Modal Analysis Using UAV-Deployable Wireless Sensor Network

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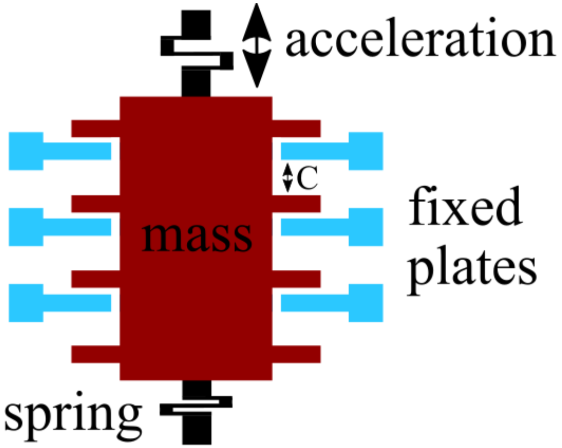
Methodology | Experimentation | Results and Discussion | Future work

Outline

- Methodology:
  - Sensor package breakdown
- Experimentation:
  - Power testing
  - Latency testing
  - Beam testing
  - Structure testing
- Results and Discussion:
  - Experimental outcomes
  - Findings and limitations
- Future work:
  - Sensor improvement

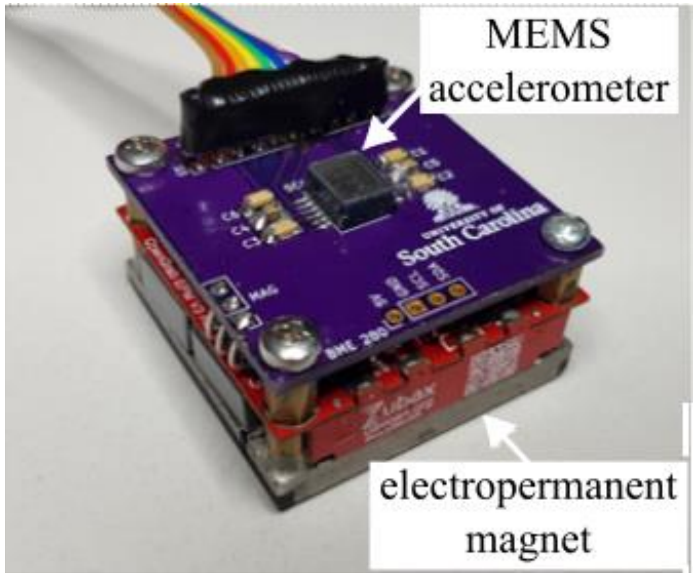


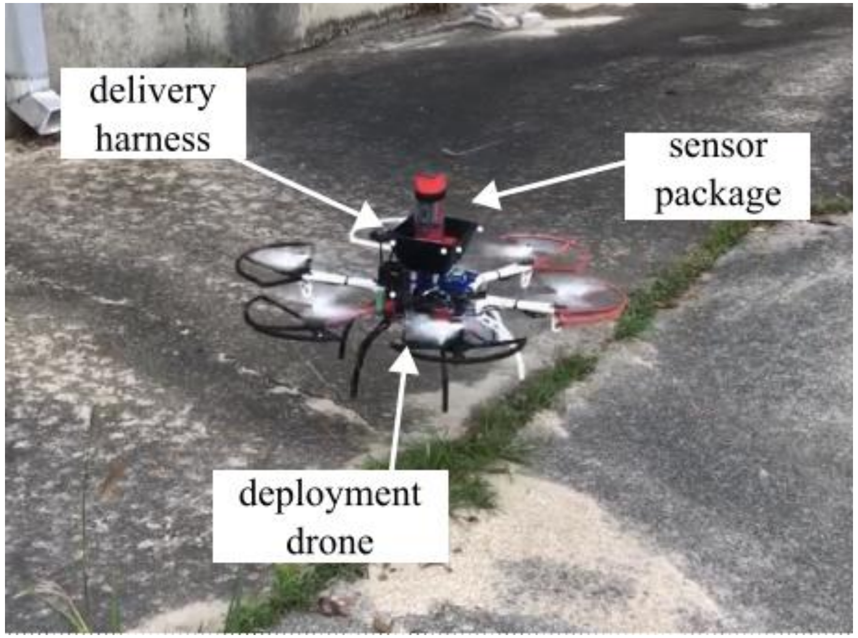
Introduction

- Importance of structural health monitoring.
  - Accelerometers are used to observe how vibrations propagate in structures
- Problem statement:
  - Single sensor packages provide limited information.
  - Rapid large-scale deployment.
- Proposed approach:
  - Network of sensor packages.
  - UAV-delivery system.
  - Radio frequency system for wireless triggering.
  - Open-source.

Sensor package breakdown

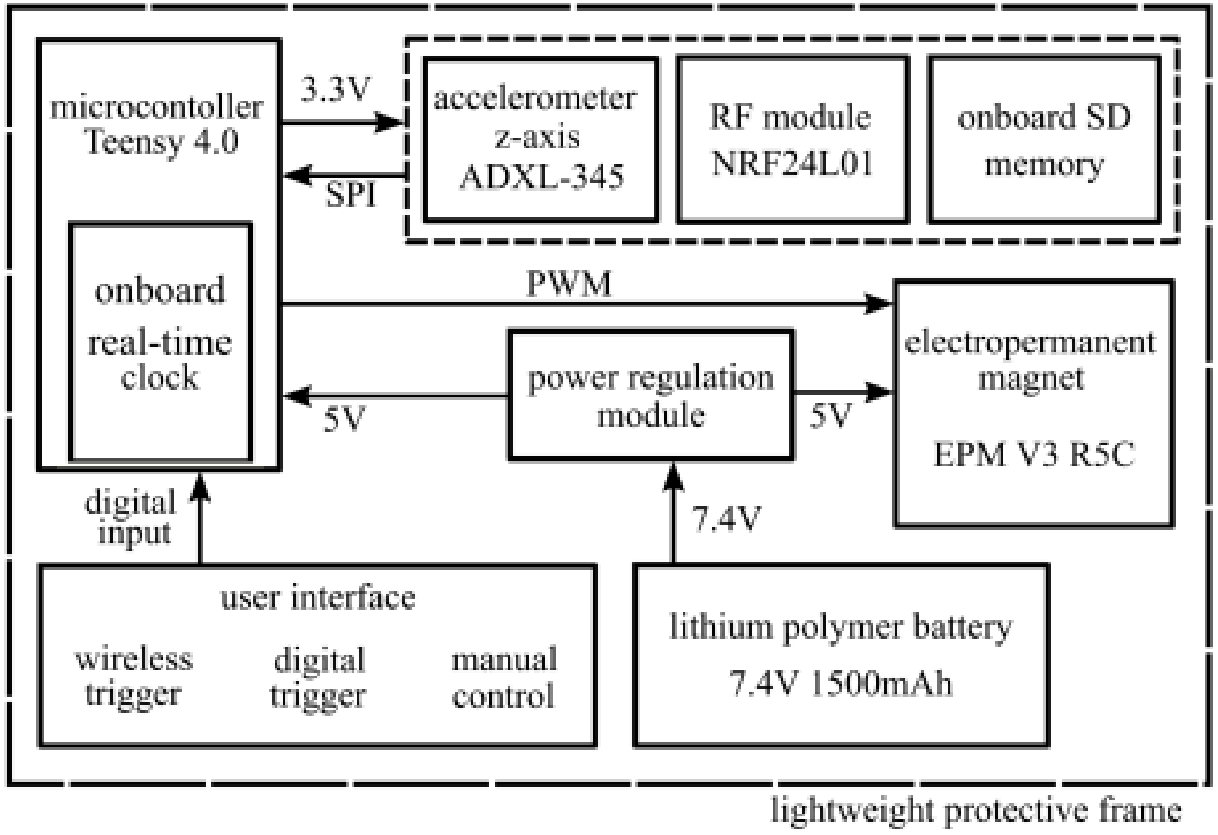
- Features:
  - High mobility UAV-deployable sensor package.
  - Equipped for long-term deployment with power and memory subsystems.
  - Wireless subsystem for triggering and IO commands.
  - Docking subsystem using electropermanent magnets.
  - Lightweight frame optimized to minimize transmission losses.
  - Capable of a sampling rate of 28 kS/s.





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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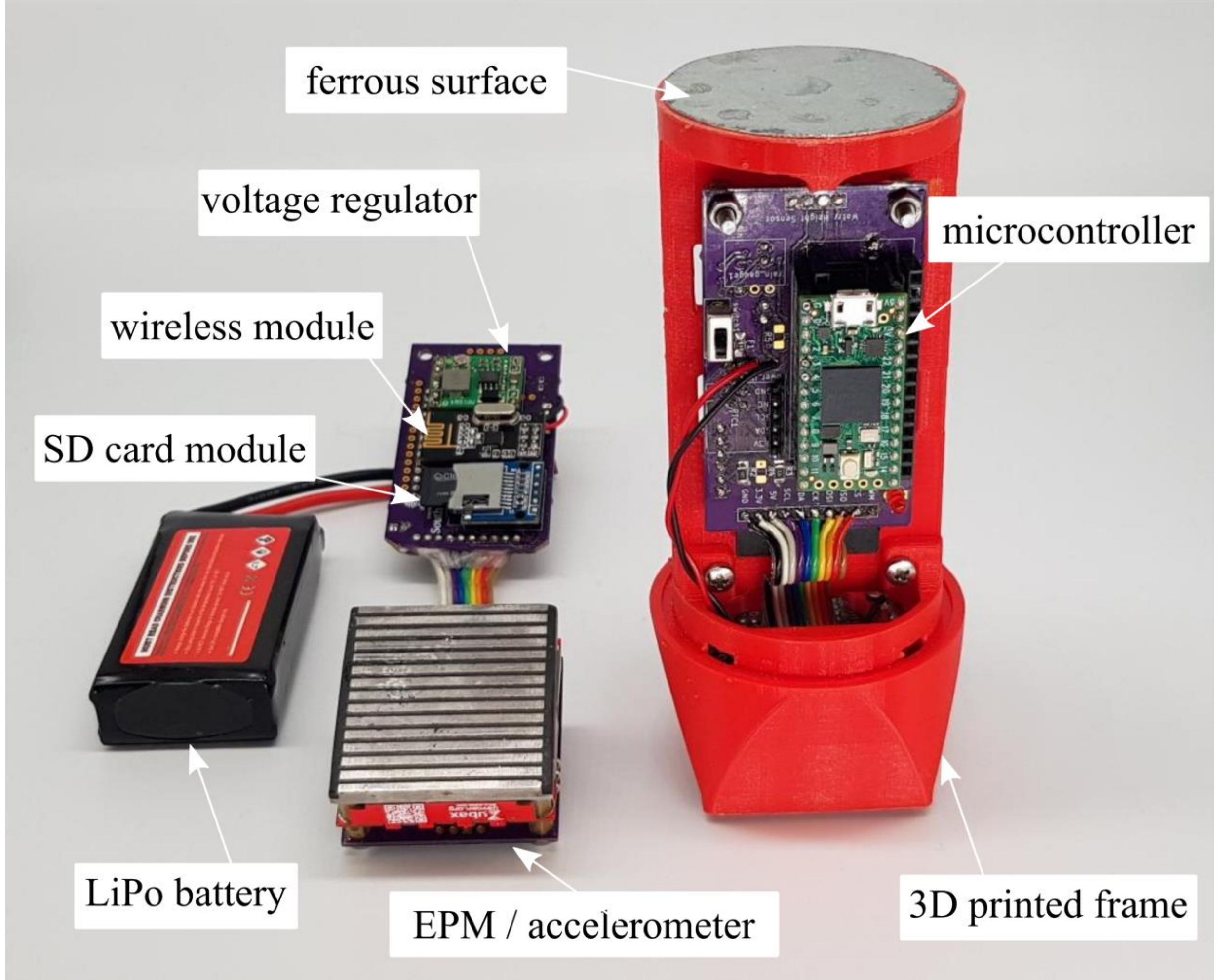
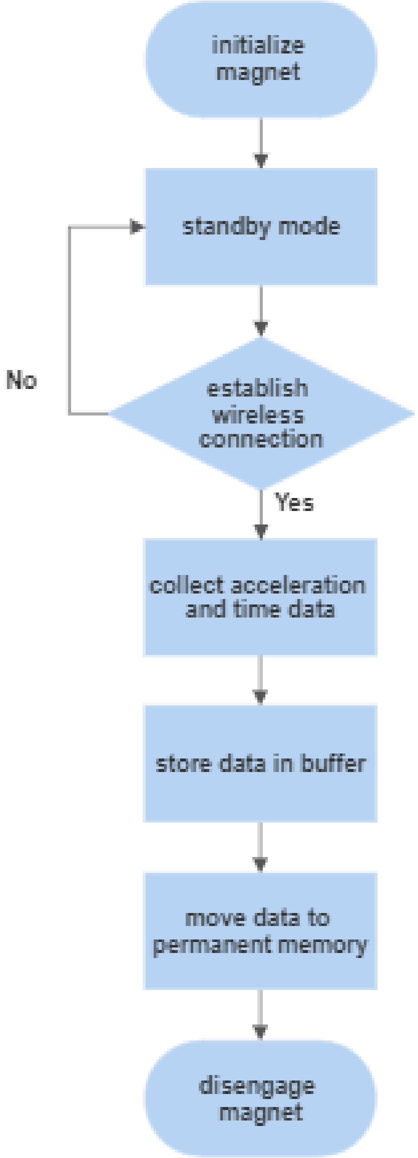


Sensor package breakdown

Developed on Arduino IDE.

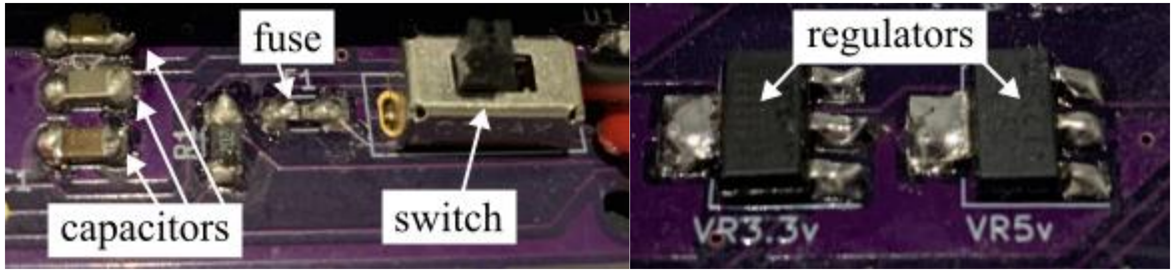
- Algorithm:
  - Deployment starts with magnet initialization.
  - Code enters standby mode to conserve power.
    - Microcontroller/RF stay on for communication.
  - Acceleration data is collected after communication.
  - Data collected in a buffer to enable high sampling rates.
  - 74,000 samples collected then transferred onto the memory.

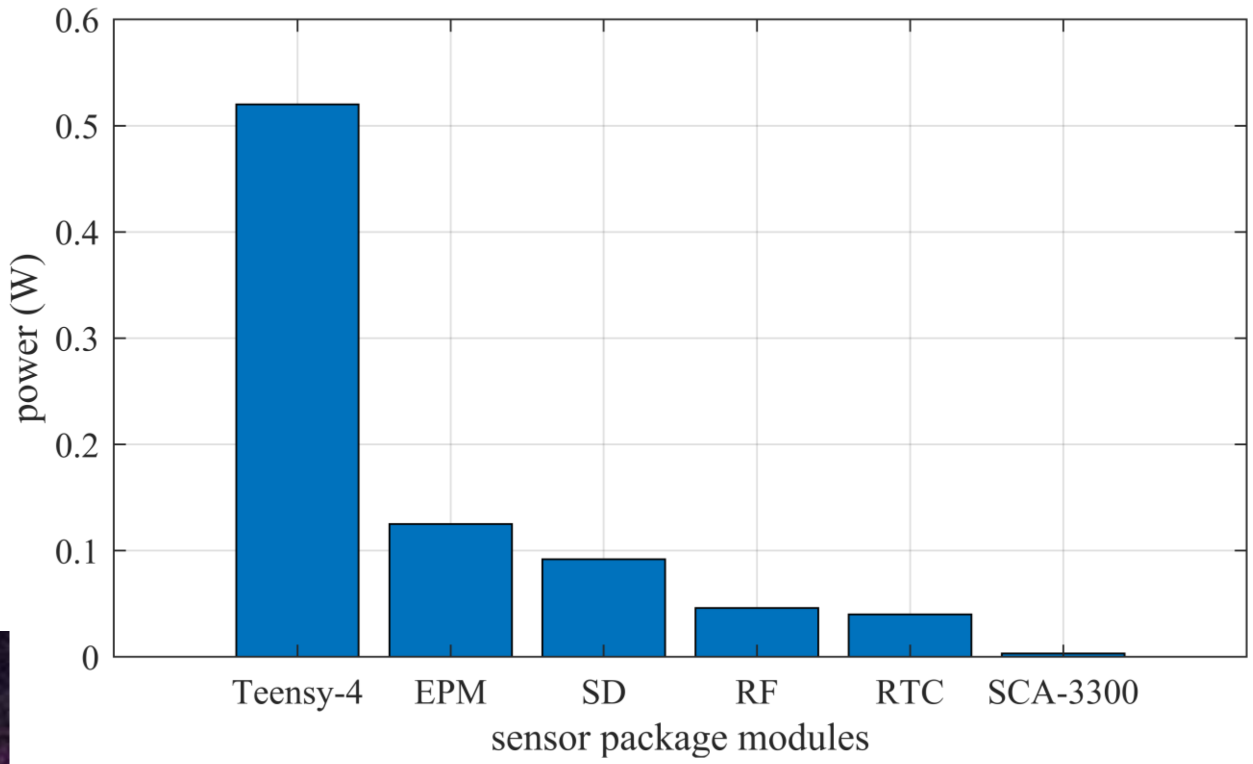
- User interface:
  - A connection is achieved over 2.4 GHz ShockBurst protocol.
  - Sensor package operating conditions can be monitored.
  - Retrieve stored data from micro-SD card.
  - Commands issued to electro-permanent magnet for retrieval.



Power testing

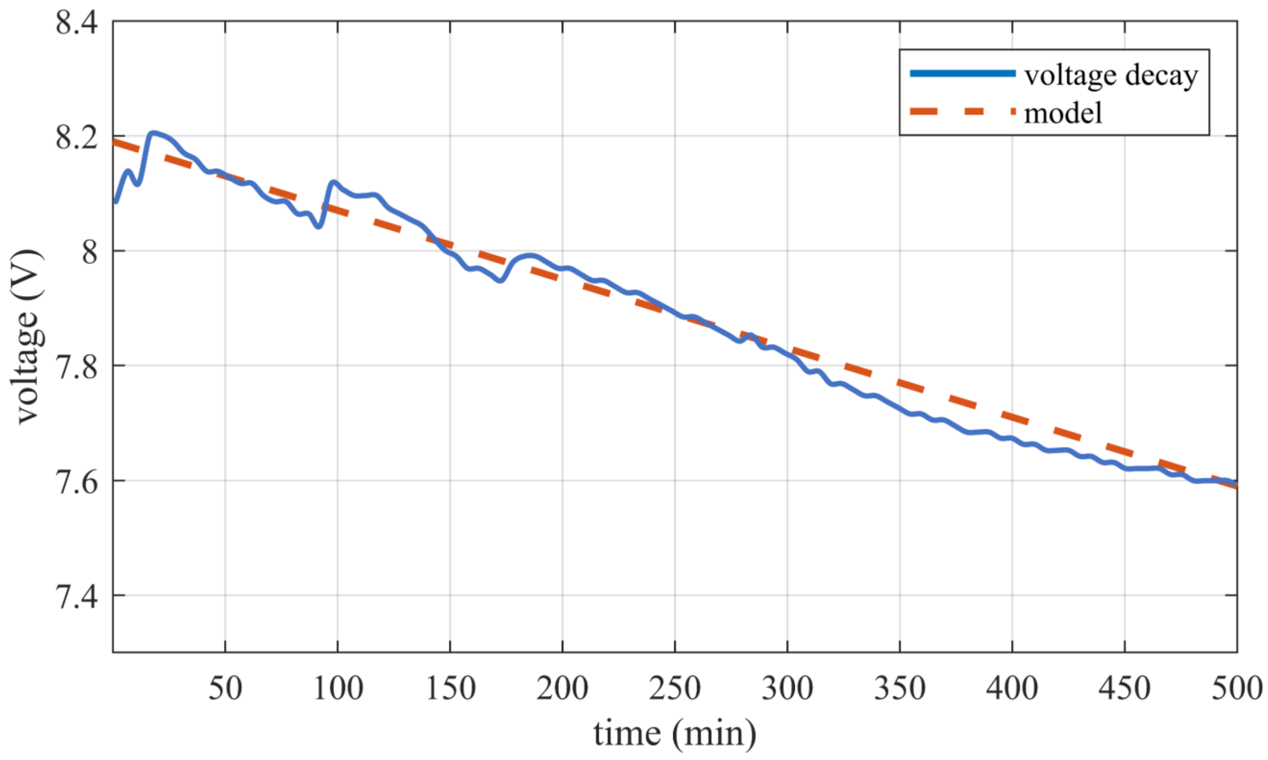
- Standalone power subsystem has voltage regulators and conditioning capacitors.
- Microcontroller has highest consumption at 0.52 W.
    - Can be turned off for power-saving.
- SCA3300 accelerometer has the lowest consumption at around 0.01 W.





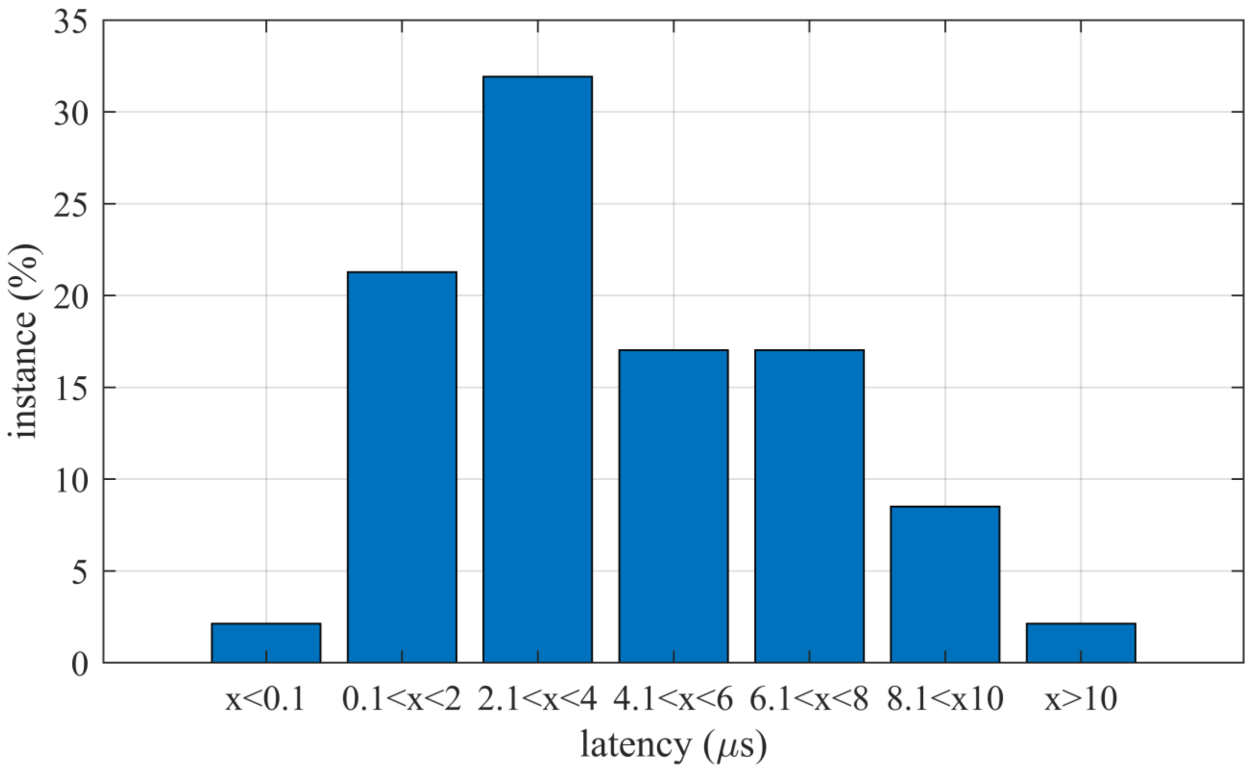
Power testing

- Lithium polymer battery was chosen for desirable power density per footprint.
- Temperature dependencies observed with voltage drops due to charge output degradation.
- Test for estimated possible deployment time.
    - Battery life approximately 8.3 hours.



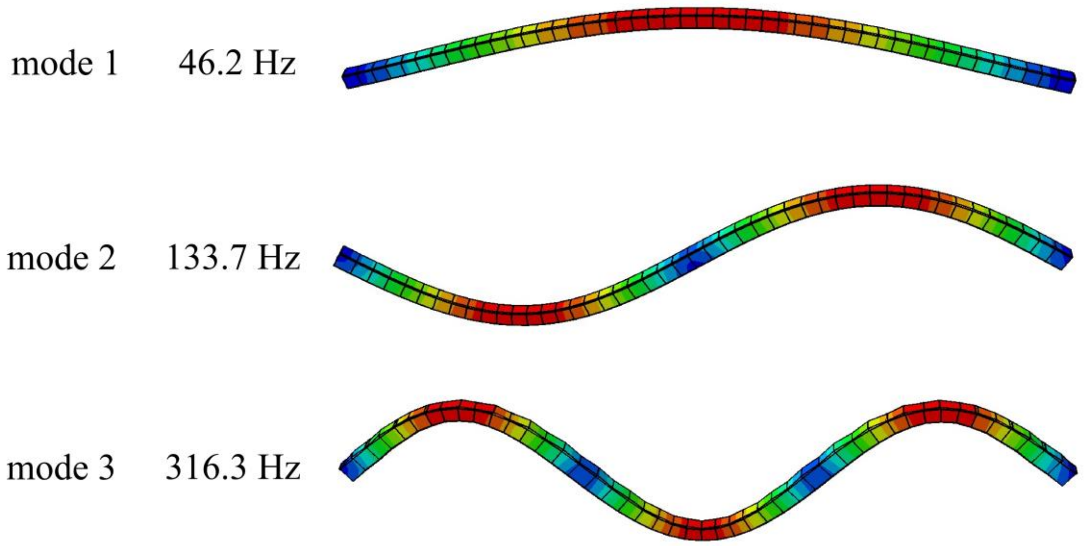
Trigger latency testing

- Investigation into trigger latency between two sensor packages.
- Measured using high-resolution oscilloscope and wireless trigger command.
- Time difference recorded over multiple iterations, normalized as percentage.
- Latency influenced by antenna orientation and distance between transmitter and receivers.
- System latency mainly below 10 microseconds.



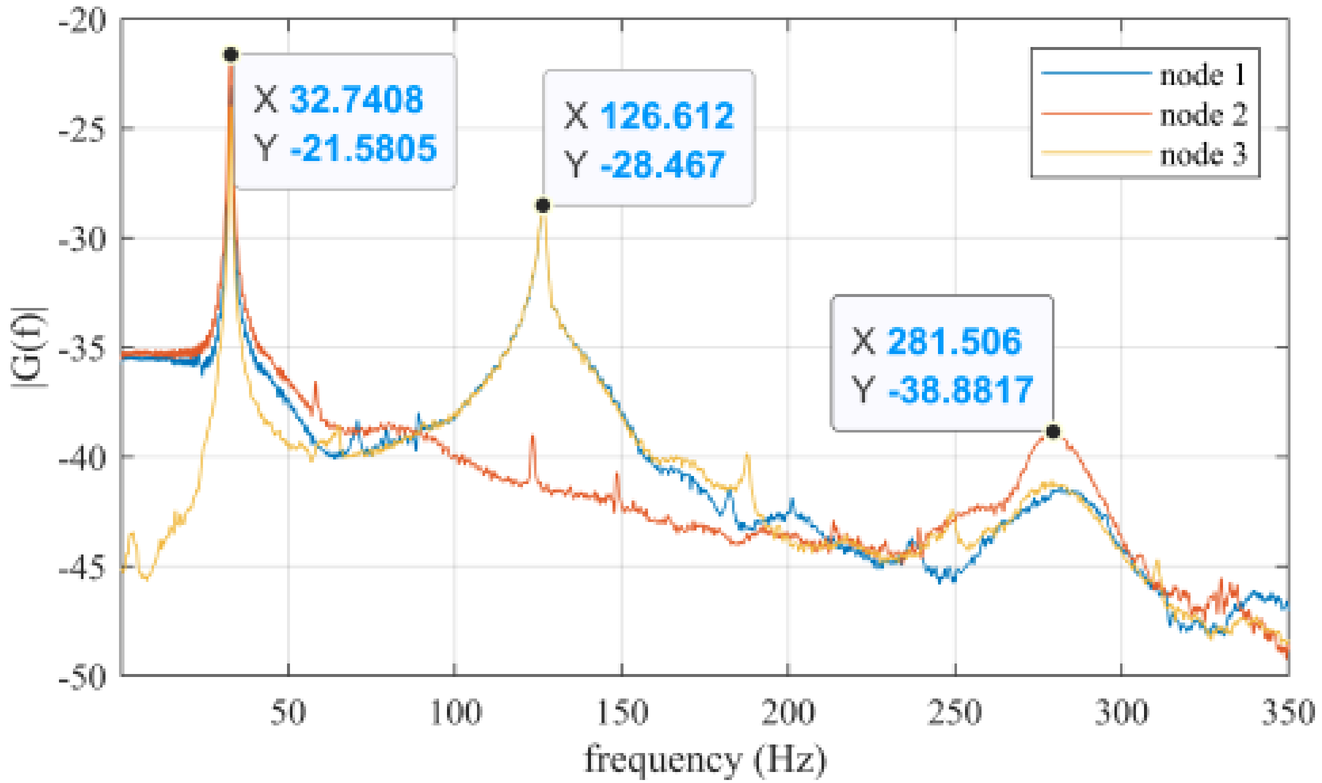
Beam testing

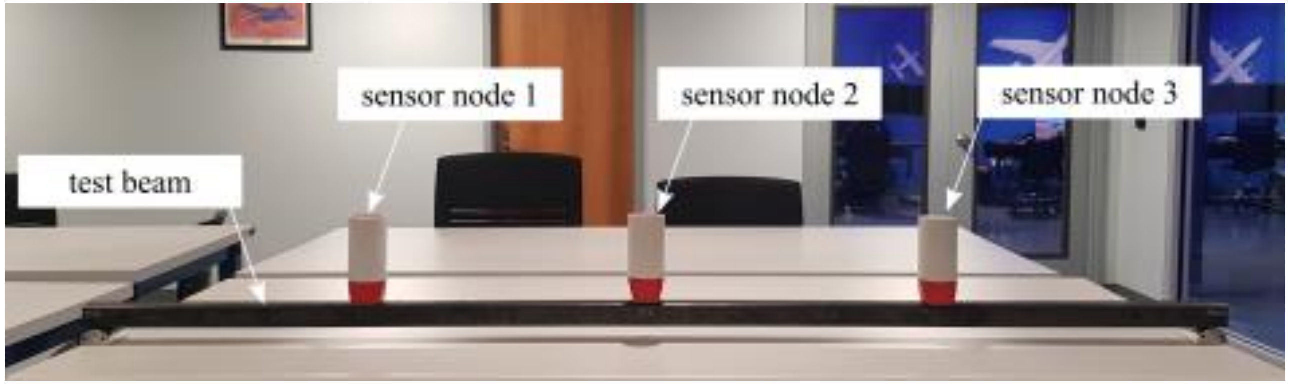
- Validation of the sensor network’s ability to determine mode shapes of a structure.
- Model used: simple square beam with roller supports.
- Model done using finite element modal analysis on a software.
- Model estimated first three modal frequencies: 46.2 Hz, 133.7 Hz, 316.3 Hz.



Beam testing

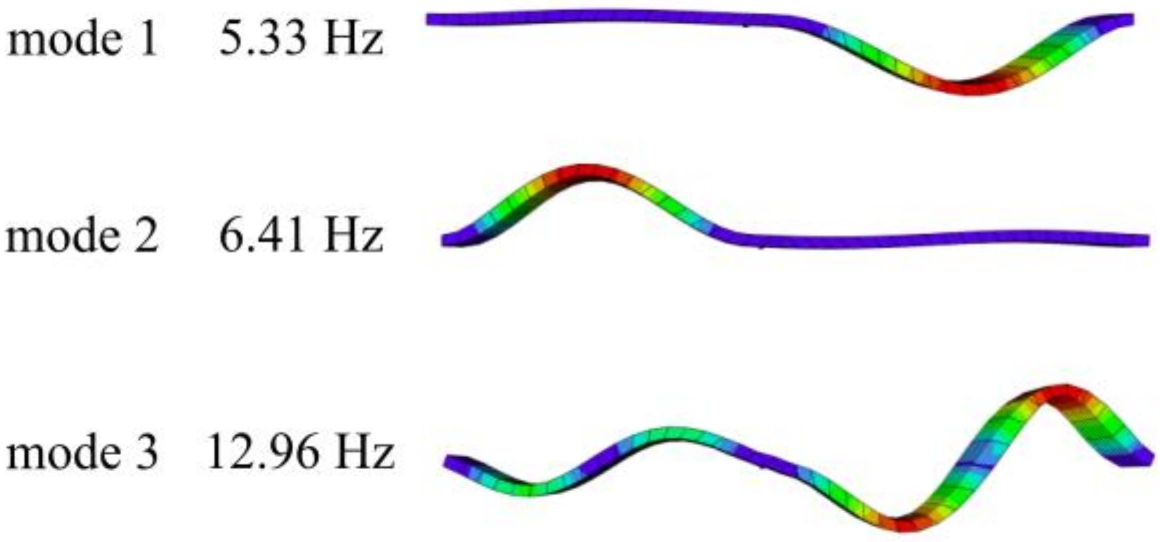
- Three sensor nodes and wireless transmitter used.
- Sensors mounted at antinodes for highest signal strength.
- Beam excited with impulse response and data collected.
- Time-domain data converted to frequency domain.
- Three peaks found in frequency domain.
- Mode 1: 32.7 Hz
- Mode 2: 126.6 Hz
- Mode 3: 281.5 Hz





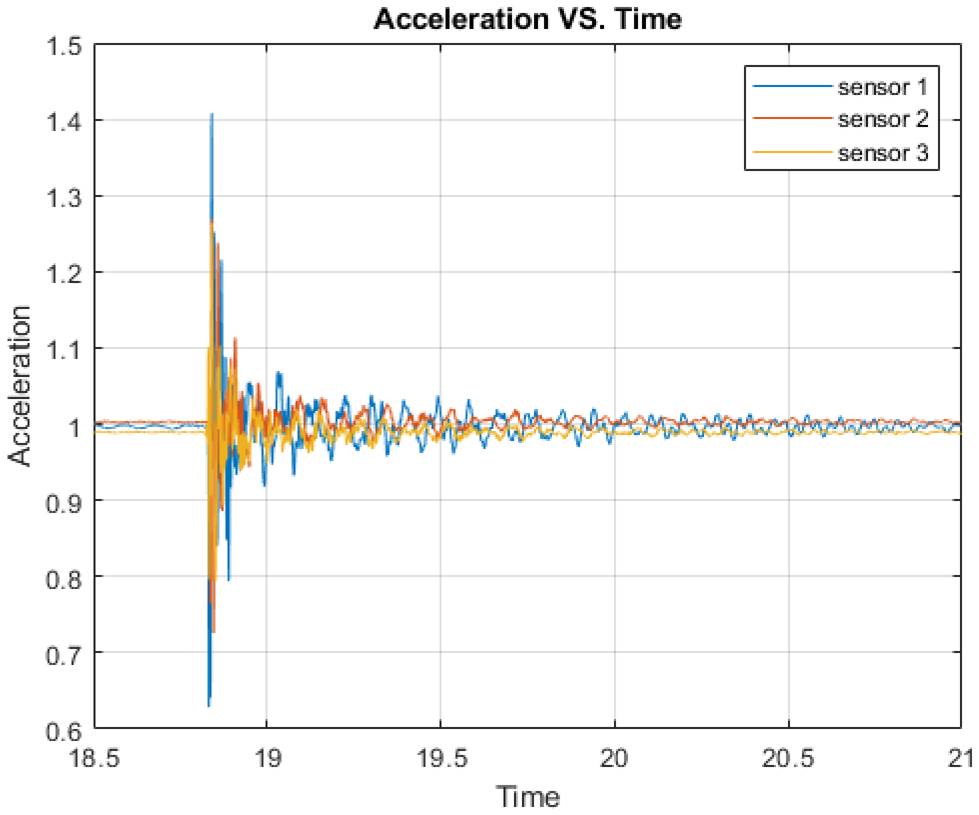
Structure test (pedestrian bridge)

- Finite Element Analysis of the bridge.
- 3D model of the bridge constructed in FEA software.
- Modeled the boundary conditions, measurements, material properties, and meshing.
- Simulated modal analysis.
- Mode shapes and frequencies extracted.
- Mode 1: 5.3 Hz
- Mode 2: 6.41 Hz
- Mode 3: 12.96 Hz



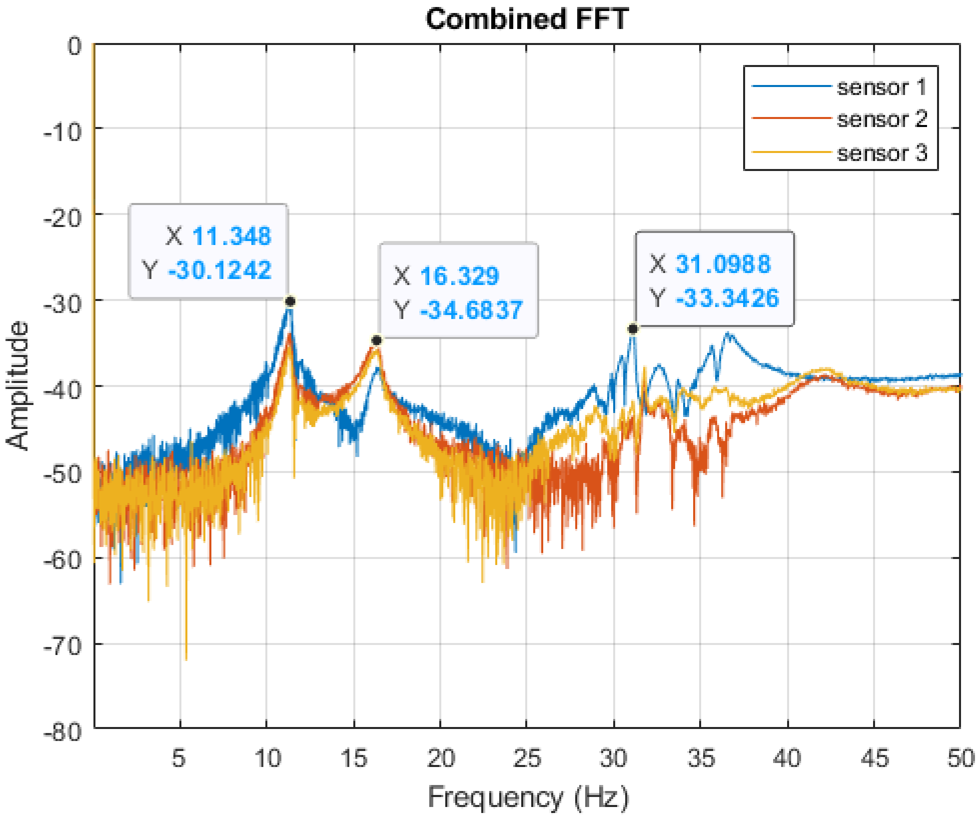
Structure test (pedestrian bridge)

- Experimental procedure:
  - Three sensor packages mounted onto the bridge.
  - Bridge excited with modal hammer.
  - Multiple tests with impacts at different locations.



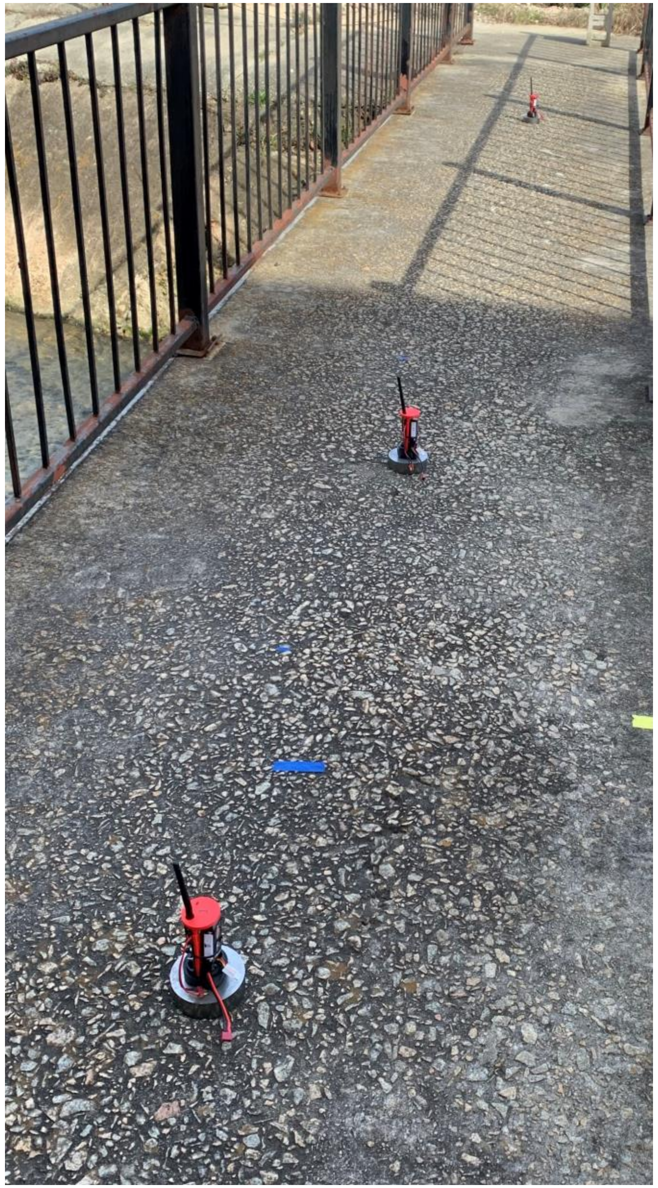
Experimental outcomes

- Structure test (pedestrian bridge):
    - FFT data from the impact tests.
        - Some peaks are distinguishable as possible modal frequencies.
        - Experimental frequencies: 11 Hz, 16 Hz, 31 Hz.

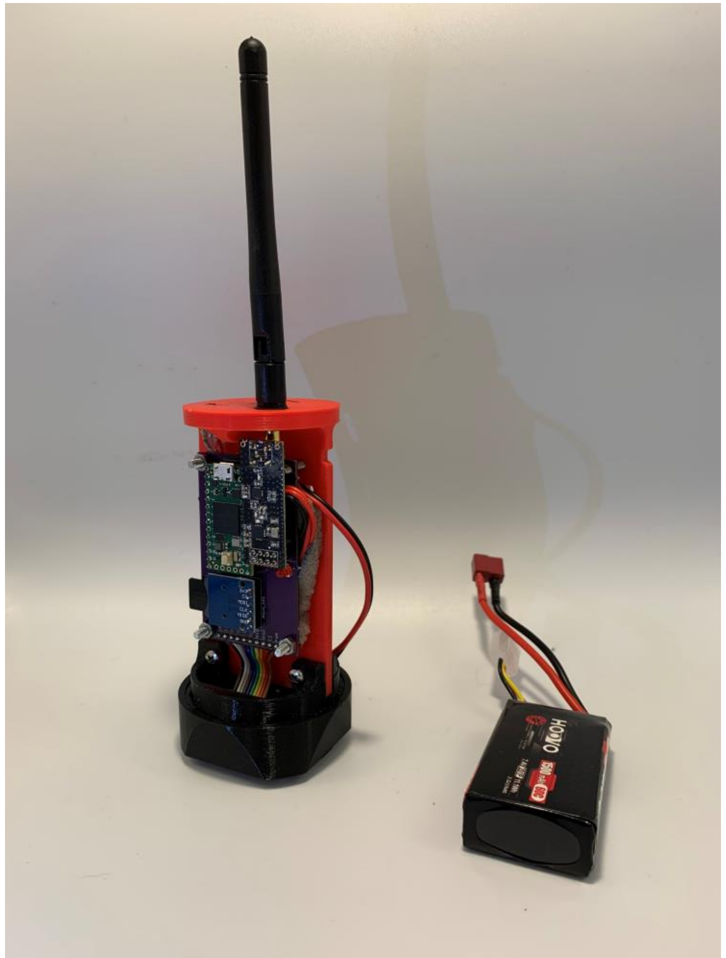


Conclusions and Overview

- Examined an open-source high-mobility sensor network for structural health monitoring.
- Potential to be reliable tool for vibration analysis.
- Optimal for UAV deployment where human access is difficult.
- Can be quickly deployed for rapid assessment.
    - Example: after extreme weather
- Limitations: lack of certainty of wireless latency.



- **Future work**
  - Sensor improvement
    - Improve wireless triggering latency.
    - Investigate RTC synchronization for data alignment.
    - Enhance sensor package compact footprint.
    - Optimize power consumption for longer deployment.
    - Add more sensors for a larger network.
    - Integrating data storage and processing for easier analysis and visualization.



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Drone-Delivered-Vibration-Sensor

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

Thank you

Questions?

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