# Frequency-Based Damage Detection using Drone-deployable Sensor Package with Edge Computing

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# Outline

- Methodology:
    - Sensor package breakdown
- Experimentation:
    - Synthetic data testing
    - Real data testing
    - Computational power draw testing
    - Structure testing
- Results and Discussion:
    - Experimental outcomes
    - Findings and limitations
- Future work:
    - Sensor improvement

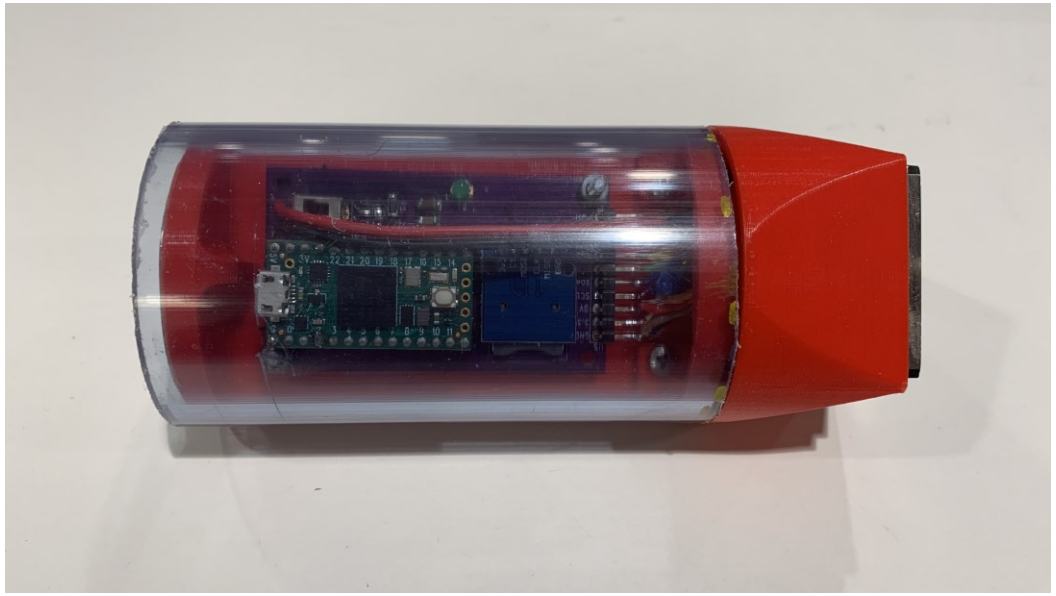
# Introduction

- Importance in structural health monitoring:
  - Accelerometers are used to observe how vibrations propagate in structures
- Problem statement:
  - Traditional SHM relies on off-site computational analysis
  - Can cause delays in data processing and transmission
  - No real-time insights
- Proposed approach:
  - Sensor package computation on the edge
  - UAV-delivery system
  - Radio frequency system for wireless triggering
  - Open-source

a) b) c)

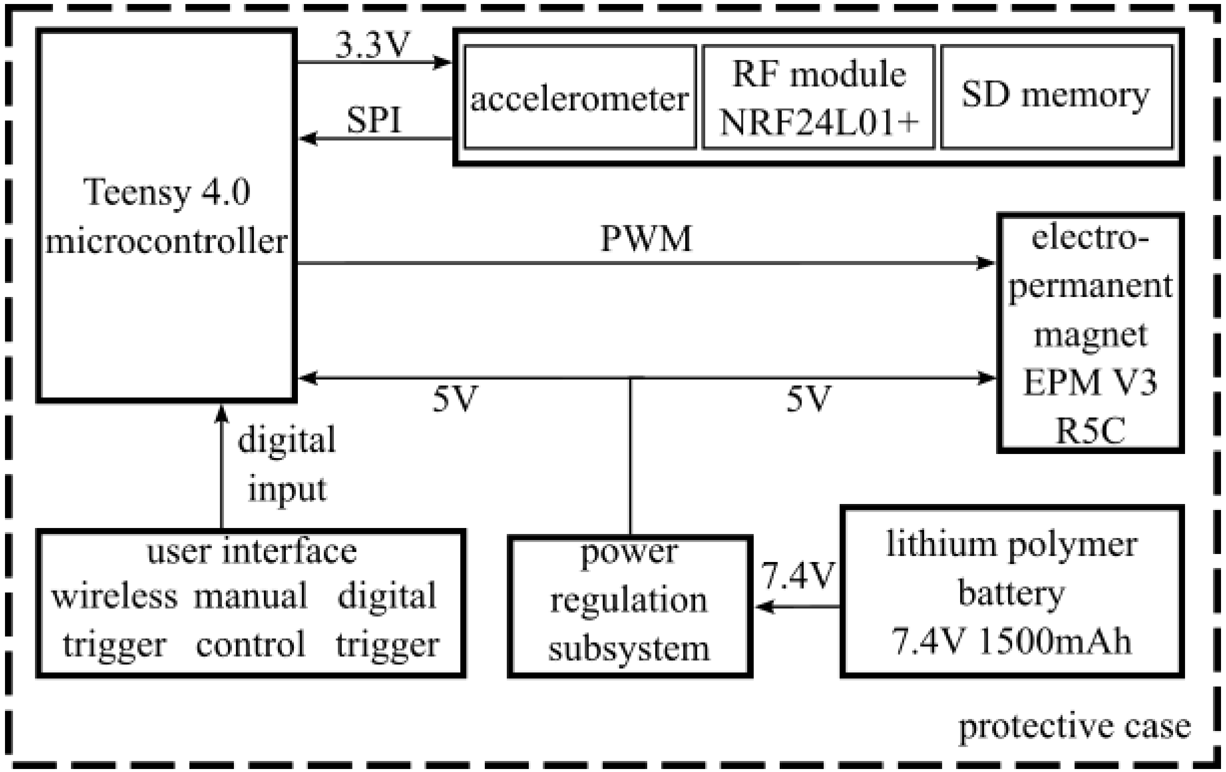
# Sensor package breakdown

- Features:
  - Designed for high mobility UAV-deployment.
  - Equipped for extended deployment with power and memory subsystems.
  - Wireless subsystem for triggering and IO commands.
  - Docking subsystem utilizing electropermanent magnets.
  - Lightweight frame optimized to reduce transmission losses.
  - Data capture up to a sampling rate of 28 kS/s.
  - On board edge processing for modal frequencies.



## Sensor package breakdown

- Hardware:
  - Processor: ARM Cortex-M7 on Teensy 4.0 microcontroller.
  - SCA3300-d01 MEMS accelerometer.
  - EPM V3R5C electropermanent magnet.
  - Nonvolatile memory (SD card) for long-term storage.
  - 1500mAh 2-cell lithium polymer battery, voltage regulation and monitoring.
  - NRF24L01 Nordic Semiconductor wireless transceiver.
  - DS3231 real-time clock (RTC) for data logging and trigger time reference.



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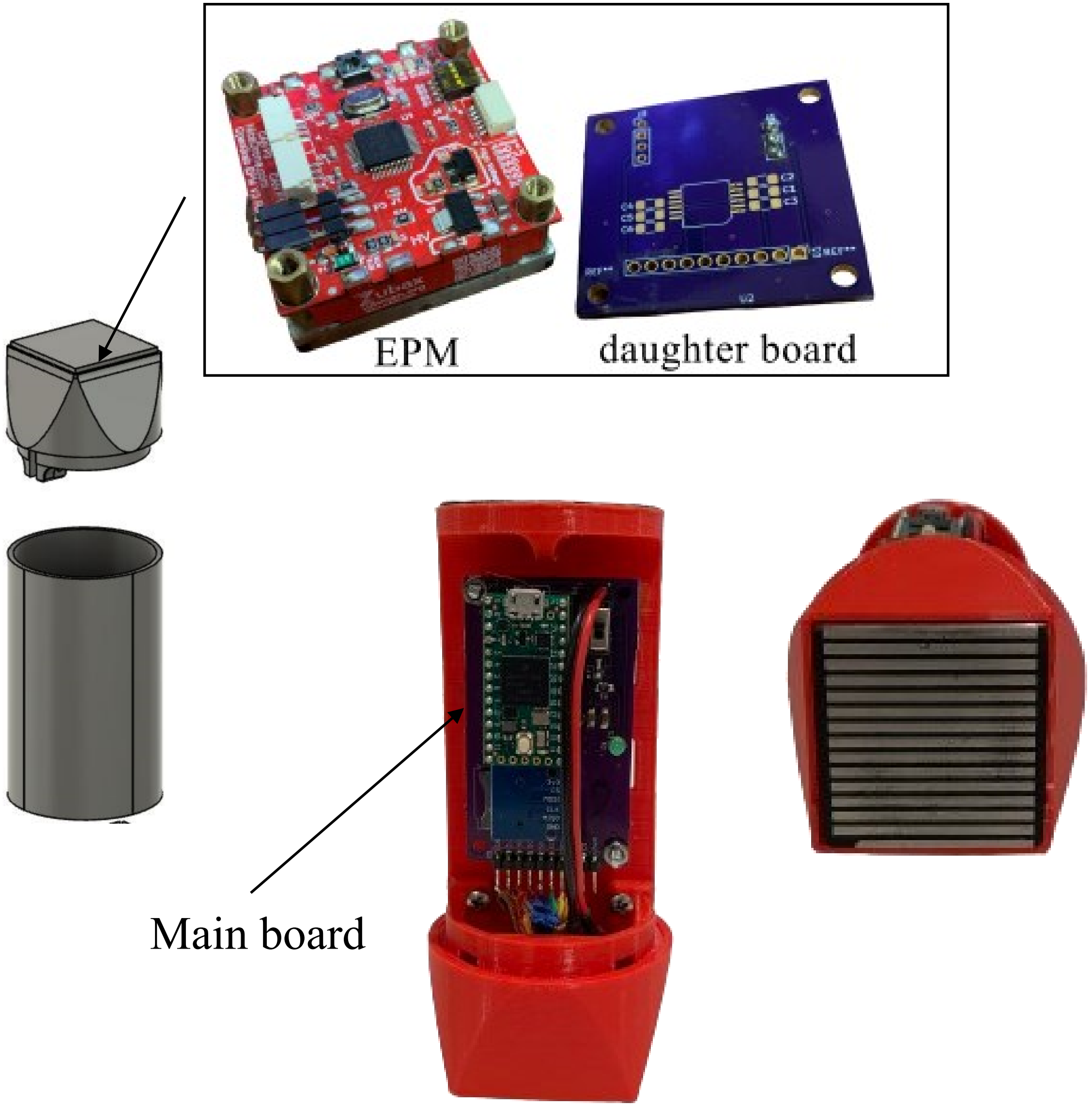
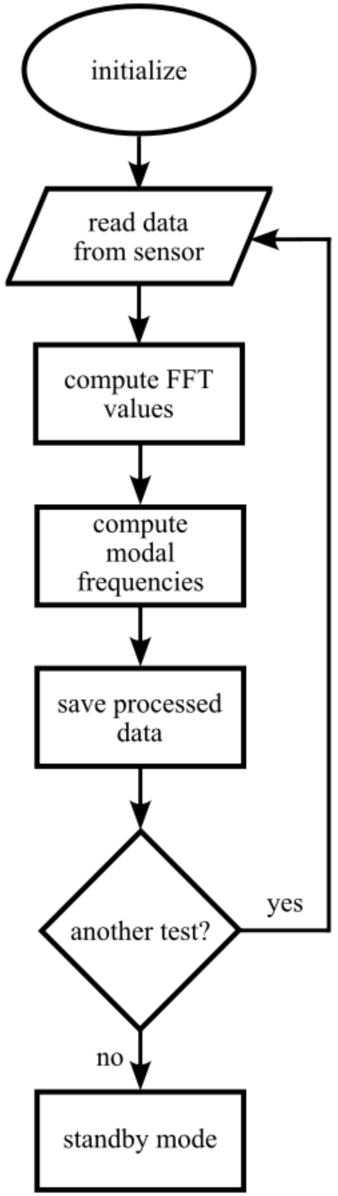


# Sensor package breakdown

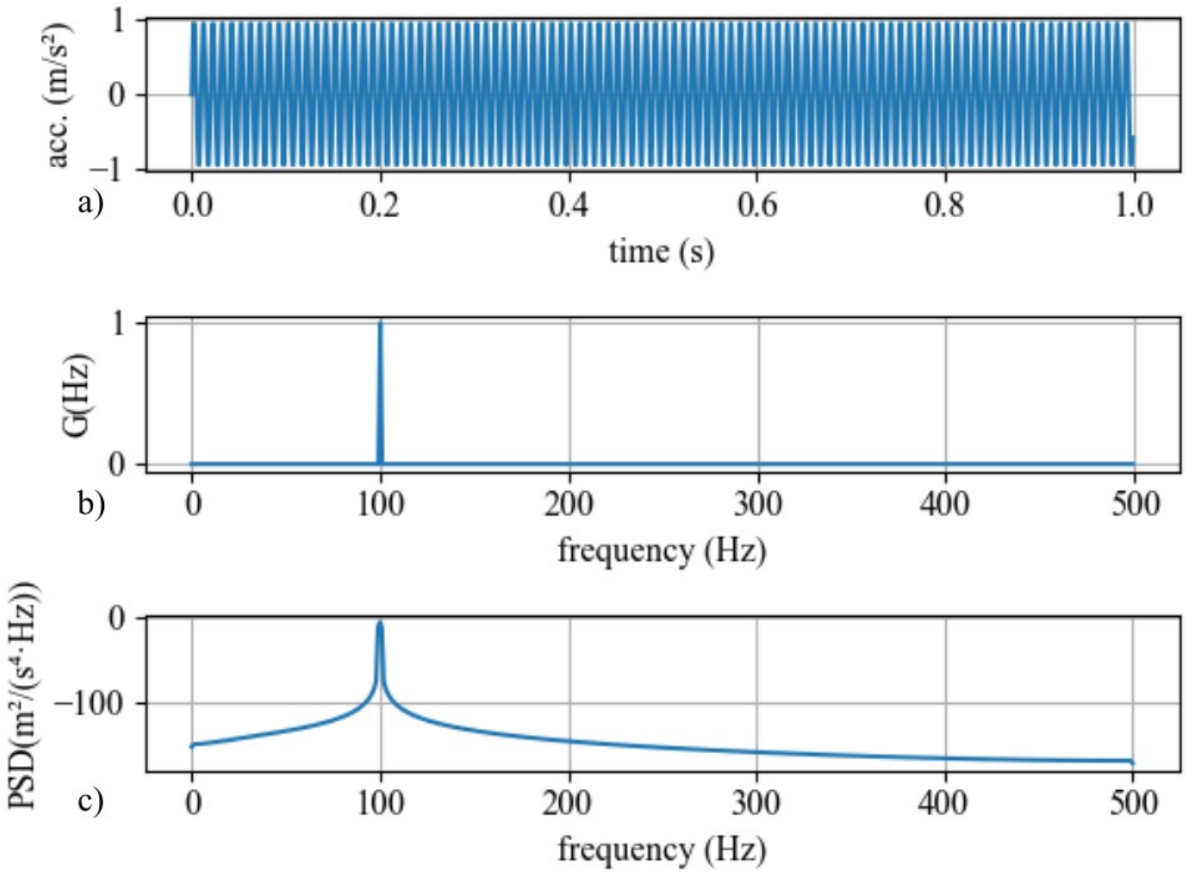
- Algorithm:
  - Developed on Arduino IDE
  - Deployment starts with sensor initialization
  - Code enters into sensing phase, pulling accelerometer data
  - 16,384 samples collected then transferred onto the memory
  - The FFT values are computed and then run through a peak finding algorithm to find the first modal frequency
  - Processed data is also stored on non-volatile memory in the form of new files

- User interface:
  - Sensor package operating conditions can be monitored with LED indicators
  - Retrieve stored data from on-board micro-SD card
  - Commands can be issued to electro-permanent magnet for retrieval



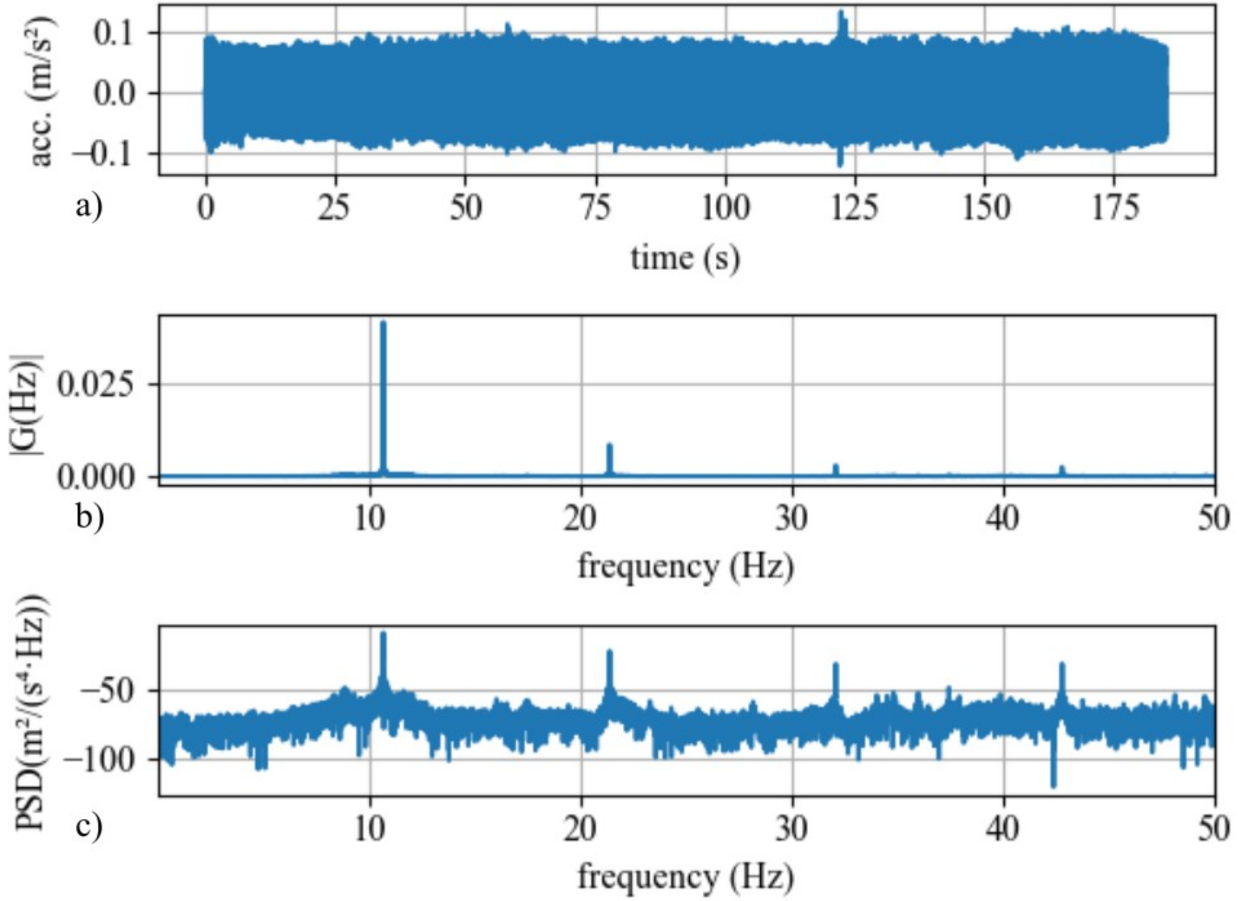
# Synthetic data testing

- Aimed to evaluate the capability of edge processing on the sensor package
- Synthetic 100 Hz sinusoidal signal
- Utilized the edge processor to compute the FFT and PSD values
- These are graphs of the values computed
    - A) Synthetic signal
    - B) FFT values
    - C) PSD values
- Values are computed on the sensor package and graphed separately for evaluation



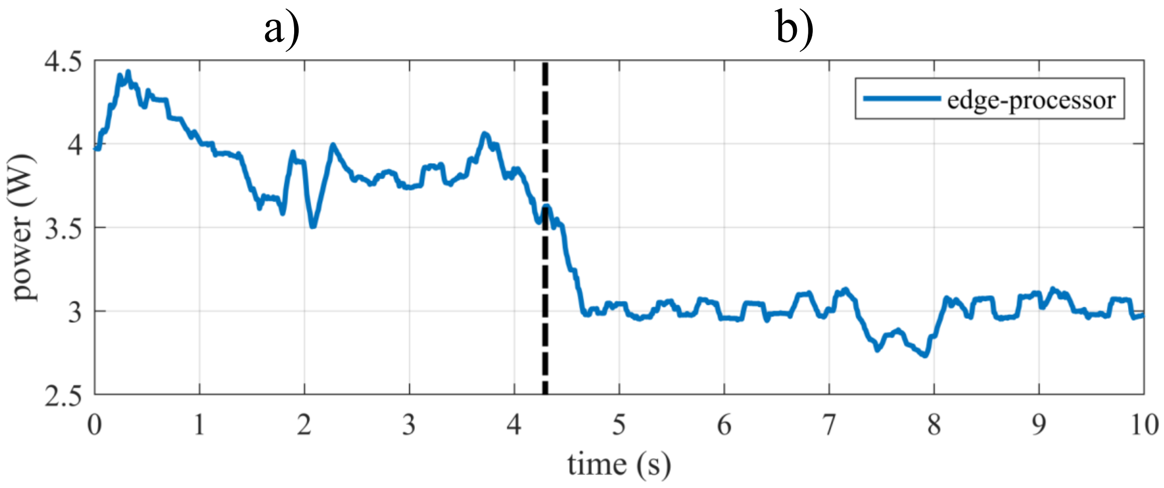
## Real data testing

- Ideally evaluate the sensor's effectiveness using real world acceleration data from a pedestrian bridge
- Utilized acceleration data previously captured
- Conducted similar calculations as the synthetic data testing resulting in:
    - A) Time domain data
    - B) FFT values
    - C) PSD values
- As the data was captured previously, it could be compared to other data received from the bridge



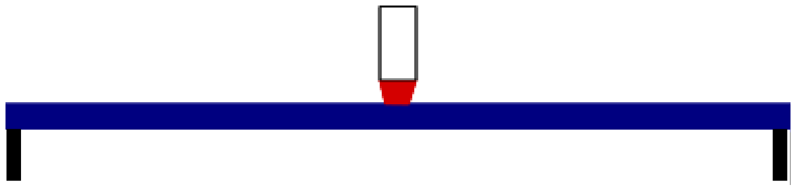
# Computational power draw testing

- Objective: determine efficiency of the system in terms of power draw during sensor computation
  - a) sensor processes, b) standby
- Only the computation phase
- Largest power draw approximately 4.4 W
- Lowers to stay around 4 W during the rest of the process
- Rests at 3 W during standby
- Due to the power draw, we decided to handle the computation on the existing microcontroller rather than an additional processor.



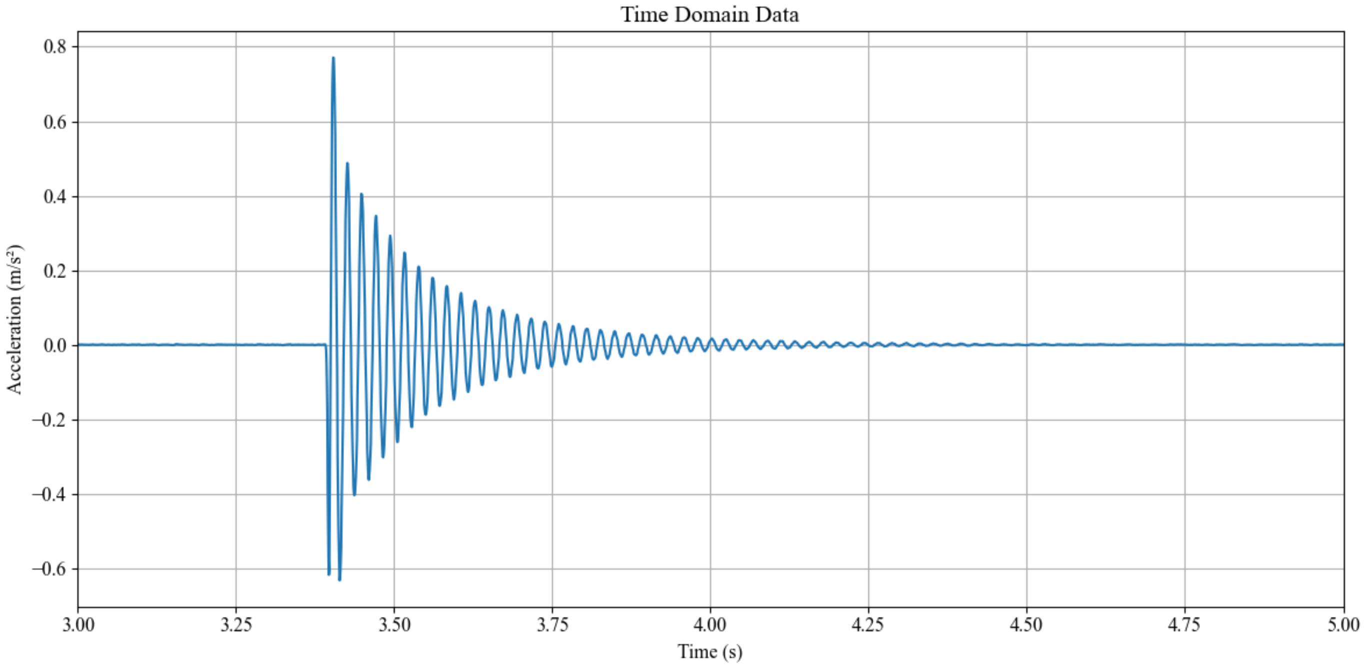
# Structure test

- Investigated vibrational behavior of a square stock beam with roller supports on each end
- The primary goal was to assess the sensor's ability to measure across varying structural conditions
- A single sensor package was positioned in the center of the beam
- A series of three tests were performed, each intended to simulate a different structural state
  - Initially, both supports start evenly spaced from the center of the beam
  - After the first test, the left support was moved closer to the center incrementally



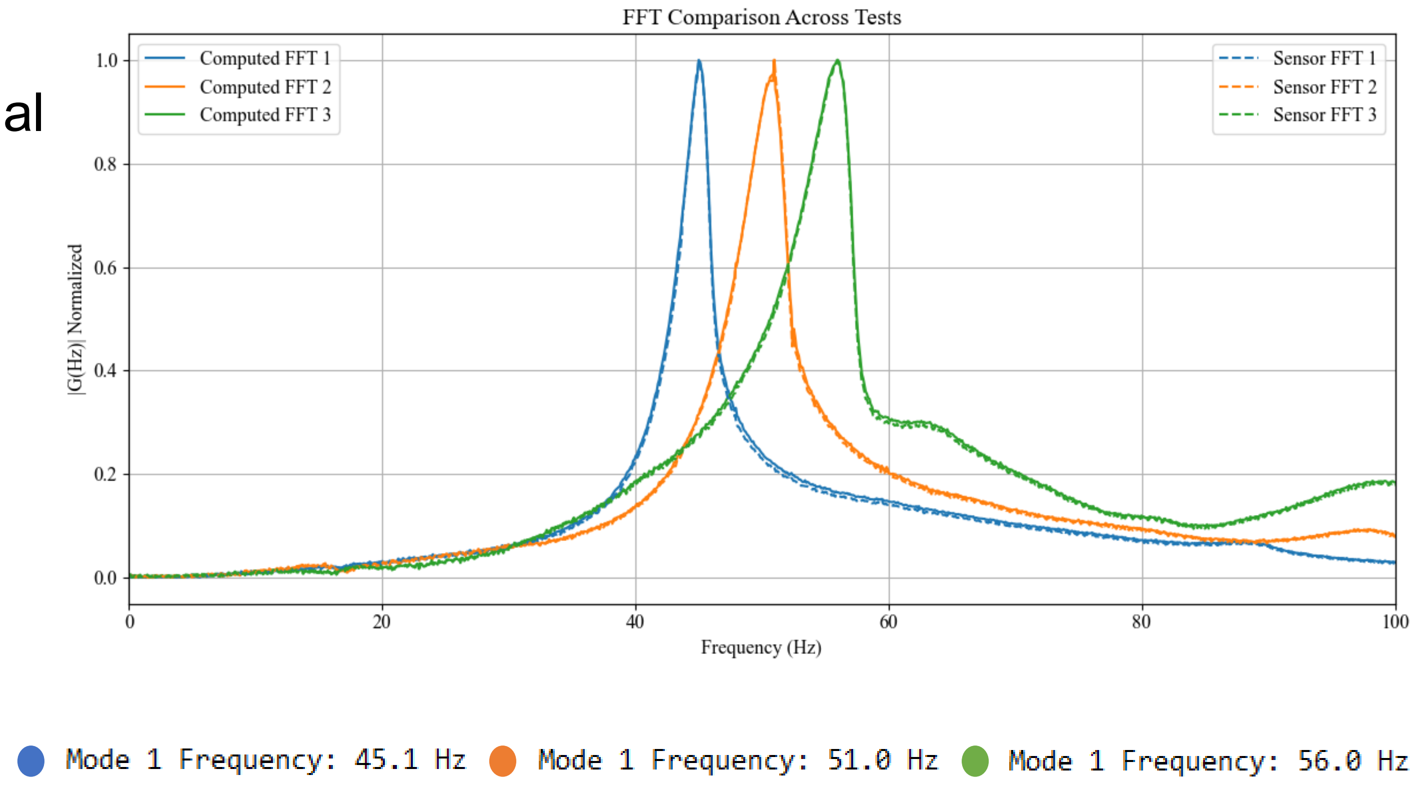
## Structure test

- A modal impact tool was used to create an impulse response in the beam
- During each test, the sensor package continuously recorded vibration data from the beam
- The collected data was then subjected to FFT analysis
- The primary focus was to identify the first modal frequency of the system



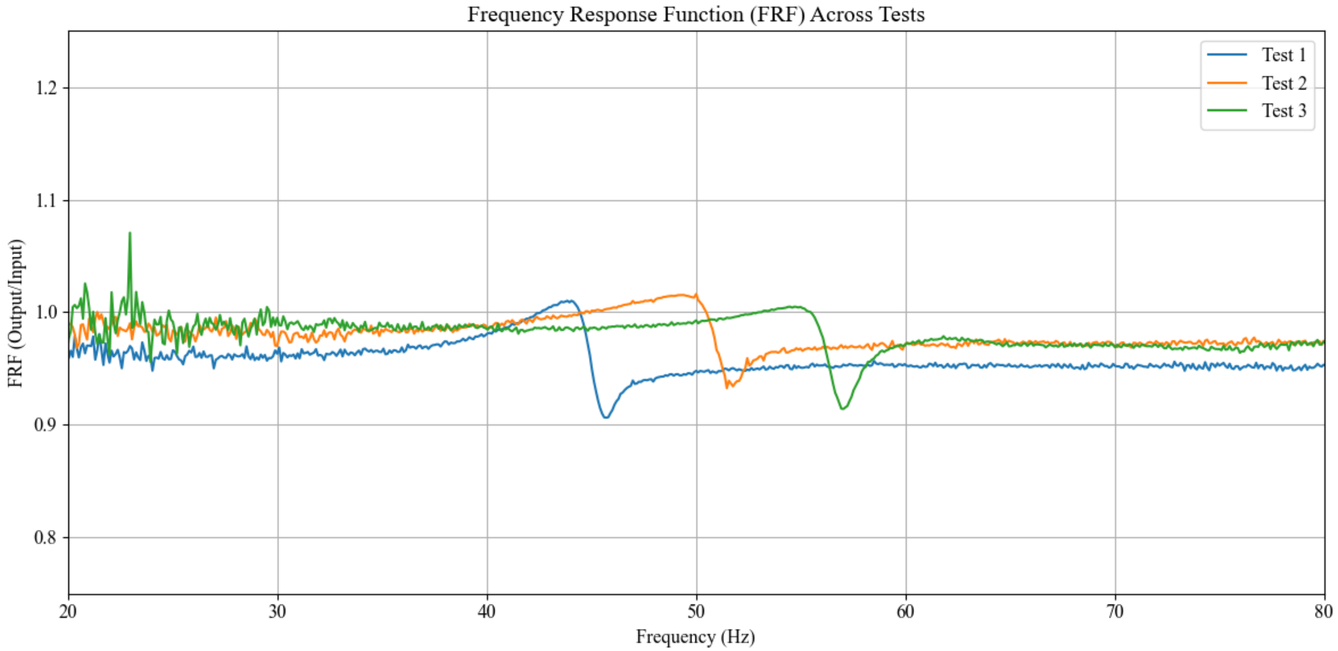
# Experimental outcomes

- The sensor was able to run the FFT successfully and determine the first modal frequency of the system
  - Test 1: 45.1 Hz
  - Test 2: 51.0 Hz
  - Test 3: 56.0 Hz
- An offsite FFT calculation was made to compare the precision of the sensor's algorithm
- Offset in the natural frequency of the system can be attributed to damage



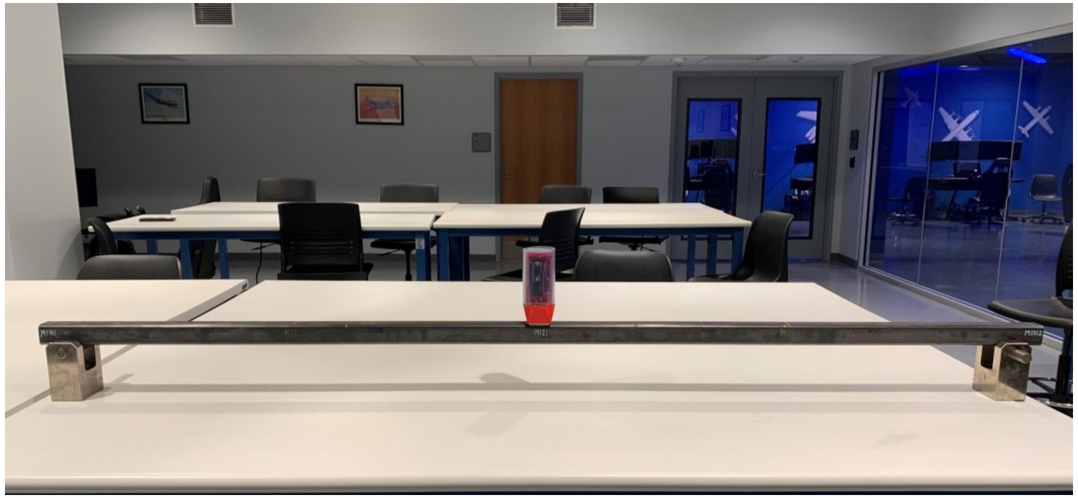
# Experimental outcomes

- A frequency response calculation was made to determine how close the FFT run by the sensor package was to the offsite FFT
- Ideally, the FRF should be flat, indicating the sensor FFT is calculated with the same precision as an offsite program
- Around the three calculated modes, the largest difference is 0.906/1 giving a percent error of around 9.4%

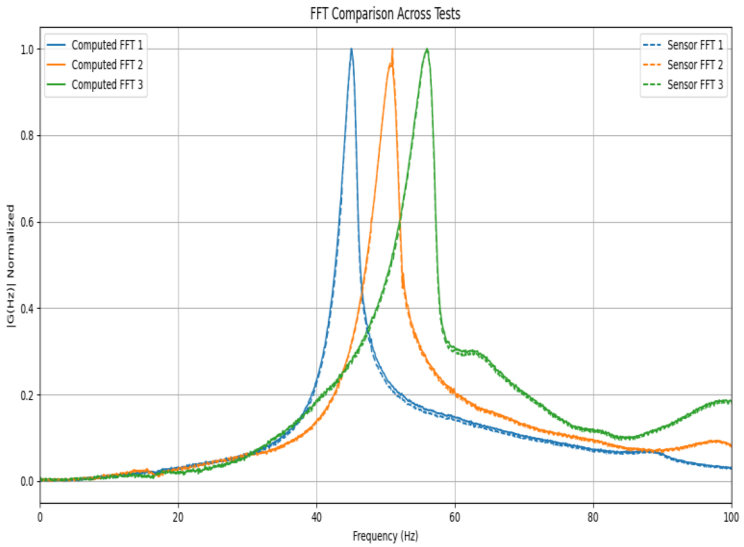


## Conclusions and Overview

- Examined an open-source high-mobility edge processing sensor package for structural health monitoring
- Holds potential as a useful tool for vibration analysis
- Well suited for UAV-deployment in challenging or human-inaccessible areas
- Enables quick deployment for rapid assessment
- Limitations:
    - Sensor requires physical retrieval for data viewing
    - FFT and peak finding code had to be optimized for space on the microcontroller



- **Future work**
  - Sensor improvement
    - Investigate sensor synchronization for data alignment in a sensor network
      - This approach aims to enable rapid edge computation across an entire structure rather than a single point
    - Enhance sensor package compact footprint
    - Optimize power consumption for longer deployment
    - Investigate more complicated peak finding techniques for better modal identification

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# Drone-Delivered-Vibration-Sensor



https://github.com/ARTS-Laboratory/Drone-Delivered-Vibration-Sensor

# Thank you

# Questions?

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**Pictures:**

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