SENSOR PACKAGE DEPLOYMENT AND RECOVERY CONE WITH INTEGRATED VIDEO STREAMING FOR RAPID STRUCTURAL HEALTH MONITORING

Joud N. Satme; Department of Mechanical Engineering
Ryan Yount; Department of Mechanical Engineering
Nikita Goujevskii; Department of Mechanical Engineering
Luke Jannazzoi; Department of Mechanical Engineering
Austin R.J. Downey; Department of Mechanical, Civil and Environmental Engineering

UNIVERSITY OF SOUTH CAROLINA

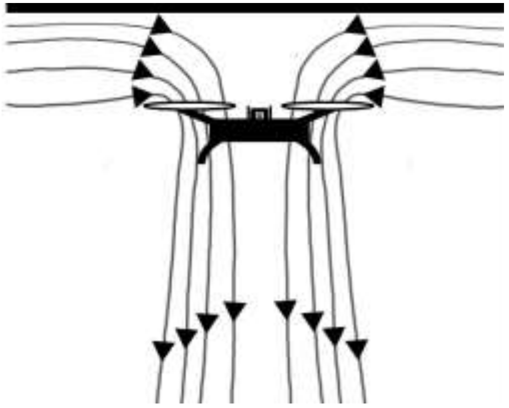
Outline:

Methodology:
- Introduction
- Ceiling effect
- EPM technology
- Sensor deployment system

Experimentation:
- Experimental setup
- Sensor delivery procedure

Results and Discussion:
- On-board camera system
- Sensor delivery timing

Future work:
- Automate delivery procedure

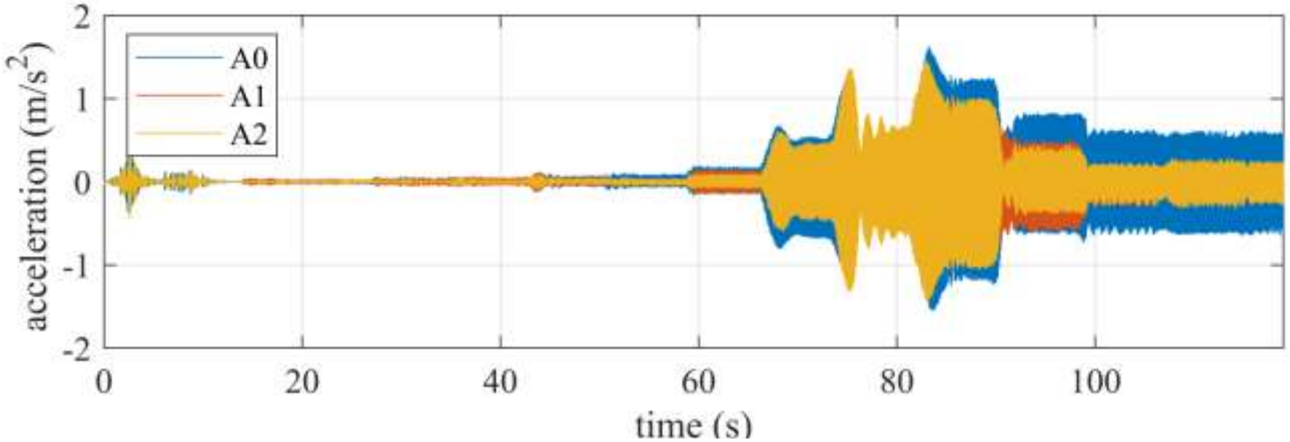


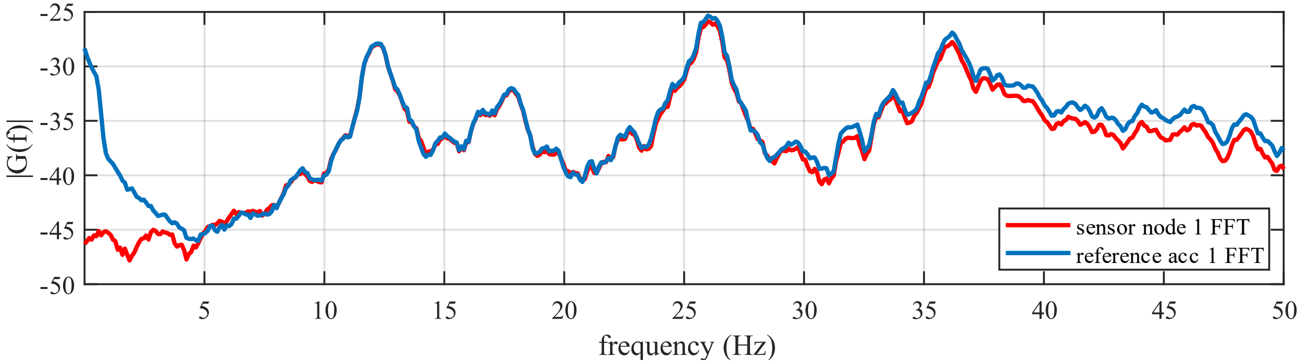
Introduction:

- Structural health monitoring systems currently operational are pushed to their limits due to the need for safer, faster, and more cost-effective solutions to the challenge of high-mobility sensing for rapid SHM applications.
- SHM traditionally involves dedicated equipment and highly trained personnel.
- Challenges of sensor deployment in remote areas, hazardous conditions, or on damaged structures causes delays in SHM.
- Tasking humans with sensor placement can be costly and dangerous due to unstable nature of decaying structures.
- Rapid structural health monitoring:
  - Real-time data-driven process by which insight into a structure’s health state is acquired.
    - Safe And rapid means of sensor delivery
    - Effective wireless systems for command and communication.

Introduction:

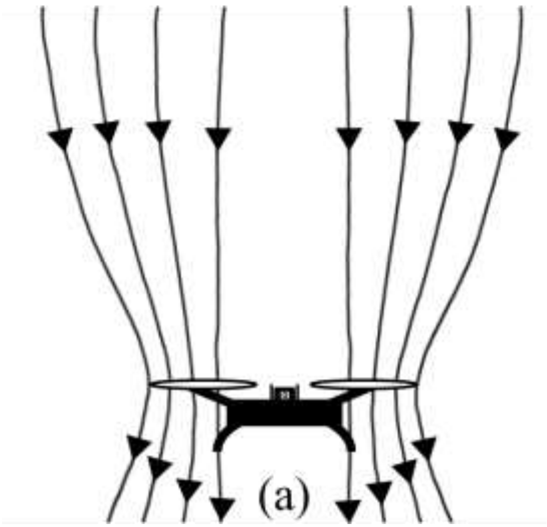
- Challenges in UAV Sensor Deployment
  - UAVs are often piloted by line of sight, which is not always feasible in all SHM scenarios.
  - Sensor placement may occur in locations with limited pilot visibility during navigation.
  - Spatial awareness is crucial to avoid collisions and ensure successful sensor delivery.
- Deliverable is a rapid aerial sensor deployment system
  - Incorporates wireless video streaming and Electropermanent magnetic technology.
  - Redundancy measures to increase safety and reliability of aerial deployments.
  - Recovery cone to guide sensor packages into a magnetic docking station.
  - Offers multiple camera views for docking and navigation.



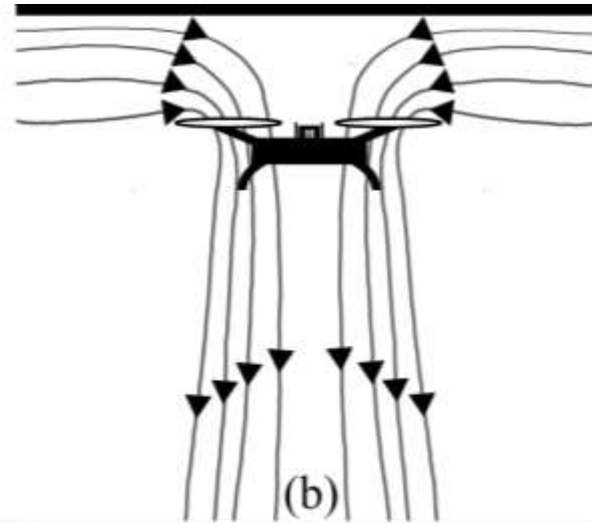


Ceiling effect:

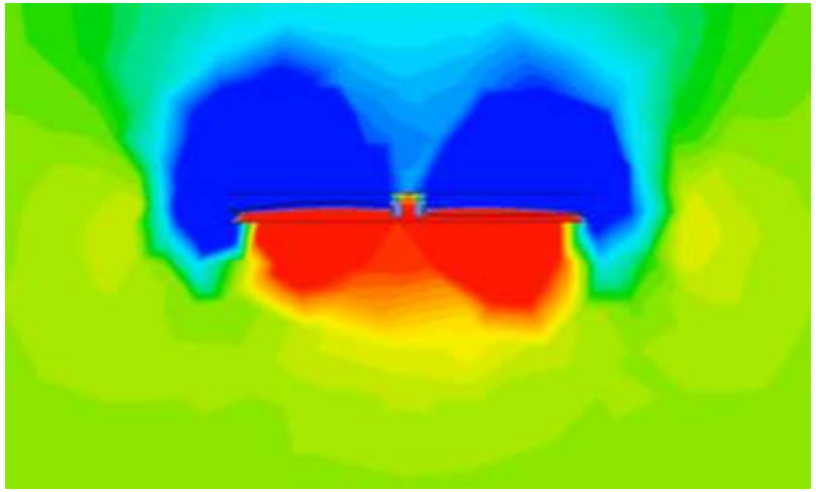
- Occurs when a rotating propeller is in close proximity to a barrier such as a ceiling
- Pressure drop above propeller due to impeded airflow
- Registered to the UAV operator as a sudden increase in lift or lack of adequate control
- CFD simulations indicate the formation of low pressure region

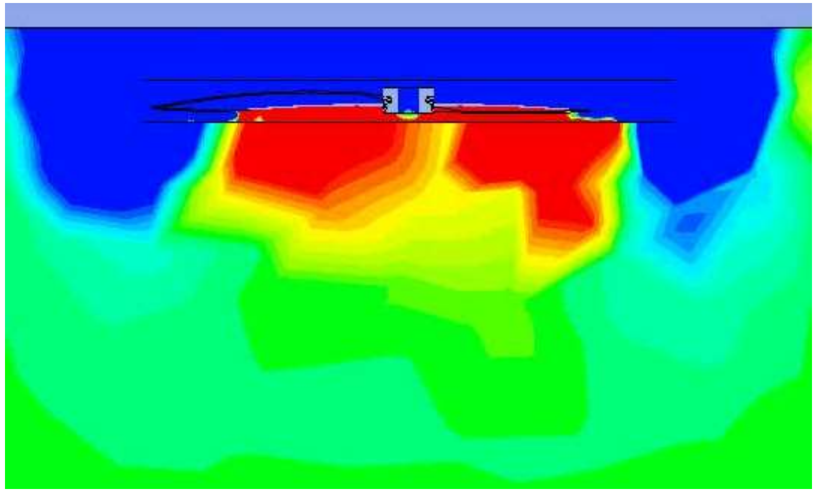


propeller in open air



propeller under ceiling effect





Ceiling effect:

- Sensor deployment challenges in SHM:
  - Rapid change in ceiling effect
  - Pilot-induced isolations
  - Degraded signal around metal structures
  - Hazardous objects in flight path
  - Lack of a clear line of site

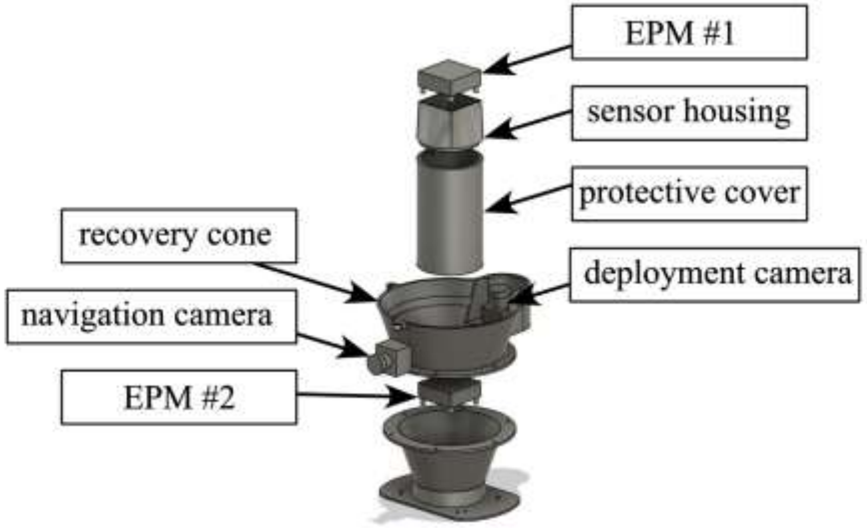
No researchers were harmed during this endeavor!

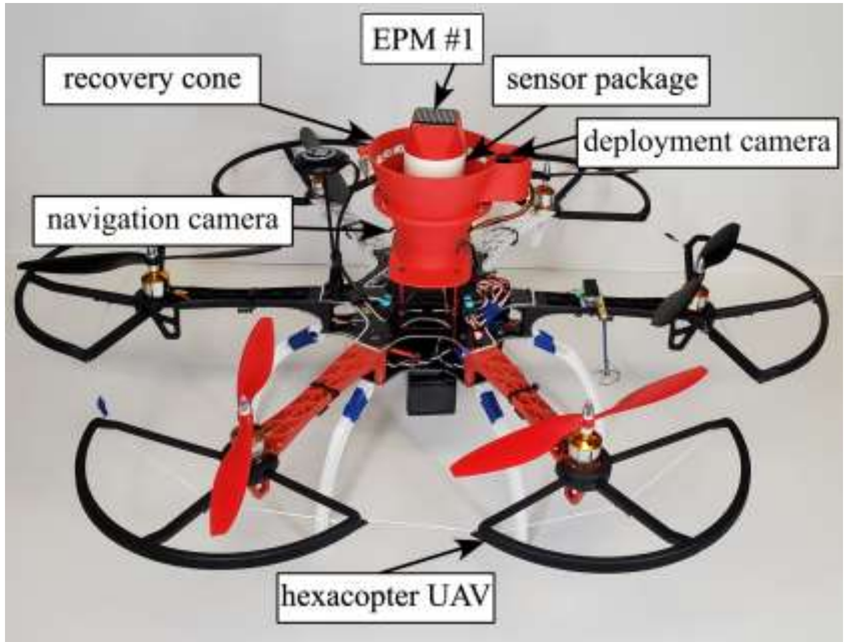
Elecropermanent magnet technology:

- Single magnetic field
- Two magnet fields
  - South-South
  - South-North
- Magnet array field
- Magnetic field is manipulated through doping metal alloy
- EPMs consume no power in either on or off state.

Sensor deployment system

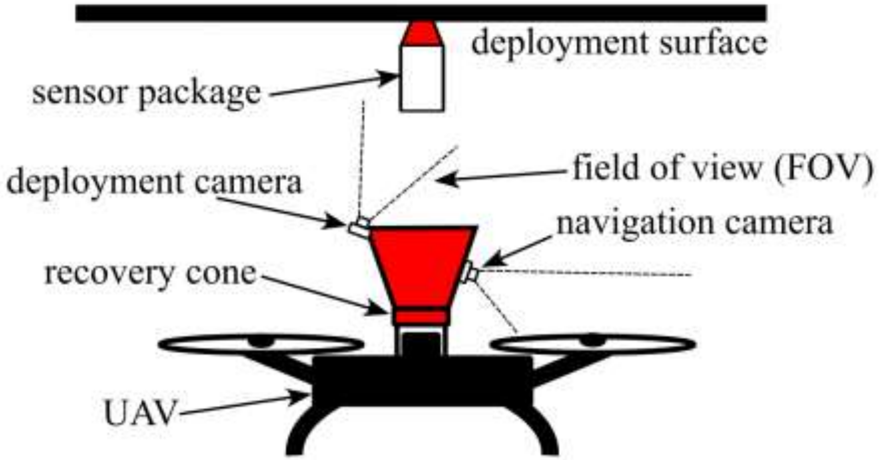
- Hexacopter UAV
- Integrated EPMs for sensor mounting
- Sensor recovery cone
- Camera system for navigation and sensor alignment

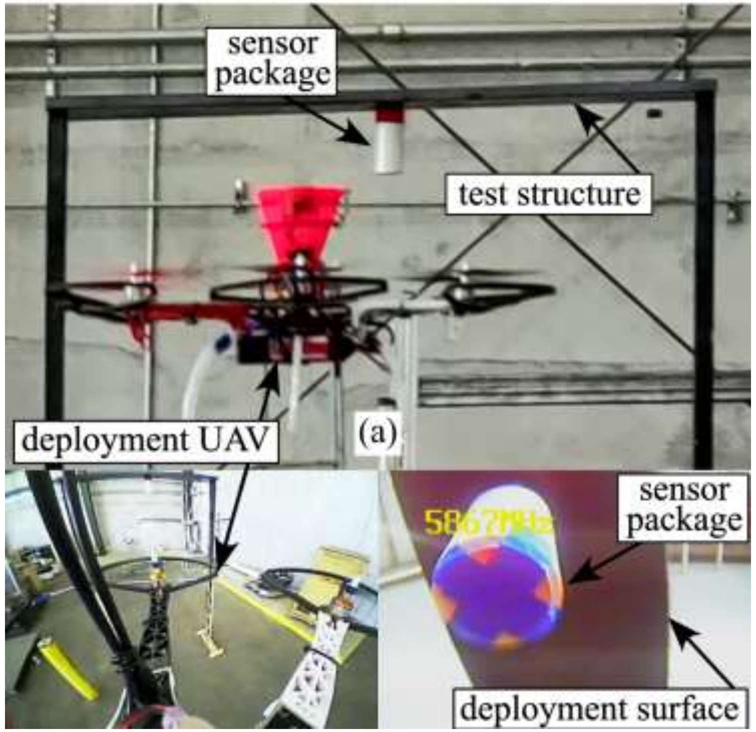




Experimental setup

- Structure is setup to simulate an I-beam of a bridge
- Camera views are streamed into displays views by the UAV operator
- Sensor deployment period is recorded for line of sight vs. streaming cameras
- Test is repeated to get an average time for
  - Approach
  - Deploy
  - Retreat
- Motion picture is used to track
  - Structure
  - Sensor package
  - UAV

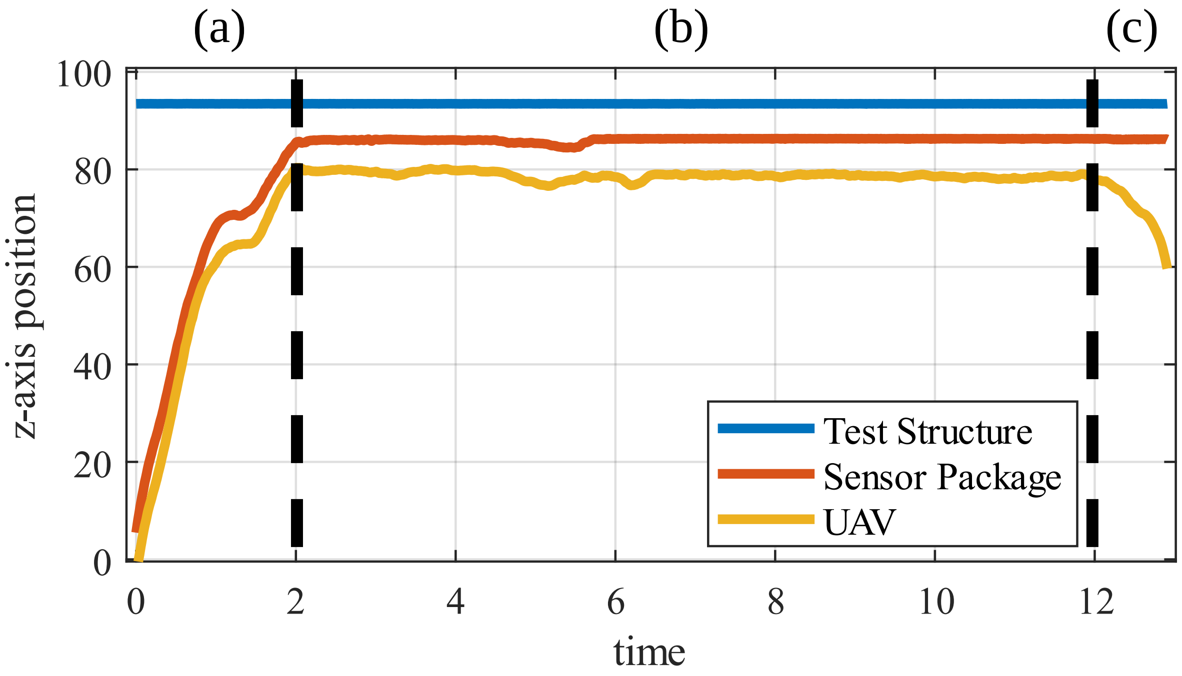




Sensor delivery procedure

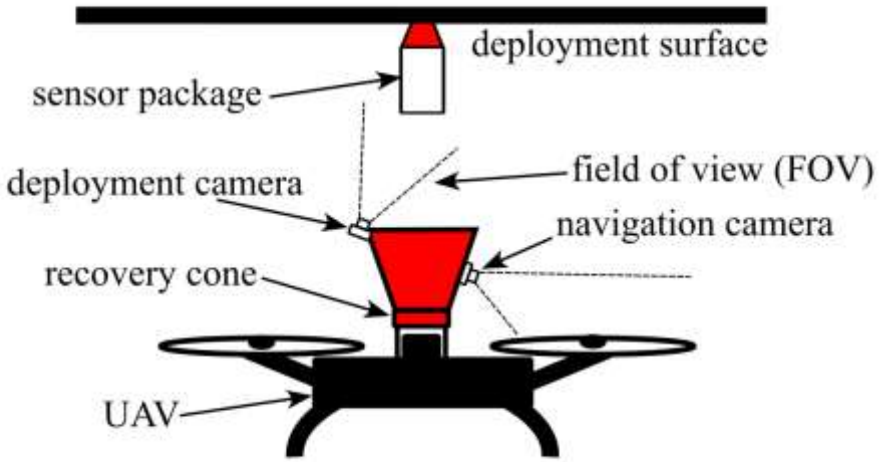
- UAV approaches the structure (a)
- Contact structure and deploy sensor (b)
- UAV disengages structure and retreat (c)

	(a)	(b)	(c)
EPM #1	Off	ON	ON
EPM #2	ON	ON	Off



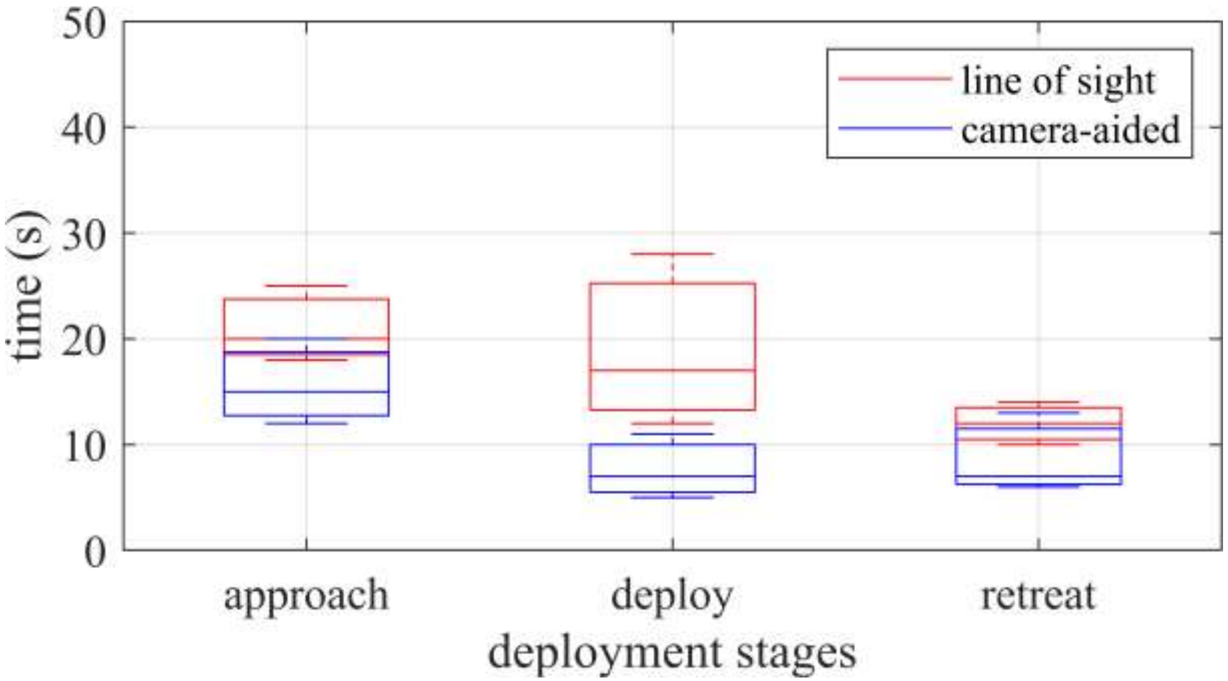
On-board camera view

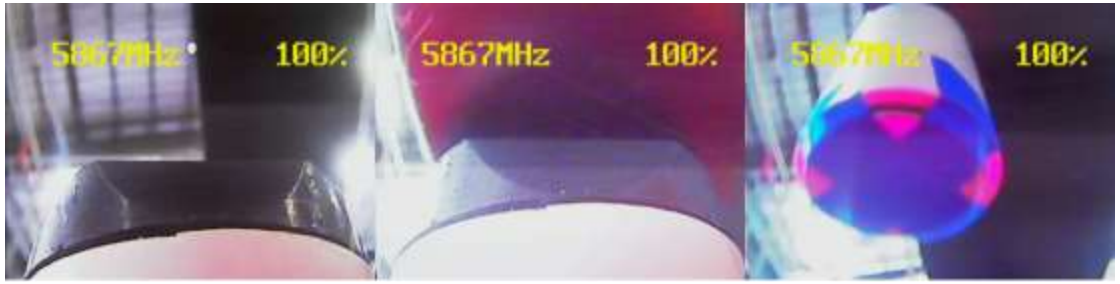
- Navigate to structure
- Locate sensor package
- Alight package with recovery cone
- Initiate EPM recovery sequence



Sensor delivery timing

- Trials indicate an average of 38% increase in sensor delivery speed.
- UAV operator indicate more special awareness during approach
- Experiment showed significantly less failed approaches
- No accidental contact with structure when cameras are in use

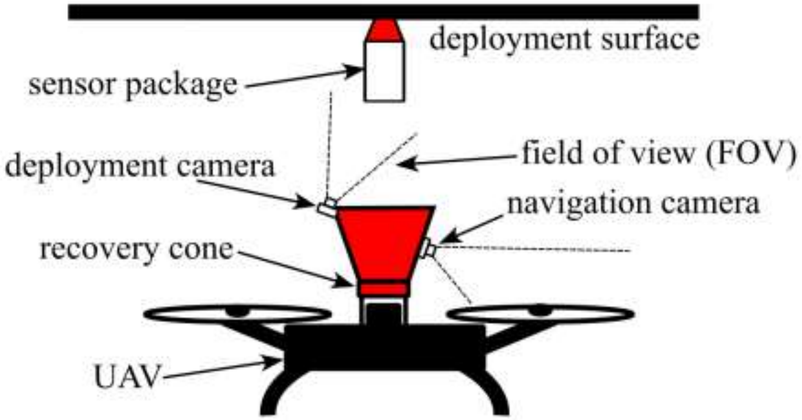




(a) (b) (c)

Future work

- Automate delivery procedure
- Sensor network delivery
- Enhance streaming quality



ACKNOWLEDGEMENT:

This work is supported by the National Science Foundation, United States Grant numbers 2152896 and 2344357. The support of the National Science Foundation is gratefully acknowledged. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Thank you

Questions?

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

References:

[1] Hong, J., Laflamme, S., Dodson, J., and Joyce, B., 2018. “Introduction to state estimation of high-rate system dynamics”. Sensors, 18(2), Jan., p. 217. [2] Dodson, J., Downey, A., Laflamme, S., Todd, M. D., Moura, A. G., Wang, Y., Mao, Z., Avitabile, P., and Blasch, E., 2021. High-Rate Structural Health Monitoring and Prognostics: An Overview. Springer International Publishing, Oct., pp. 213–217. [3] Lall, P., Panchagade, D., Iyengar, D., Shantaram, S., Suhling, J., and Schrier, H., 2007. “High speed digital image correlation for transient-shock reliability of electronics”. In 2007 Proceedings 57th Electronic Components and Technology Conference, IEEE, pp. 924–939. [4] Lall, P., Pandurangan, A. R. R., Dornala, K., Suhling, J., Deep, J., and Lowe, R., 2019. “Effect of shock pulse variation on surface mount electronics under high-g shock”. In 2019 18th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm), IEEE, pp. 586–594. [5] Amy, R. A., Aglietti, G. S., and Richardson, G., 2009. “Reliability analysis of electronic equipment subjected to shock and vibration–a review”. Shock and Vibration, 16(1), pp. 45–59.

[6] Steinberg, D. S., 2000. “Vibration analysis for electronic equipment”.

[7] Liu, K.-T., Lu, C.-L., Tai, N., and Yeh, M. K., 2020. “Stress analysis of printed circuit board with different thickness and composite materials under shock loading”. Computer Modeling in Engineering & Sciences. [8] Esser, B., and Huston, D., 2004. “Active mass damping of electronic circuit boards”. Journal of Sound and Vibration, 277(1–2), Oct., pp. 419–428. [9] Chomette, B., Chesné, S., Rémond, D., and Gaudiller, L., 2010. “Damage reduction of on-board structures using piezoelectric components and active modal control—application to a printed circuit board”. Mechanical Systems and Signal Processing, 24(2), Feb., pp. 352–364. [10] Downey, A., Dodson, J., Vereen, A., Satme, J., and Nelson, C., 2022. Dataset-5-extended-impacttesting. https://github.com/High-Rate-SHM-WorkingGroup/Dataset-5-Extended-Impact-Testing. [11] Satme, J., and Coble, D., 2024. Paper-online-healthmonitoring-of-electronic-components-subjected-torepeated-high-energy-shock. https://github.com/ARTSLaboratory/Paper-Online-Health-Monitoring-ofElectronic-Components-Subjected-to-Repeated-Highenergy-Shock. [12] Thompson, Z., Vereen, A., Downey, A., Bakos, J. D., Dodson, J., and Moura, A. G., 2023. Online Backpropagation of Recurrent Neural Network for Forecasting Nonstationary Structural Responses. Springer Nature Switzerland, pp. 133–137.