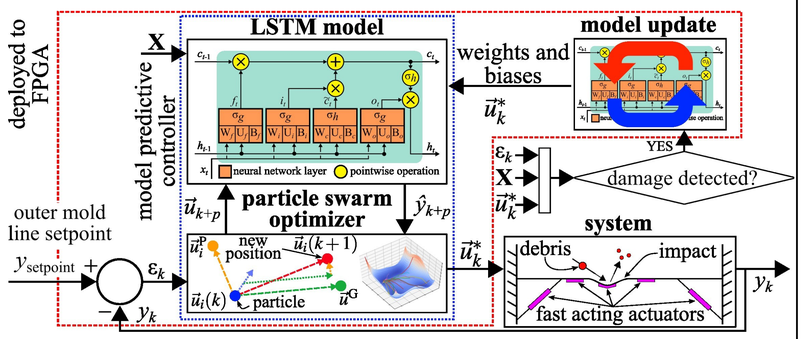
CAREER: Data-Driven Control of High-Rate Dynamic Systems

Austin Downey, University of South Carolina

Objective: Enable microsecond-scale, real-time ML control for high-rate systems by developing integrated frameworks, IoT-ready tools, hardware-in-the-loop validation, and open-source educational resources.



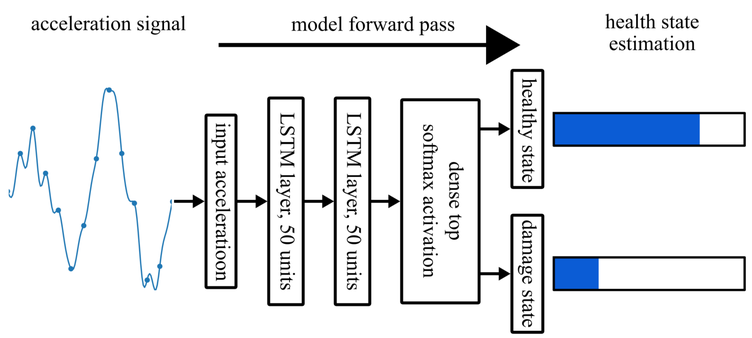
Real-time Model Predictive Controller formulated to maintain the outer mold line for the structure given a set of potential fast acting actuator inputs, where an LSTM is used to model the system.

Challenges: Deterministic model–controller knowledge transfer under strict latencies, maintaining stable control with fast actuators, limited educational resources for real-time high-rate control, lack of FPGA-based validation tools, and accurately validating ultra-low-latency, hardware co-designed control schemes in real-world environments.

Scientific Impact:

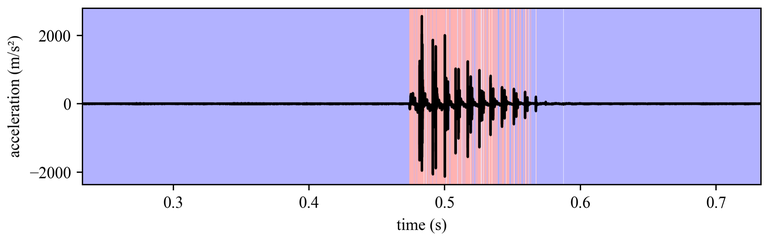
- **Hardware–Software Co-Design:** Meeting ultra-low latency and accuracy needs through integrated frameworks.
- **Real-Time LSTM Models:** Pioneering advanced architectures for dynamic systems.
- **FPGA Resource Sharing:** Establishing deterministic ML processes with efficient hardware utilization.
- **Microsecond Control:** Balancing accuracy, performance, and resource demands at extreme timescales.
- **Latency & Uncertainty:** Documenting impacts on controllability of advanced structures.

Progress This Year:



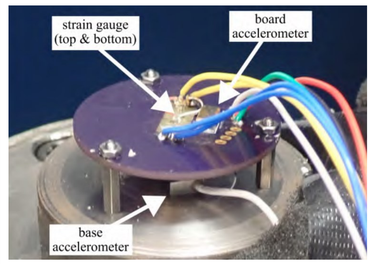
Online health state estimator taking in accelerometer signal and predicting the health of electronic components.

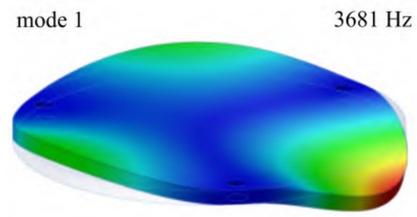
Introduced an LSTM-based approach that detects damage to PCB-mounted electronics within 4 ms by monitoring impedance changes, supported by a new shock dataset (30 repeated impacts at 10,000 g_n) demonstrating perfect real-time classification between “healthy” and “damaged.”



Shock states estimated by the EM algorithm. Blue shading indicates the algorithm predicted the system was not in a state of shock. Red shading indicates the algorithms predicted the system was in a state of shock.

Compared two online change-point detection methods—Cumulative Sum (CUSUM) and Expectation Maximization (EM)—to classify shock vs. normal vibration in near-real-time from single-axis data. EM yields fewer false positives pre-shock, while CUSUM runs faster—showcasing trade-offs for ultra-low-latency shock detection.

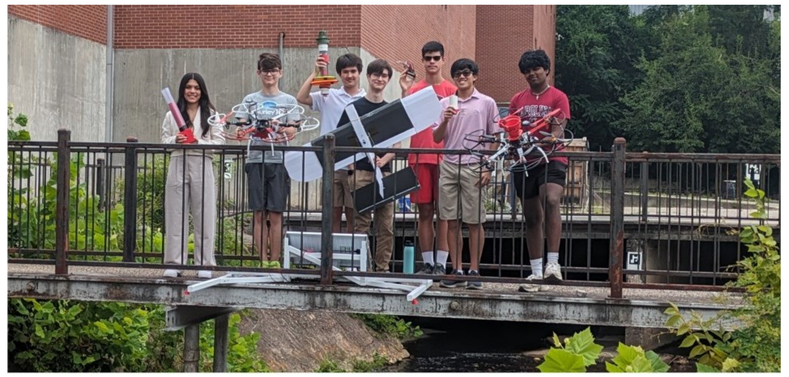




Experimentally tested a circular PCB (5,000–15,000 g_n impacts) for shock mitigation in extreme environments measuring strain and acceleration.

Broader Impact: Streamlining control design for complex systems, widening STEM access (especially in underserved areas), creating open-source FPGA-based ML tools, and driving innovation in fields like automotive safety, cybersecurity, and energy.

Education and Outreach: Focused on developing modular, open-source learning materials on real-time ML control for audiences ranging from high school to professional levels, bridging theory and application. This year, we expanded our open-source resource on vibrations, led a physics-informed ML tutorial at SEM-IMAC (70+ attendees), and collaborated with Benedict College (an HBCU).



Research Group High school students from the summer of 2024 holding UAV deployed sensors they developed through their efforts.

Project Dates: February 1, 2023 – January 31-2028

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Award ID#: 2237696