Using Resonance to Mechanically Amplify Floor Vibrations and Improve Force Estimation and Event Localization (FEEL)

Zoe Haynes[1] and Melanie McCloy[2]

1 Department of Civil and Environmental Engineering, University of California Berkeley , Berkeley, California
2 Department of Civil and Environmental Engineering, Princeton University, Princeton, New Jersey

Motivation

Monitoring the structural dynamics of a building has been used to determine the health of structures, but floor vibrations in a building can also be used to determine the health of its occupants. Being able to detect human activity can be a powerful asset to healthcare, security, and smart building applications. Force Estimation and Event Localization (FEEL) utilizes accelerometer transfer functions to do exactly this, measuring walking gait and detecting falls. However, vibrations -- especially those from lighter movements such as footfalls -- can be very small resulting in less accurate transfer functions and therefore less accurate force estimations.

Objectives

1. Design a system that mechanically amplifies floor vibrations using resonance
2. Use amplified vibration data to implement FEEL
3. Test whether amplified data is reliable, accurate, and effective

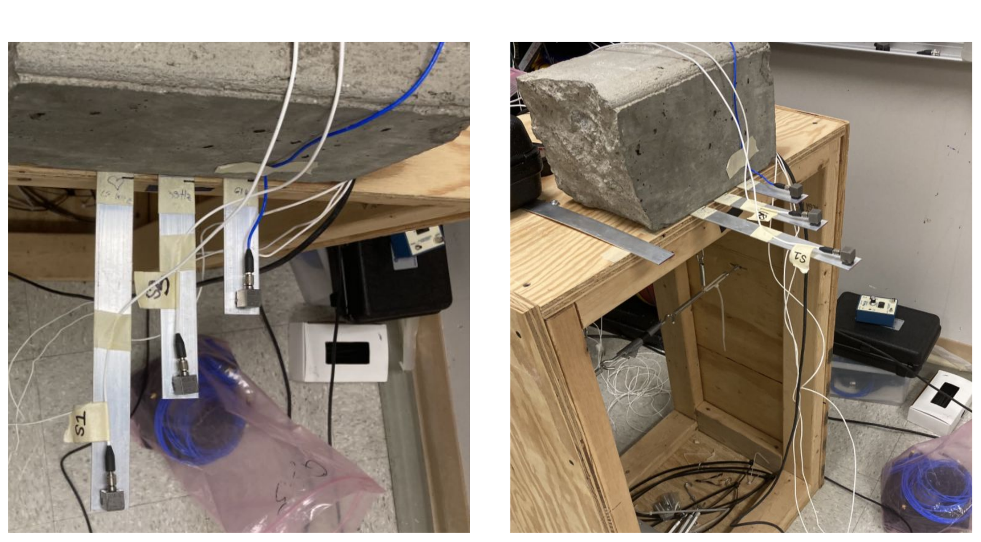
Methodology

Process:

- Estimate transfer function of metal plate to test theory and establish procedure
- Estimate transfer function of floor and identify natural frequencies
- Tune and test current resonator (single spring design) to first natural frequency of floor
- Design and construct new resonator
- Tune and test new resonator (cantilever design)
- Determine if FEEL can be implemented using resonator

Design of Resonator:

- Cantilever design with three aluminum flat bars
- Place accelerometer on end of each cantilever
- Adjust cantilever length to tune to first three natural frequencies of floor (15, 30, 60 Hz)
- Two resonators with three cantilevers each and one accelerometer per cantilever totaling six accelerometers
- Reduces damping, increases acceleration

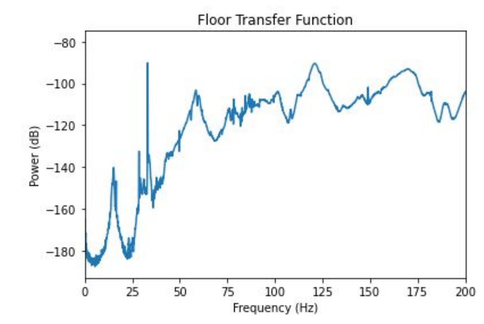


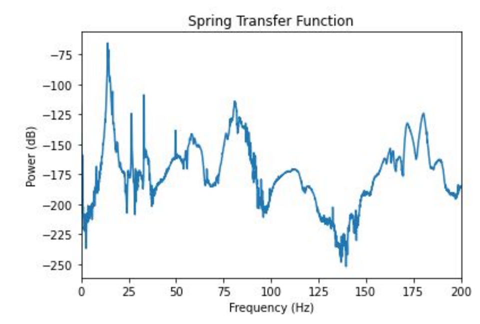
Constructed Resonator Mechanism

Results

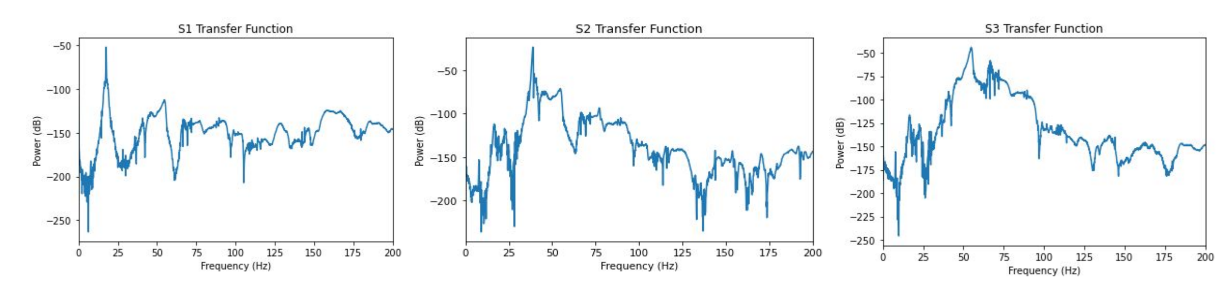
Amplification of Transfer Functions through Mechanical Resonator

Initial | First Design (Spring)



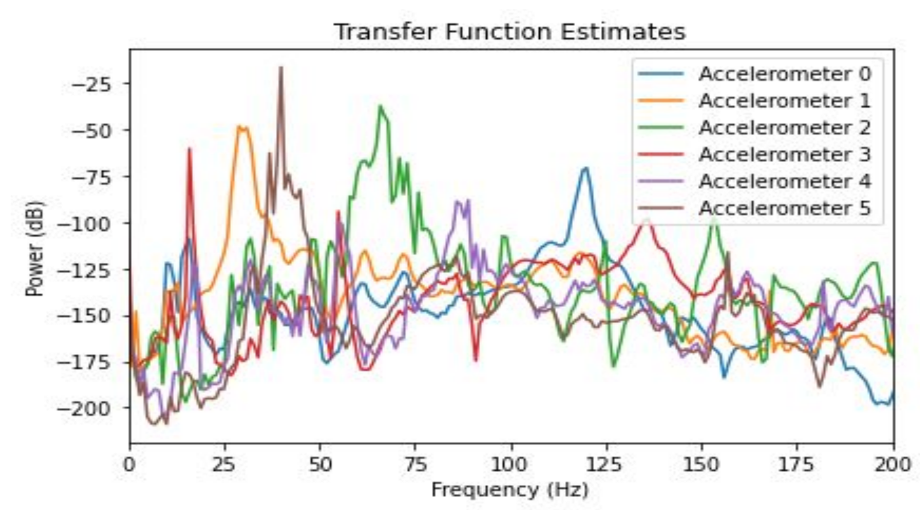


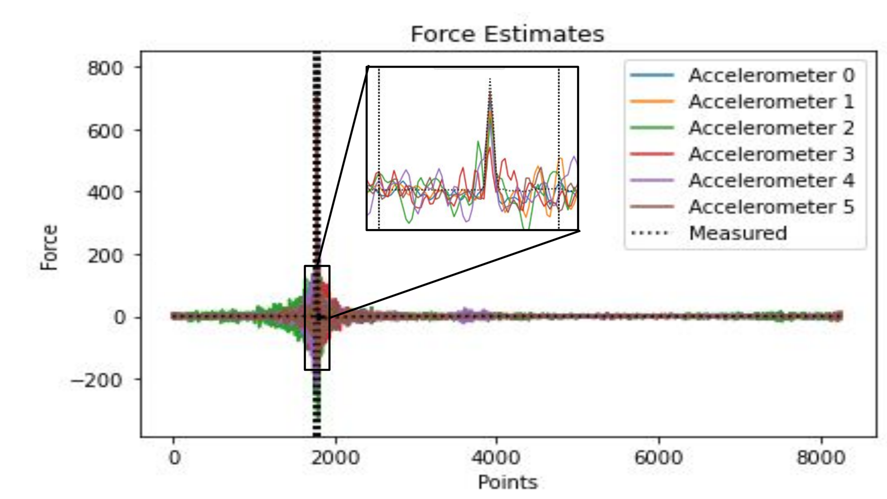
Current Design (Cantilevers Tuned to Natural Frequencies)

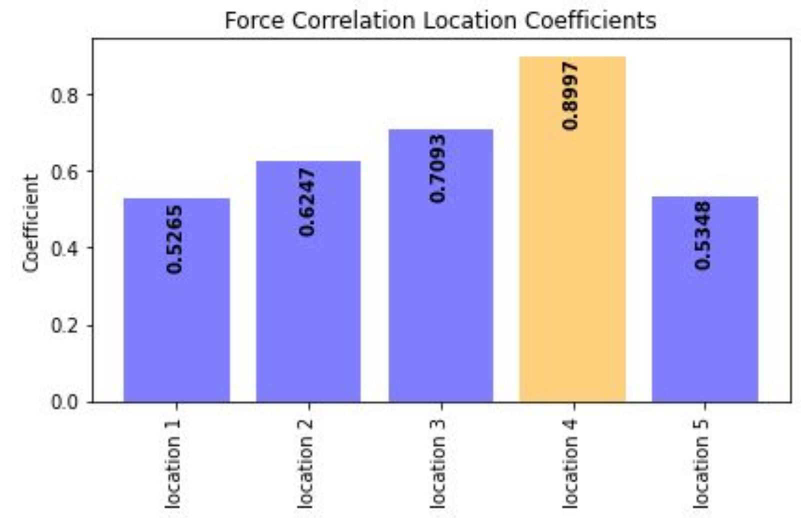


Sensor 1: Tuned to 15 Hz *Sensor 2: Tuned to 30 Hz* *Sensor 3: Tuned to 60 Hz*

Implementing FEEL using Resonator and Amplified Vibrations - Single Location Example



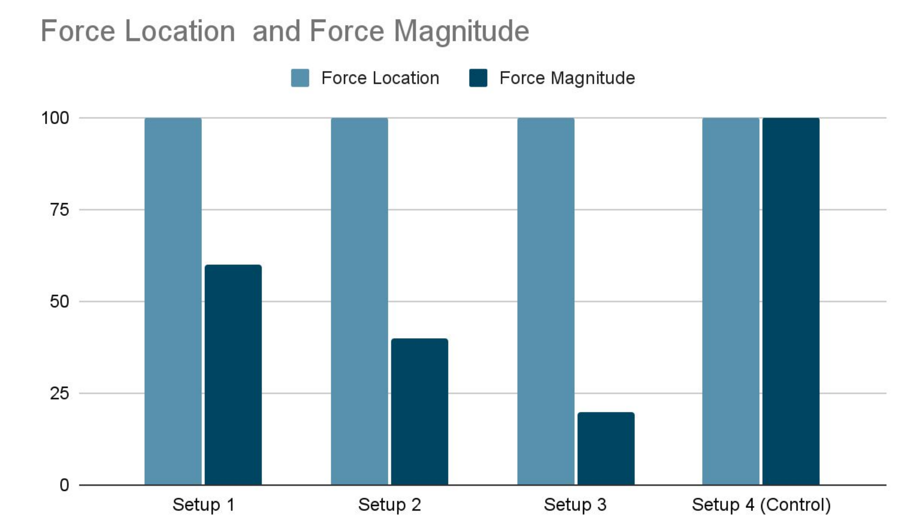




Results	
Estimated Force	808.89 N
Actual Force	793.43 N
Estimation Error	1.95 %

Discussion

- FEEL was calibrated with 5 hits at 5 locations and tested using 1 hit at each of the 5 locations
- Four setups were tested:
  1. All six resonator accelerometers
  2. Two resonator accelerometers from the same resonator
  3. One resonator accelerometer from each resonator
  4. Two accelerometers placed directly on the floor (control)
- All setups correctly identified force location
- Resonator setups (1-3) were only able to correctly estimate some of the force magnitudes, but control setup correctly estimated all of the force magnitudes
- Percentage of correct force location and force magnitude estimations for each setup:



The results show that the resonator was effective in amplifying the vibrations and doubled the power range of the transfer function with peaks at the appropriate natural frequencies. This amplified data was sufficient to run FEEL to identify where the force occurred, but the success of the force estimation is still limited. However, the location of the force is more important than the exact magnitude of the force in FEEL's applications, so the resonator shows promise as an improvement to the FEEL system.

Conclusion

Amplified vibrations can be used to calibrate and run FEEL to identify force locations and sometimes force magnitudes. The amplified vibrations are reliable and allow for more sensitive detection of forces without changing the sensor. Detecting smaller forces allows the system to detect loads from further away, covering a greater surface area and making it more cost efficient and effective than previous systems. The implications of this project hold great possibilities for gait analysis and fall detection for healthcare, security, and smart buildings.

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