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Structural Health Monitoring of Railroad Bridges for Impact Detection

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Summary

Researchers at UIUC conducted a study that shows the potential of using ultralow-power accelerometers to detect collision impact in bridge structures and trigger an entire network of sensors in response to imminent collision by means of wireless smart sensors. The goal of the research is to develop an integrated structural health monitoring system to detect collision impacts in the context of railroad operations.

Railroad lines often intersect with other means of transportation, and as a result many railroad bridges receive numerous impacts by vehicles (barge, highway traffic, etc.) during their life span. Such impacts can cause immediate damage to the bridge or cause hidden damage that may eventually lead to accelerated degradation of the structure. Impacts from traffic on highways and in navigable waters pose danger to the bridge users and can cause service interruptions. Catastrophic failures of bridge structures caused by vehicular impacts have occurred in the past (e.g., the Amtrak accident on Big Bayou Canot Bridge near Mobile, Alabama in 1993). Vehicle impacts on bridges are sources of operational risk and maintenance. After such an impact occurs, accurate and rapid condition assessment is critical, including identification of impact location(s) and estimation of potential primary/secondary damage.

This digest presents a study aimed at monitoring such events in the context of railroad operations using ultra-low power accelerometers. The ultra-low power accelerometer continuously monitors bridge vibration and triggers itself when excessive vibration is detected and then alerts the base station. The data with the measured excessive acceleration is saved into a FIFO (First Input First Output). The entire network of wireless smart sensors is triggered and awake during impact events. The post-event synchronization scheme allows recording transient response of the bridge for understanding consequences of the impact to the bridge.

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INTRODUCTION

The results of the recent study conducted by UIUC researchers show the potential of detecting an impact and triggering an entire network in response to collision to a structure by means of wireless smart sensors. This digest presents a framework for using this technology to detect and monitor impacts to railroad bridges. The ultralow-power accelerometer continuously monitors bridge vibration. The measured excessive movement is saved into the FIFO (First Input First Output) buffer. The entire network of wireless smart sensors is triggered and awake during impact events and the post-event synchronization scheme allows recording transient response of the bridge for understanding consequences of the impact to the bridge (Figure 1).

BACKGROUND

Railroad lines often intersect with other means of transportation, as a result many railroad bridges receive numerous impacts by vehicles during their life span (barge, highway traffic, etc.) Such impacts can cause immediate damage to the bridge, or cause hidden damage that leads to accelerated degradation of the structure. The growth of traffic volume increases the risk of accidental collisions between those vehicles and railroad bridges. Researchers reported that flood and collisions are the most frequent causes of the bridge collapse within the United States.[1] Collisions are caused by over-height trucks and lateral impact from ships. More recently, Otter et al. identified that approximately 50 percent of railroad bridge service interruptions are caused by strikes from highway traffic.[2] Thus, monitoring bridges subject to impact is important.

In monitoring bridges under collisions, a rapid and accurate assessment is critical. An early warning to the bridge owners of the existence of an impact may be the first step, followed by reports on the location and the severity of the impact. Additional required features for the monitoring systems should be estimations of potential primary and secondary damages. While obtaining transient response of the bridge during impact can help making those decisions, due to unpredictable nature of those events, only a few attempts have been partially successful.

Traditional wired and wireless sensors have been implemented in the field on operational structures to monitor bridge impact. For example, to utilize wireless sensors for timely capturing the earthquake response of bridges, Cheng and Pakzad implemented a pulse-based media access control approach on the main span of the Golden Gate Bridge.[3] Although the network of sensors was successfully triggered and scheduled with a message sent from the observation site, other events such as barge or vehicle impacts could not wake up the network. To monitor any kind of impact using wireless smart sensors, Yuan et al. proposed a framework using piezoelectric (PZT) sensors.[4] In their scheme, a cluster was composed of up to six PZT sensors, which could detect impact. Once triggered, signals were digitized into a subsequent threshold to localize the impact within a cluster. Such a decentralized scheme could detect impact without requiring large amounts of data, but it lacked an appropriate triggering mechanism for the system. So, an integrated system that triggers the network and monitors transient responses of the structure has not been developed.

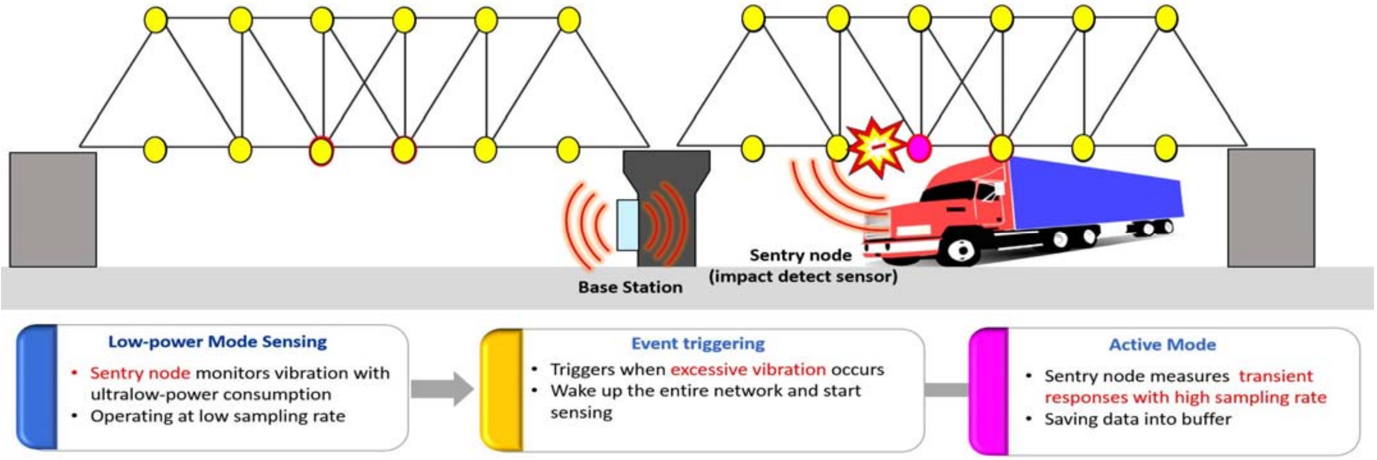

Figure 1. Railroad Bridge Impact Detection Framework

IMPACT SENSOR

Impact sensing systems need to allow sensors to stay awake during the entire period and trigger themselves when measured vibration exceed a certain threshold due to impact loading. In this study, impact sensing hardware was configured through micro-power Micro-Electro-Mechanical Systems (MEMS) accelerometer and Arduino UNO.[5]

Arduino Platform

The Arduino board is an open-source electronic prototyping platform that allows creating interactive electronic objects. It consists of an Atmel AVR® 8-, 16- or 32-bit microcontroller with complementary components that facilitate programming and incorporation into other circuits. The Arduino UNO is an Arduino platform built on an 8-bit microcontroller, ATmega328. It has 6 analog inputs, a 16 MHz crystal oscillator, and 14 digital input/output pins that allow communication through serial, SPI (Serial Peripheral Interface) and I2C. The platform provides the software framework needed to support the microcontroller.[5]

WIRELESS SMART SENSORS

The impact sensors have to accommodate (1) continuous operation with micro power, (2) fast sampling rate to capture transient responses, (3) a FIFO buffer, and (4) adequate sensing resolution.

The study used the ADXL362, an ultralow-power, 3-axis MEMS accelerometer, with specifications shown in Table 1. The very low power requirements allow a long operating time between servicing.

Table 1. ADXL362 Impact Sensor

Model	ADXL362
Measurement	3-axis acceleration
Resolution (Bit)	12
Sampling Rate (Hz)	12.5 ~ 400@active 6@Inactive
FIFO size(samples)	512
Power Consumption (μA)	2.7@active 15@ultra-noise 0.27@inactive
Noise Density ($\mu g/\sqrt{Hz}$)	380@normal mode 175 @ultra-noise mode

Unlike other accelerometers, the ADXL362 uses power duty cycling to achieve low power consumption. It has several activity detection modes including adjustable threshold sleep and wake-up operation that can run as low as 270 nA at a 6 Hz measurement rate. The ADXL362 provides an interrupt triggered on various status, including (but not limited to) active, inactive, and data ready. It has a relatively large FIFO buffer size that can save up to 512 samples, which corresponds to 1.7 seconds in each *x*, *y*, and *z* axes when sampled at 100 Hz. Finally, the ADXL362 has minimal power consumption, using only 15μA at 3.3 V, which corresponds to 49.5 μW even using the higher precision ultralow noise mode. The ADXL362 best fit the need of the study.[6]

Figure 2 shows a schematic diagram of the ADXL362 configured with the Arduino platform. The communication with the ADXL362 is carried out on an SPI bus using 4 digital pins (10~13) on Arduino. INT1 and INT2 are interrupt pins that can be programmed, whereby just INT1 is set as an active indicator that is triggered when measured vibration exceeds a previously specified threshold. The 0.1μF capacitor is connected to both VS (power supply) and Vdd (digital I/O supply) to suppress signal noise. The software for testing the ADXL362 was designed to capture transient response as well as the response before the trigger. The parameters for active and inactive vibration thresholds are 200 mg for 0 second and 2,000 mg for 5 seconds; the sampling rate is set to 100 Hz in active mode. The FIFO buffer is set in the trigger mode to enable saving data into the buffer after the trigger, including a selected number of data before the trigger.

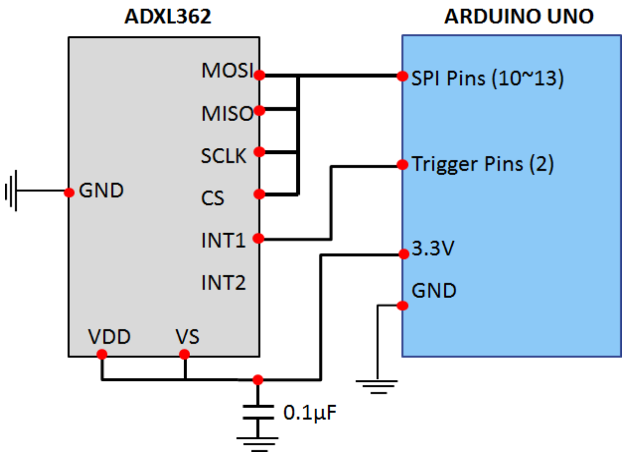

Figure 2. Hardware Configuration

Figure 3 shows the operational sequences for testing the impact sensor; the ADXL362 starts in inactive mode and operates at a sampling rate of 6 Hz. Once the ADXL362 detects that an active threshold has been exceeded, the mode automatically switches to active mode and sends an interrupt to pin INT2 on the Arduino to inform the processor that the sensor is in the active mode. After sensing is done and data is saved in the FIFO buffer, the status switches back to inactive and waits for the next trigger.

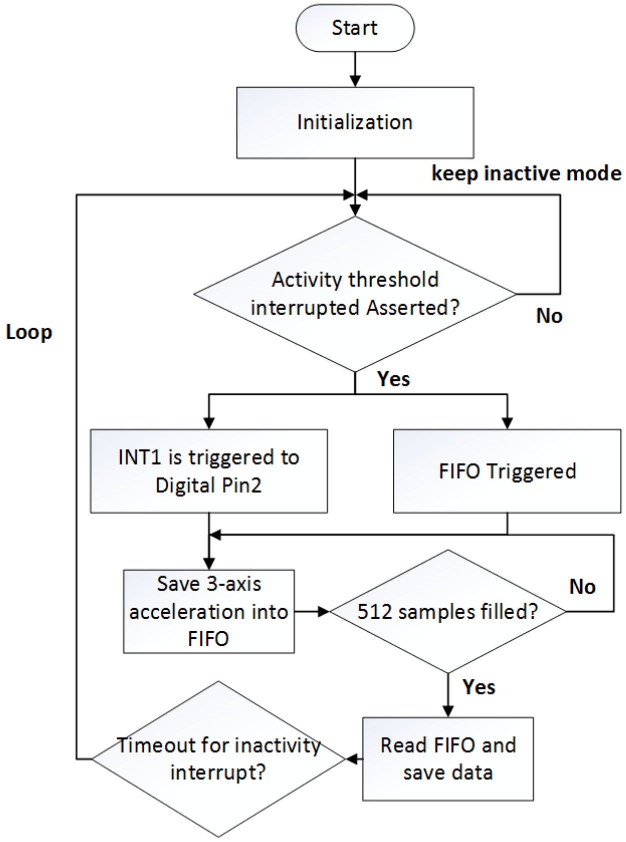

Figure 3. Flow Chart for Testing Impact Sensor

The hardware and software designed for testing the impact sensor was validated on a small-scale test on a railroad bridge pier modeled as a cantilever column. The length, width, and thickness of the pier was 220 mm by 20 mm by 1 mm. The impact sensor was installed in the middle of the beam, and impact was exerted on the tip of the beam. Figure 4 shows the saved impact response in the FIFO buffer. The result captured data before and after the sensor was triggered.

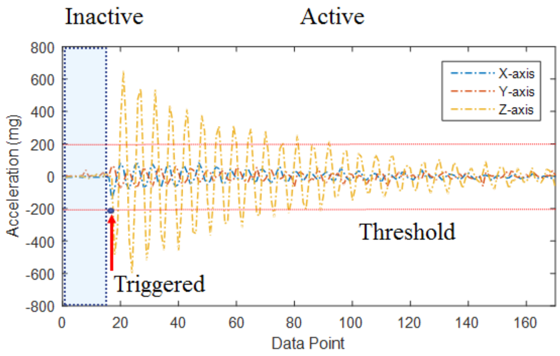

Figure 4. Saved Impact Responses in FIFO Buffer

CONCLUSIONS AND WAY FORWARD

UIUC researchers successfully demonstrated the potential of monitoring and assessing a structure after unpredicted impact events using wireless smart sensors. A low-power accelerometer was used to trigger a sentry node in the network. The ADXL362 sensor was used due to its ultralow-power consumption and large FIFO buffer size compared to other commercially available sensors. A laboratory-scale test revealed that responses prior to the impact and the transient response can be collected from the sensors using wireless smart sensors. Current efforts are underway to implement this technology on the Xnode, a next generation wireless smart sensor. Future efforts include field testing to assist in avoiding false-positive signals, to assess the level of accelerations caused by impacts, and to incorporate small cameras capable of capturing information regarding the offending vehicle.

ACKNOWLEDGEMENT

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