Case Study for using Open-Source UAV-deployable Wireless Sensor Nodes for Modal-based Monitoring of Civil Infrastructure

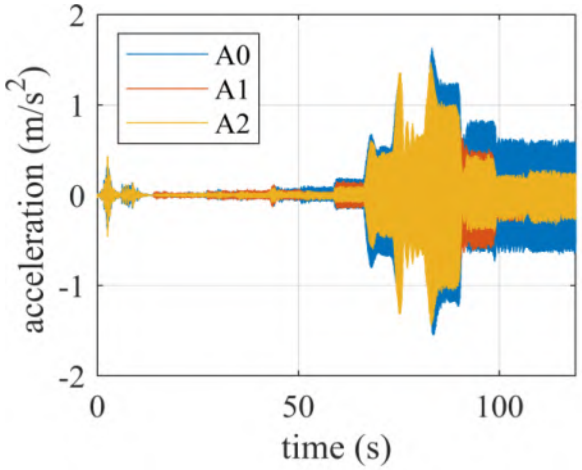
Joud Satme; Department of Mechanical Engineering
Ryan Yount; Department of Mechanical Engineering
Jason Smith; Department of Mechanical Engineering
Austin R.J. Downey; Department of Mechanical, Civil and Environmental Engineering

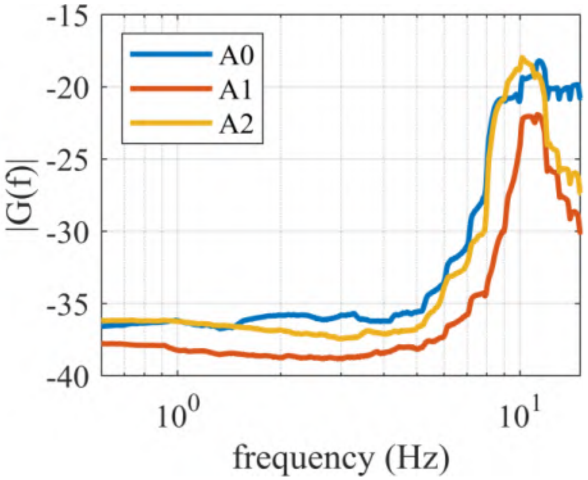
UNIVERSITY OF SOUTH CAROLINA

Methodology → Experimentation → Results and Discussion → Future work

Outline

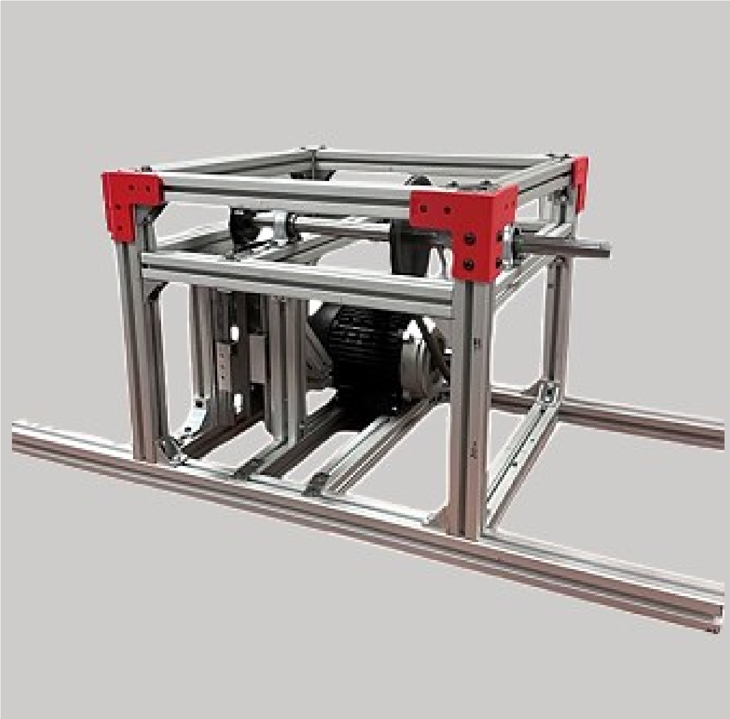
- Introduction:
  - rapid structural health monitoring
  - modal analysis for structural state estimation
  - rapid SHM sensing systems
- Methodology:
  - UAV-deployable sensor hardware
  - sensing network algorithm breakdown
  - active SHM using external excitation
- Experimentation:
  - case study of active modal detection using UAV-deployable sensing network on a pedestrian bridge
- Results and Discussion:
  - time and frequency responses
  - sensing system strengths and experimental challenges
- Future work:
  - sensor network algorithm enhancements
  - rapid modal reconstruction on-edge





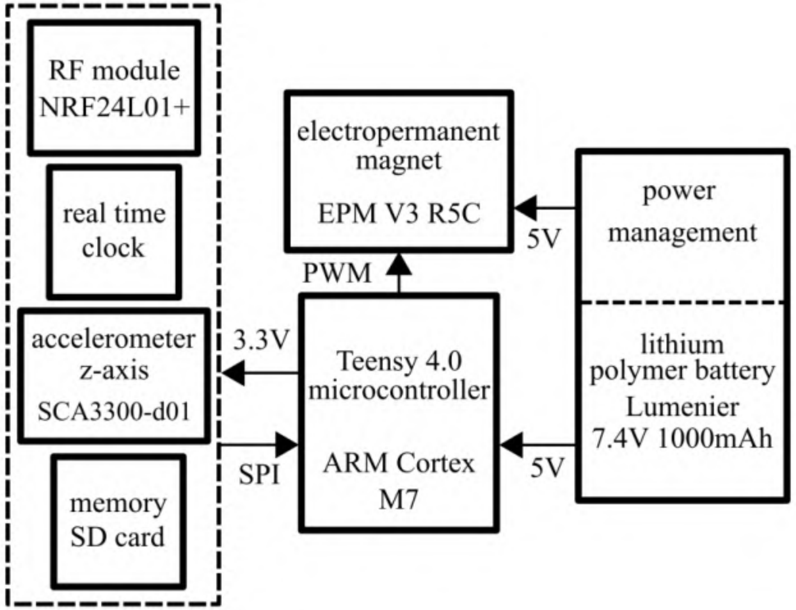
Introduction

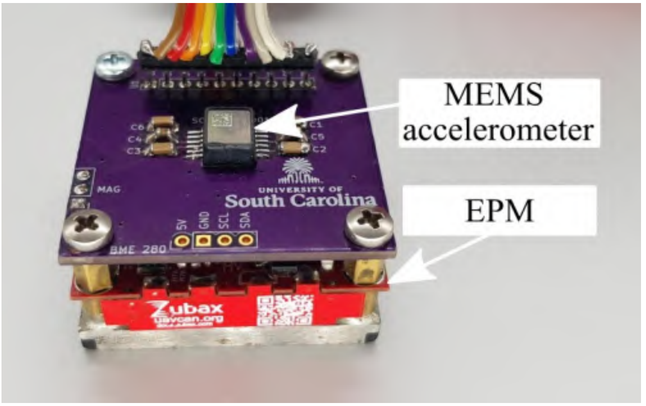
- rapid structural health monitoring
- modal analysis for structural state estimation
- rapid SHM sensing systems

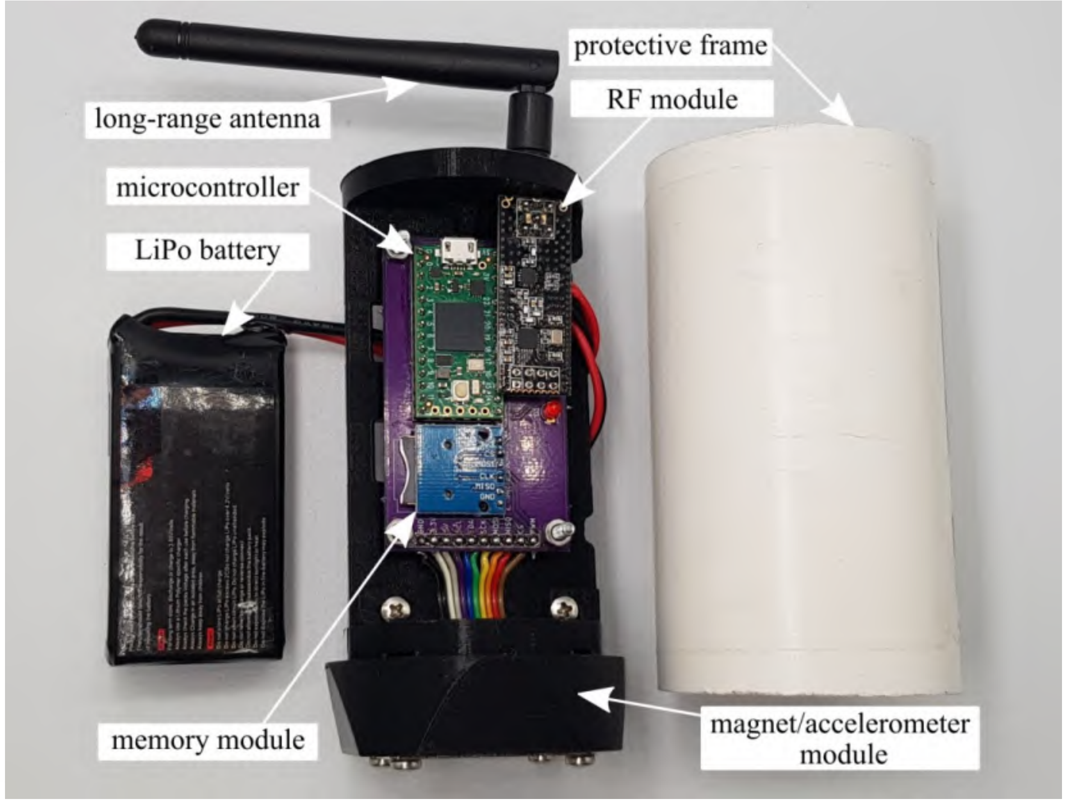


UAV-deployable sensor hardware

- features:
  - MEMS accelerometer-based sensor
  - standalone power system
  - multi-link wireless communication
  - independent nonvolatile memory
  - real-time reference for data logging
  - electropermanent magnet-based docking
  - UAV-deployable capabilities

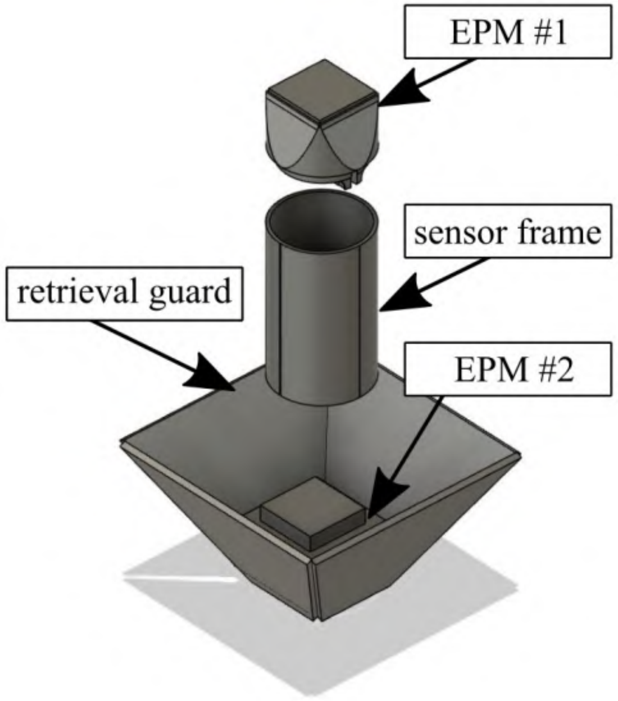






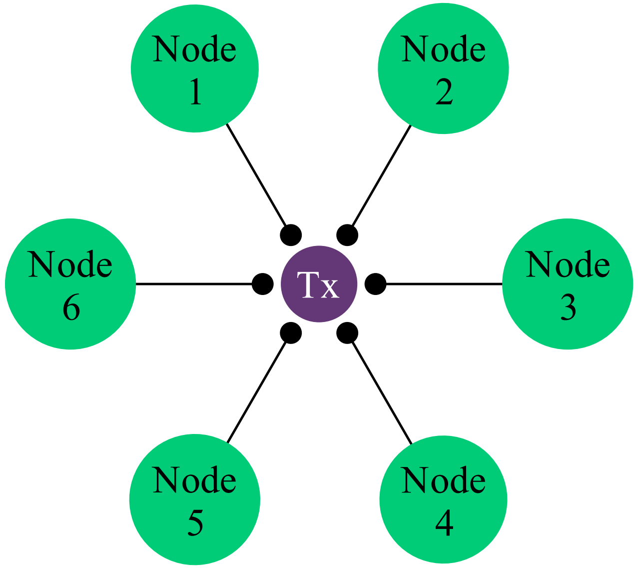
UAV-deployable sensor hardware

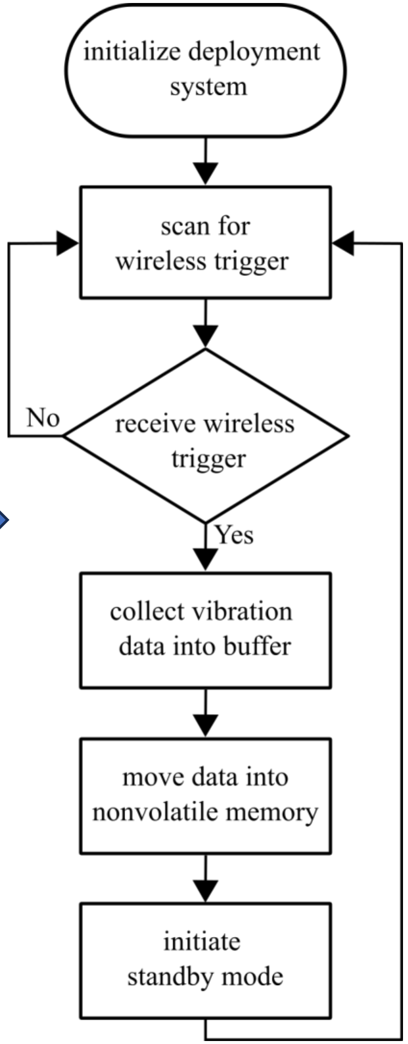
- Deployment and retrieval system
  - Hexcopter drone
  - Two electro permanent magnets
  - Retrieval guard
  - Standalone control system



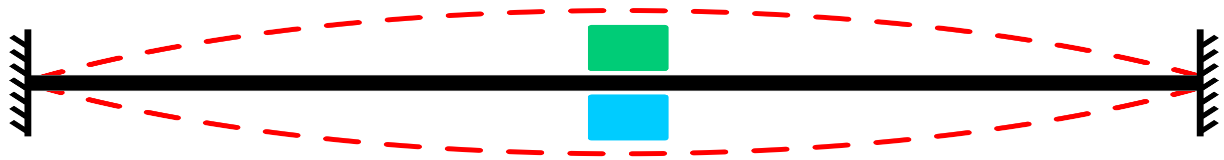
sensing network algorithm breakdown

- protocol: Enhanced ShockBust
- bandwidth: 2.4 GHz
- data rate: 2 Mbps
- RF links: 6 channels



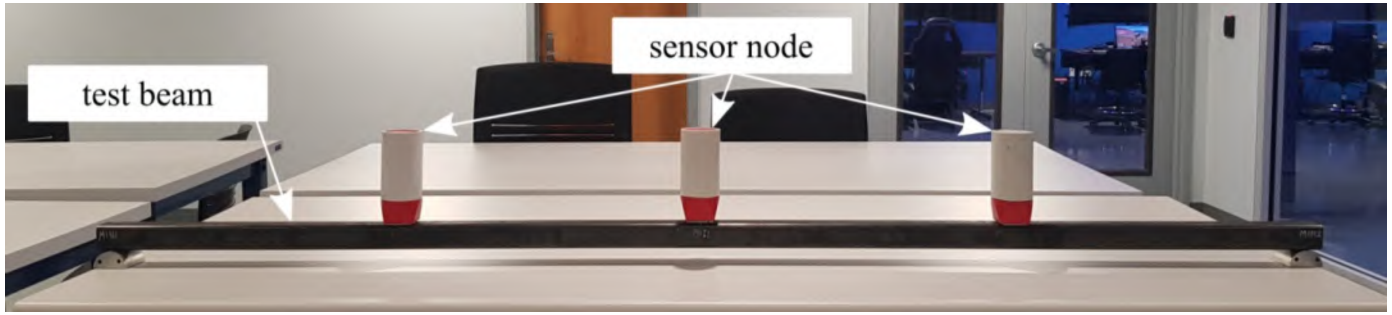


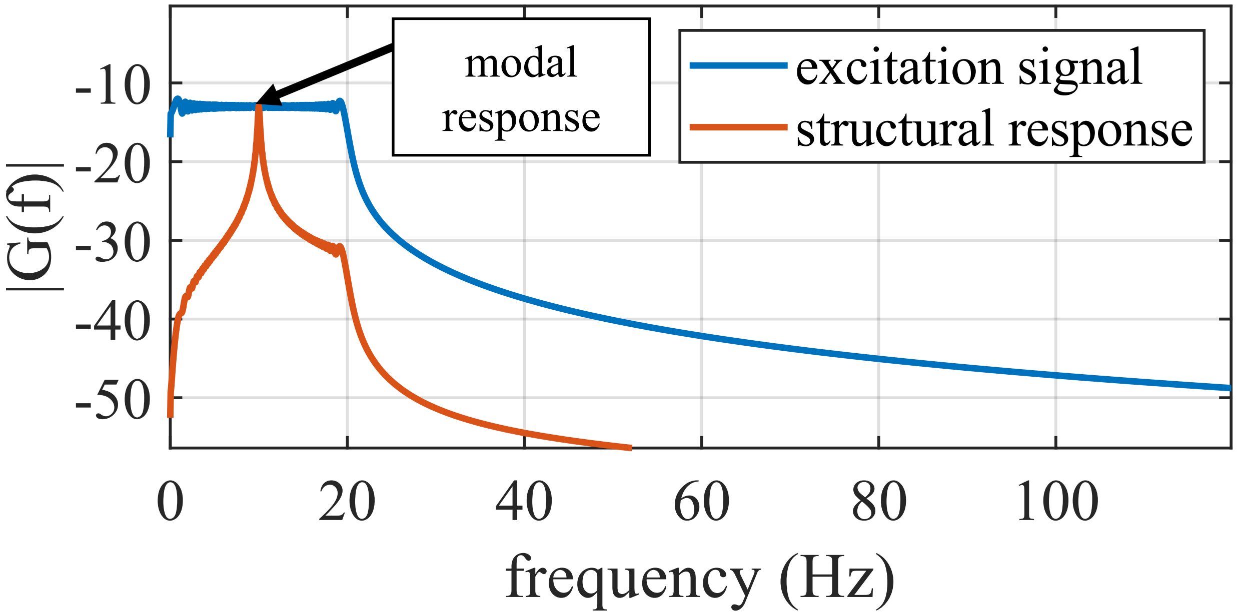
- structural shaker
- sensor package



active SHM using external excitation

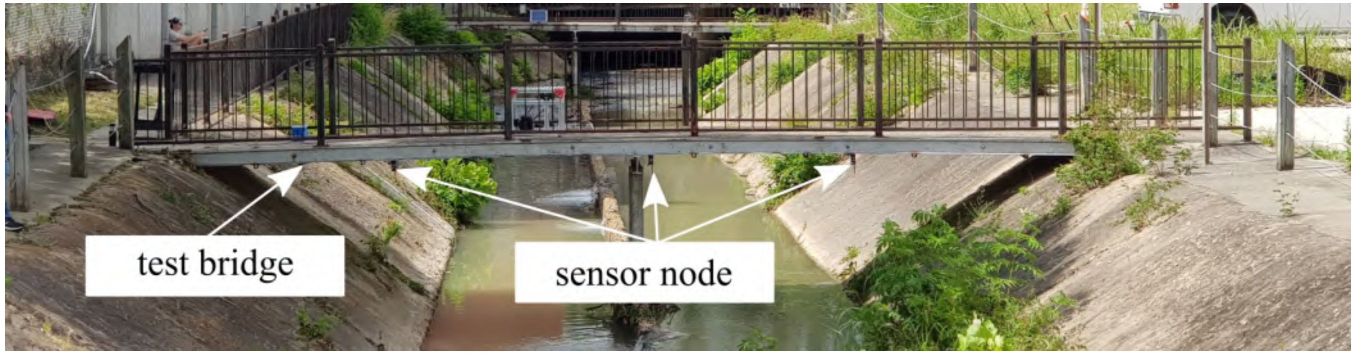
- sensors and actuators
- data acquisition and signal processing
- dynamic response and modal detection

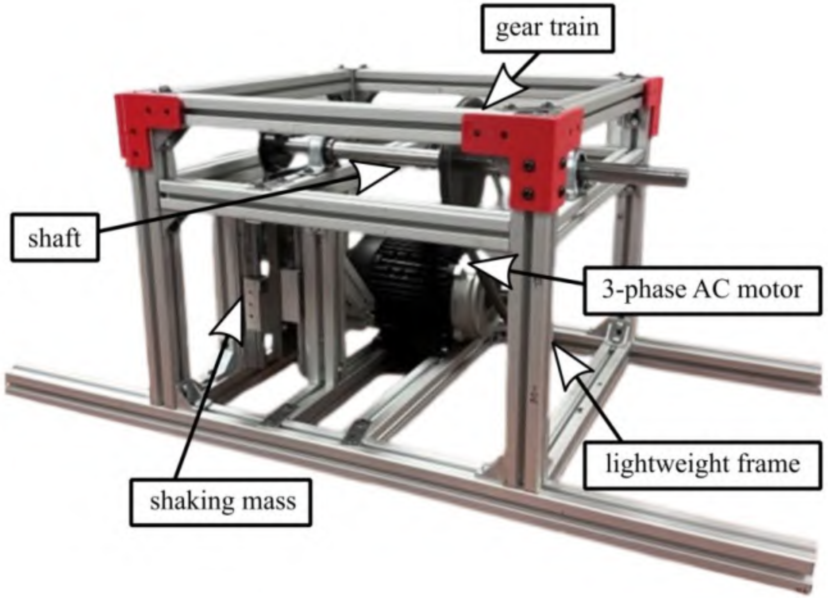


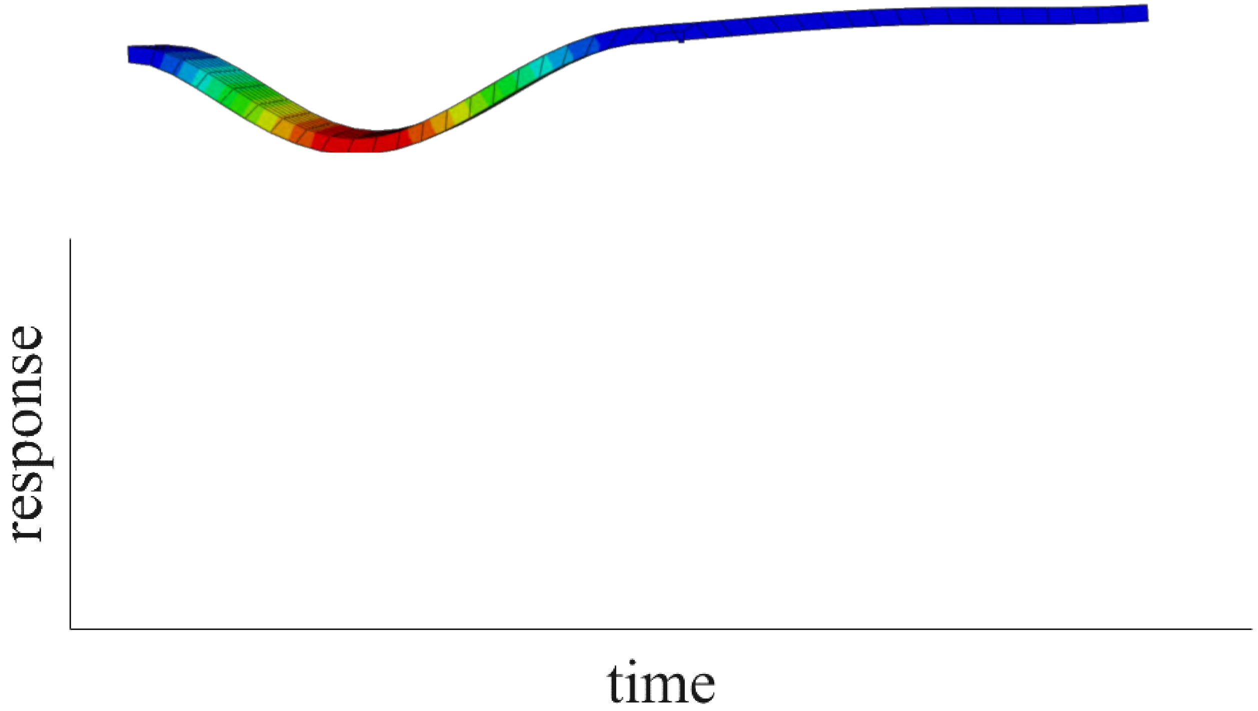


active modal detection using UAV-deployable sensing network

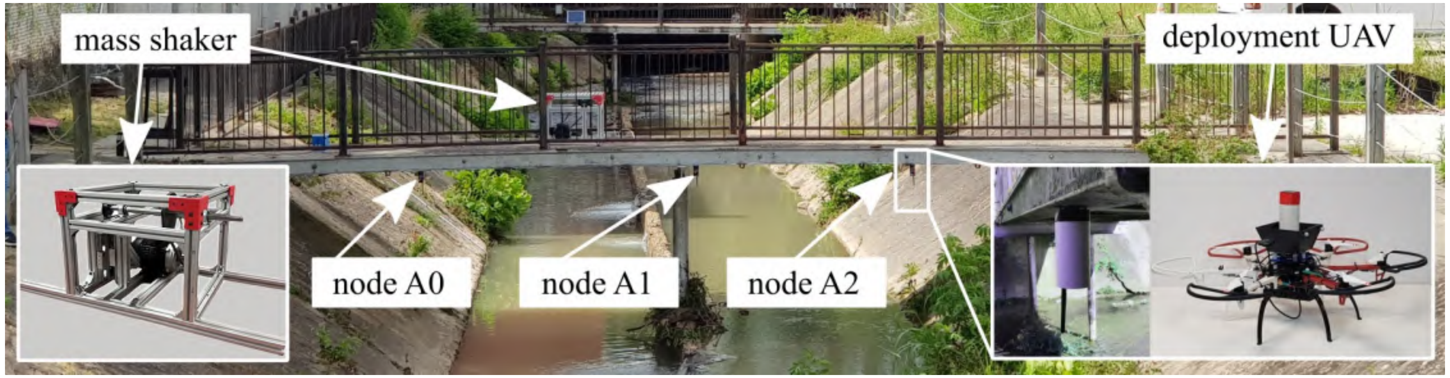
- data acquisition and real-time synchronization
- signal processing and state estimation

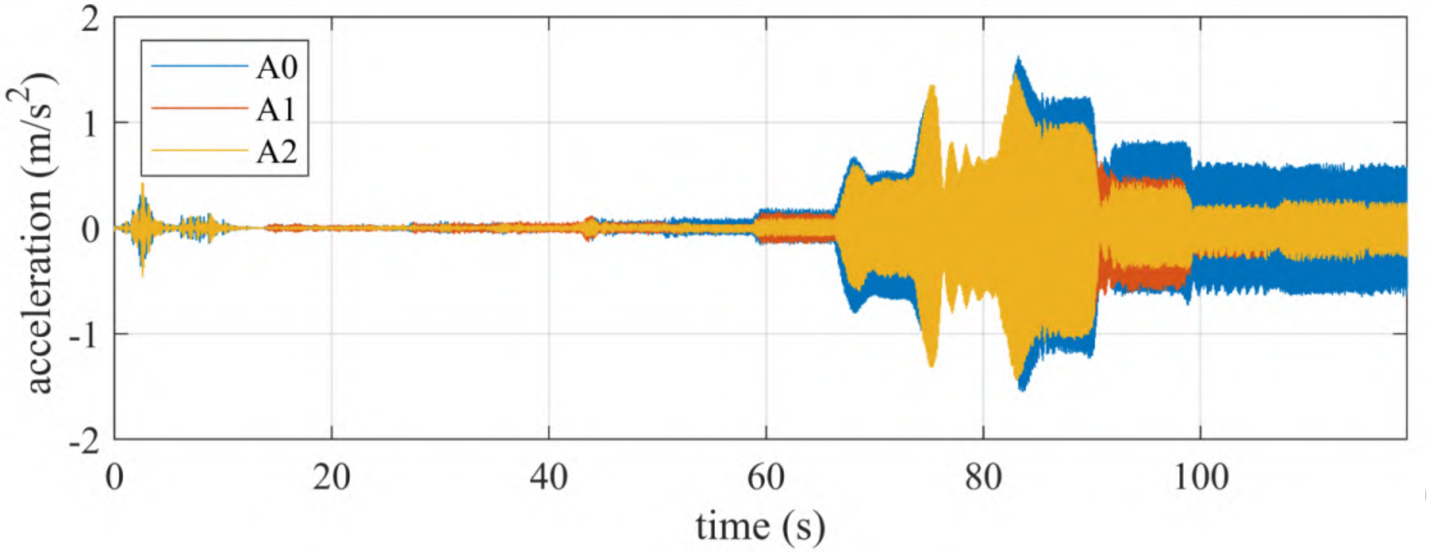




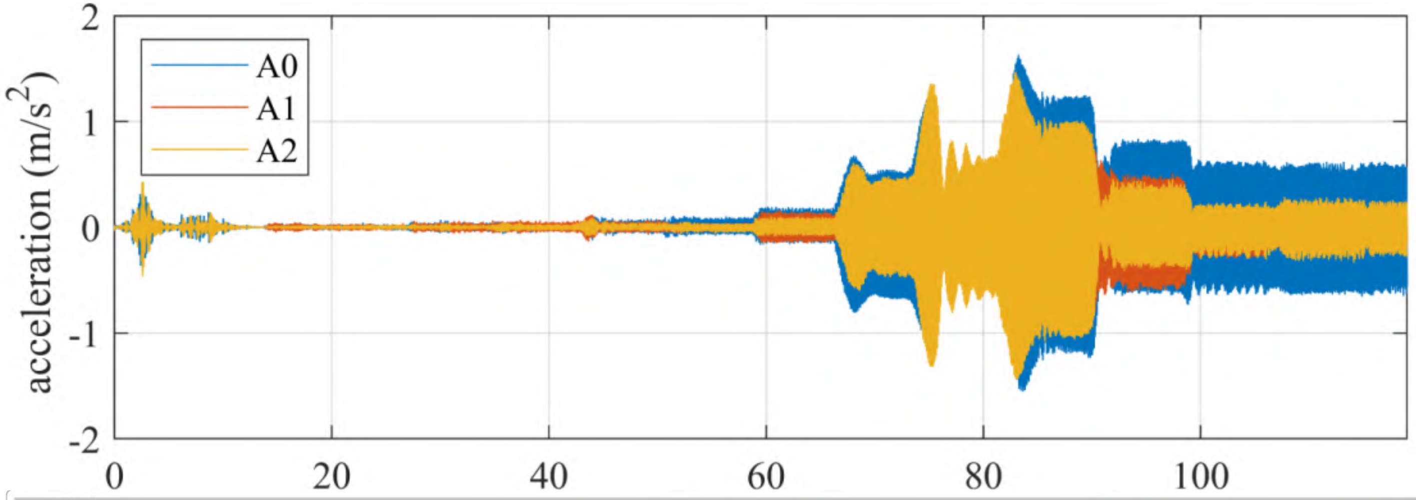


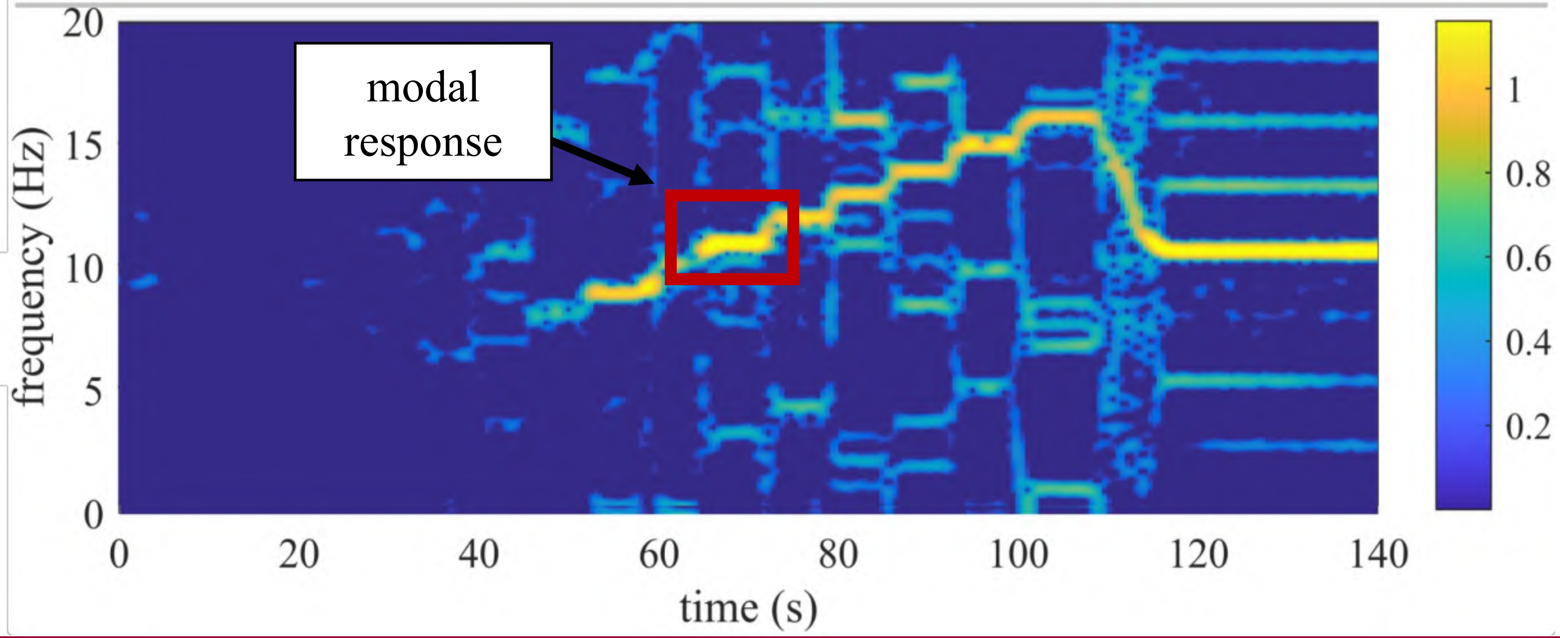
time and frequency response





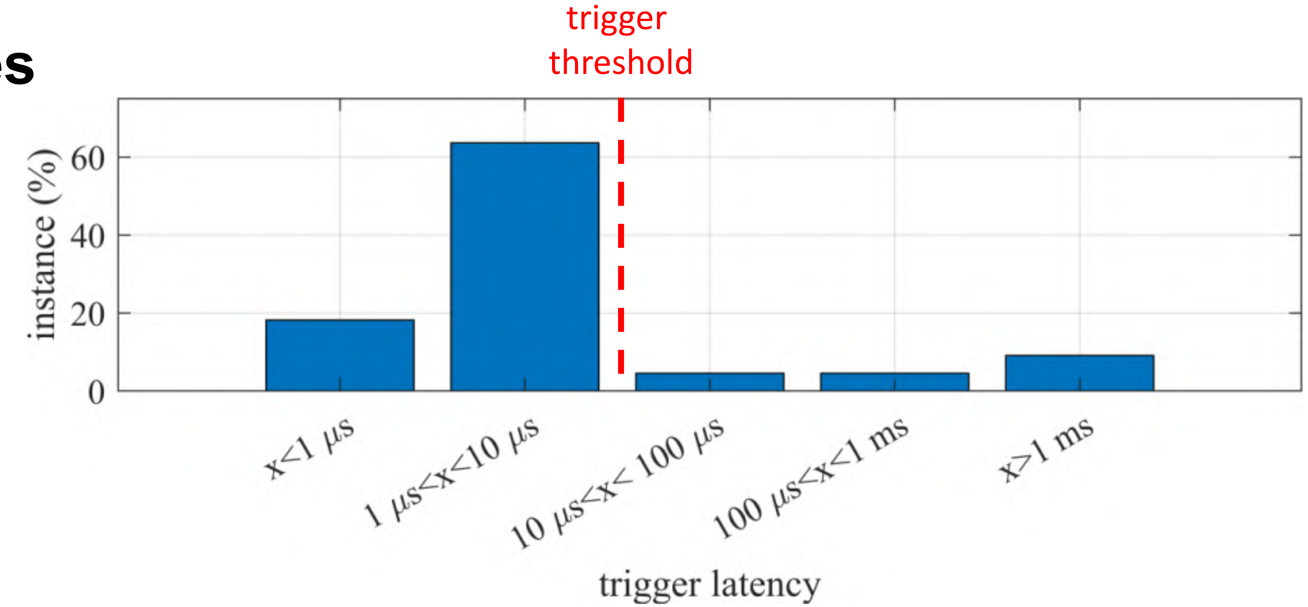
time and frequency response

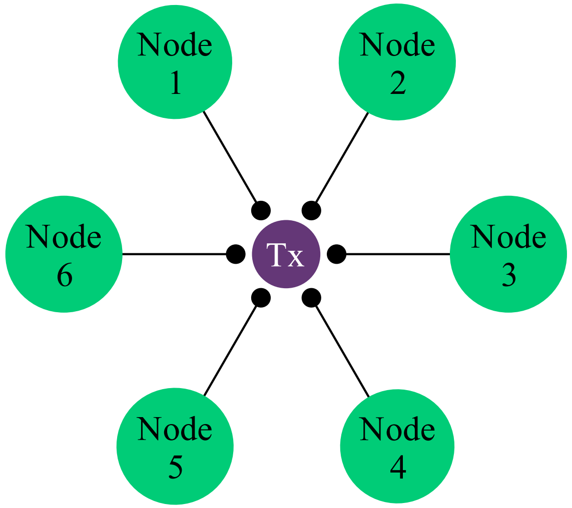


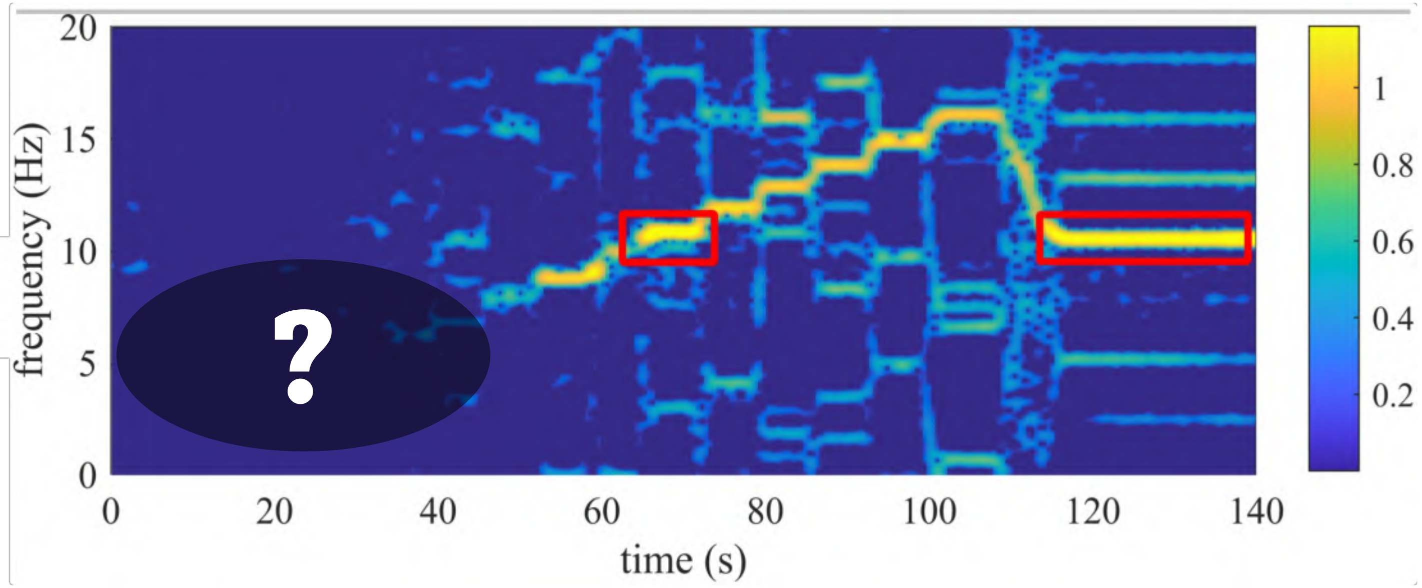


sensing system experimental challenges

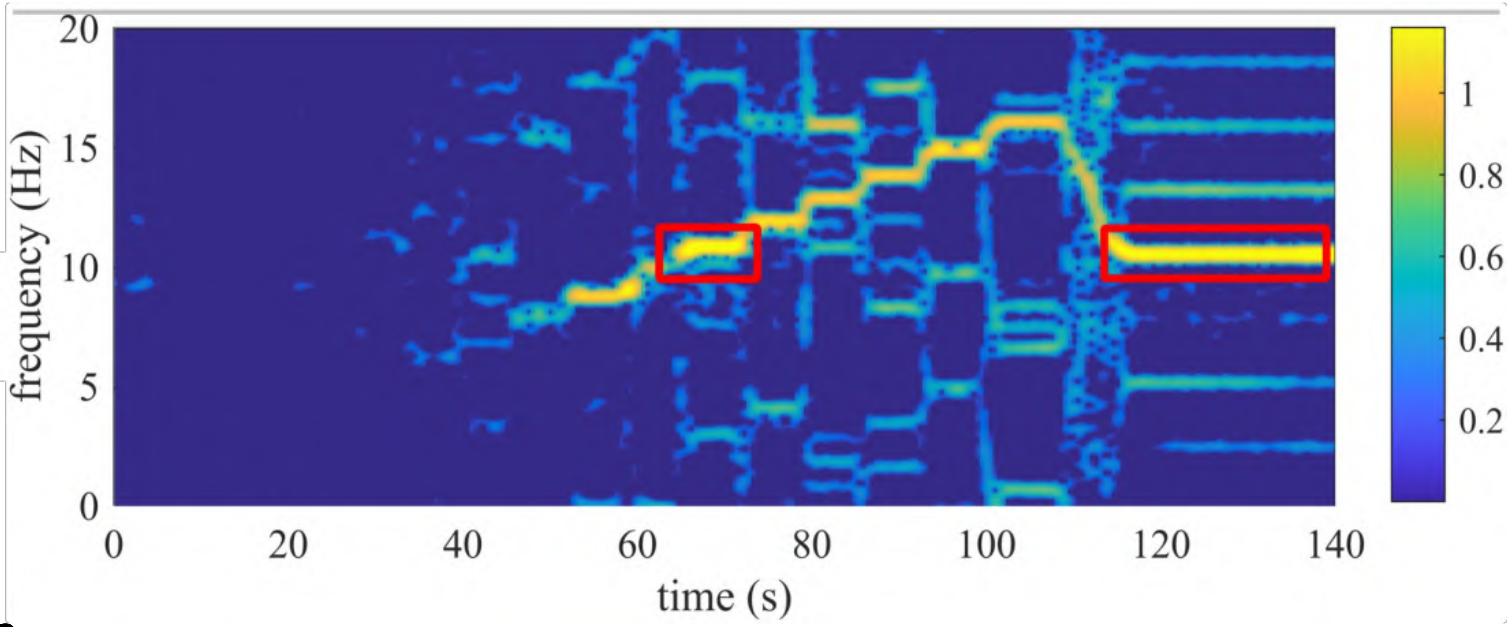
- wireless trigger time latency (~85% < 10 μs)
- low-magnitude low-frequency response detection

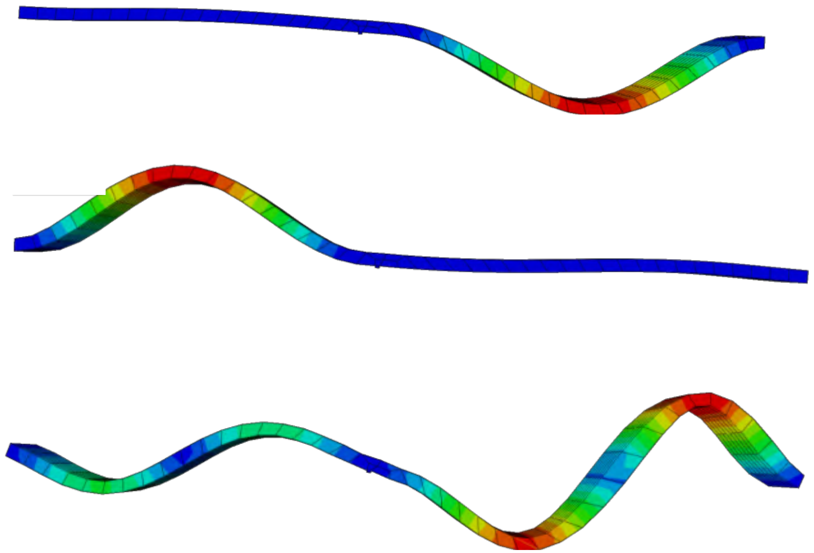






- Sensor network algorithm enhancements for error-handling and data transfer
- Modal reconstruction on-edge for rapid state assessment and prognostics

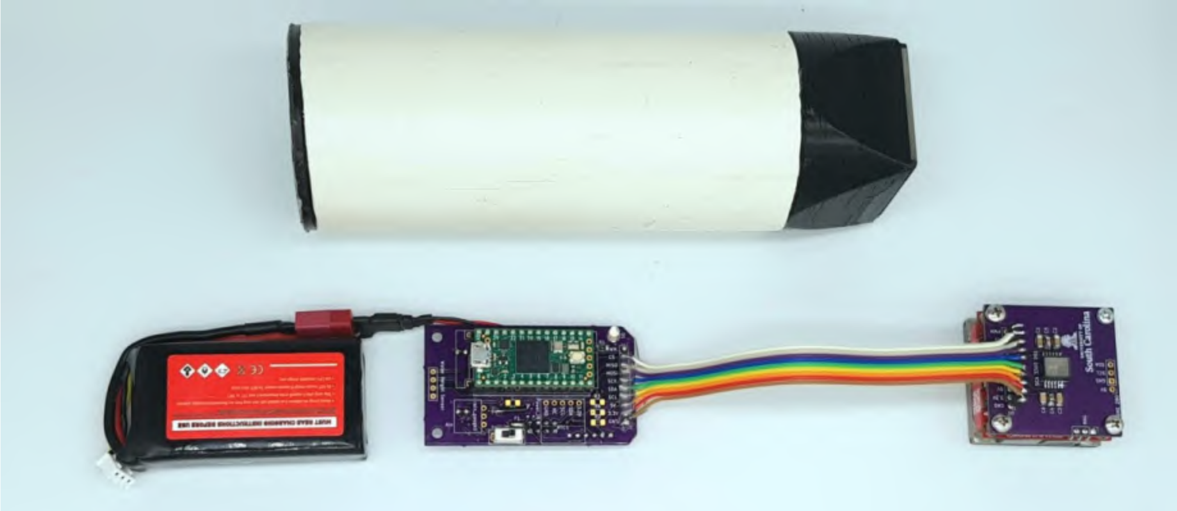




Open-source UAV-deployable vibration sensor package

Open-Source hardware Designs

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



ACKNOWLEDGMENT

This material is based upon work supported by the National Science Foundation grant numbers 2152896 and 2237696 with additional support from the Air Force Office of Scientific Research (AFOSR) through award no. FA9550-21-1-0083. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation, or the United States Air Force.

Thank you

Questions?

Author Information
Name: Austin R.J. Downey
Email: austindowney@sc.edu

References:

1. Kot, P., M. Muradov, M. Gkantou, G. S. Kamaris, K. Hashim, and D. Yeboah. 2021. “Recent Advancements in Non-Destructive Testing Techniques for Structural Health Monitoring,” Applied Sciences, 11(6), ISSN 2076-3417, doi:10.3390/app11062750.
2. Magalh˜aes, F., A. Cunha, and E. Caetano. 2012. “Vibration based structural health monitoring of an arch bridge: From automated OMA to damage detection,” Mechanical Systems and Signal Processing, 28:212–228, ISSN 0888-3270, doi:https://doi.org/10.1016/j.ymssp.2011.06.011, interdisciplinary and Integration Aspects in Structural Health Monitoring.
3. Sony, S., S. Laventure, and A. Sadhu. 2019. “A literature review of next-generation smart sensing technology in structural health monitoring,” Structural Control and Health Monitoring, 26(3):e2321, doi:https://doi.org/10.1002/stc.2321, e2321 STC-18-0009.R1.
4. Reagan, D., A. Sabato, and C. Niezrecki. 2018. “Feasibility of using digital image correlation for unmanned aerial vehicle structural health monitoring of bridges,” Structural Health Monitoring, 17(5):1056–1072, doi:10.1177/1475921717735326.
5. Holford, K. M. 2009. “Acoustic Emission in Structural Health Monitoring,” in Damage Assessment of Structures VIII, Trans Tech Publications Ltd, vol. 413 of Key Engineering Materials, pp. 15–28, doi:10.4028/www.scientific.net/KEM.413-414.15.
6. Liu, X., H. Liu, and C. Serratella. 2020. “Application of Structural Health Monitoring for Structural Digital Twin,” in Offshore Technology Conference Asia, OnePetro.
7. Arnaud Deraemaeker, K. W. 2010. New Trends in Vibration Based Structural Health Monitoring, CISM Courses and Lectures, vol. 520, SpringerWienNewYork.
8. Carroll, S., J. Satme, S. Alkharusi, N. Vitzilaios, A. Downey, and D. Rizos. 2021. “Drone-Based Vibration Monitoring and Assessment of Structures,” Applied Sciences, 11(18):8560, ISSN 2076-3417, doi:10.3390/app11188560.
9. Satme, J. N., R. Yount, J. Vaught, J. Smith, and A. R. Downey. 2023. “Modal Analysis using a UAV-deployable Wireless Sensor Network,” Society for Experimental Mechanics, International Modal Analysis Conference.
10. Satme, J. and A. Downey. 2022, “Drone Delivered Vibration Sensor,” GitHub.
11. Takeuchi, K., A. Masuda, S. Akahori, Y. Higashi, and N. Miura. 2017. “A close inspection and vibration sensing aerial robot for steel structures with an EPM-based landing device,” in H. F. Wu, A. L. Gyekenyesi, P. J. Shull, and T.-Y. Yu, eds., SPIE Proceedings, SPIE, doi:10.1117/12.2260386.