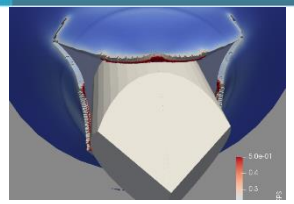
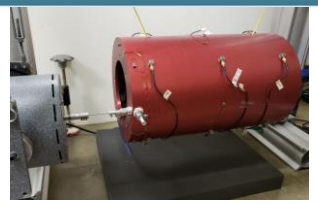
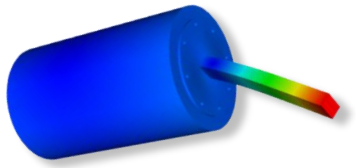
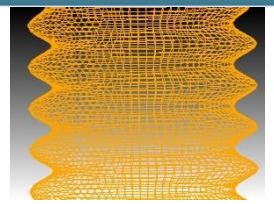
Measurement and Visualization of Nonlinear Vibration Response Using Neuromorphic Event-Based Sensing

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Agenda

1

Motivation and Background

- Why Nonlinearity Matters
- Intro to Event-Based Sensing
- Project Objectives and Outline

2

Experimental Setup

- Linear and Nonlinear Testing

3

Results and Analysis

- Event-Based Data Post-Processing
- Nonlinear Testing Results

4

Conclusions and Further Work

Characterizing Nonlinear Vibrational Response of Structures

Sources of nonlinearity:

- Material properties
- Large deflection (geometric nonlinearities)
- Contact and boundary condition changes

Why it matters:

- Unexpected failure
- Reduced accuracy
- Resource intensive testing

Various Sensors and Techniques Used to Resolve Vibrational Responses

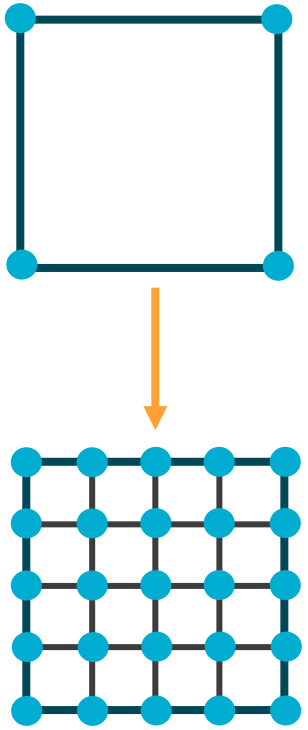
Accelerometers

[PCB Piezotronics]

Laser Doppler Vibrometer

[Polytec]

Modal Expansion

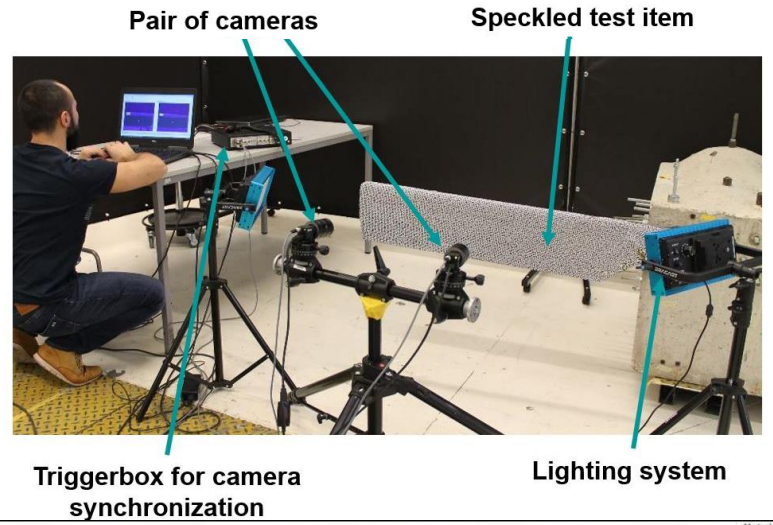


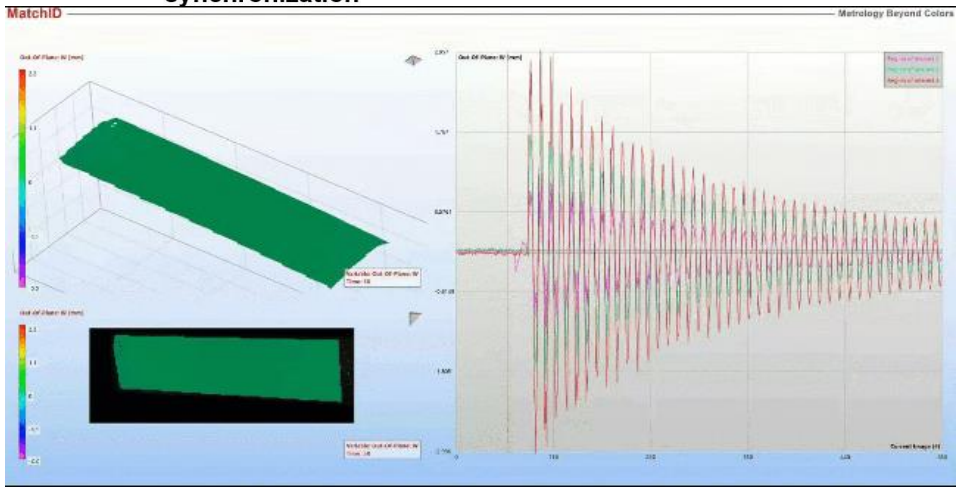
Local

Global

Vibration Response Using Image Processing Techniques

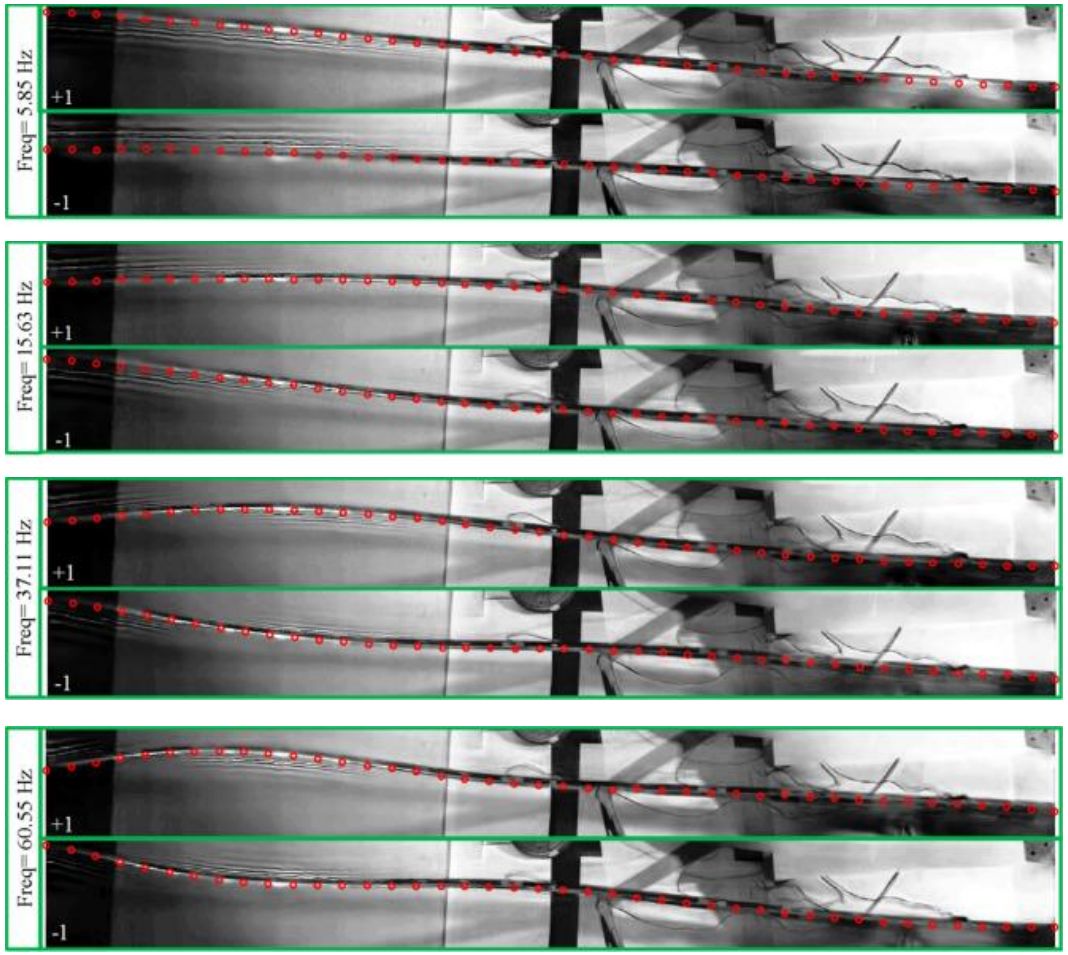
Digital Image Correlation





[Siemens]

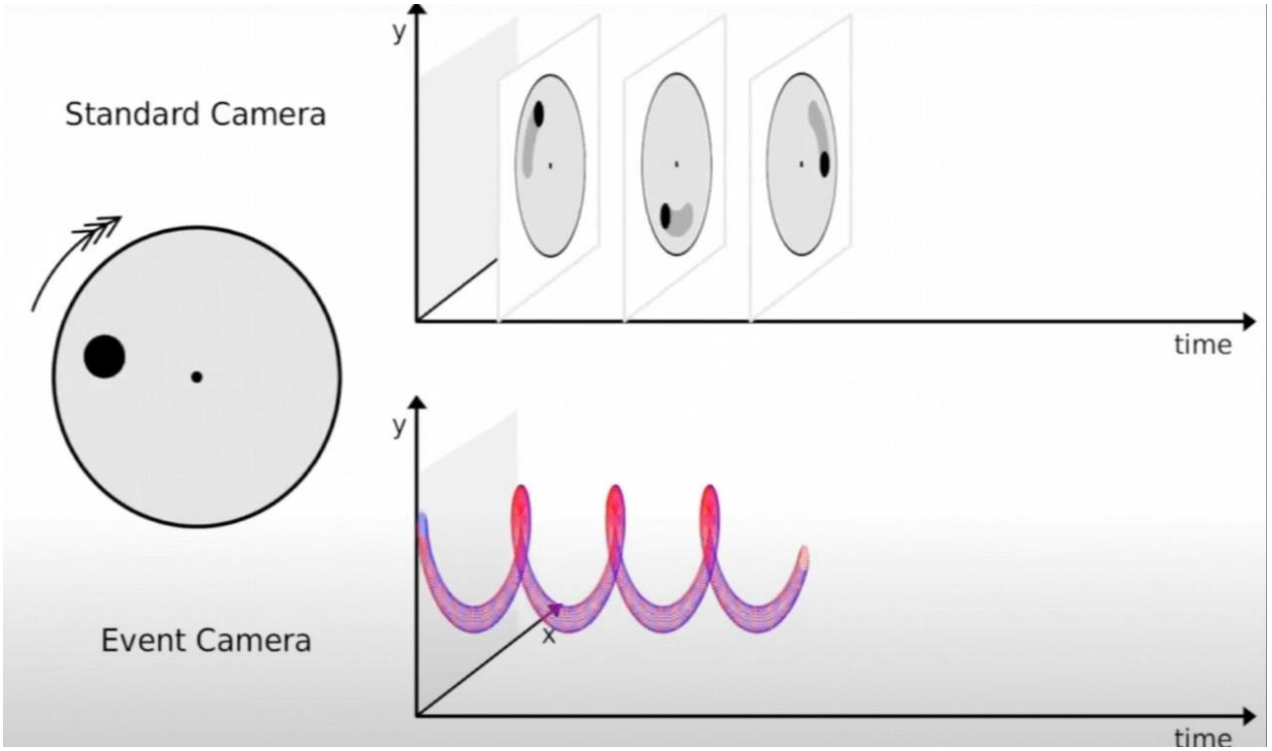
Phase-Based Motion Magnification

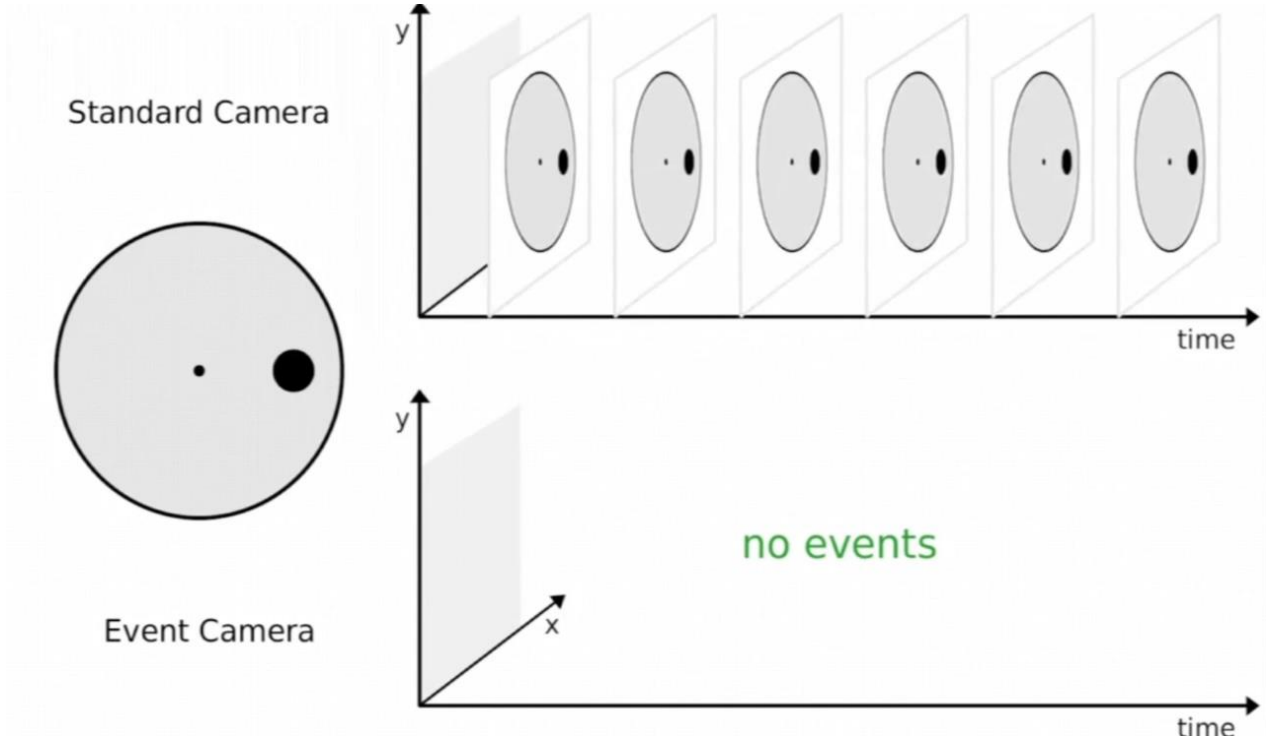


[Sarrafi, 2018]

Neuromorphic Event-Based Sensors for Low-Latency, Contactless, Vibrational Response Data

Event-based sensors: Detect changes in light intensity and generate data only when an event occurs, resulting in an asynchronous data stream





Neuromorphic Sensor Data Stream

Pixel Array

Data Stream

Time	X	Y	Polarity
1	1	1	1
1	3	4	1
2	1	1	-1
2	3	4	-1
5	4	2	1

Event stream = e (t, x, y, p)

- t = time of event
- x = horizontal pixel location
- y = vertical pixel location
- p = event polarity
  - Change in light intensity greater than threshold, $p = +1$
  - Change in light intensity less than threshold, $p = -1$

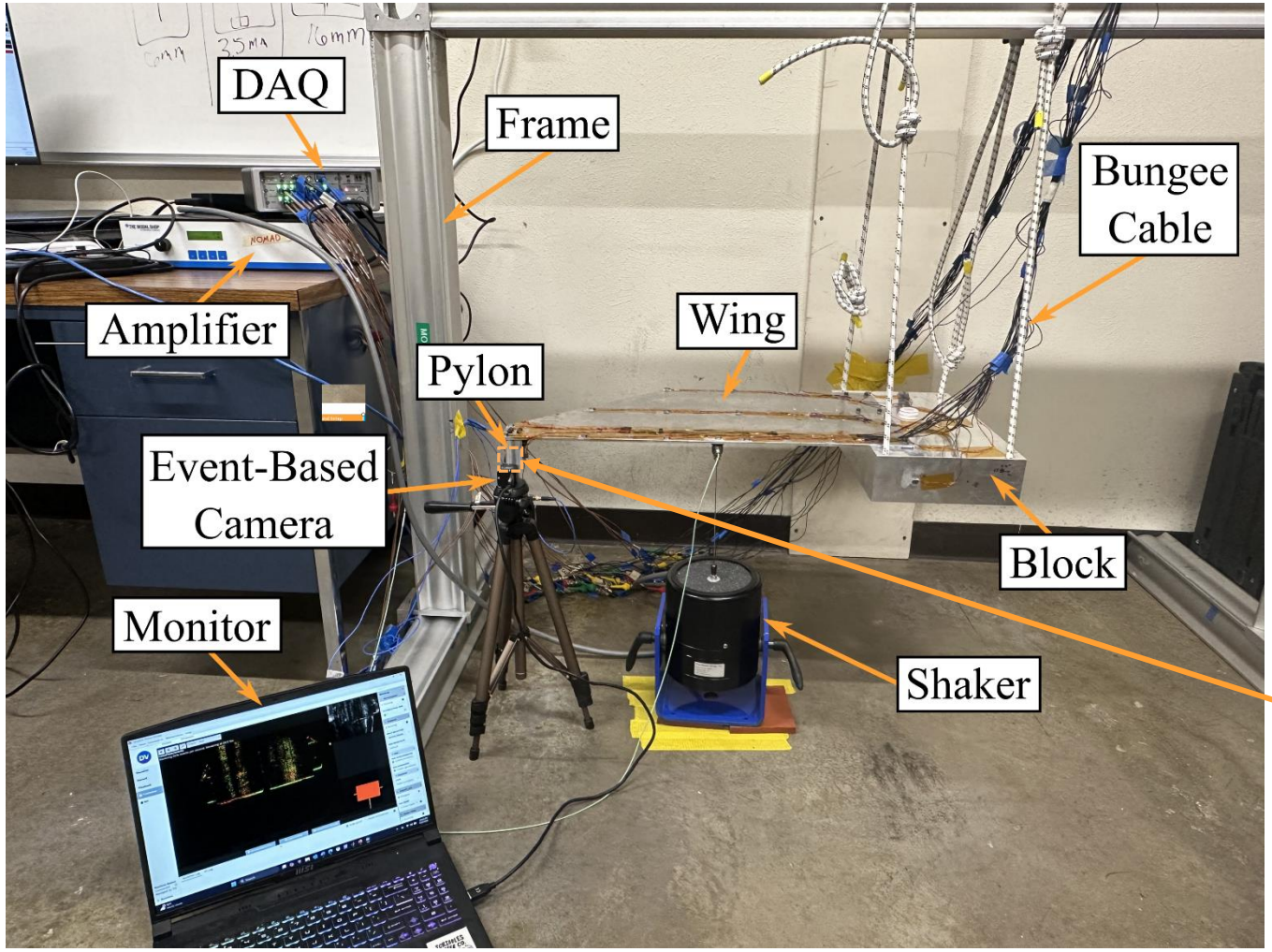
Project Objectives and Outline of Work

Objective: Assess the ability of an event-based sensor to accurately capture the response of a non-linear structure by comparing results to conventional methods

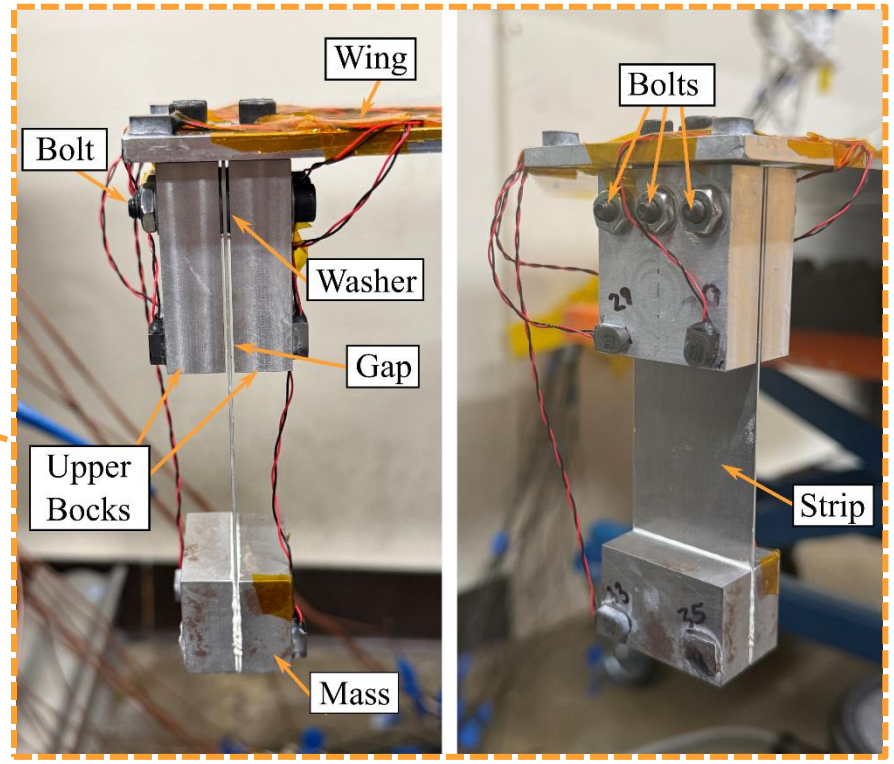
Outline of Work

Linear modal testing and nonlinear testing of wing-pylon structure → Explore various event-based data post-processing methods → Compare event-based sensor results with accelerometer and modal expansion results

Experimental Set-Up for Vibration Tests



DVXplorer Mini



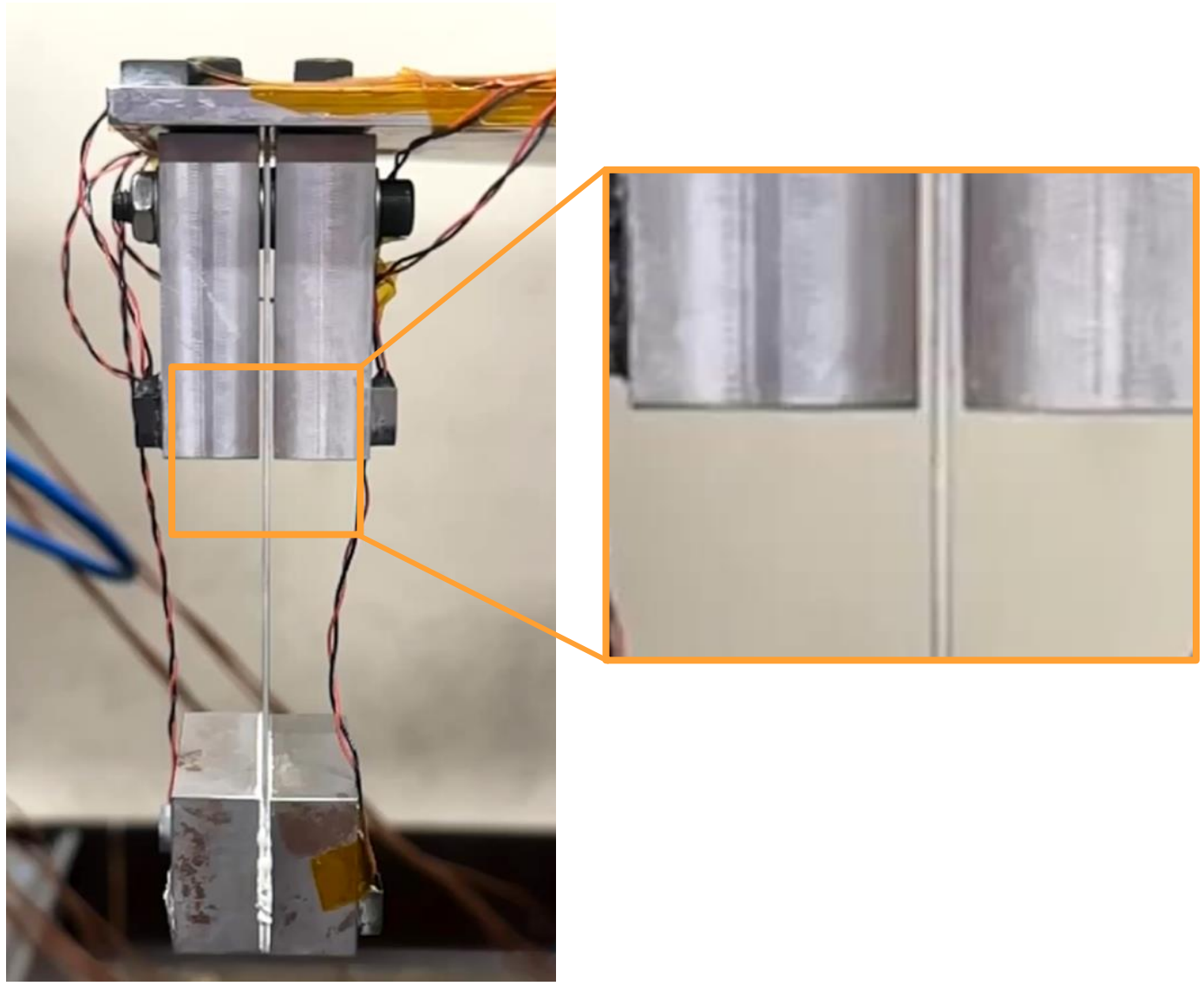
Identifying Pylon Strip-Upper Block Contact

Major cause of the nonlinear vibrational response:

- Contact between the pylon strip and upper blocks

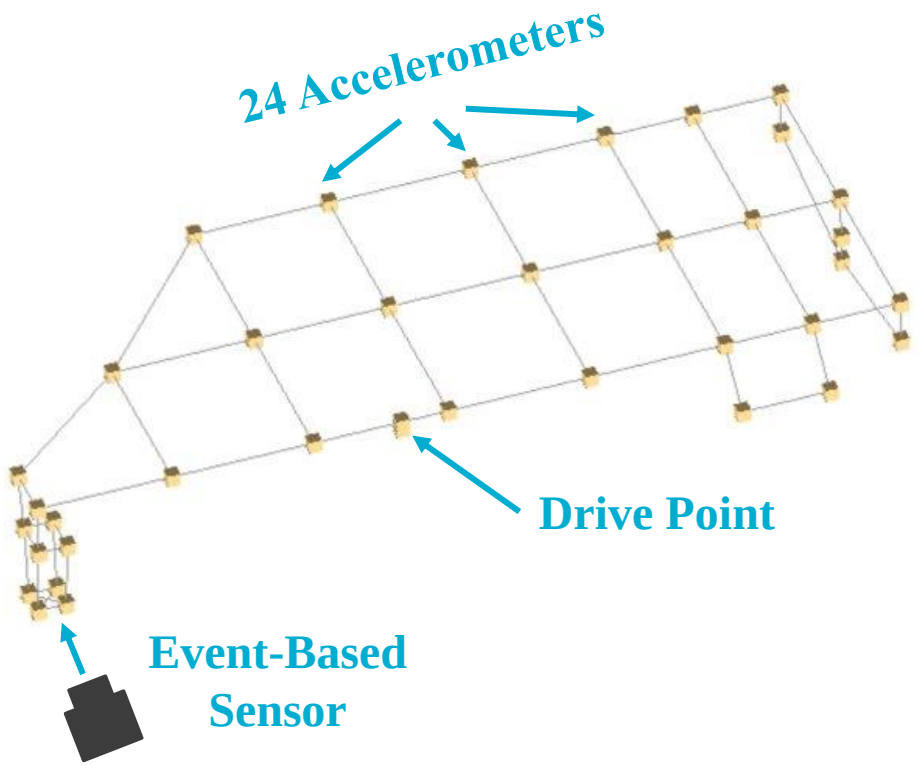
Goal:

- Investigate how the event-based sensor can identify if contact is occurring



Linear and Non-Linear Shaker Testing

- **Sinusoidal excitation**
- Excited at frequency ~**94 Hz**
  - Mode where deflection of pylon strip is observed
- Various forces used to measure response before and after contact

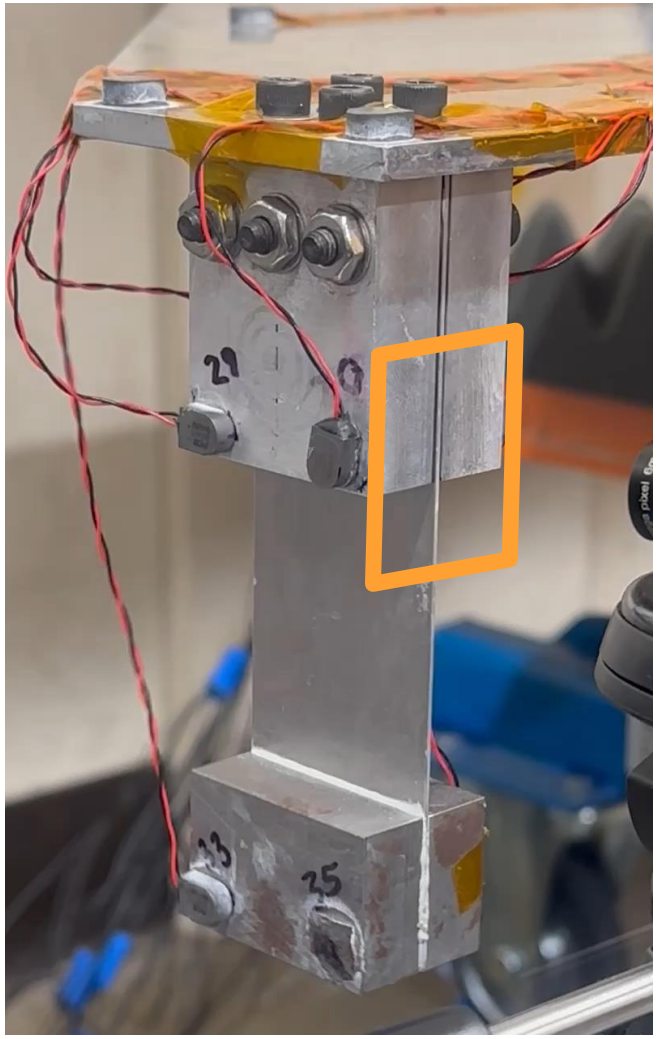


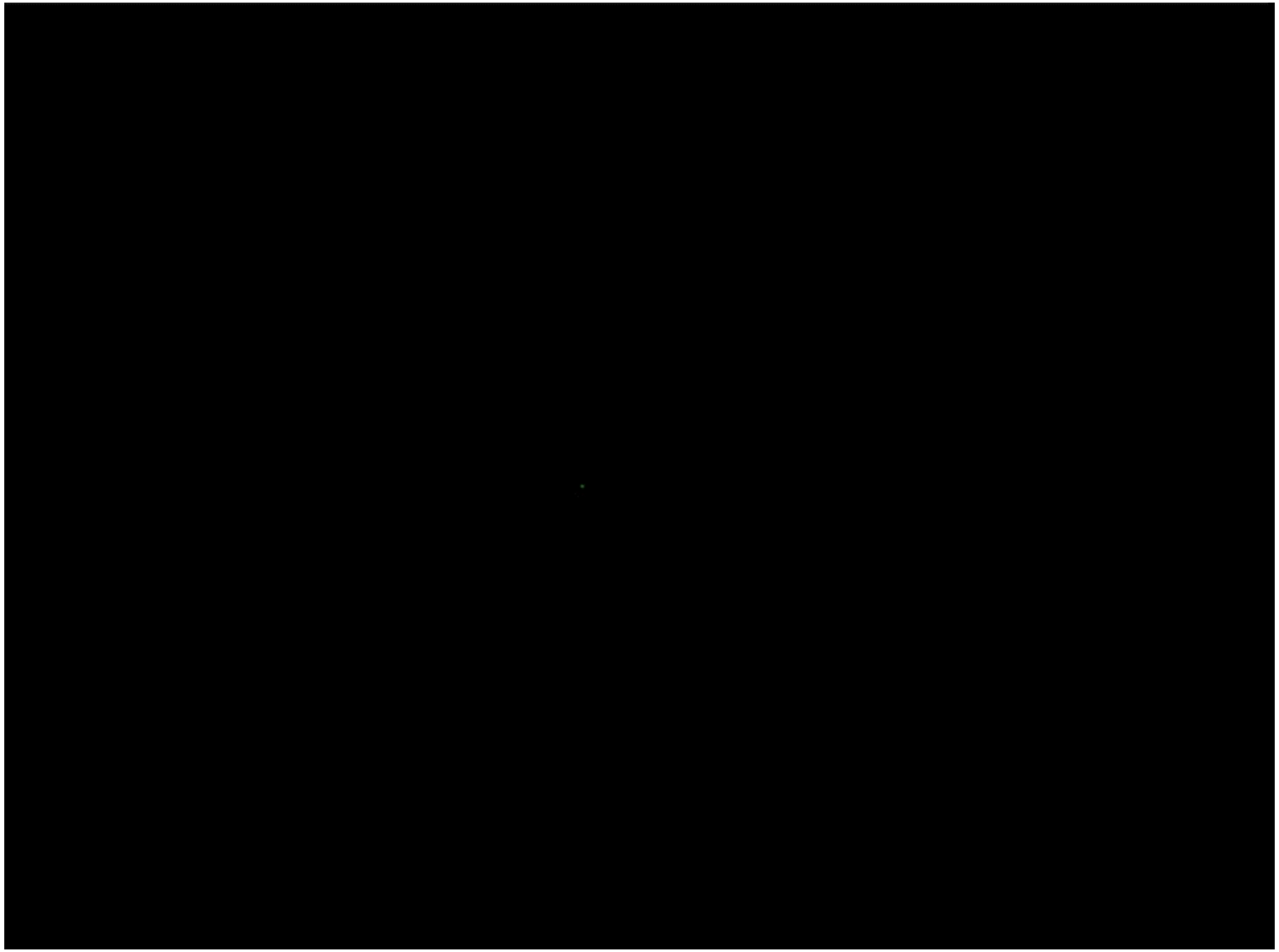
Linear ⟷ Non-Linear

Force Amplitude (N)	1.9	4.8	5.5	5.7

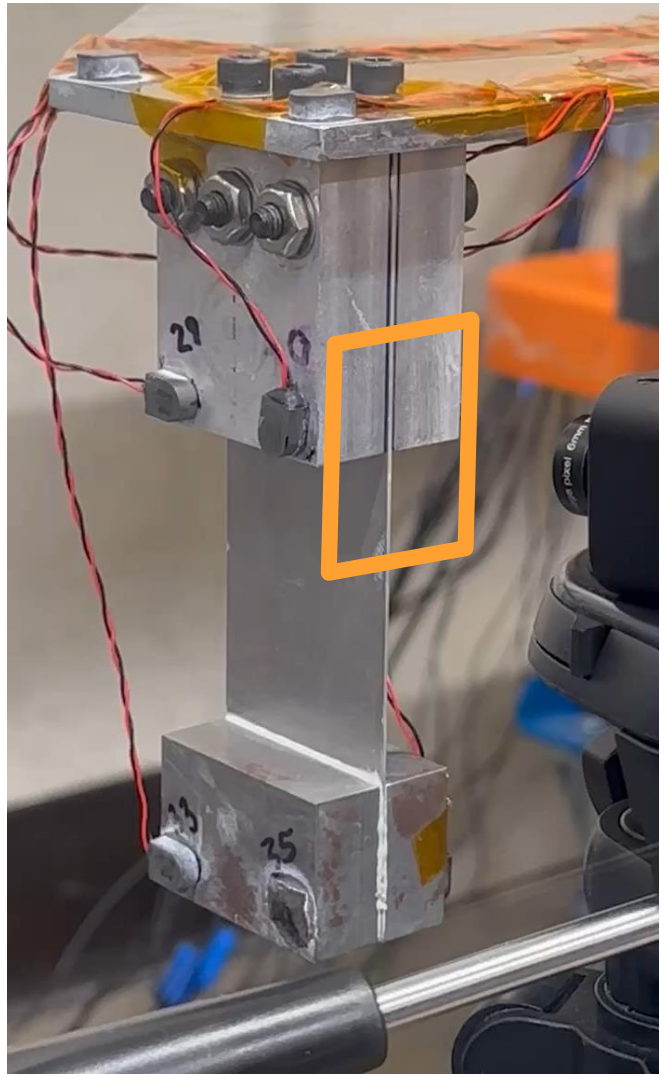
Contact Occurs

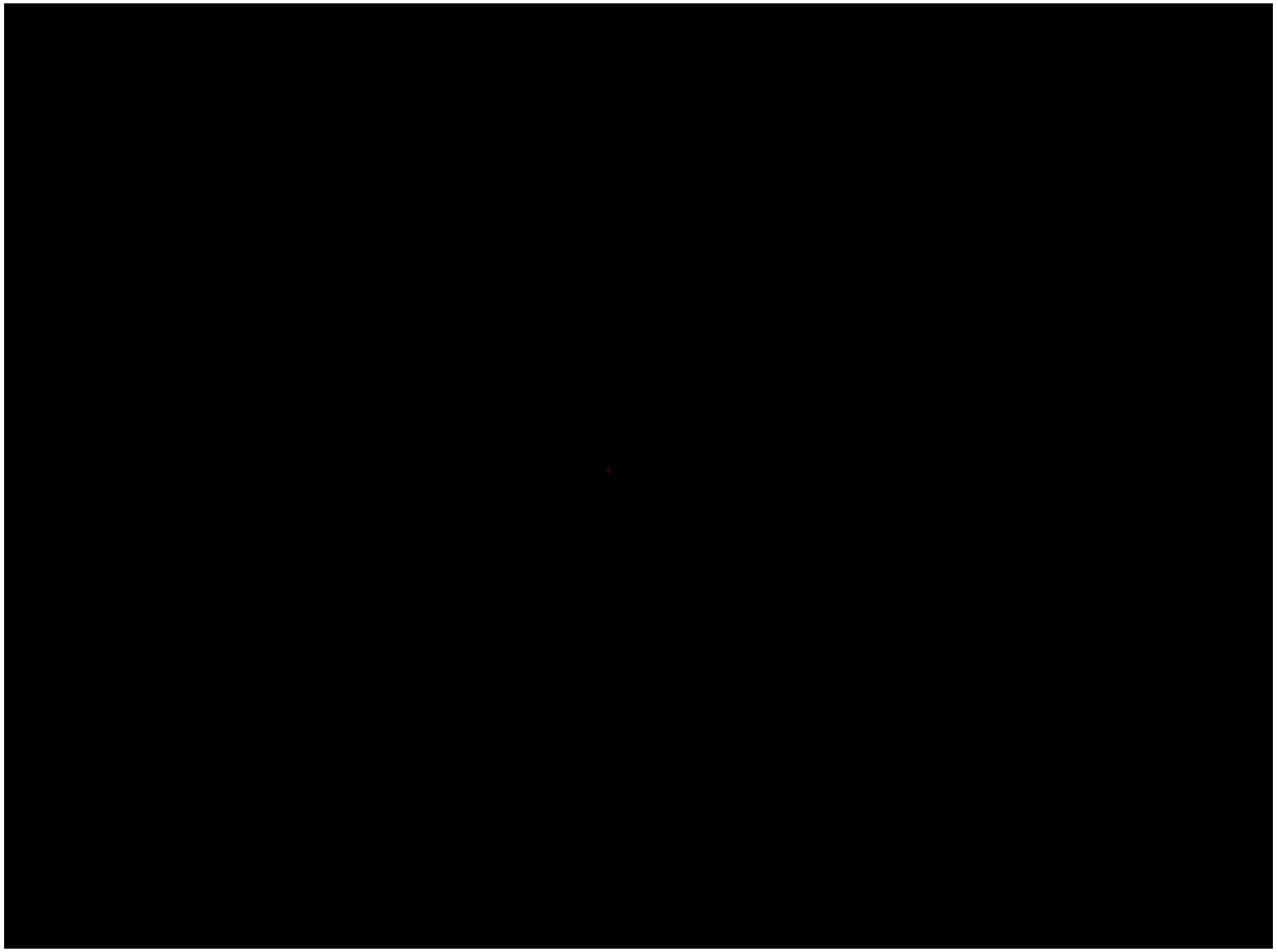
Visualization of Non Contact Behavior using Event-Based Sensor





Visualization of Contact Behavior using Event-Based Sensor

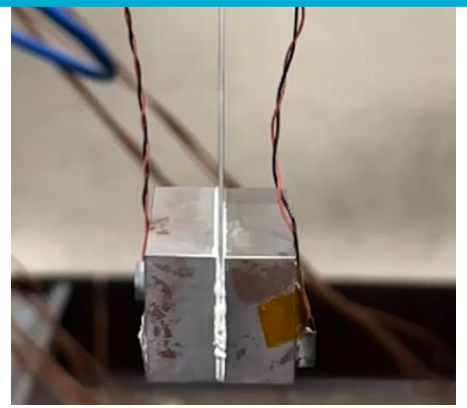


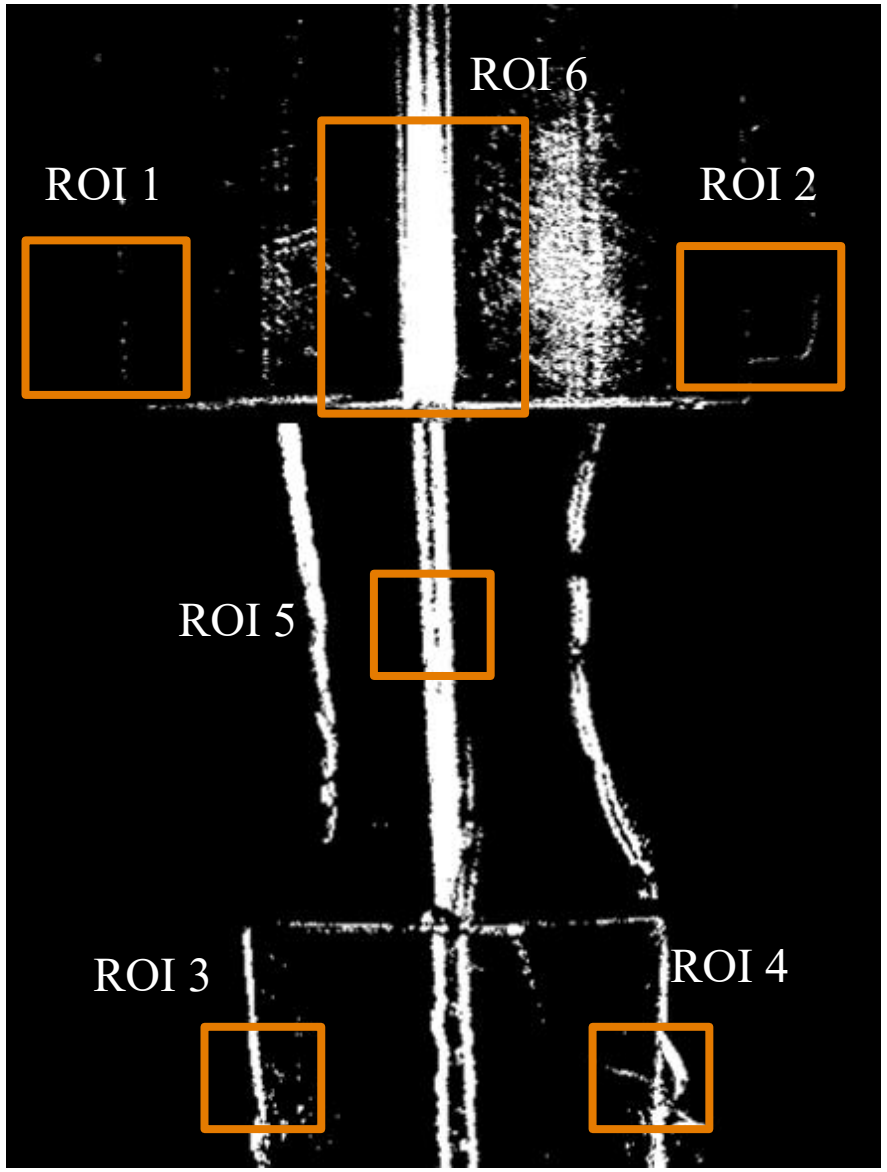


Event Reconstruction and Region of Interest (ROI) Selection

Each tracked region shows motion in a different part of the

Using the selected ROI, different post processing techniques were investigated, as no standard method exists.



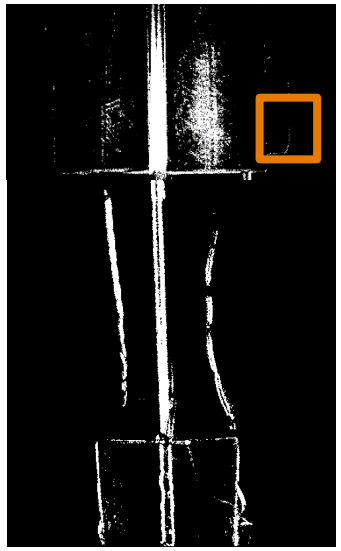


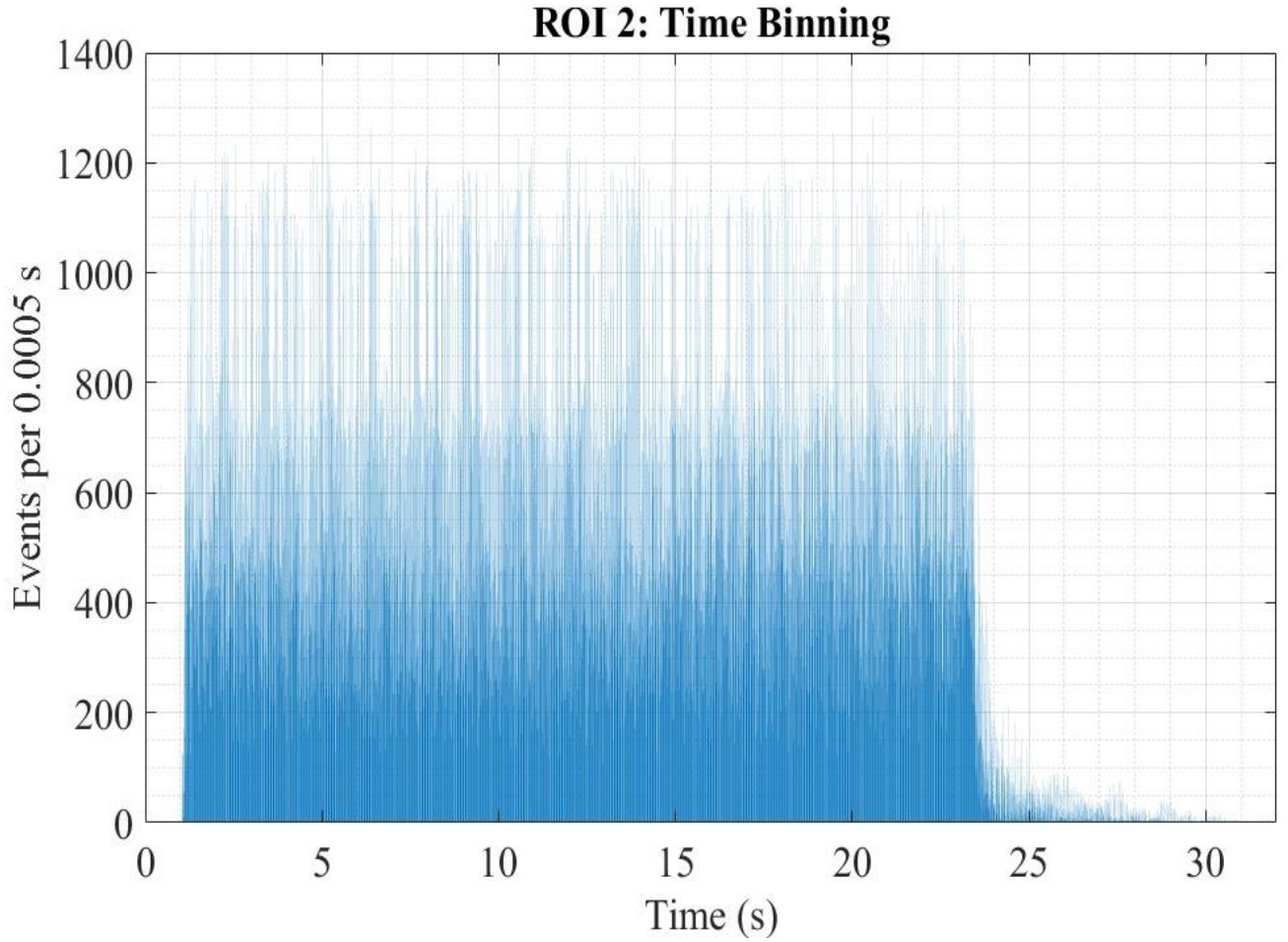
Method 1: Time-Binning for Vibration Tracking

Process: Sorts events into uniform time bins (0.5 ms) and counts the number of events within each bin to form a time history.

Output:
Number of events per time bin

Techniques Used:
- ROI filtering
- Timestamp (μs to s)
- Histogram binning
- FFT of event count signal



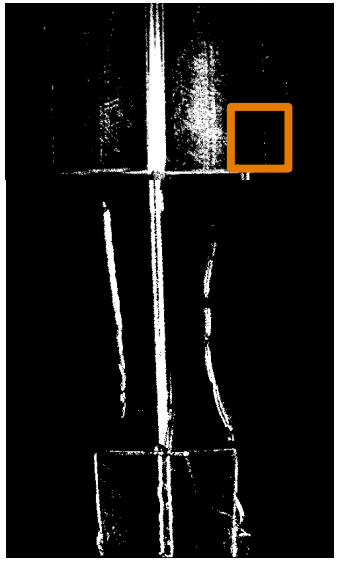


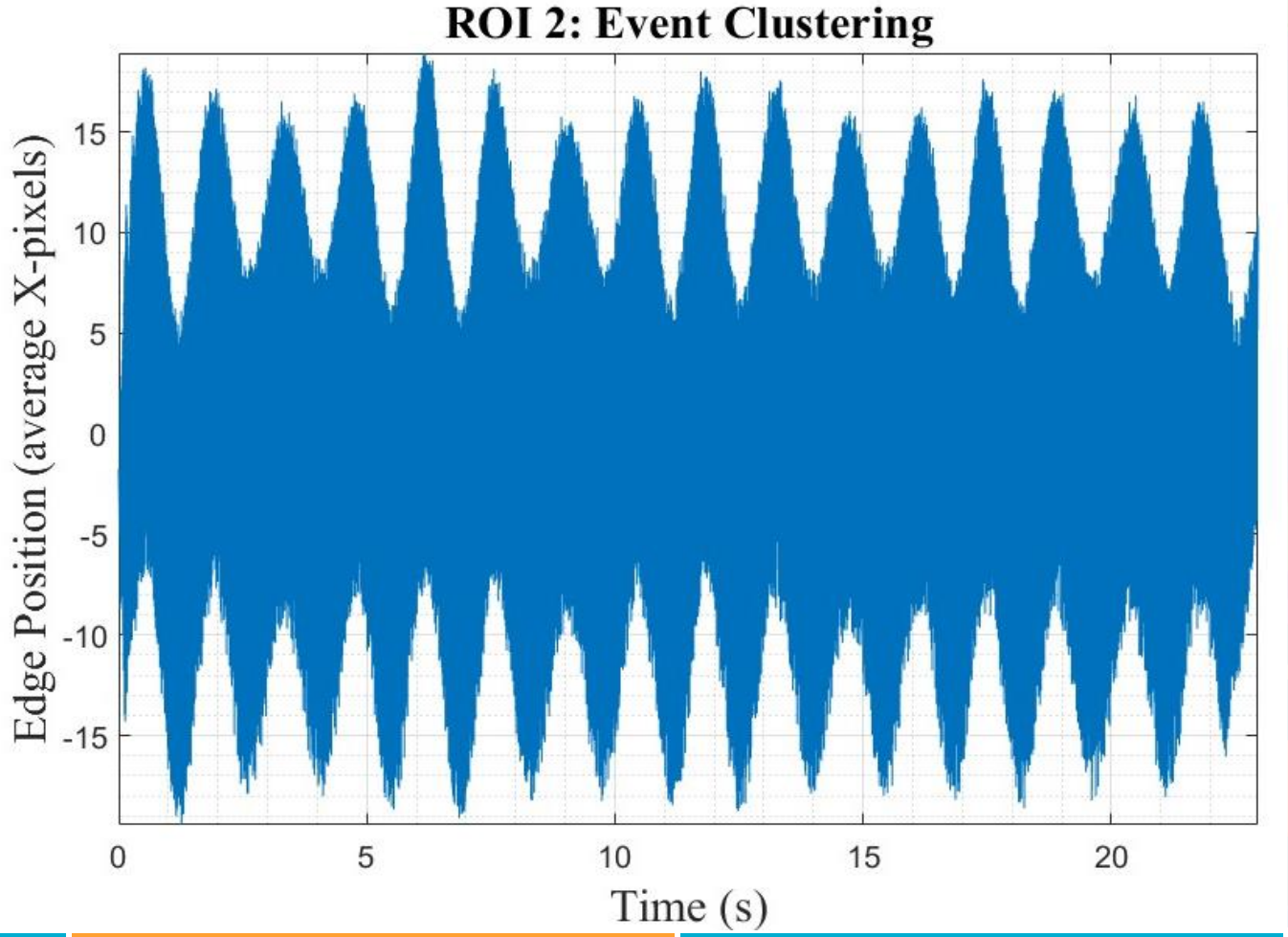
Method 2: Event Clustering for Vibration Tracking

Process: Groups raw events into clusters of N events (N=100) to reduce noise and extract temporal trends in structural response.

Output:
Mean x-position per cluster, which gives a smooth edge displacement signal over time.

Techniques Used:
- ROI filtering
- Hampel smoothing
- Detrending, interpolation
- Low-pass Butterworth
- FFT of event clustered signal





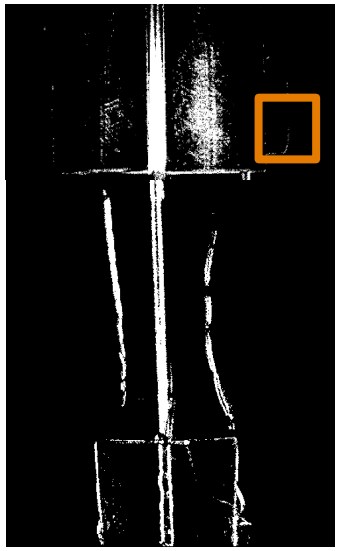
Method 3: Least Squares Spectral Analysis (LSSA)

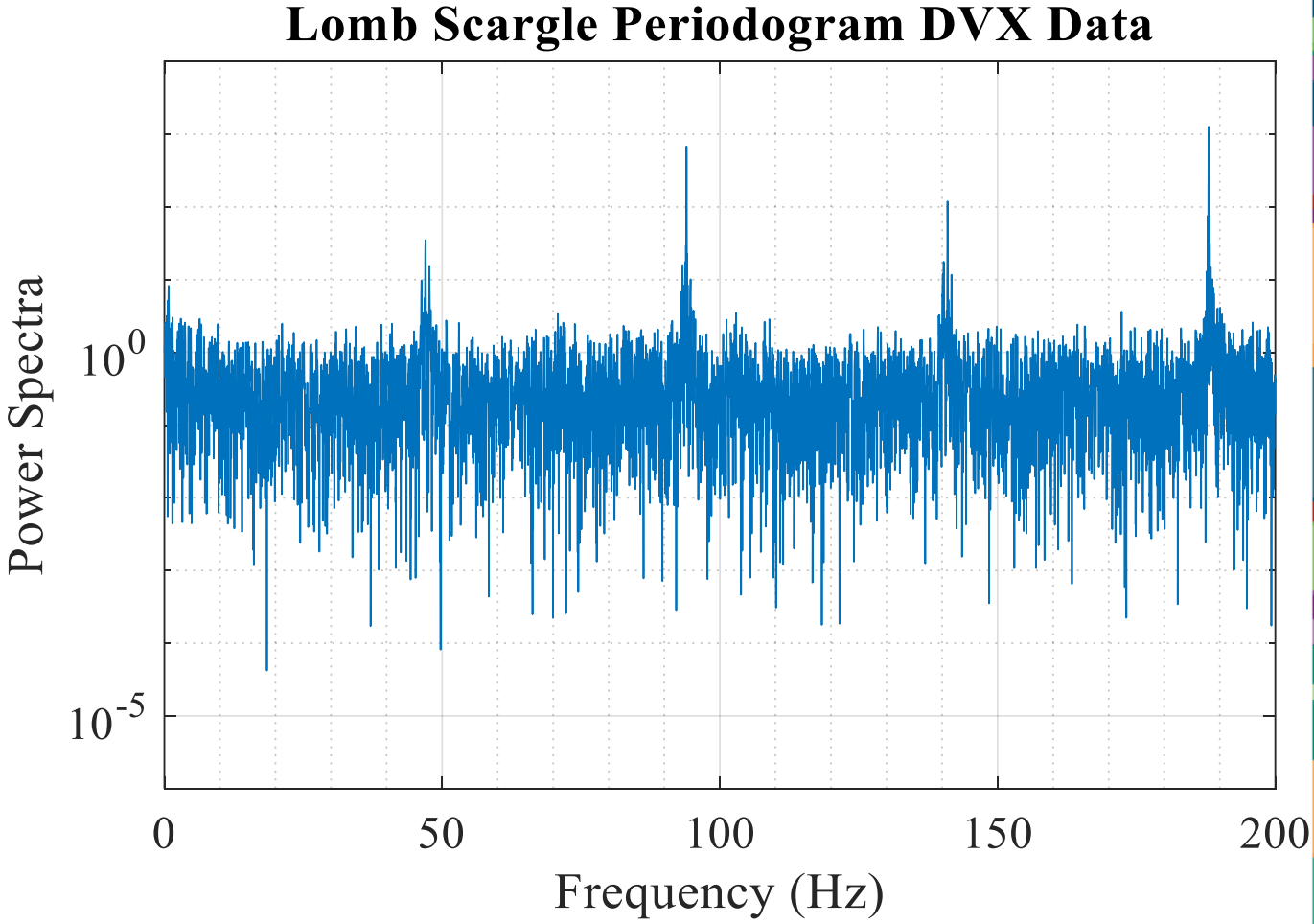
Process: Applies Lomb–Scargle Periodogram method to the non-uniformly sampled event-stream. Uses x-pixel location and time stamp for every event.

Output:
Power spectrum showing dominant frequencies over time.

Techniques Used:

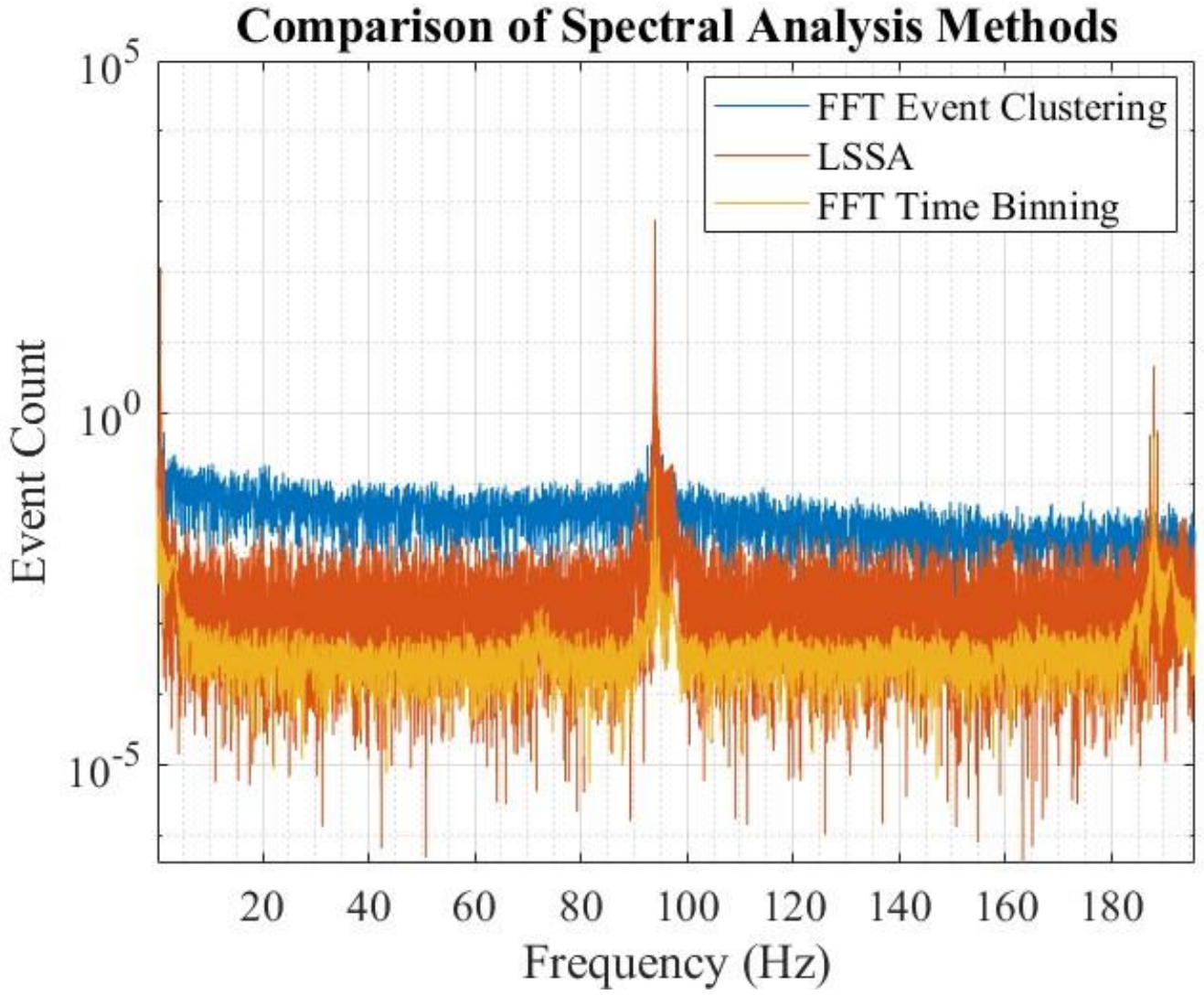
- No additional filtering used
- Plomb function in MATLAB





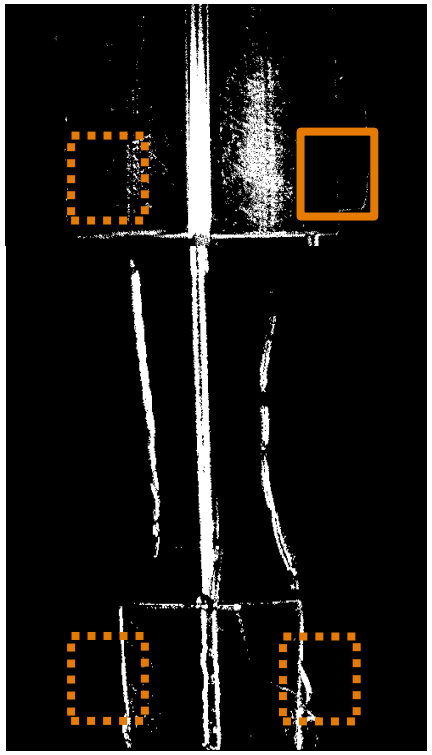
Comparison Between All Three Methods

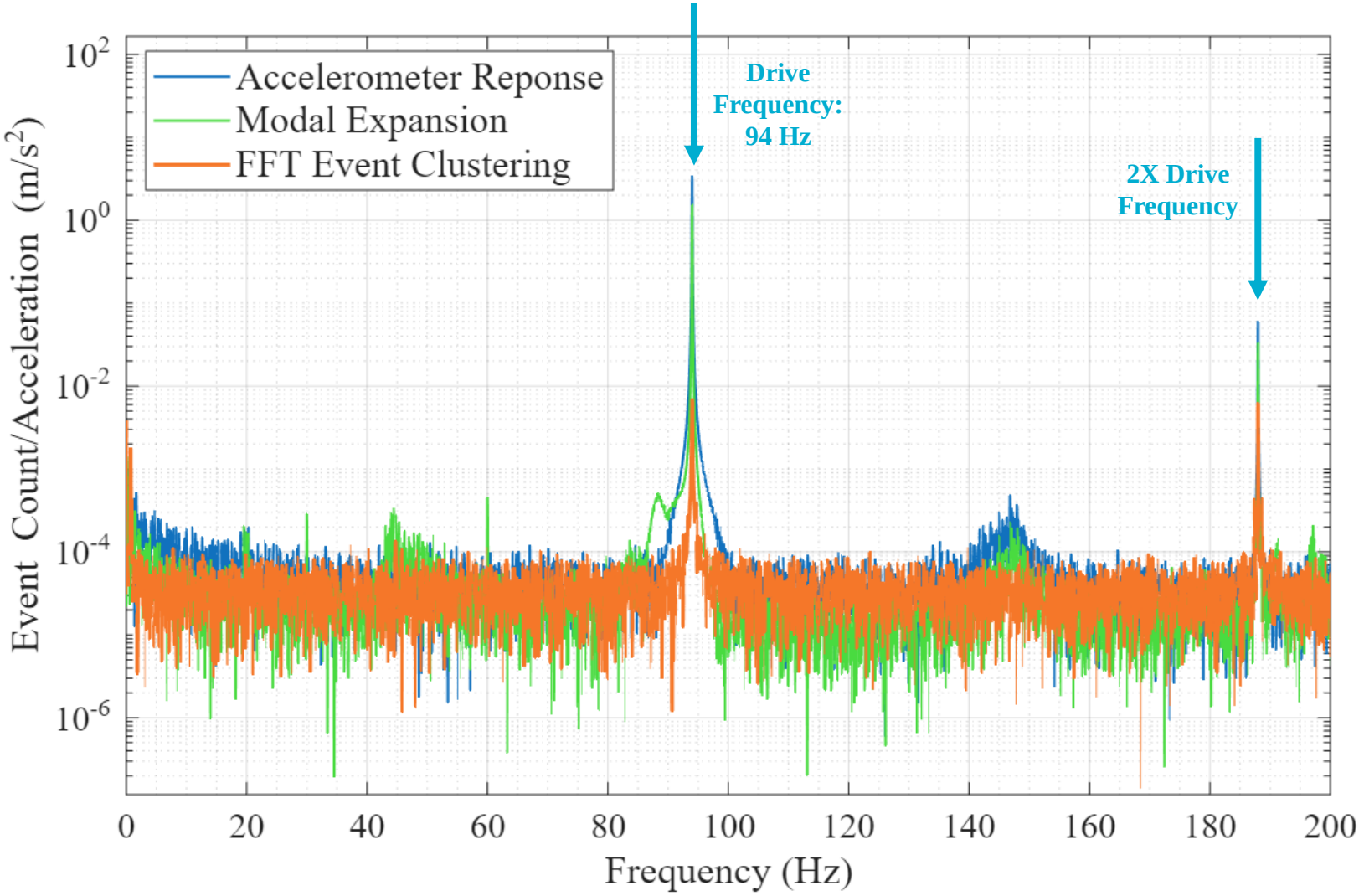
- All three methods were comparable
- Event clustering is chosen processing method for event-based sensor results shown



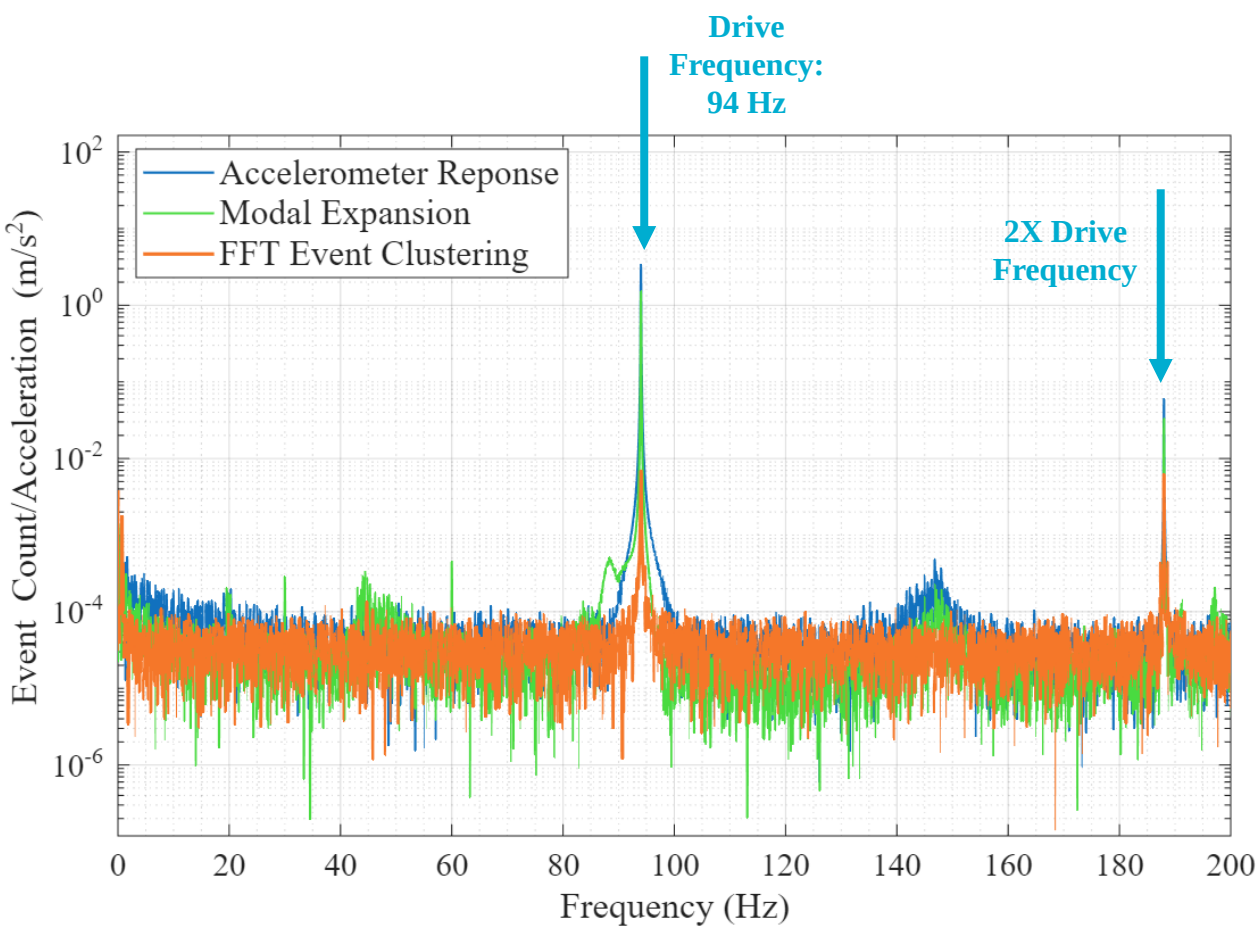
Verification of Event-Based Sensor Results: Response at ROI 2

*Low-level test,
No contact case

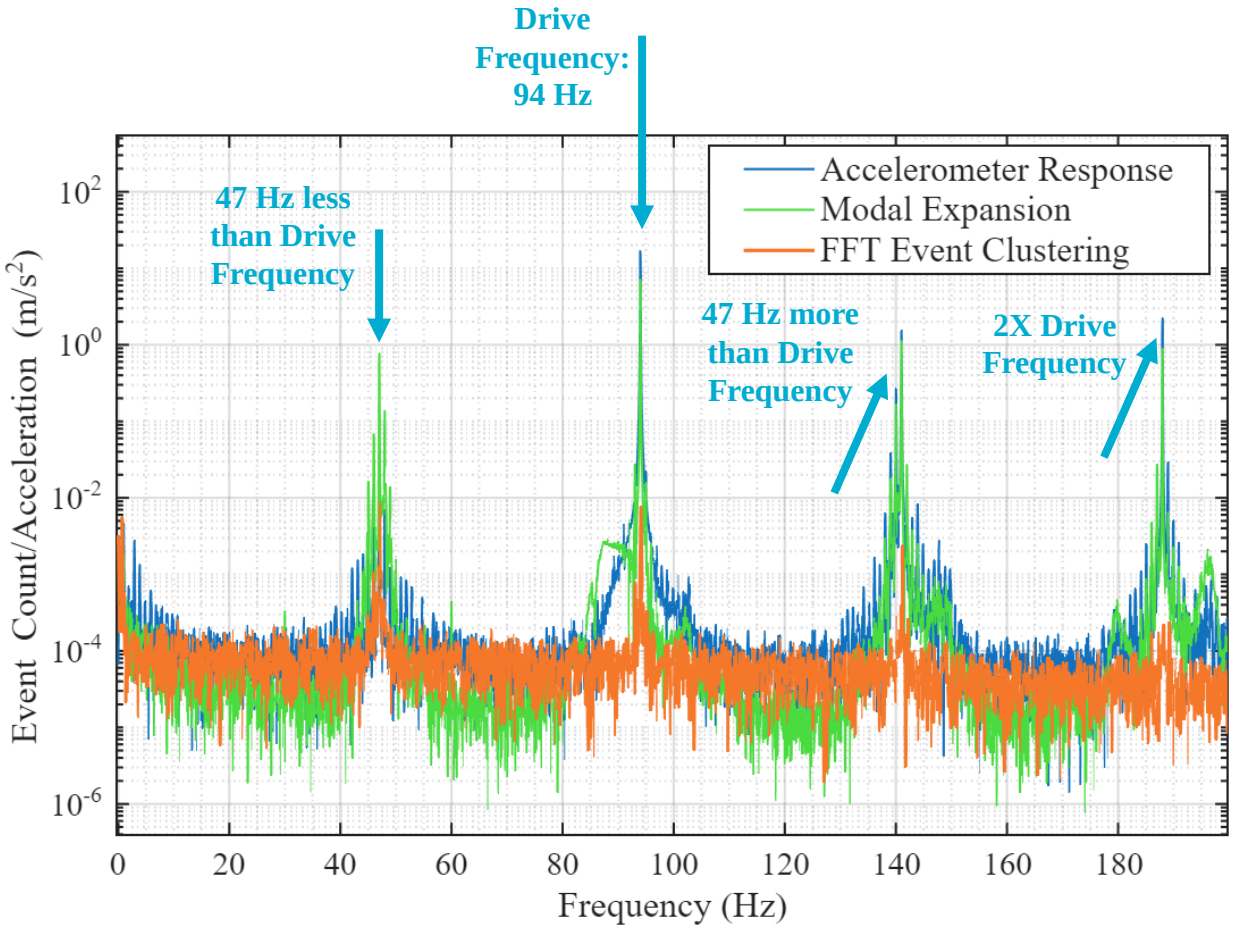




Additional Harmonics Observed After Contact Occurs

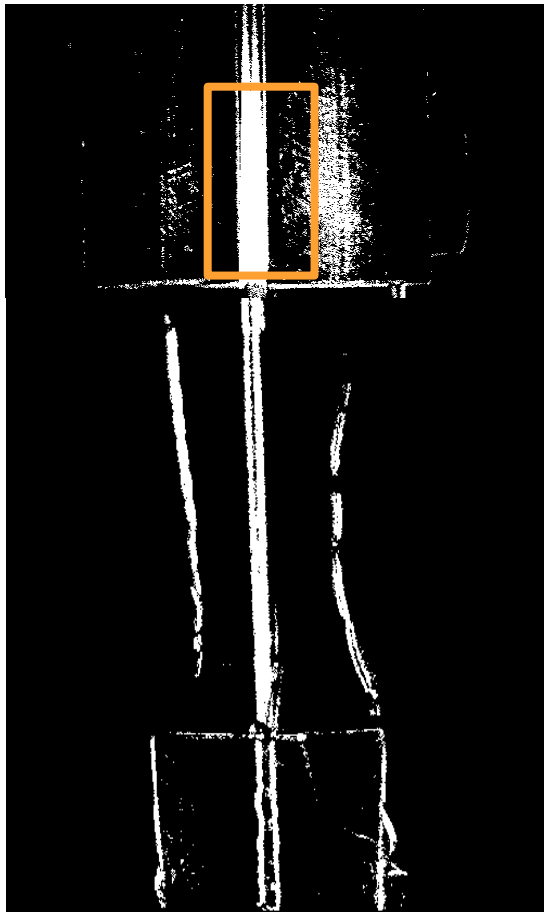


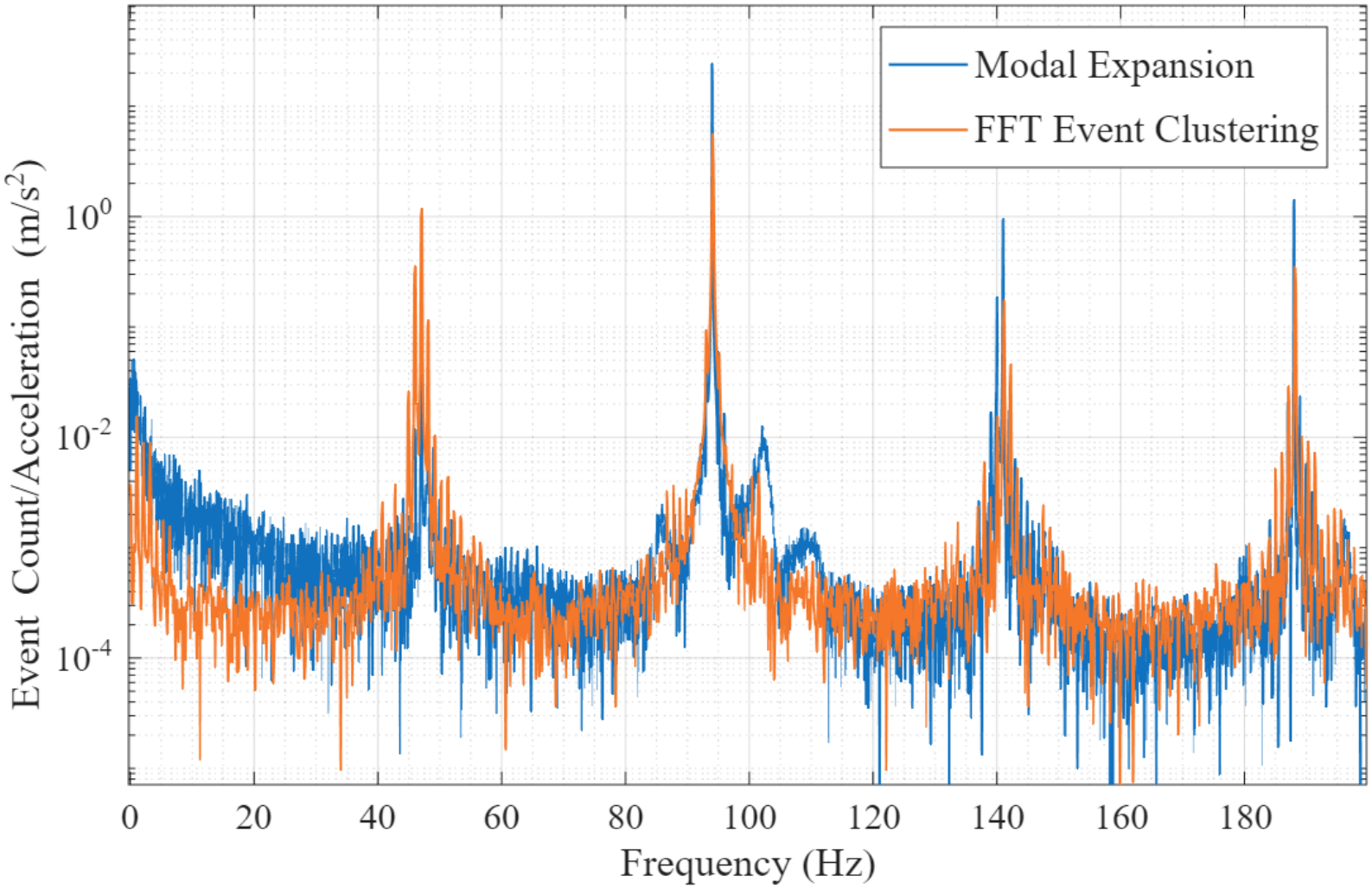
Low-level, no contact



High-level, contact

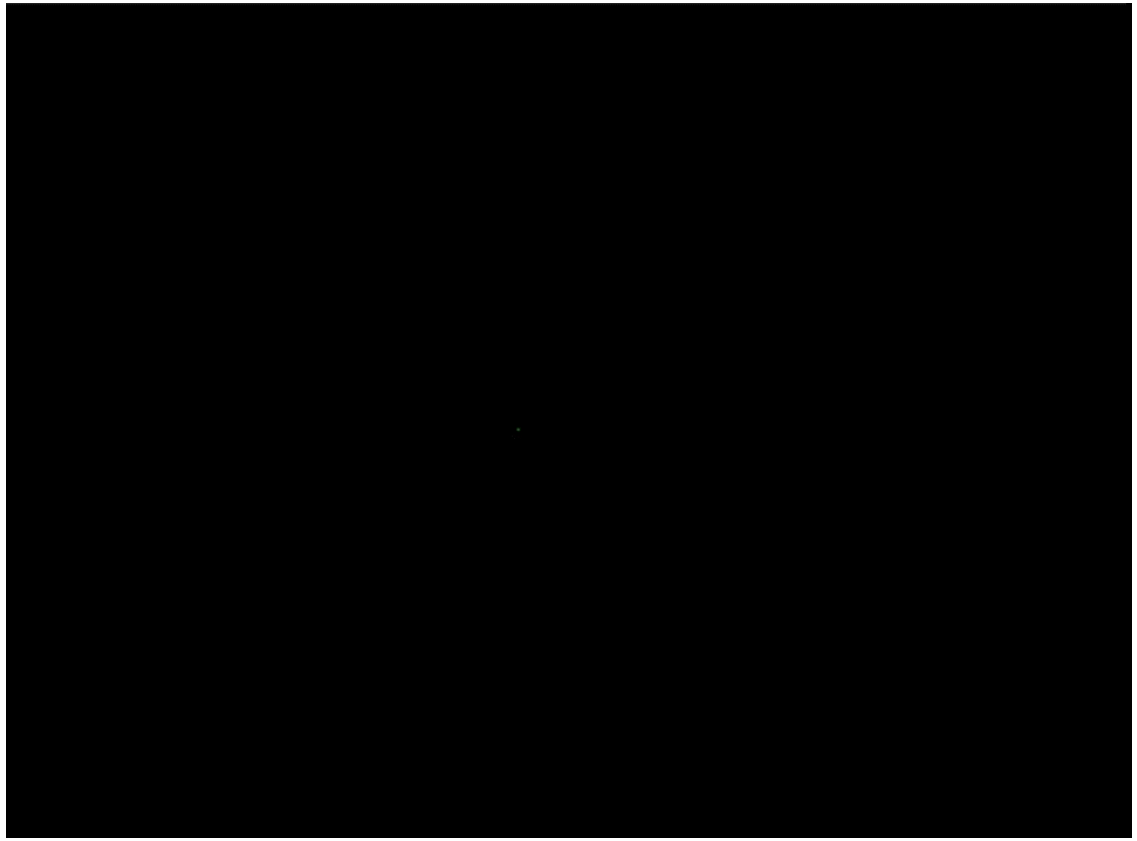
Event-Based Sensor Results at ROI 6



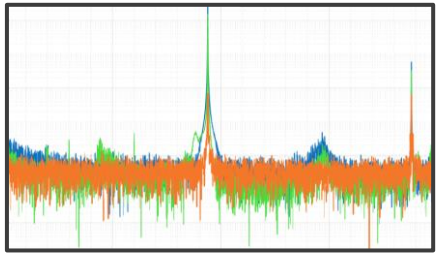


Visualization of Contact Behavior using Event-Based Sensor

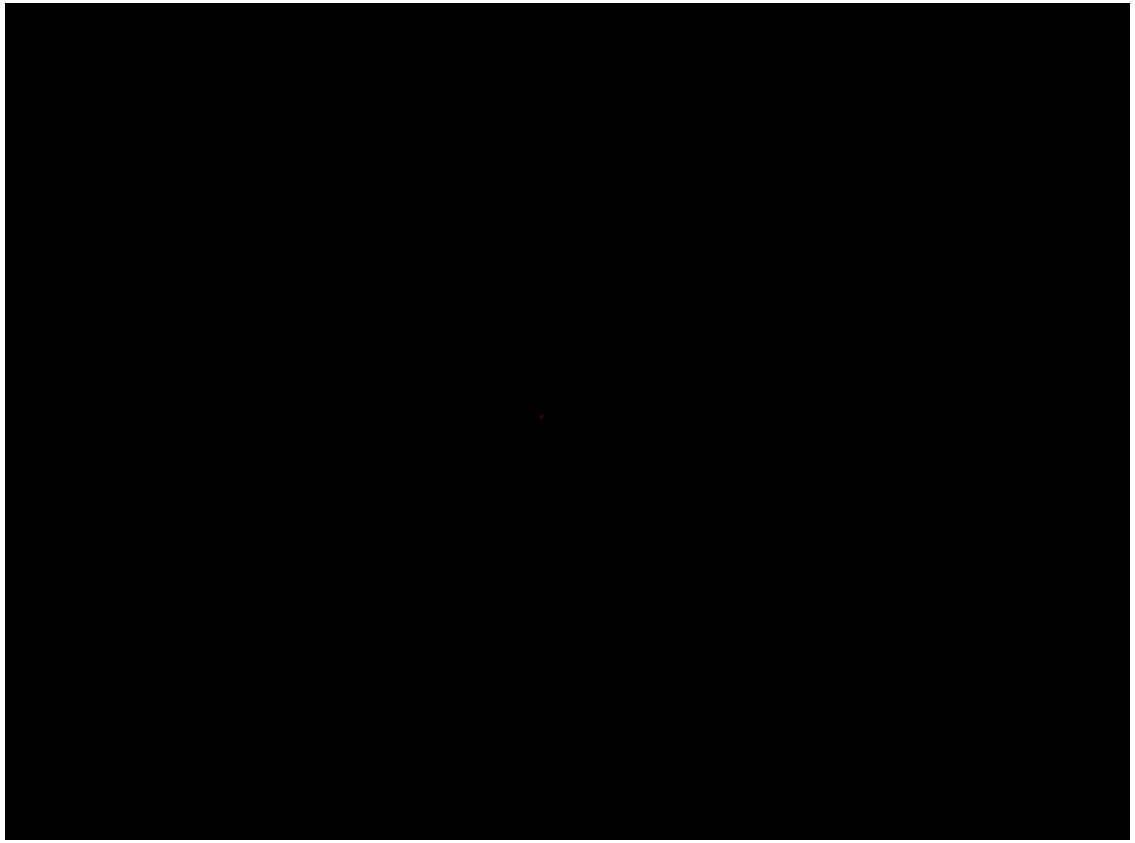
No Contact



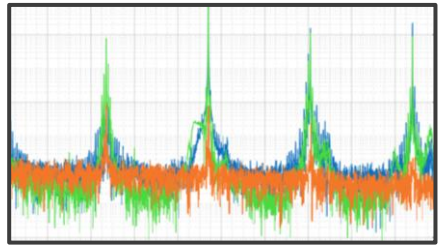
Force Level: 1.9 N



Contact



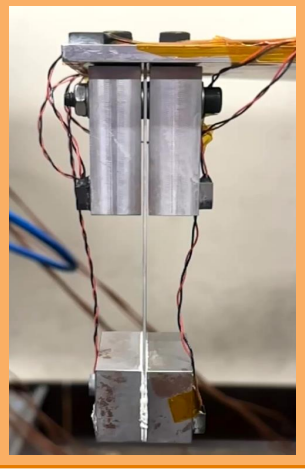
Force Level: 5.5 N



Four Areas of Further Work

Test On Different Structures

- Manipulate surfaces
- More flexible structure with higher displacement



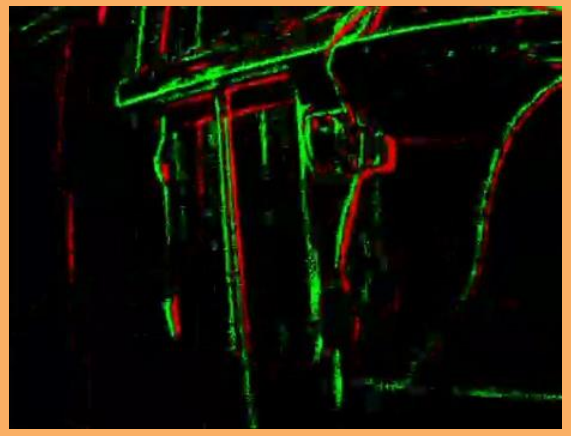
Improved Sensor Post-Processing

- Higher resolution sensor
- Study how post-processing affects results

[Prophese]

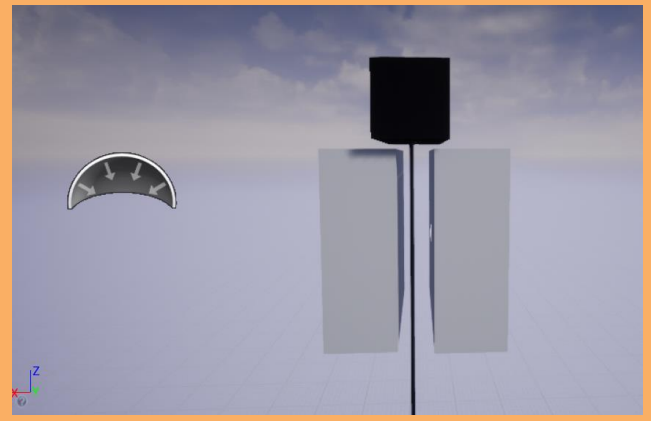
Capturing 3-D Responses

- Using stereo setup



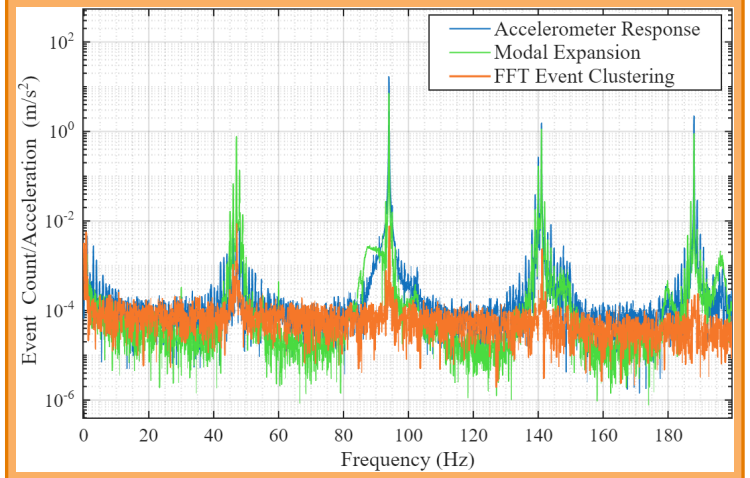
Unreal Engine

- Real time simulation of event based data



Three Key Conclusions

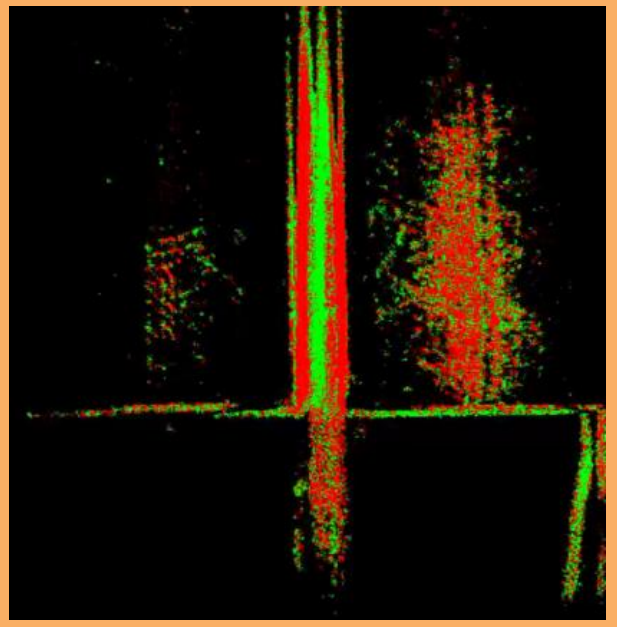
Event-based sensor gives comparable result to accelerometer and modal expansion results.



Various processing methods using event-based data can be used for frequency analysis

- **Method 1:** Time Binning
- **Method 2:** Event Clustering
- **Method 3:** Lomb-Scargle Spectral Analysis

Contact phenomenon can be visualized through event accumulation



Acknowledgements

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- We would like to acknowledge the support from Bill Flynn at Siemens and Rob Warmbold at Polytec for providing experimental equipment and software to equip the laboratories at NOMAD.
- Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

Thank You! Questions?