Post Earthquake Structural Evaluation System

After a major earthquake, inspectors and engineers risk their own safety to inspect buildings. PESES is an automated replacement to this process; using an easily-installed, scalable, and web-connected sensor network, we can estimate building deformations following earthquakes, reducing risk by giving inspectors a new tool.

Motivation

Following an earthquake, it is crucial for first responders, engineers, and inspectors to quickly understand the damage incurred by a building. Currently, this investigation takes about 15-30 minutes per structure, and given the widespread damage of large earthquakes, a thorough survey of an urban area could take more than 70,000 man-hours to complete.

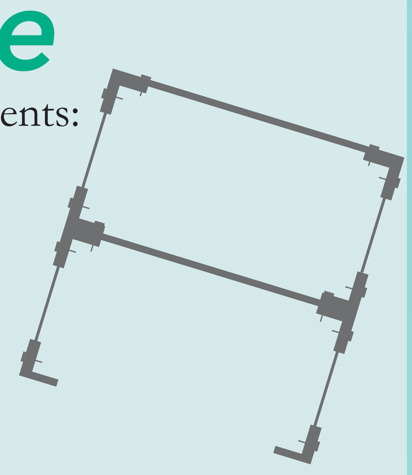
PESES uses networked accelerometers to monitor building drift during an earthquake, and therefore estimate structural damage following shaking. This system is meant to be:

1 Easy installed and affordable
2 Operates autonomously
3 Scalable to include many structures

PESES will save tens of thousands of man-hours, enhance first responder and inspector safety, reduce building down time, and allow communities to efficiently allocate disaster recovery resources.

Hardware

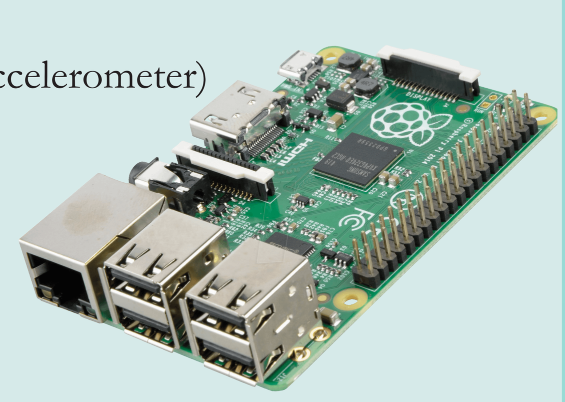
Our system is comprised of several components:

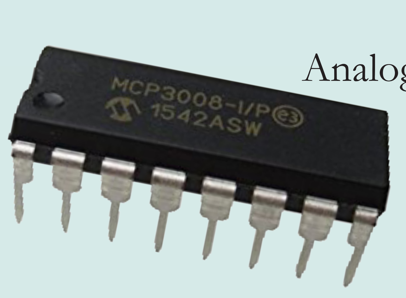


Test Structure (Custom-Fabricated)
2 stories (Simple 2 DOF Structure)
Rigid aluminum plate floors
Interchangeable, malleable steel strip columns

Accelerometer (One per Floor)
SparkFun Triple Axis Accelerometer
Accurate to within 0.01 g
$16 (retail price)

Raspberry Pi 1 Model B+(One per Accelerometer)
26 digital input/output pins
3.3 V power output
USB compatibility
Micro SD Card compatibility





Analog to Digital Converter (One per Accelerometer)
10-bit SPI 8 Chl IND TEMP, PDIP16
6.35mm x 19.05mm x 3.3mm
$2.32 (retail price)

Our Team

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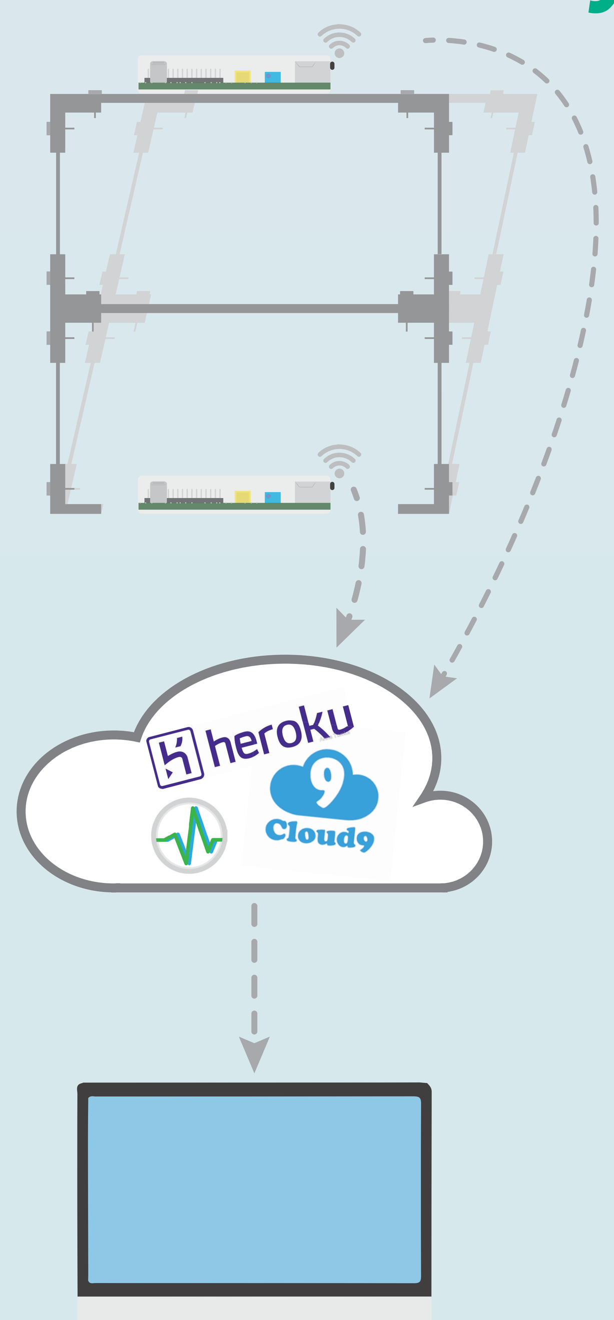
Our System



Data Collection & Primary Analysis

The Raspberry Pi collects Data once a threshold acceleration has been met, and continues collecting data until another stopping Criteria is met. It then filters and integrates to calculate the final displacement.

Transmission

The final displacements are sent to an off site server via Wifi. The off site server manages the offload priority of each node.

Secondary Analysis & Storage

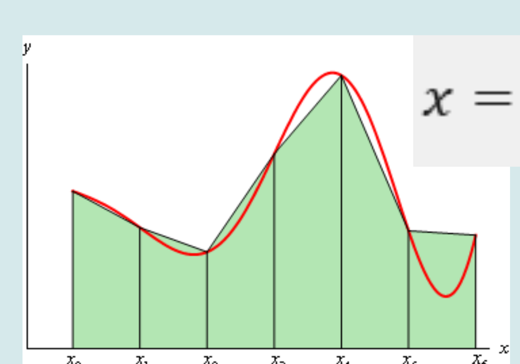
After all of the data has been collected, the server compares displacements among all of the nodes to determine the building health.

Web Visualization

The server is accessed by users and the data is visualized on any browser.

Analysis

Our data analysis is centered about double integrating our accelerometer to achieve displacement values, using the trapezoid rule:



$$x = \iint a\, dt$$

From these displacement values, we can calculate building drift ratio, which is an indication of structural damage. As per ASCE 7 (Seismic Design Code):

$$\Delta_i = \delta_i - \delta_{i-1}$$

$$\Delta \sim Story\ Drift \mid \delta \sim Total\ Displ. \mid i \sim i^{th} floor$$

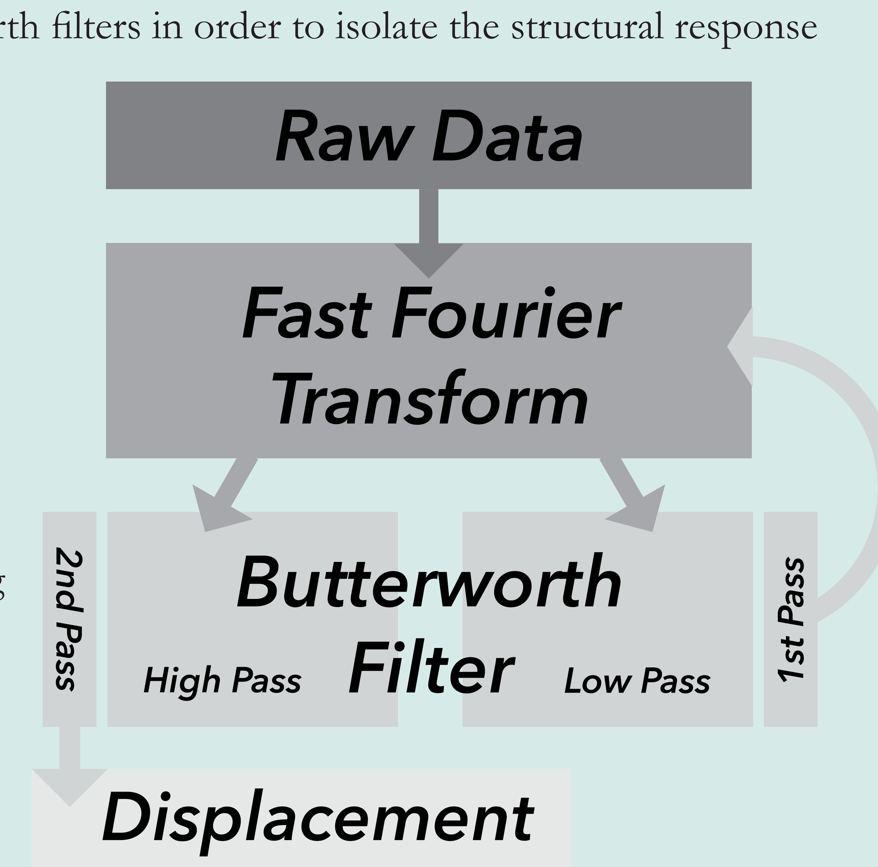
As our simple structure is not in-scale with an actual building, we substitute the allowable building drifts in ASCE 7 with our test-validated thresholds:

Allowable Building Drifts

Classification	Drift (cm)	Drift (%)*
Safe	<0.15	<1.5
Moderate	0.15 - 0.40	1.5 - 4
Unsafe	>0.40	>4

Processing

Our accelerometer readings must be filtered in order to allow for accurate integration to displacement. This is accomplished using both various butterworth filters in order to isolate the structural response from both high and low frequency noise. After iterating through various stages of our data processing (filtering and integration), we have concluded that the following procedure results in the most realistic displacement plots.

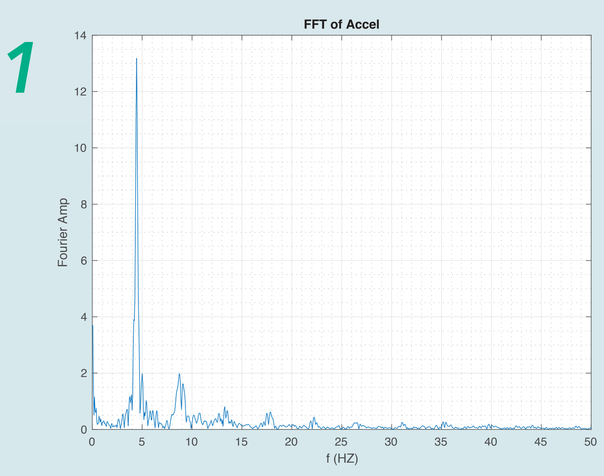


Data Management

To prevent accumulation of uneventful data, a memory management system was developed. Data acquisition only occurs when a threshold is met (~0.05 g's), and then ceases when end conditions are met. To ensure the entire motion is collected, a buffer is appended to the beginning of the file.

Results

1



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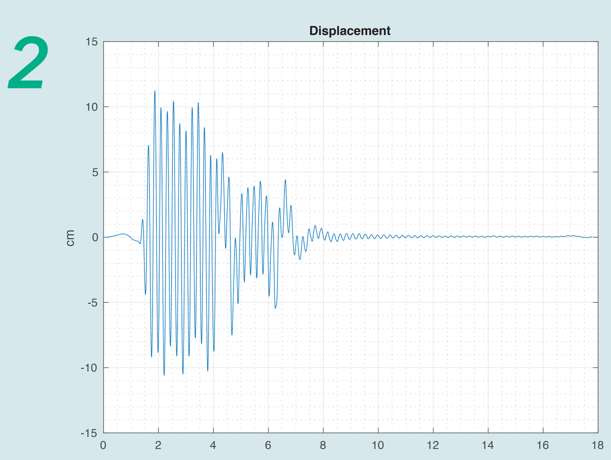

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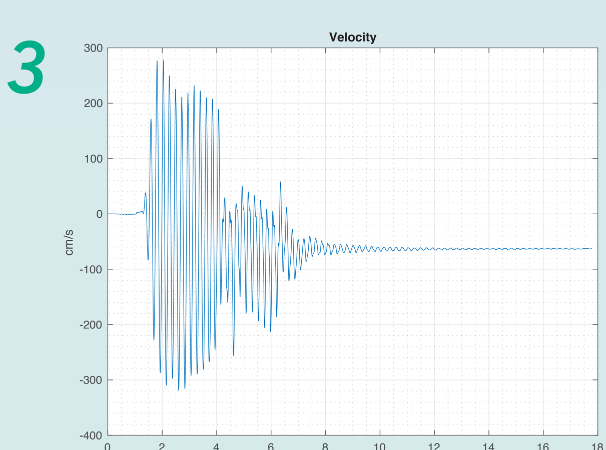

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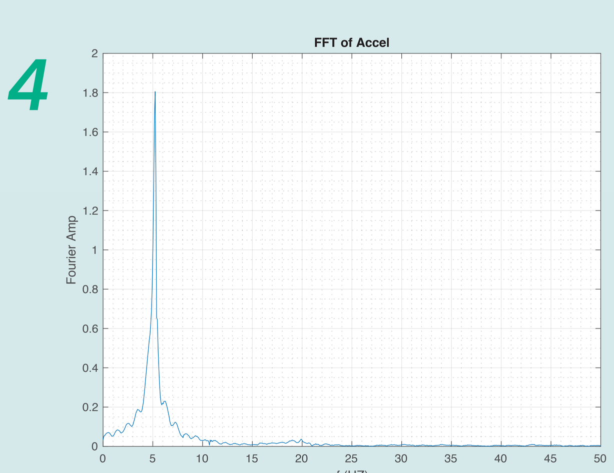

The physical validation of our system proved to be very educational, combining the fields of structural dynamics, signal processing, and networks/communications. Once our sensor network was properly collecting data from our accelerometers, the more difficult task was processing that data to discern useful results.

By using a combination of high- and low-pass filters, we were able to construct realistic waveforms of our structural response to the ground shaking. The cutoff frequency was determined by interpreting the FFT of the raw data (Figure 1). We determined the 20 Hz peak to be of shake table noise, and then higher frequency noise to be of ambient origin. Figure 2 shows that the displacement ultimately returns to the initial equilibrium, this is to be expected because both high pass filters remove both low frequency noise (such as DC offset) and residual displacement.

Now, we must consider what information concerning the plastic behavior of our structure is kept in the higher frequency band. We can see in Figure 2 that at the point of failure (~ 4 seconds), the natural frequency of the structure has changed. Future work on this project will explore the relationship between elements' elasticity and the whole building's natural frequency. We also note that in Figure 3, which shows the integrated acceleration of a plastic test. Despite a high-pass filter being applied to the accelerations, which is expected to eliminate any permanent offsets in our data, we still see an offset visible in the velocity plot that results from the failure of the structure.

In Figure 4 we can also see the decrease of the natural frequency of our simple frame structure as we add more mass to the top floor. This was a useful piece of information in the implementation of our filters.

Acknowledgments

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