchers plotted the results pertaining to similar event on top of each other to view acceleration trends caused by each event. The time-domain results for every experiment in both the X (transverse) and Z (vertical) directions are shown (see Figure 5). The top left plot shows the 'decelerating' event data, which shows a slight decrease in acceleration amplitude throughout time. The bottom left plot shows the 'accelerating' event data, which clearly shows an increase in amplitude through time. The top right plot shows the bridge crossing data, which appears to have impulses in the signal throughout time which likely represent the times when the train entered and exited the bridge. Finally, the bottom right plot shows the steady-state response data, which has the greatest constant magnitude of all the tests and appears as a pure random signal.

The researchers then examined the auto-spectral densities (ASDs) of each recorded signal to examine the frequency content of the train car. The researchers plotted the frequency signals in the X direction (see Figure 4 left) and plotted the frequency signals in the Z direction (see Figure 4 right). The data appears to show that the first transverse and longitudinal resonances are around 1.5 Hz. It also seems like the second transvers resonance is around 12 Hz.

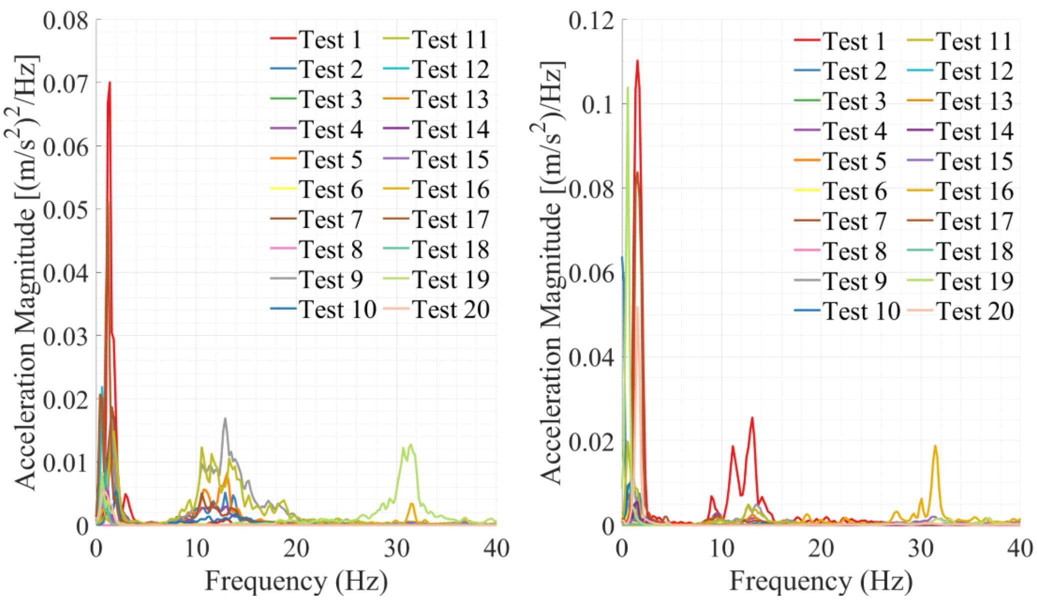

Figure 3. Frequency domain characteristics of the Rail runner.

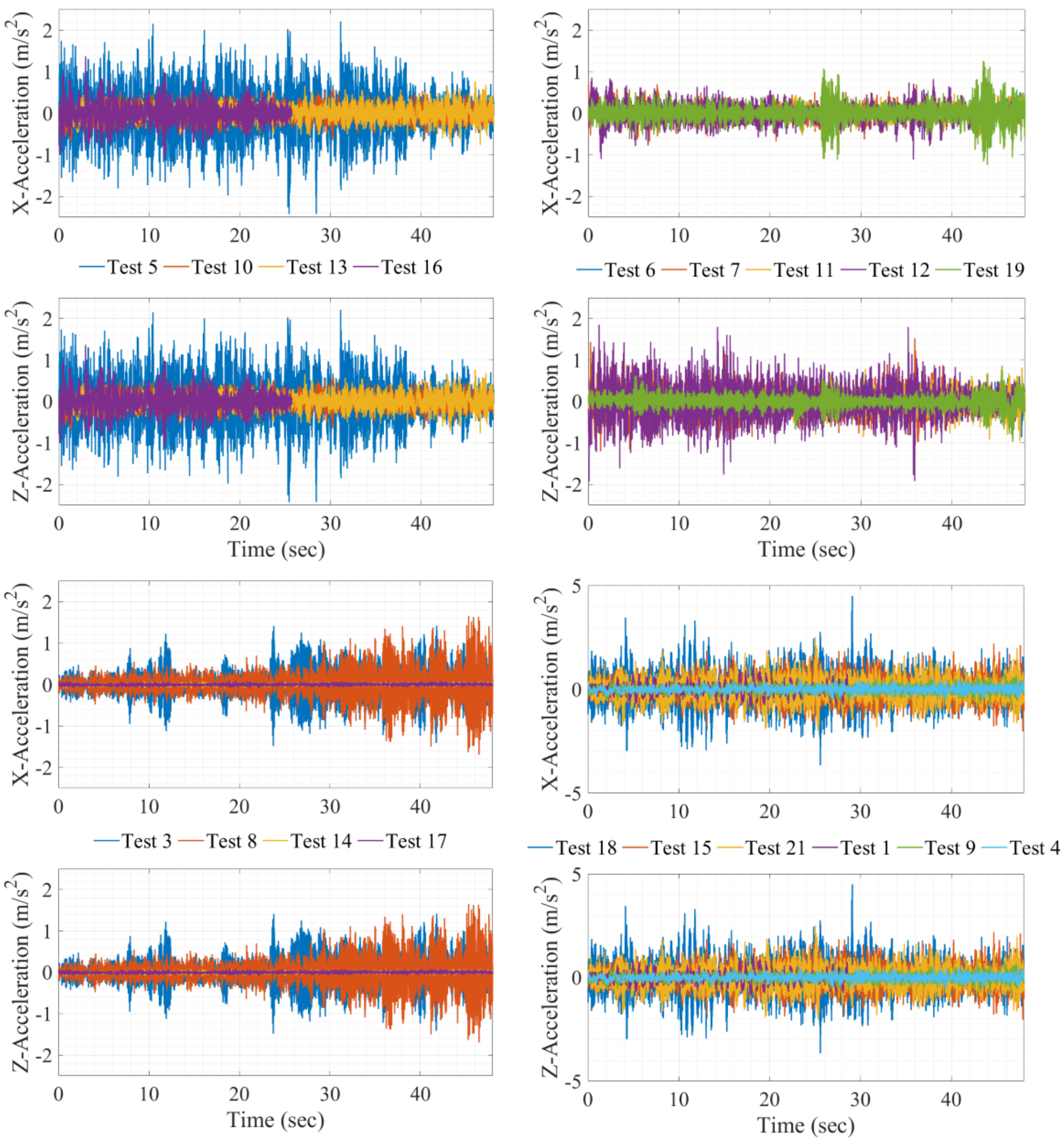

Figure 4. Time domain data of the various events recorded on the Rail runner.

CONCLUSIONS & FUTURE WORK

The results of this study suggest that the LEWIS1 accelerometer can be deployed on a train to effectively identify various events and modal properties. By timing data collection and noting the current event description, the researchers were able to cluster the time domain data into 4 event categories and clearly show data trends unique to each event. The researchers also used the data to effectively identify both transverse and vertical resonances of the train. This data could be used as training sets for artificial intelligence to train event recognition. This work could be advanced by combining the acceleration data with the mode shapes of the train and modal decomposition and expansion techniques to estimate the strain that these events inflict onto the train.

REFERENCES

1. https://railroads.dot.gov/
2. Farkas, András. "Measurement of railway track geometry: A state-of-the-art review." *Periodica Polytechnica Transportation Engineering* 48.1 (2020): 76-88.
3. Sanei, M., Atcitty, S., and Moreu, F. Low-cost Efficient Wireless Intelligent Sensor (LEWIS) for Engineering, Research, and Education, arXiv preprint arXiv:2303.13688. 4.
4. Murillo, J.S., Moreu, F., and Ball, M. 2021. "5th Generation Low-cost Efficient Wireless Intelligent Sensors (LEWIS 5) for Transportation," 100th Annual Meeting of Transportation Research Board, Transportation Research Board, Washington, D.C.
5. Sanei, M., Atcitty, S., & Moreu, F. (2024). Low-Cost Efficient Wireless Intelligent Sensor (LEWIS) for Research and Education. *Sensors*, *24*(16), 5308. https://doi.org/10.3390/s24165308