High-Rate Structural Health Monitoring and Prognostics: An Overview

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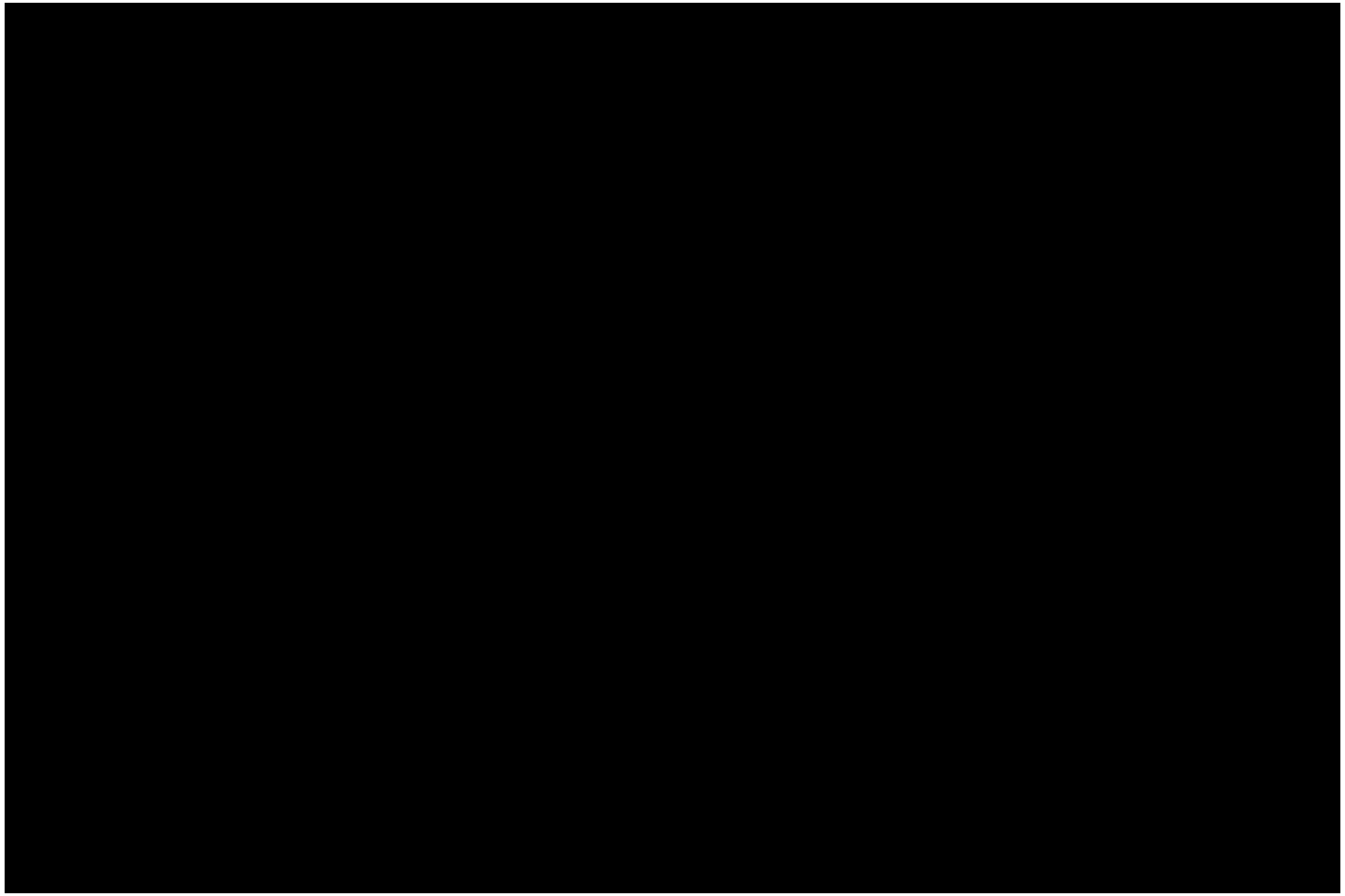
Motivation – Air Force

Air Force Weapon Components – Extreme Mechanical Environments



<u>Input Characteristics</u>

- Repeated shocks
- Multiaxial
- Short rise time/high frequency
- Short & Long duration

Definition – High Rate Dynamics

A dynamic response from:

- **high-rate** (< 100 ms) and
- **high-amplitude** (acceleration > 100 g_n)

  event such as a blast or impact.

High-rate dynamics contains:

1. Large **uncertainties** in the external loads;
2. High levels of **non-stationarities** [in the structure] and heavy disturbances;
3. **Unmodeled dynamics** from changes in system configuration.

Blast against civil structures

Automotive impact and crashes

High Speed aircraft and airframes

Lightning Strikes on aircraft

Hong, J. *et.al*. Introduction to state estimation of high-rate system dynamics. *Sensors,* 18(2):217, Jan 2018.

Definition – "High Rate" Timescales

The high-rate structural health monitoring problem has multiple time-scales to address:

Time scales of...	Time Scales	Examples
duration of the event	30 µs – 100 ms	Structural loading - blast, high-speed impact, automotive crash
sensor response	3 µs – 10 µs	Accelerometer, strain gage, etc.
different physical behavior regimes	250 µs – 1 sec	Energy propagation, structural resonance
algorithm execution and decision-making	100 µs – 1 ms	Damage detection, uncertainty quantification, state awareness, decision making

We have defined **3 timescale regimes** for the time elapsed between event detection and decision-making (i.e. latency):

1. High-Rate – 1 ms **Current Goal**
2. Very High-Rate – 100 µs
3. Ultra High-Rate – 1 µs

Technical Challenges of HR-SHM

Goal: Determine the condition of a structural system and make system decisions in *less than a millisecond*, while the structure sustains unknown/unmeasured, high-magnitude, and short-duration impacts

Technical Challenges:

Adequate Sensing

Need to achieve multiresolution (time, space, and frequency) ***sensing awareness***

Lack of System Knowledge

Need to [partially] understand physics and approximate dynamics for ***structural awareness***

High Variability and Uncertainty in Loading

Due to unmodeled dynamics occurring during high-rate dynamics; Need to be able to establish ***environmental awareness***

Limited resources for algorithm implementation

Need to identify algorithms and hardware for 1 ms timescales while maintaining ***energy awareness***

Technical Objectives and Approaches to enable HR-SHM

To achieve…

Sensing Awareness:

- Non-inertial and non-contact sensing methods
- Full field sensing algorithms and data fusion, contextual-artificial intelligence approaches

Structural & Environment Awareness:

- **Physics-enhanced machine learning (PEML)** models
- Real-time fusion of high-speed dynamic data augmented by model-based data
  - Model reduction and model-updating (offline and real-time) approaches
- Uncertainty quantification (UQ) methods to enable decisions connected to confidences

Energy Awareness:

- **Cognitive sensing** – configuring sensors and hardware to measure at various timescales
  - Combining both hardware and software to enable high-rate executions

System Development

- **Experimental Validation** for high-rate algorithms
  - Suite of experimental data sets and apparatus for different aspects of the dynamics

Summary

There is a need **for High-Rate Structural Health monitoring (HR-SHM)**, structural prognostics, and real-time decision making for both military and commercial applications.

HR-SHM should target **1 ms timescales** from event detection to decision-making (current goal)

Summary of Technical Objectives and Needs are:

Technical Objectives	Technical Challenges/Needs
Sensing Awareness	Adequate Sensing
Structural Awareness	System Knowledge Understanding
Environment Awareness	High Variability in Loading
Energy Awareness	Limited Resources for Algorithm Implementation
System Development	Experimental Validation
Risk-based Decision Making	High-Rate Uncertainty Quantification

During the Virtual IMAC XXXIX, join the panel discussion on "High-Rate Structural Health Monitoring and Prognostics"

High-rate Structural Monitoring, Damage Detection, Prognostics, and Reactions Working Group

WWW http://www.me.sc.edu/Research/Downey/high_rate_working_group.html

Applied Research Associates, Inc. *Dr. Alain Beliveau* *Dr. Adriane Moura* *Mr. James Scheppegrell*

Novel Variable Input Observer for High-Rate State Estimation
PI: *Dr. Simon Laflamme, Iowa State Univ.*

Real-time Impact Load Identification for Nonlinear Dynamical Systems
PI: *Dr. Yang Wang, Georgia Institute of Technology*

Nonlinear Force Identification and Localization for External Forces
PI: *Dr. Peter Avitabile, Univ. of Massachusetts at Lowell*

Real-Time State Monitoring for Air Force Structures
PI: *Dr. Austin Downey South Carolina University.*

Multiscale SHM using Data-Driven Methods
PI: *Dr. Zhu Mao, Univ. of Massachusetts at Lowell.*

Prognosis of Damage Using Uncertainty-Quantified Failure Forecast Method
PI: *Dr. Michael Todd, Univ. of California, San Diego*

Research Opportunities at AFRL/RW

AFRL Scholar

Undergraduate/Graduate Students

- Summer Internship Program
- 8-10 weeks

https://afrlscholars.usra.edu/students

SMART Scholarship for Service

Undergraduate/Graduate Students

- DoD sponsored scholarship (1-5 years)
- Summer Internships at Gov. Research facility
- Employment Obligation afterward

https://www.smartscholarship.org/smart

AF S&T Fellowship Post-Doc

Recently finished Ph.D.

- Work onsite at DoD Research Labs w/ government advisor
- 1-2 Years

Structural Dynamics and Instrumentation of Electronic Systems

http://nrc58.nas.edu/RAPLab10/Opportunity/Opportunity.aspx?LabCode=13&ROPCD=134502&RONum=C0147

Air Force Science & Technology Fellowship Program
Air Force Research Laboratory ★ Air Force Institute of Technology ★ U.S. Air Force Academy

Summer Faculty Fellowship Program

Professors

- AFRL/AFOSR Sponsored
- Work with hosting research lab
- On site for 8-10 weeks

https://afsffp.sysplus.com/