Detecting Motion of a Structure Using Video Cameras

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Abstract

Occasionally, structures that appear to be in perfect condition spontaneously collapse. This is often due to small vibrations that are imperceptible to humans.

Because of this, detecting microscopic motions in buildings and structures would be a development that would improve building safety. However, using motion detectors is extremely expensive. The alternative which we have been researching is using cameras to detect and magnify the motion. Motion magnification allows us to see imperceptible vibrations in a building. By using a camera to record videos of these structures we can then utilize Phase Based Video Motion Processing to extract vibrations in the structure that cannot be seen normally. Our three primary goals were:

- To prove that a video camera can be used to measure vibrations of a structure.
- Implement this process in Matlab
- Create a system cheaper than motion detectors which uses only video to extract and magnify motion.

Background

Buildings which collapse due to motions that are undetectable without expensive equipment are a major safety liability. There are many examples of this phenomenon where structures collapse without any prior indication of doing so.

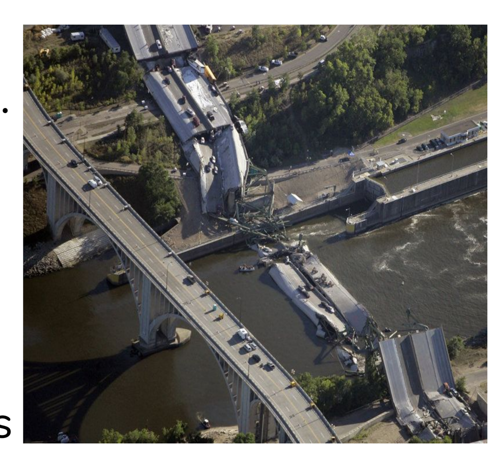


Figure 1: A bridge in Minnesota which collapsed for seemingly no reason

These collapses result in losses of both human life and monetary expenses. To solve this problem, architects have to be able to know the microscopic vibrations present in a building at any given time, so ample warning and repairs can be issued. The conventional approach to detecting the motion has been to install motion sensors which have high sensitivities in multiple locations of the building, and using them to calculate how a building moves. However, this is not practical, as motion sensors are expensive and take lots of time to deploy. The goal is to find a more optimal method of detecting vibrations in a structure.

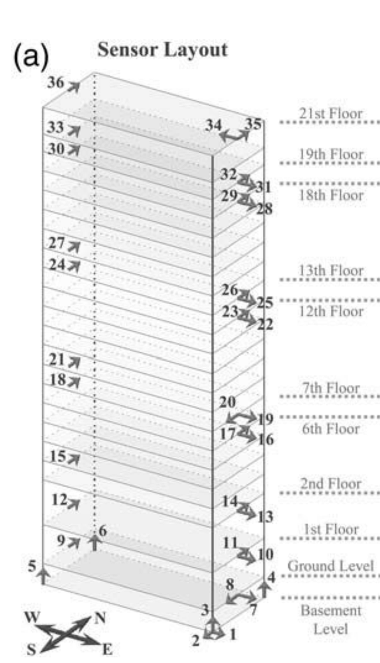


Figure 2: Accelerometer layout in the Green Building at MIT, numerous sensors are required to cover just one building.

This research is scientifically significant because it implements many image and video processing techniques in a way that gives them potential to be life saving, as well as improving our understanding of how structures move on a very low level.

Experimental Methods

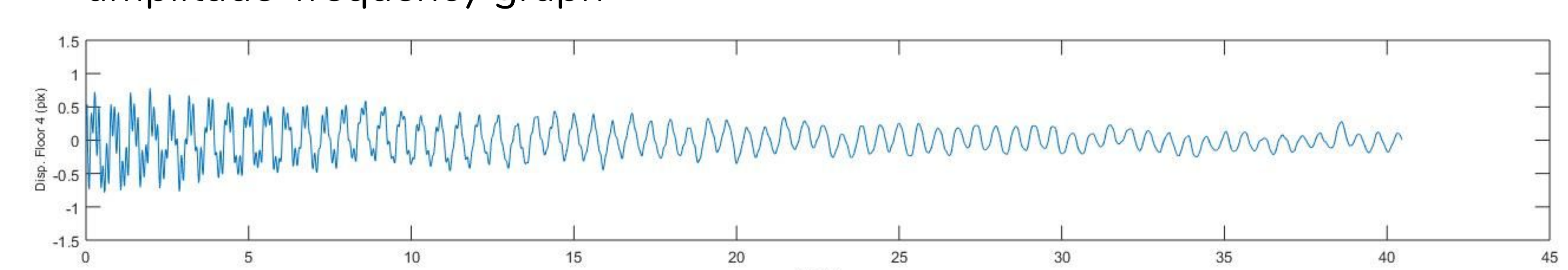
- **Recorded video of structures**
  - Travel to different structures such as bridges
  - Record high frame rate video under different conditions
- **Process video in Matlab**
  - *Phase-based motion extraction*
    - Downsampled the video to lower processing time
    - Created mask
      - Converted video to grayscale
      - Turned first frame black and white - mask

Above From left to right: Professor Hao Sun, Lab intern Alex Ianetta, YSP student Cameron Pentland. Recording video of a bridge on Northeastern's campus.

Figure 1 shows the reference frame of a video in which a hammer strikes a small cantilever beam. The reference frame is the first frame of the video but downsampled andin grayscale.

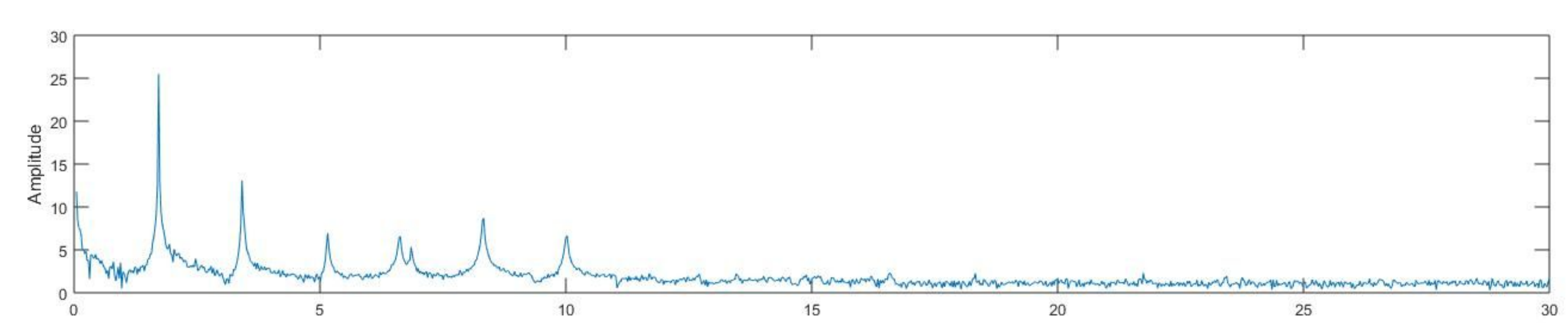
Figure 2 shows the reference frame converted to a mask, which is used to find the displacement of a pixel throughout the video.

- Compared this frame to all following frames and found displacement of one pixel
  - *Motion magnification*
    - Used fast fourier transform to turn displacement-time graph to an amplitude-frequency graph



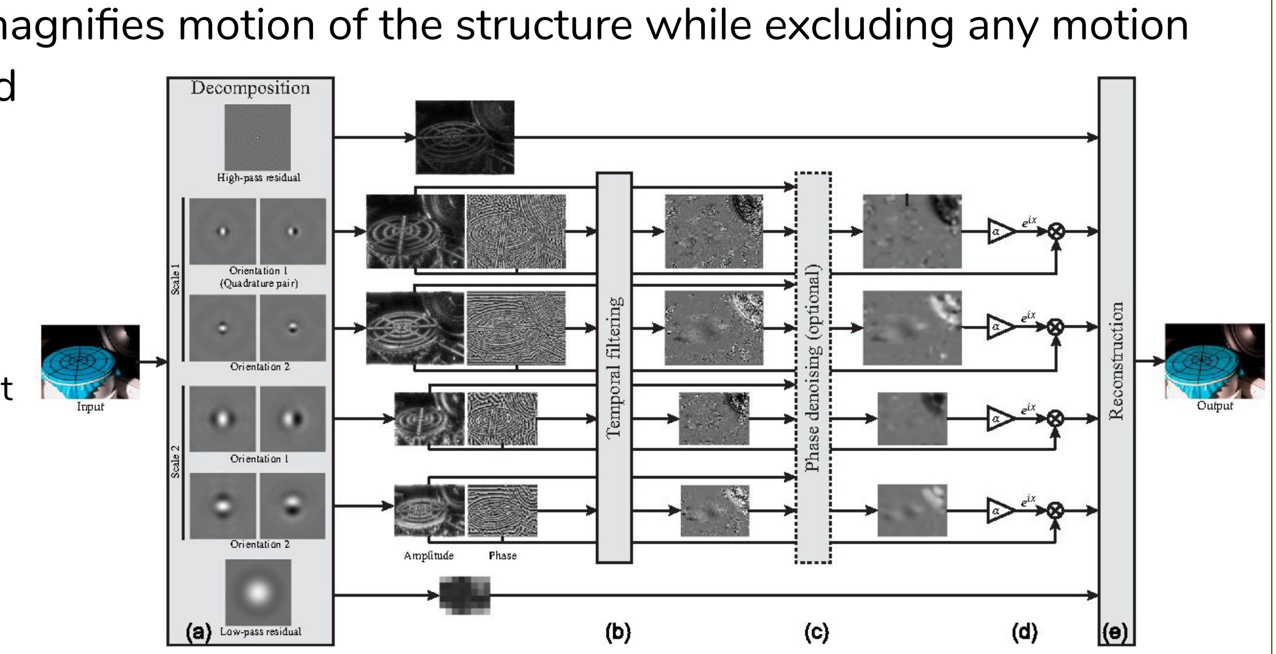
Above: Graph of a pixel's displacement in relation to time.

Below: Graph of pixel displacement amplitude in relation to frequency (Fast Fourier Transform)



- Used this frequency to generate magnified video
  - This new video magnifies motion of the structure while excluding any motion in the background

To the right is a visualization of the video processing as a flowchart



- **Assess Results**
  - Determined if selected frequency was correct
  - Determined if magnified motion was the structure or the camera
  - Potentially re-process
  - Improved method
  - Recorded new video

Results

- Using this method, we are able to magnify motions from a video
- Under ideal conditions, method is accurate and represents motion of the structure
  - Ideal camera conditions are a perfectly still camera, high video frame rate
  - Ideal structure conditions are well lit, little to no visual noise, ideal viewing angle, determinable vibration frequency.
- With proper setup, can be a practical replacement for arrays of expensive motion detectors
  - Potential to save lives
  - Allows building motion to be determined at any time
  - Inexpensive - all that is needed is a tripod and an above average camera.
- Successfully implements various image and video processing algorithms into one purpose-serving method
- Can improve architect's understanding of how a certain building type moves

Conclusion and Future Steps

- When frequency is identified, results represent real motion magnification
- Finding the frequency can take trial and error
- Building vibration can be determined from video
- Only uses one pixel of the video
- Displacement from full field - deep learning
- Unstable platforms
- Real time processing / accessibility can be improved

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Acknowledgements

Professor Hao Sun - Civil and Environmental Engineering

Lele Luan - Ph.D. Candidate

Professor Eno Ebong - Chemical Engineering

Emily Chernich - YSP Coordinator

Salima Amiji - YSP Coordinator

Claire Duggan - Director of Programs and Operations

This work was supported by the National Science Foundation