UAV-deployable Vibration Sensing Nodes

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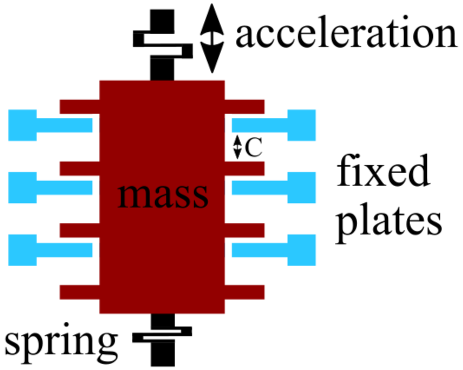
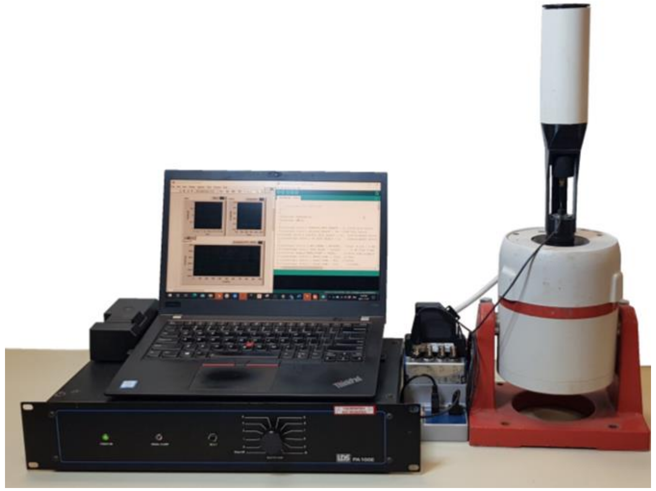
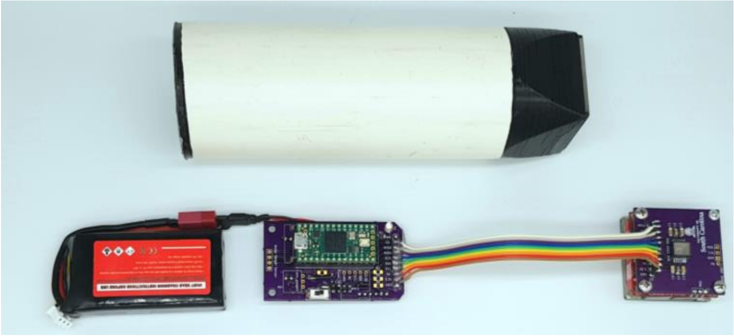
Methodology | Experimentation | Results and Discussion | Future work

Outline

- Methodology:
  - Sensor node overview
    - Features
    - Hardware
    - Algorithm
  - Deployment and retrieval system
  - White noise-based filter
    - Method and assumptions
    - Model training
- Experimentation:
  - UAV deployment mission
  - Structural vibration tests
- Results and Discussion:
  - Experimental outcomes
  - Findings and limitations
- Future work:
  - Sensor enhancement
  - Autonomy

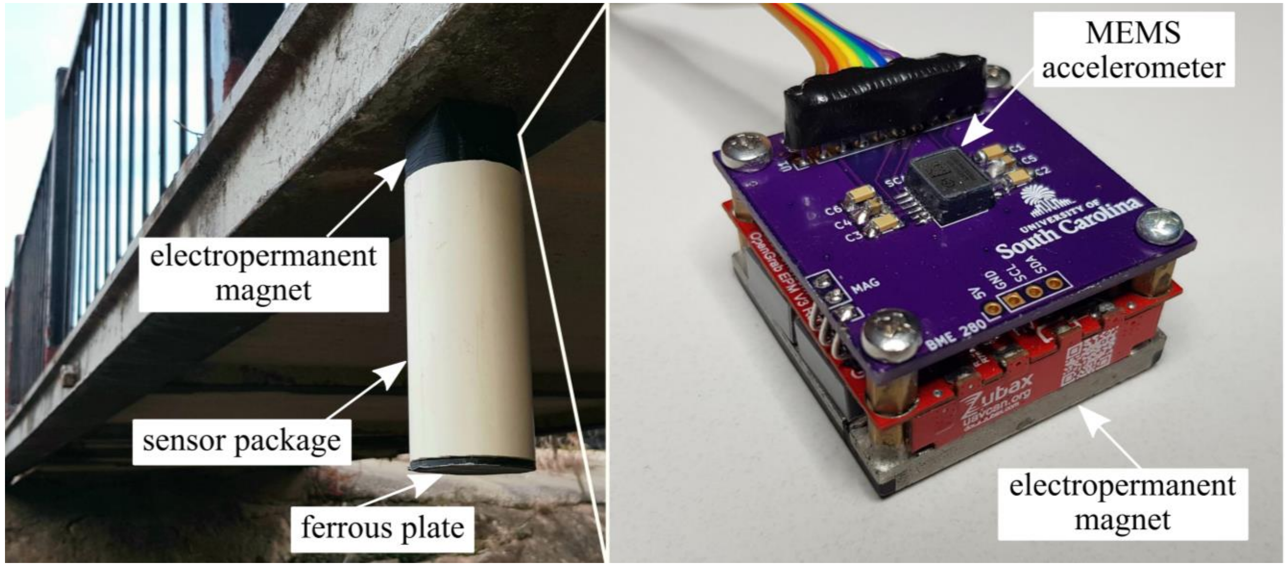






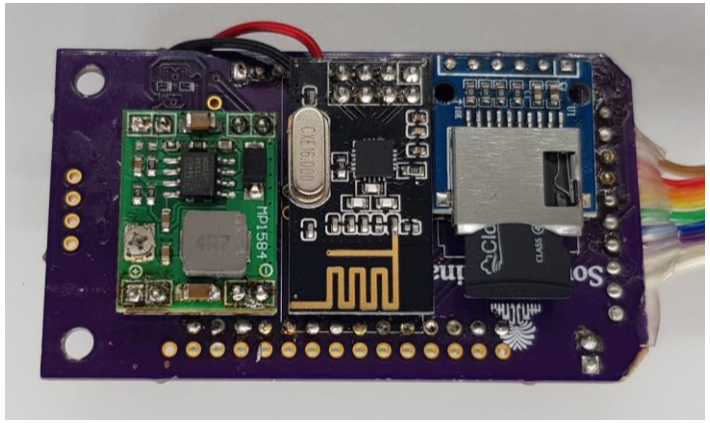
Introduction

- Sensor networks in structural health monitoring.
- Current systems and their features.
- Problem statement:
  - Rapid large-scale deployment.
  - Endurance and system robustness.
  - Signal quality and noise mitigation.
- Proposed approach:
  - Drone Deployment and Retrieval System (DDRS) for rapid structural health monitoring.
  - Power management and error handling protocols.
  - White noise-based transfer function compensation method.



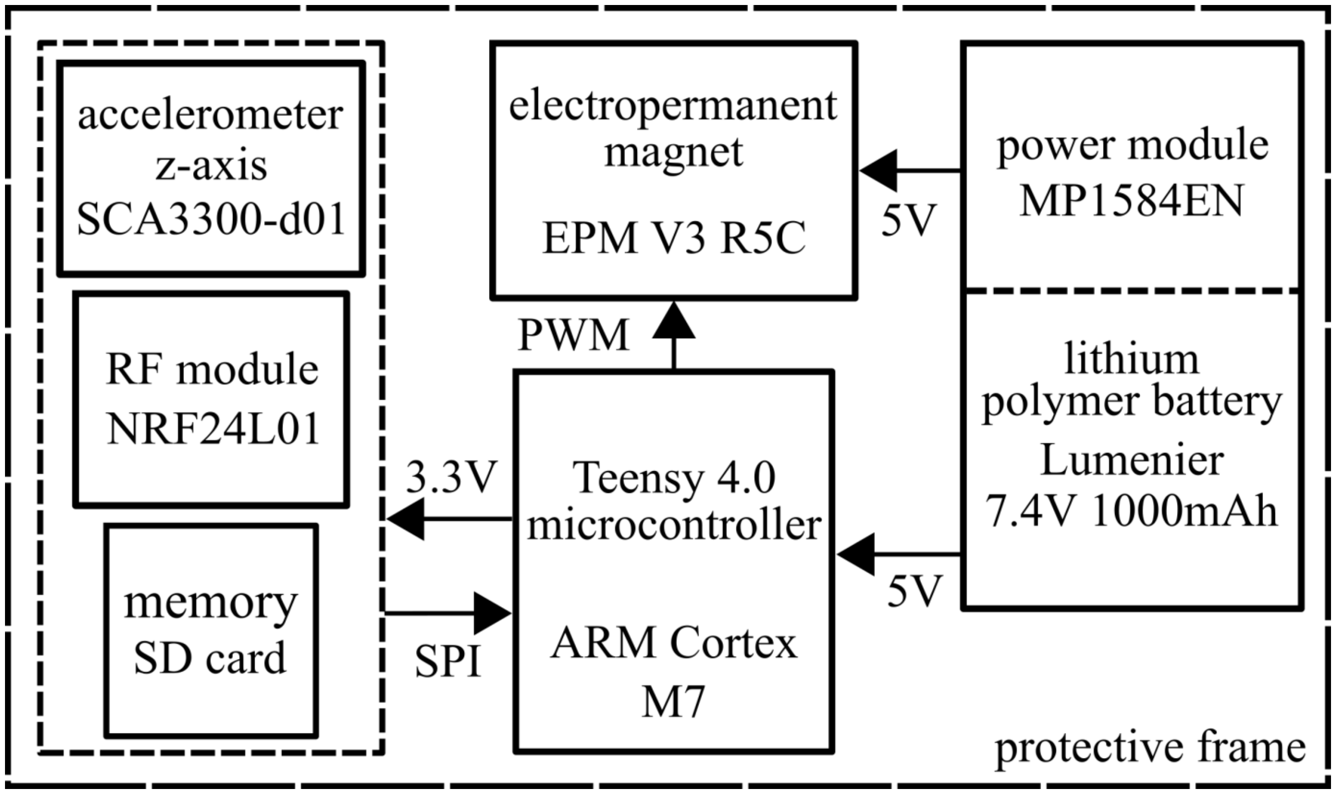
Sensor node breakdown

- Features:
  - High-mobility robust sensor node
  - Aerially deployable via DDRS
  - Power management for long deployment periods
  - Nonvolatile memory storage.
  - Wireless subsystem for data transmission and IO commands.
  - Noninvasive docking system utilizing electropermanent magnets.
  - Accelerometer maximum sampling rate 28 kS/s.
  - Sensor frame designed to minimize transmissibility loss.



Sensor node breakdown

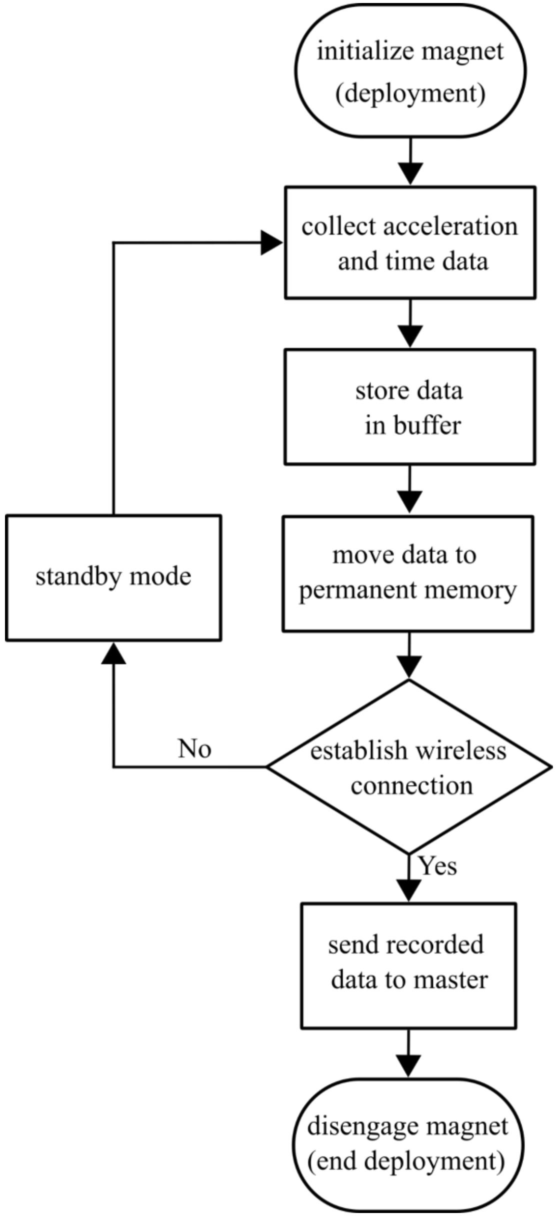
- Hardware:
  - Processor: ARM Cortex-M7 on Teensy 4.0 microcontroller.
  - SCA3300-d01 MEMS accelerometer.
  - EPM V3R5C electropermanent magnet.
  - Nonvolatile memory (SD card) for long-term storage.
  - Lithium polymer battery, voltage regulation and monitoring.
  - NRF24L01 Nordic Semiconductor wireless transceiver.



Sensor node breakdown

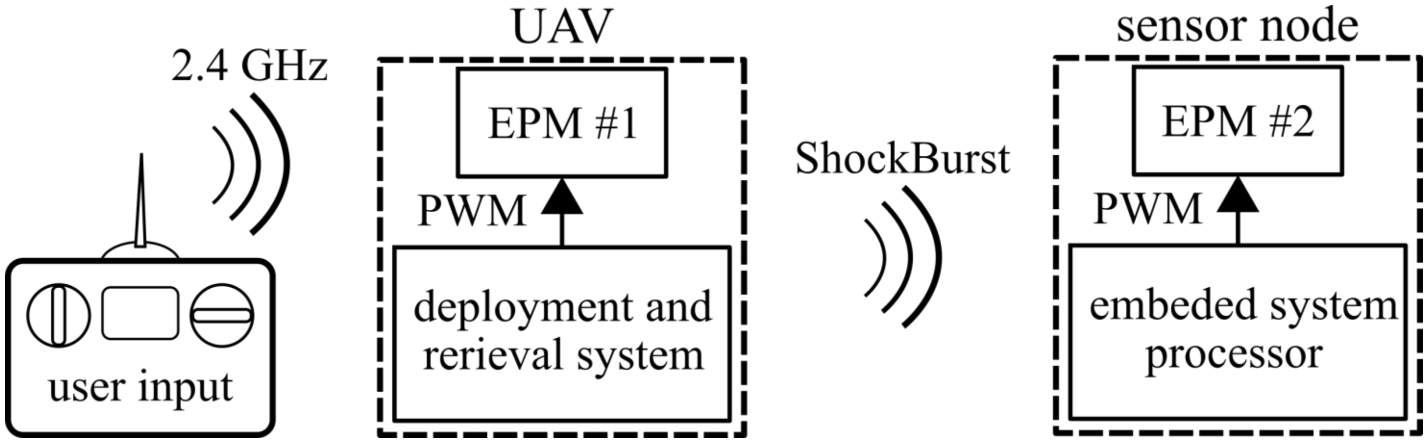
Developed on Arduino IDE and deployed on an ARM Cortex-M7 processor.

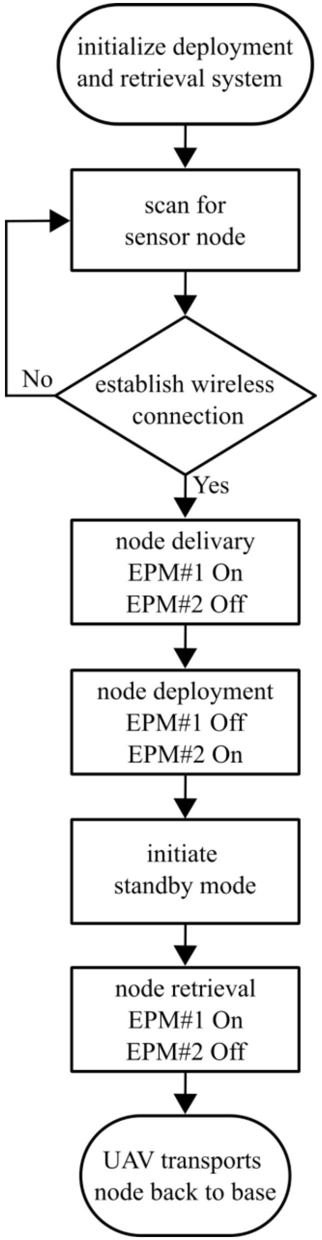
- Algorithm:
  - Initialize the magnet signaling start of deployment.
  - Acceleration data is periodically collected.
  - Data collected in a buffer to enable high sampling rates.
  - 74,000 timed samples are collected then transferred onto the memory.
  - Code initiates standby mode which turns modules off to conserve power.
  - Microcontroller and wireless module remain on for communication.



UAV deployment and retrieval system

- Delivery and retrieval sequence processor
  - Receive user command
  - Issue sequence to electropermanent magnets to secure or release package.
- Guiding rails to aid in safe retrieval
- Harness with electropermanent magnet to grip the package during flight





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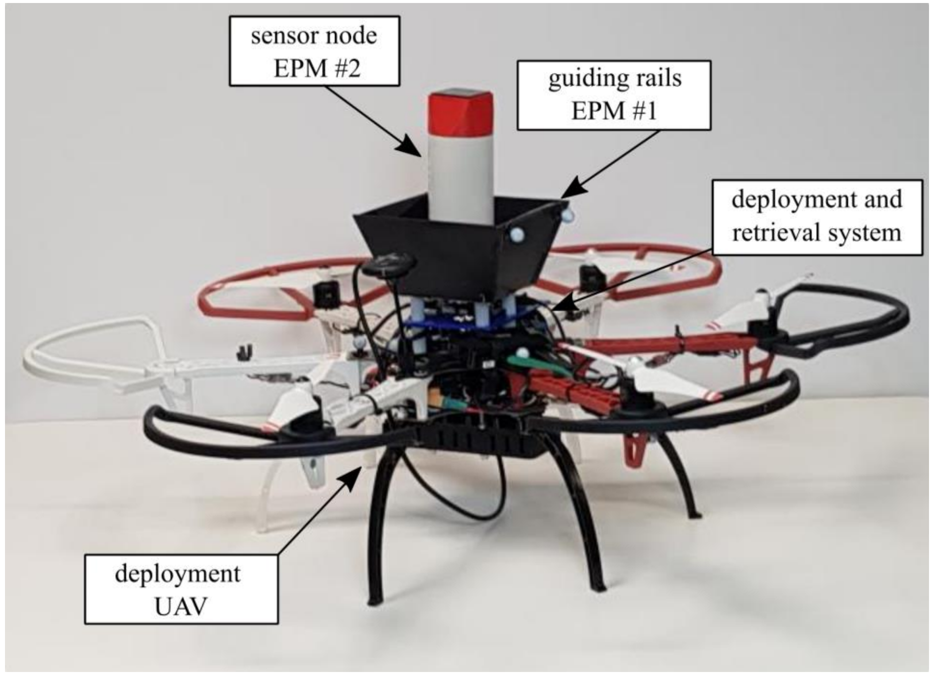
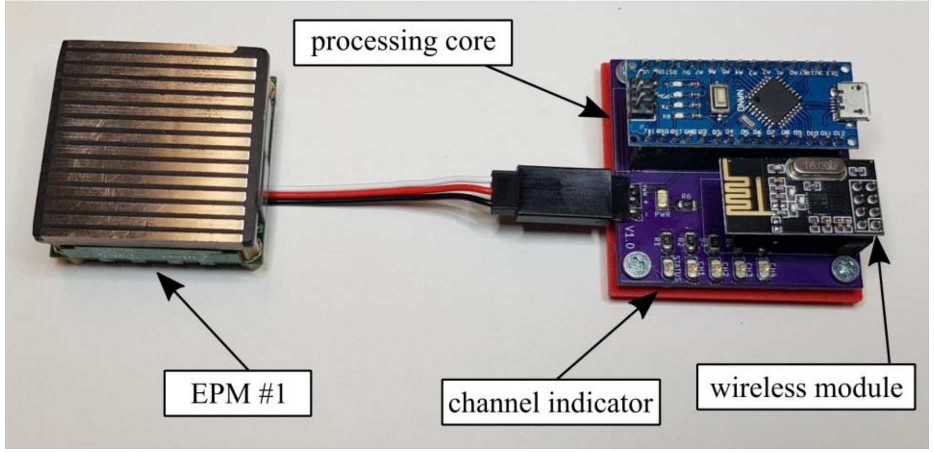
	EPM#1	EPM#2
Node delivery	On	Off
Node deployment	Off	On
Node retrieval	On	Off



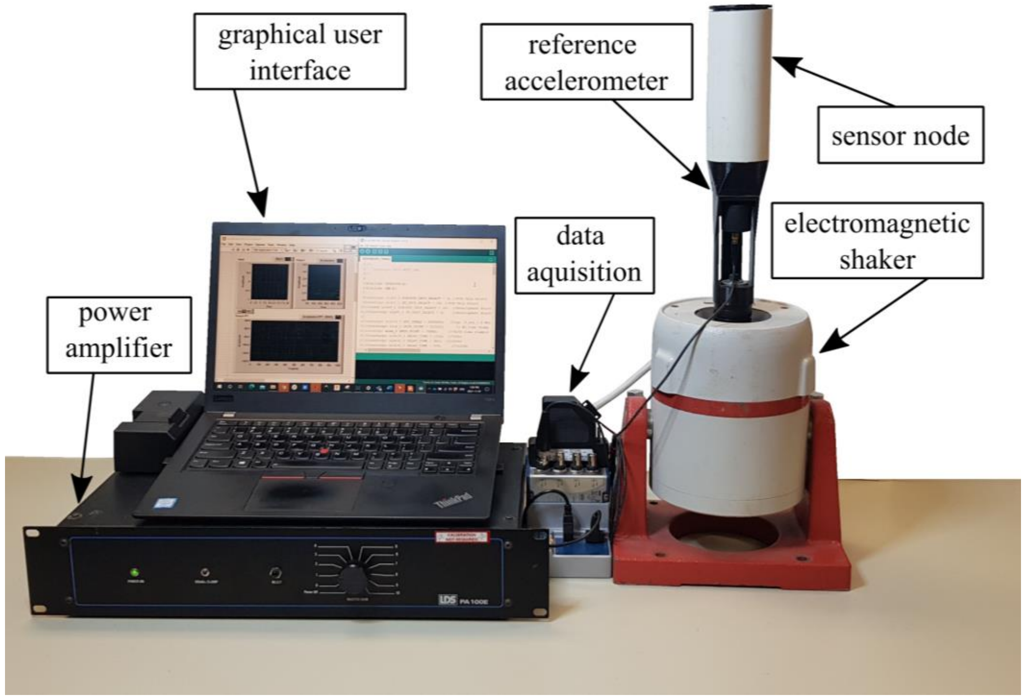


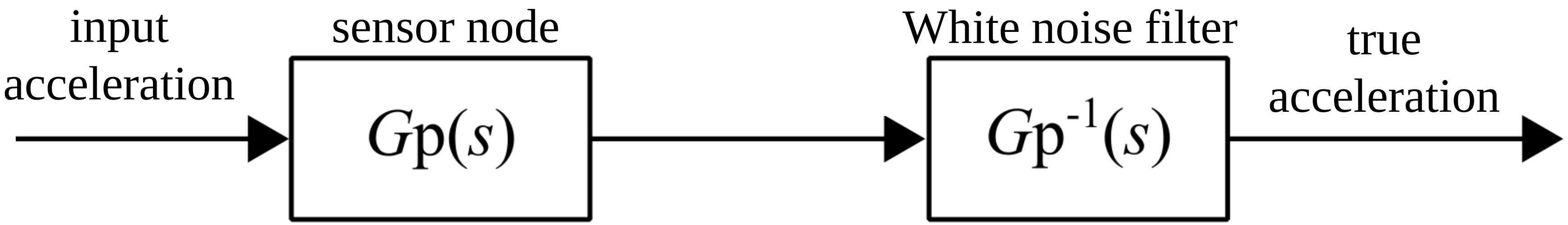
Deployment and retrieval

- Sensor node is loaded onto UAV docking system
- UAV approach structure
- Initiate EPM docking sequence
- UAV disengages
- Sensor node is deployed
- UAV approach sensor node after deployment period
- Guiding rails secure the node in harness
- Initiate EPM retrieving sequence
- UAV and sensor node retreat from the structure
- Deployment mission complete

White noise-based filter

- Approach and assumptions:
  - Input-output relationship is acquired using a limited bandwidth noise signal.
  - A Transfer function model of the physical sensor node ($Gp(s)$) is created.
  - Assumptions made about the plant $Gp(s)$:
    - Linearity
    - Causality
    - Minimal-phase system
  - An inversed Transfer function filter $Gp^{-1}(s)$ is created.
  - The plant's influence on the acceleration signal is attenuated using $Gp^{-1}(s)$
  - True acceleration obtained given only the output of $Gp(s)$.





White noise-based filter

- Model Training:
  - Using a synthetic white noise:

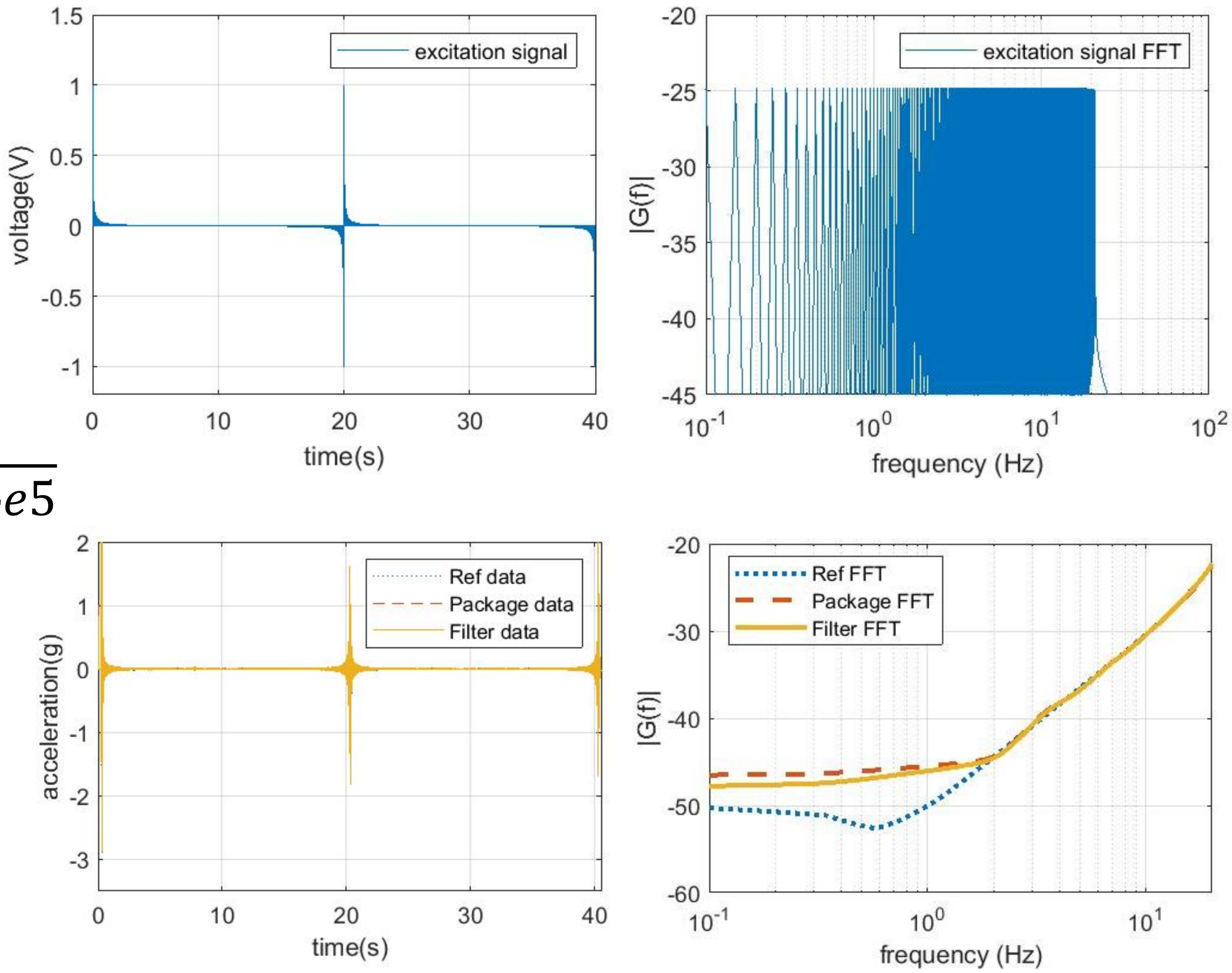
$$x(t) = a_0 \sum_{n=1}^{450} (\sin(0.1\pi n t))$$

  - Filter transfer function:

$$Gp^{-1}(s) = \frac{s^3 + 786s^2 + 1.664e5s + 2.197e5}{1.19s^3 + 7.121\mathrm{e}2s^2 + 1.687e5s + 3.994e5}$$

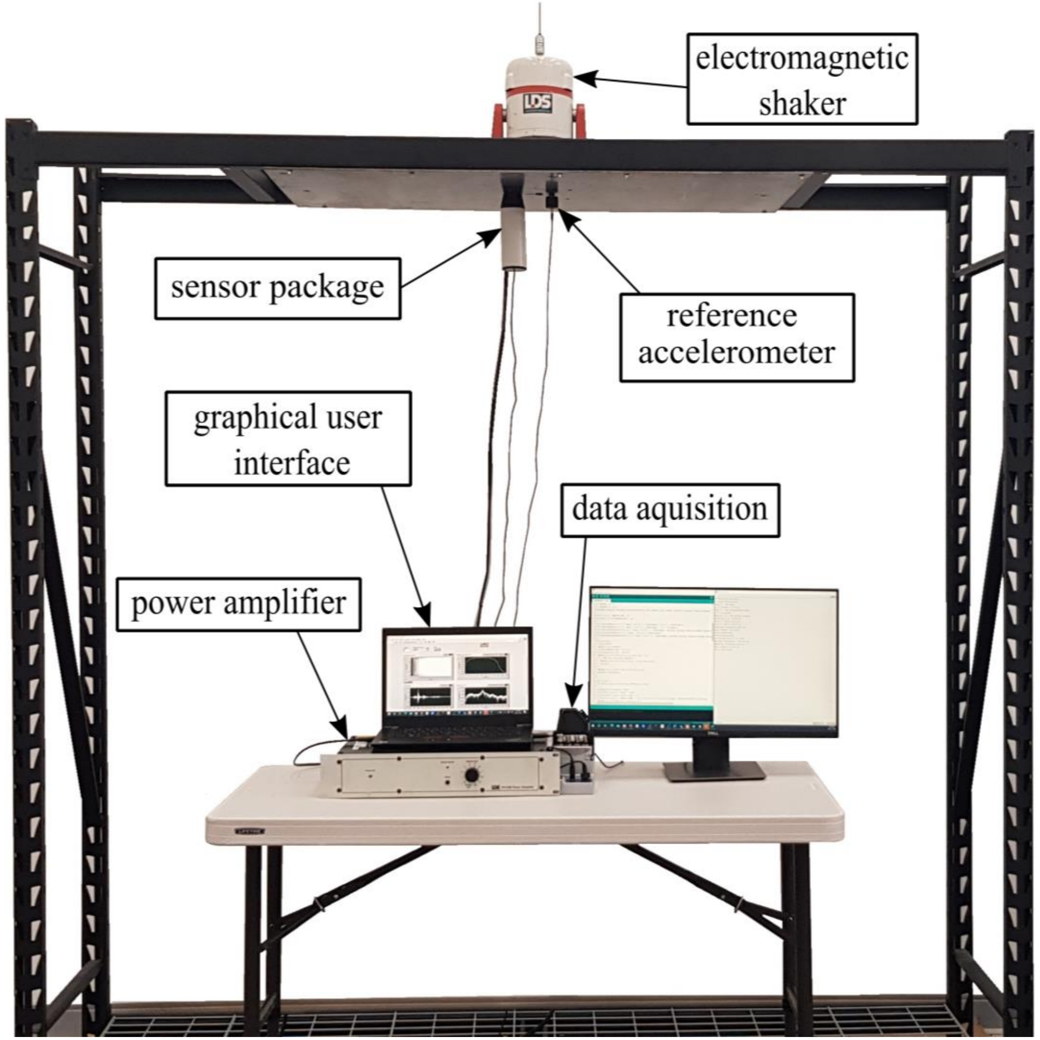
  - Signal-to-noise ratio:

$$\mathrm{SNR}_{\mathrm{dB}} = 10\log_{10}\left(\frac{\Sigma_{i=1}^{74000}(S(i))^2}{\Sigma_{i=1}^{74000}(N(i))^2}\right)$$



Structural vibration test 1

- Experimental procedure:
  - The sensor node and reference accelerometer are mounted to structure.
  - Source of excitation is an electromagnetic shaker secured on top of structure.
  - The node and reference accelerometers are triggered using a data acquisition system.
  - Synthetic white noise signal as excitation signal.
  - Sensor node data is examined with and without filtering to gauge performance.



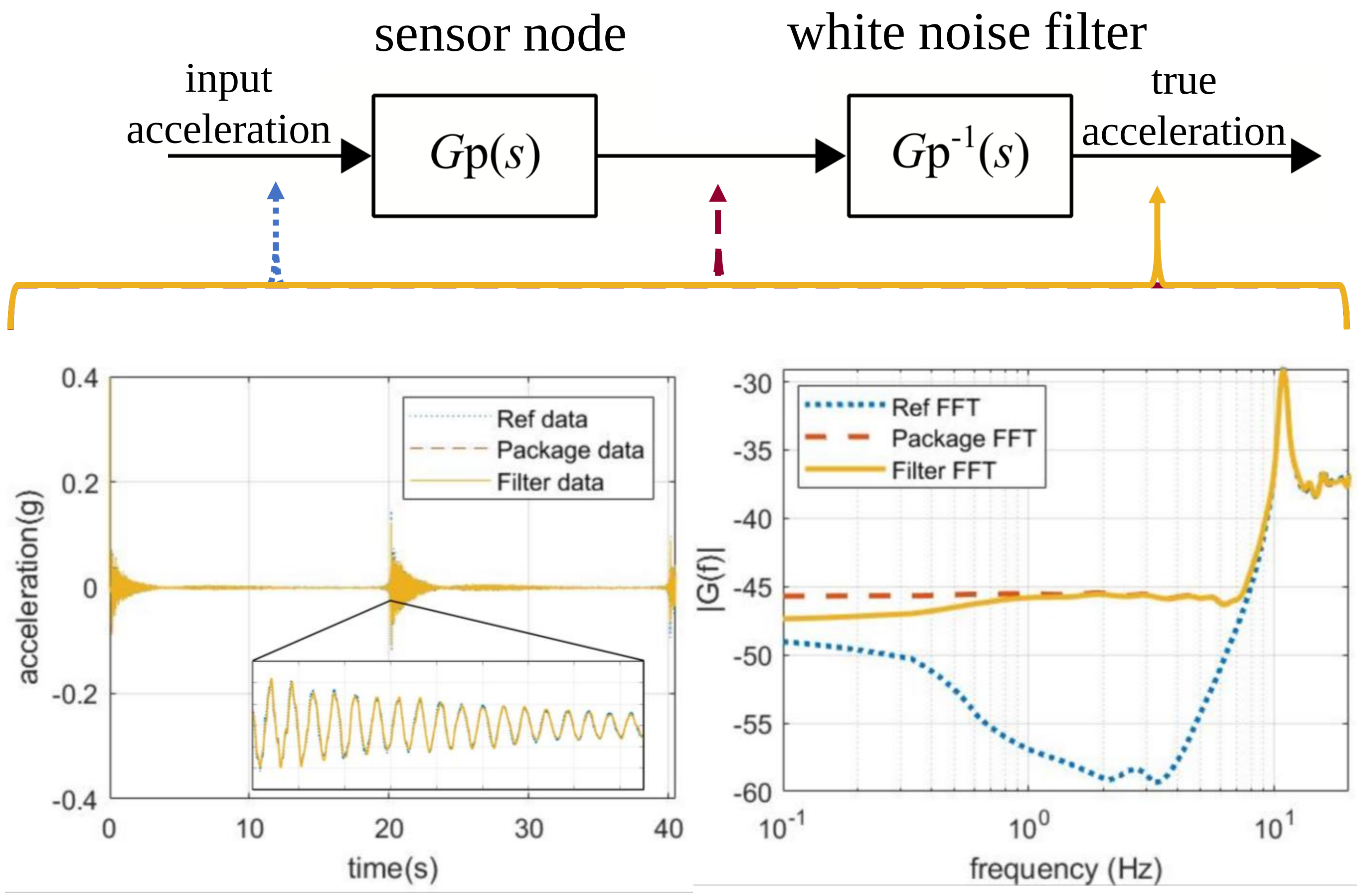
Structural vibration test 2

- Experimental procedure:
  - Sensor nodes and reference accelerometers are mounted onto structure.
  - Excitation source is a moving roller.
  - Data is collected simultaneously from all six sensors.
  - Sensor node vs reference frequency responses are investigated.

Structural vibration test 1

Experimental outcomes:
Pre Filter SNR = 6.6373dB
Post Filter SNR = 7.7415dB
SNR increase = 1.1042dB = 16.6365%

Findings and limitations:
- Enhancing signal is feasible using a pretrained transfer function model.
- Model performance is limited to the bandwidth of training
- Phase data is not accounted.



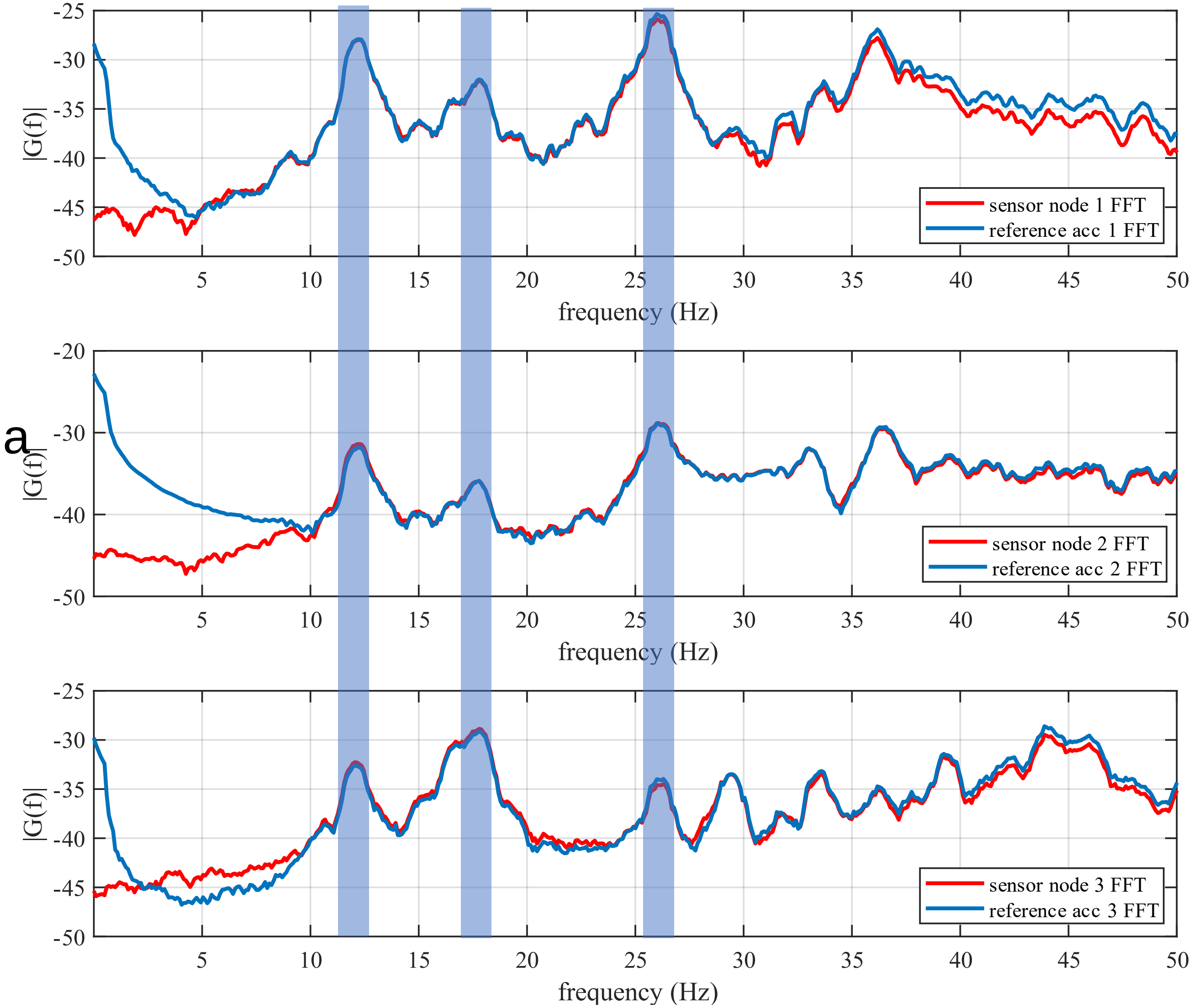
Structural vibration test 2

Experimental outcomes:

- First three modes of the structure were detected.
- Vibration signature of structure is validated via the sensor network.

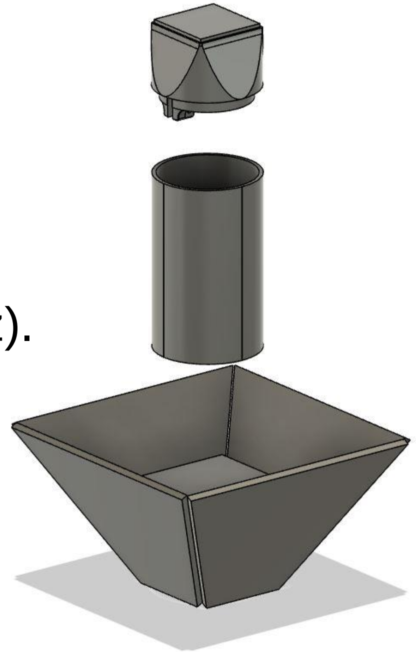
Findings and limitations:

- Low frequency resolution limitations
- Nondeterministic trigger timing
- Sturdy contact with structure is vital to vibration measurement



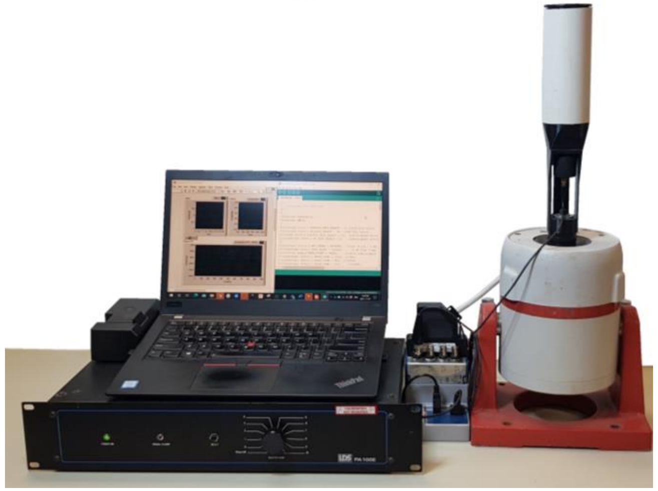
Future work

- Further enhance the signal-to-noise ratio.
- Decrease trigger timing jitter (Real-time implementation).
- Increase sensor node resolution in low frequency scale (<5 Hz).
- On-edge transfer function filter implementation.
- Develop a fully autonomous UAV delivery system



This project is open source and made available at

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



Thank you

Questions?

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