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IDETC-CIE 2022

International Design Engineering Technical Conferences & Computers and Information in Engineering Conference

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ST. LOUIS UNION STATION HOTEL,
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PROGRESS TOWARDS DATA-DRIVEN HIGH-RATE STRUCTURAL STATE ESTIMATION ON EDGE COMPUTING DEVICES

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Methodology → Experimentation → Results and Discussion → Future work

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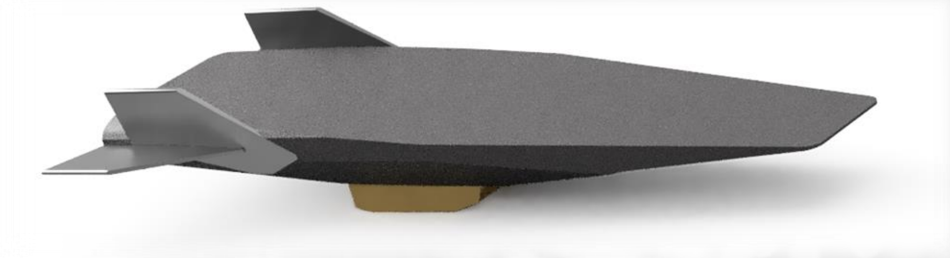
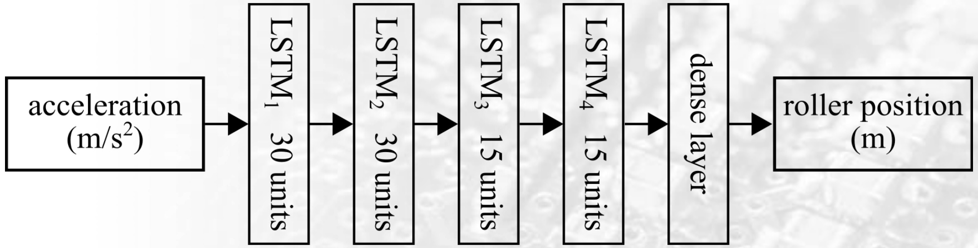
Outline



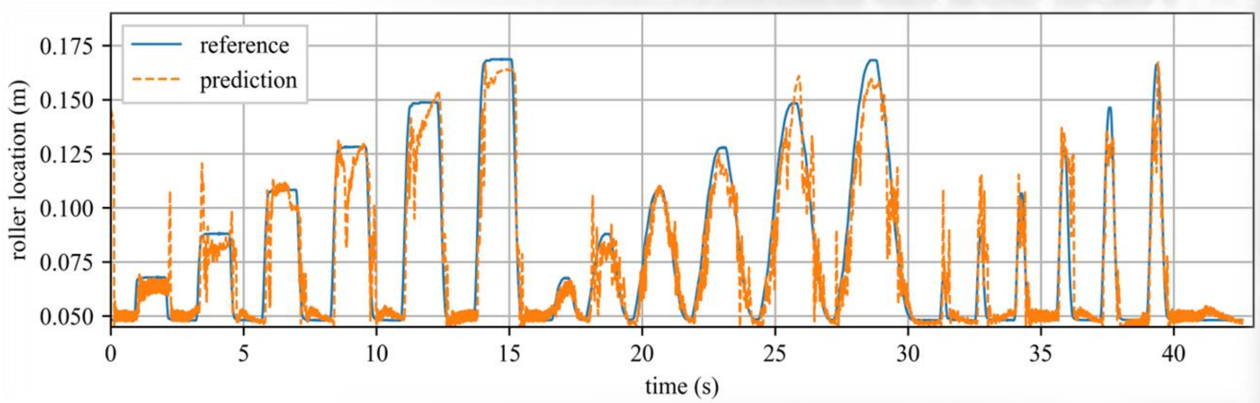
Methodology:
- DROPBEAR experimental testbed
- Long short-term memory model development
- Real-time edge implementation

Experimentation:
- Signal prediction test
- Real-time execution test

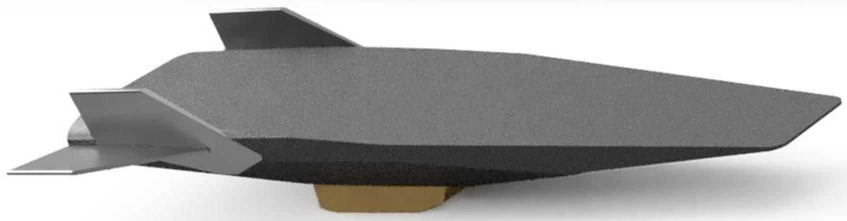


Results and discussion:
- LSTM model performance
- Timing accuracy

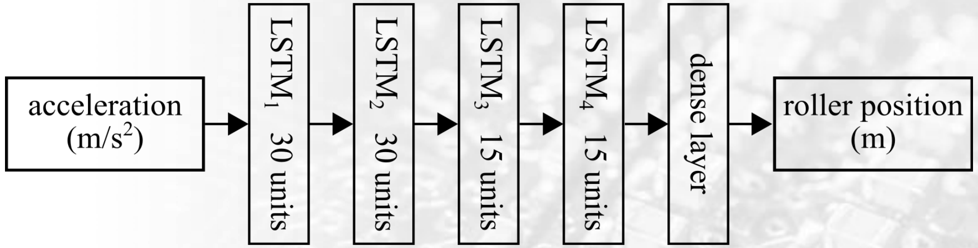
Future work:
- Prediction accuracy
- Model throughput rate

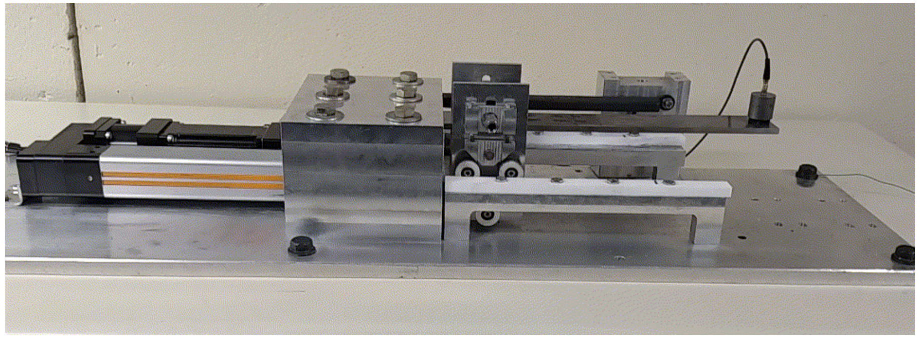


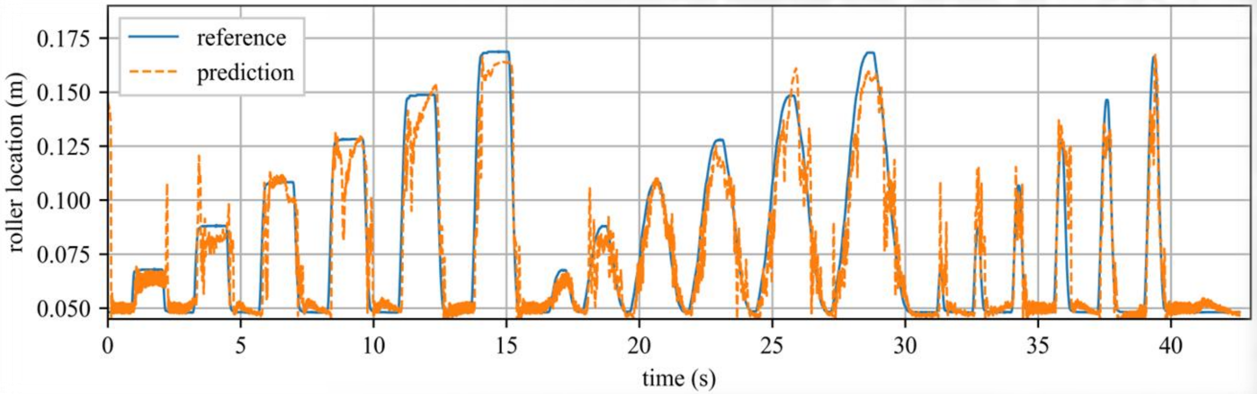
Introduction



- High-rate dynamics framework
- Advances enabling high-rate structural health monitoring (HR-SHM)
- Long short-term memory (LSTM)
- Data-driven state estimation

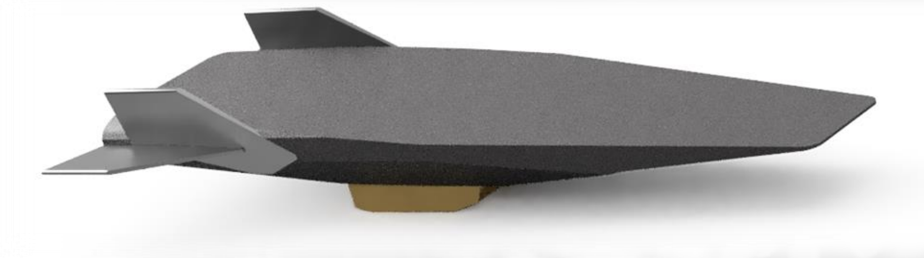


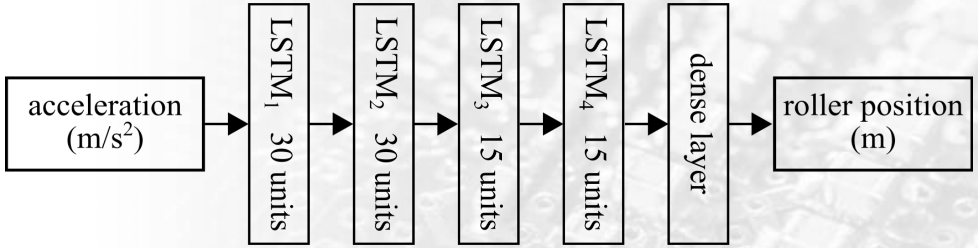


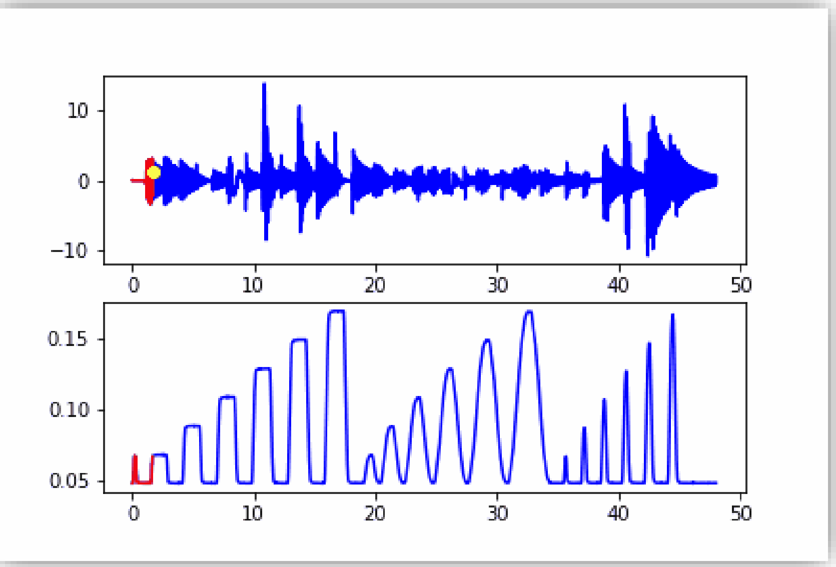


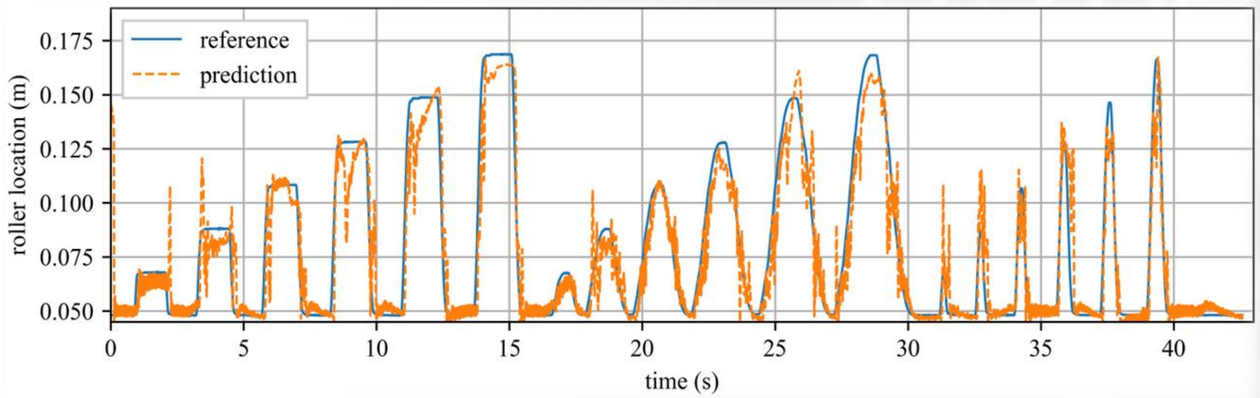
Contributions of this work

- Long short-term memory real-time state estimation framework
- Experimental validation method to gauge LSTM performance.



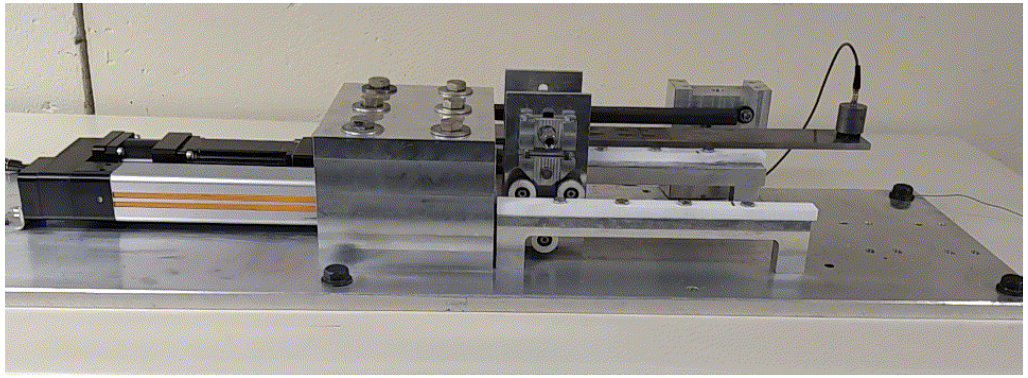


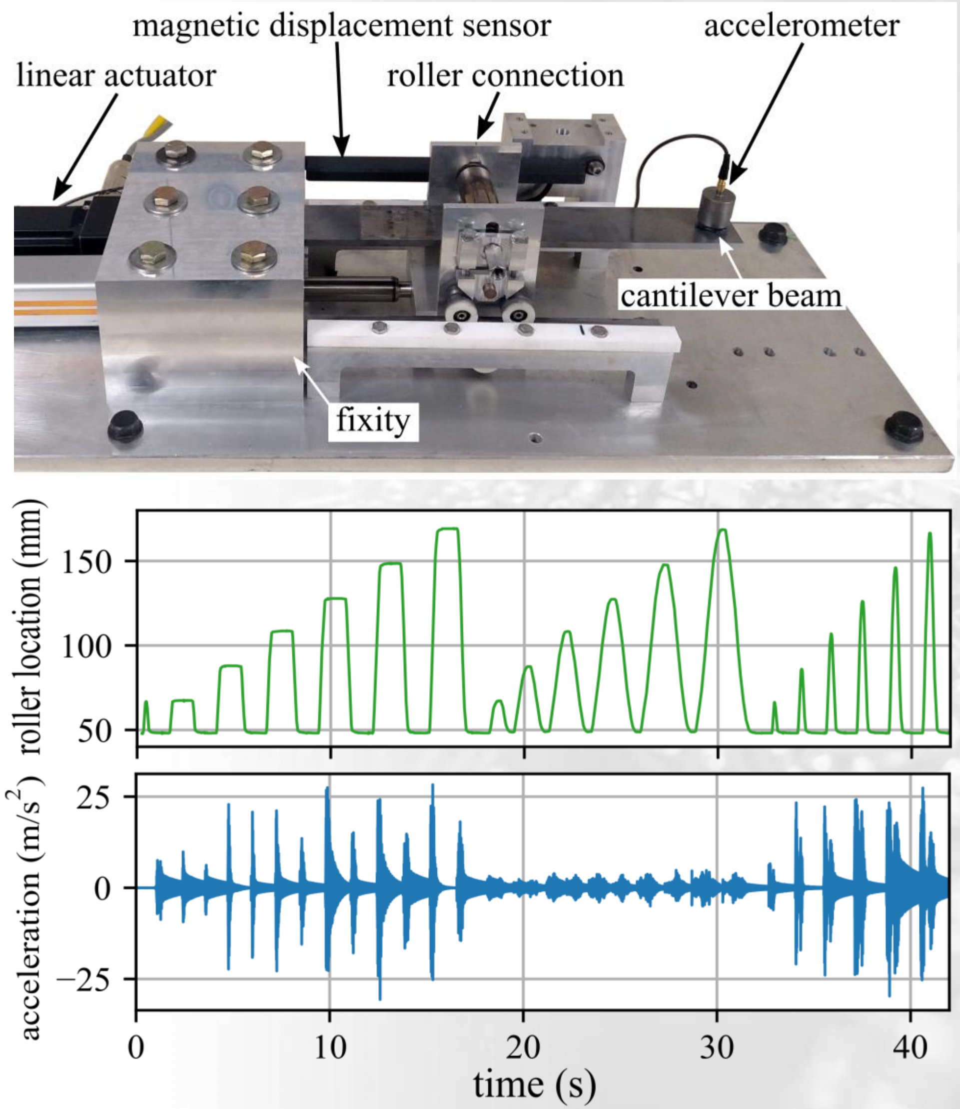




DROPBEAR experimental testbed

- The Dynamic Reproduction of Projectiles in Ballistic Environments for Advanced Research (DROPBEAR) was used to generate the experimental data in this work.
- Cantilever beam with controllable roller to alter the state.
- Acceleration and roller location are recorded.





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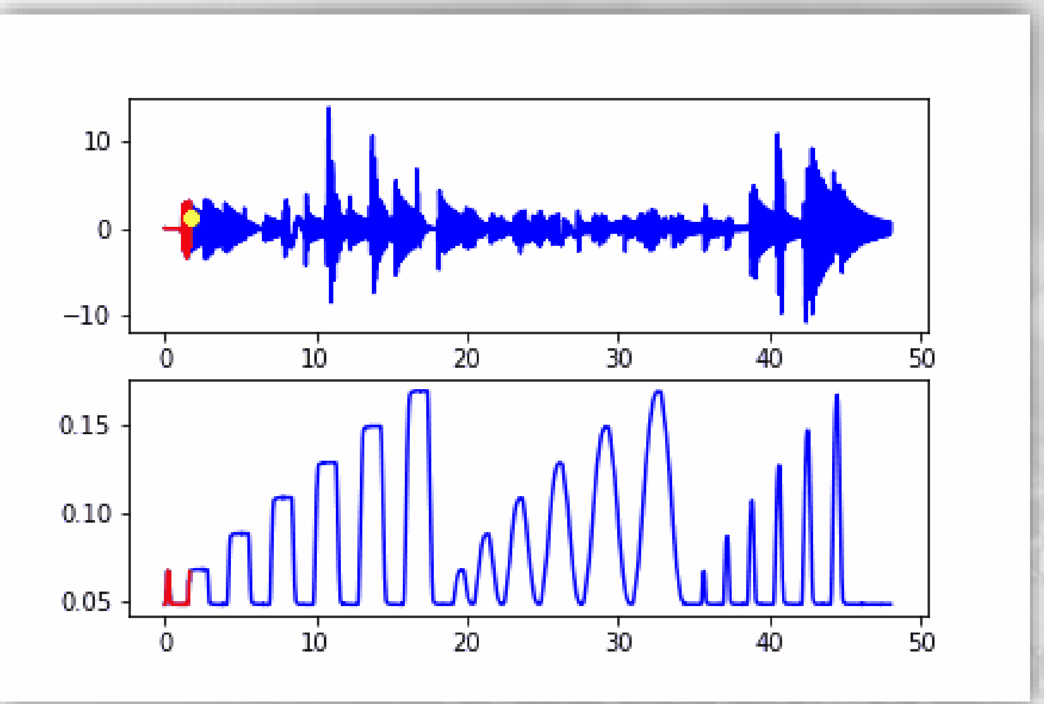
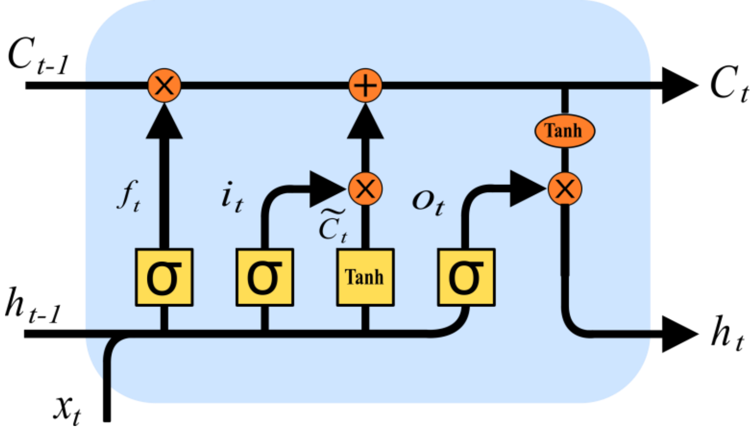
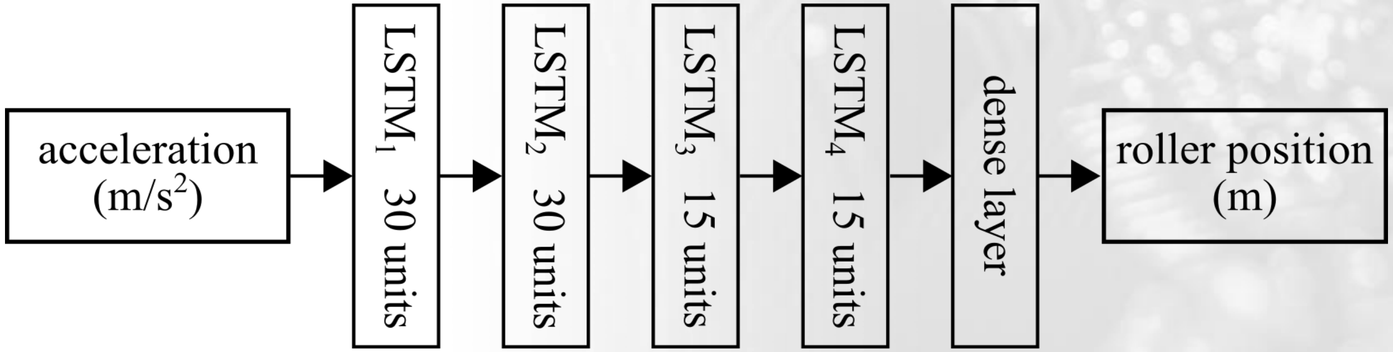
Long short-term memory model development

- Recurrent neural network that propagates through long- and short-term memory forms to make a state prediction.
- LSTM network is trained offline.
- SNR_{dB} and RMSE are used to evaluate prediction accuracy.







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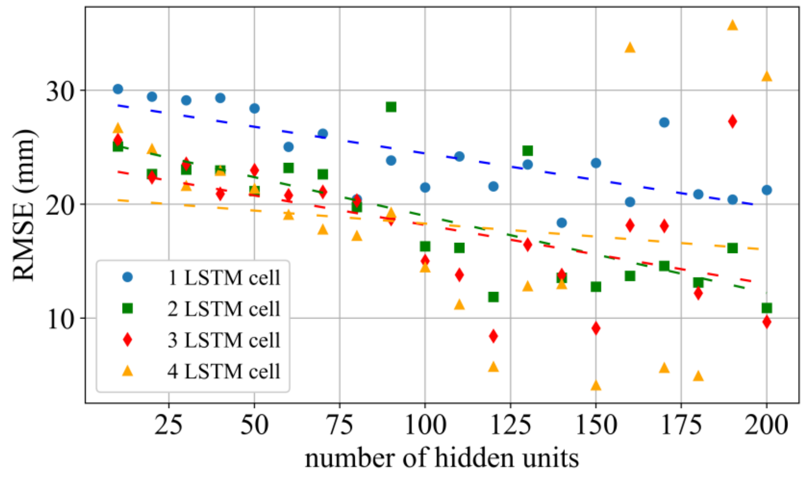
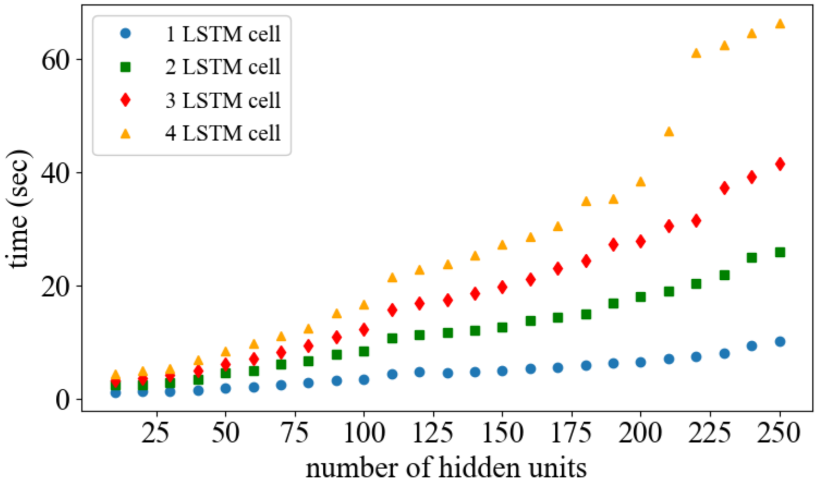
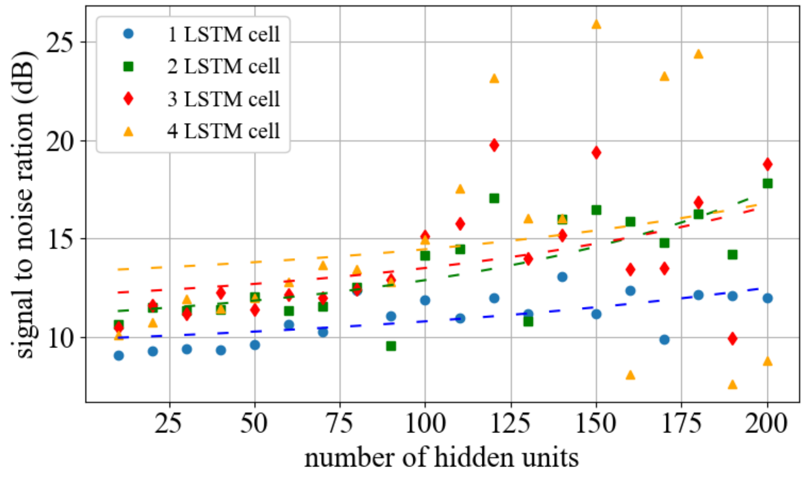
Long short-term memory model development

- Grid search of execution time and performance vs. number of hidden units.
- Four LSTM architectures with varying number of hidden units were explored.







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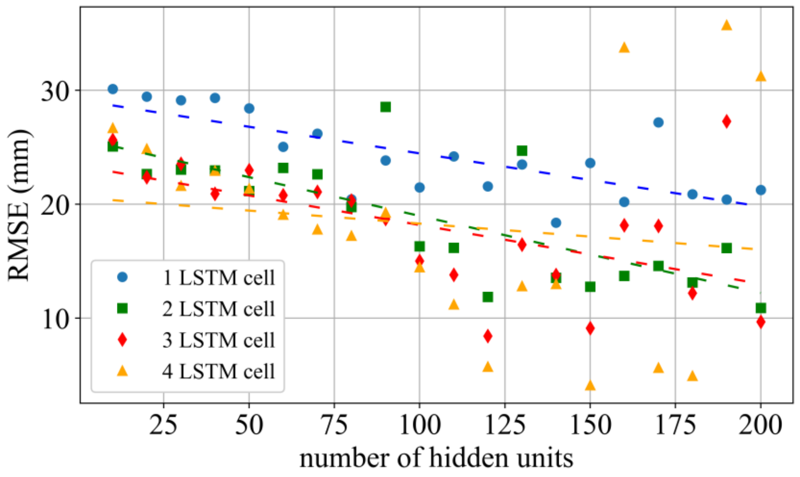
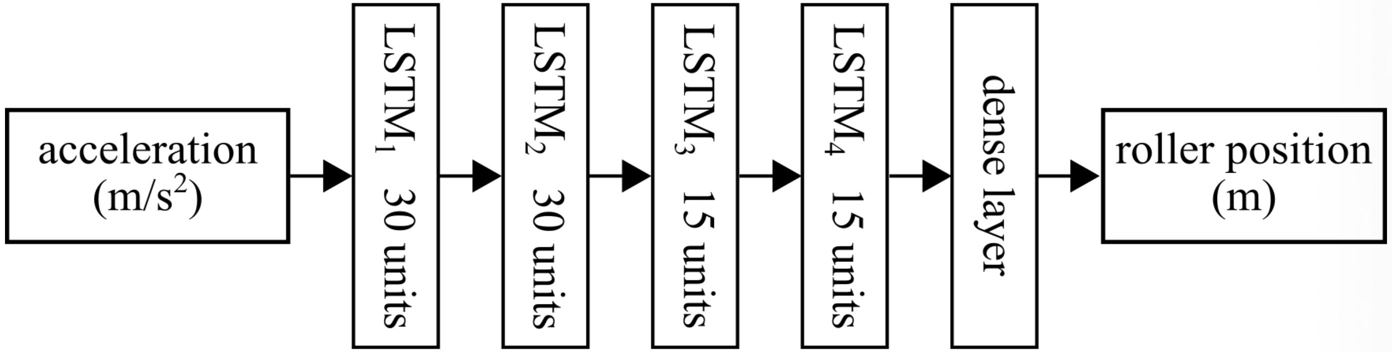
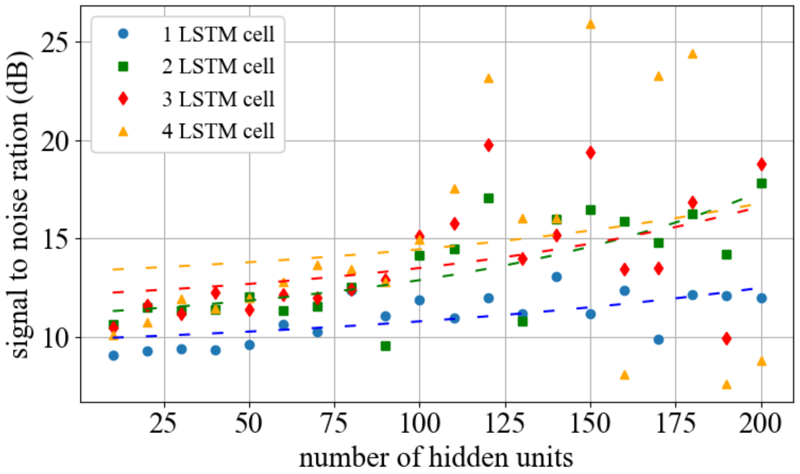
Long short-term memory model development

- Model was chosen according to execution time threshold of 2.5ms.
- Network shape is 30-30-15-15.
- Output rate of 400 S/s

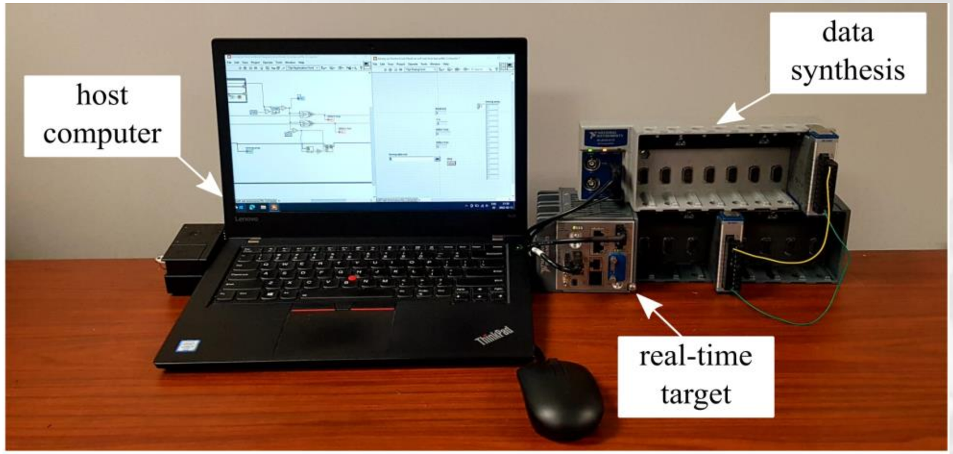






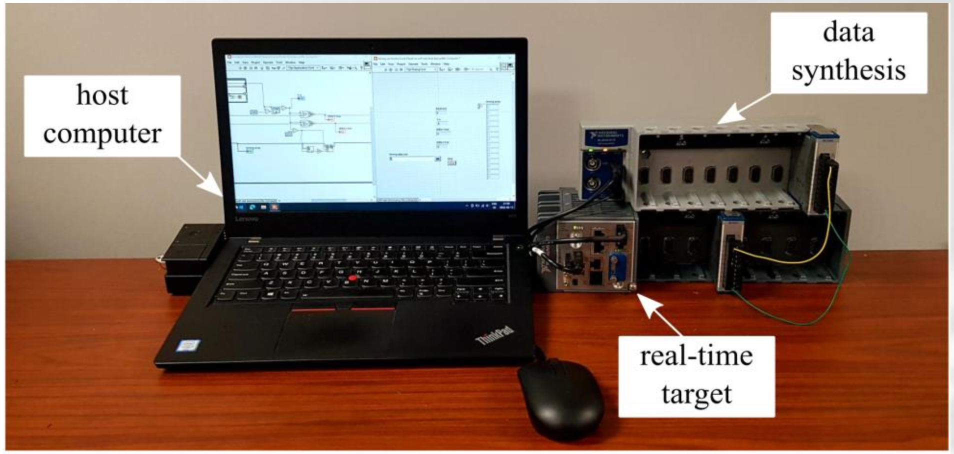
Real-time edge implementation

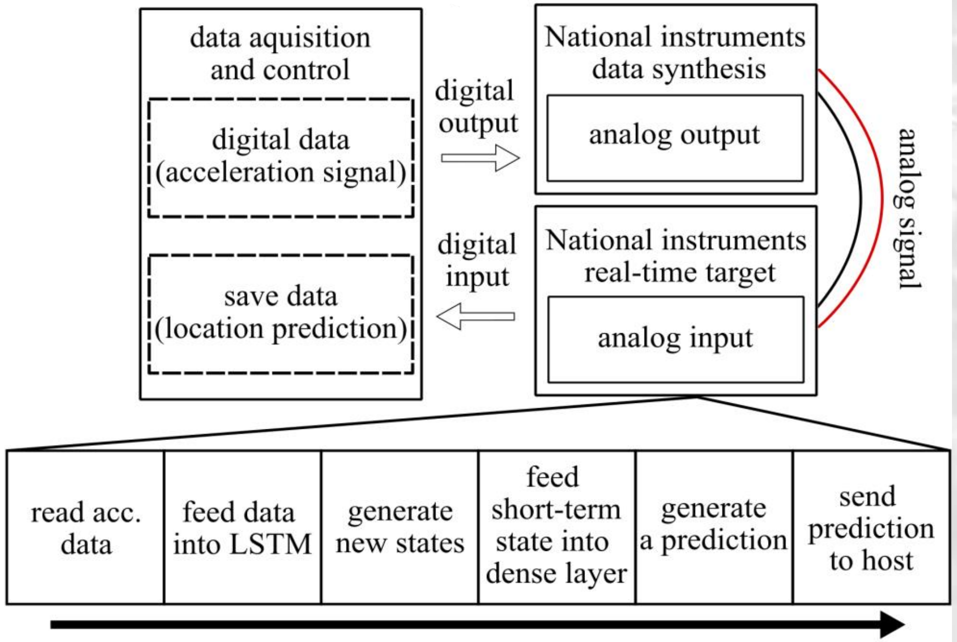
- Deployment of LSTM network to real-time operating system results in significant model constraints.
- Acceleration data is sampled at 400 S/s.
- LSTM makes a prediction every 2.5 ms.
- Hardware device is a cRIO-9035 running NI-Linux RT utilizing PREEMPT_RT patch.
- Trained model is deployed on edge device and executed in real-time.



Signal prediction and timing tests

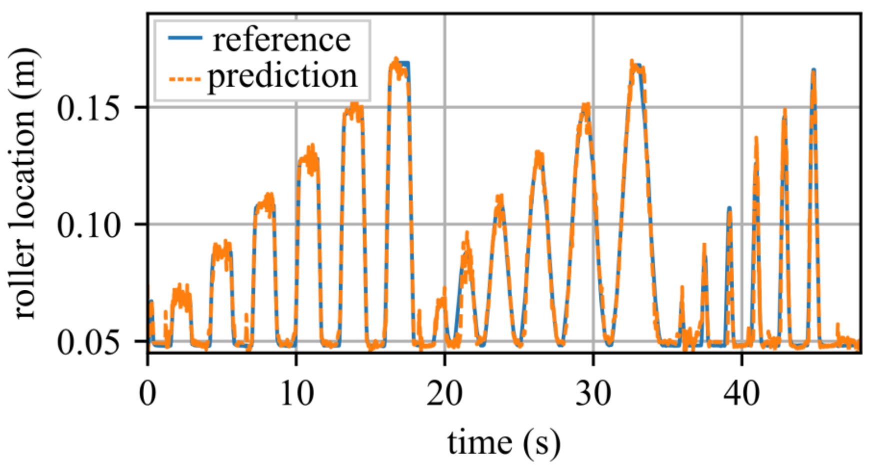
- The experimental setup consisted of two subsystems:
  - Data synthesis device reproduces the DROPBEAR dataset using a digital to analog converter.
  - The real-time system digitizes the analog voltage and feed the input into the LSTM architecture.
- A prediction is made every 2.5 ms.
- State predictions are returned via a first-in-first-out buffer to the host PC.
- SNR_{dB}, RMSE, and timing report are generated.





LSTM model performance results

- SNRdB of 43.2 dB
- RMSE of 12.8 mm
- LSTM traces reference roller location closely.

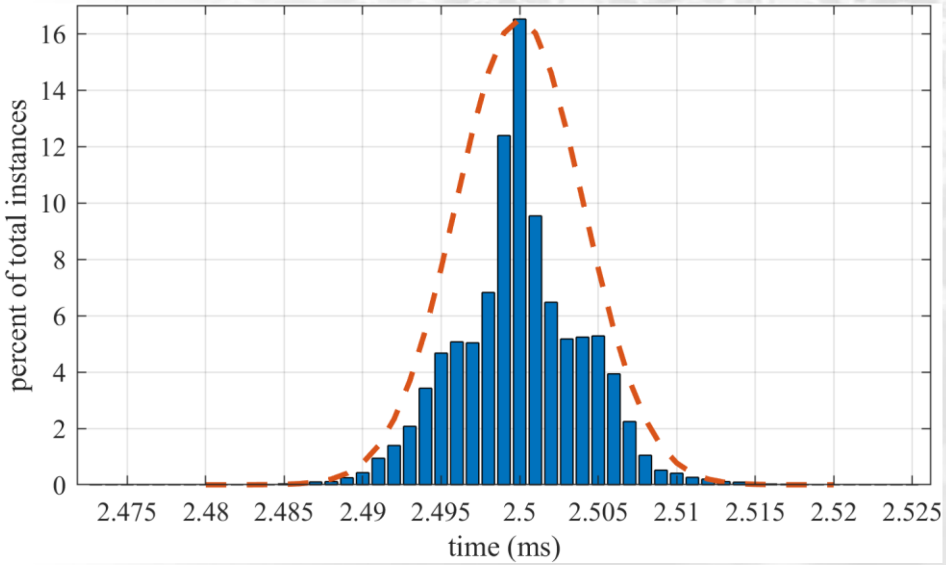


Timing accuracy results:

- Execution-time jitter in observed.
- Timing follows a normal distribution.
- A result of non-determinism in the Linux real-time system.

Algorithm execution timing report.

Mean	2.5 ms
Standard deviation	0.004 ms
Max overshoot	0.019 ms



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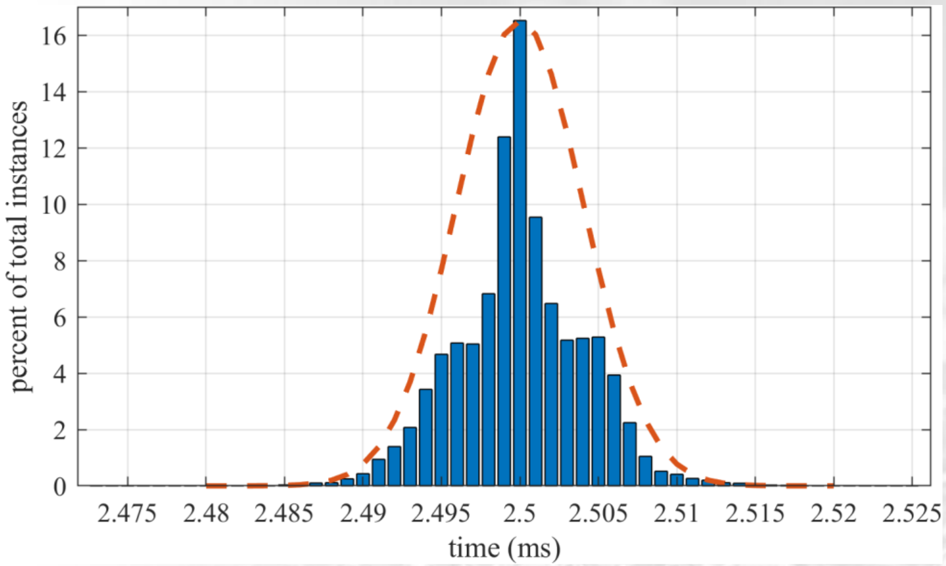
- The prediction results demonstrate that a data-driven approach using LSTMs has potential in HR-SHM applications.
- LSTMs can achieve accurate state estimations at moderately consistent latency.



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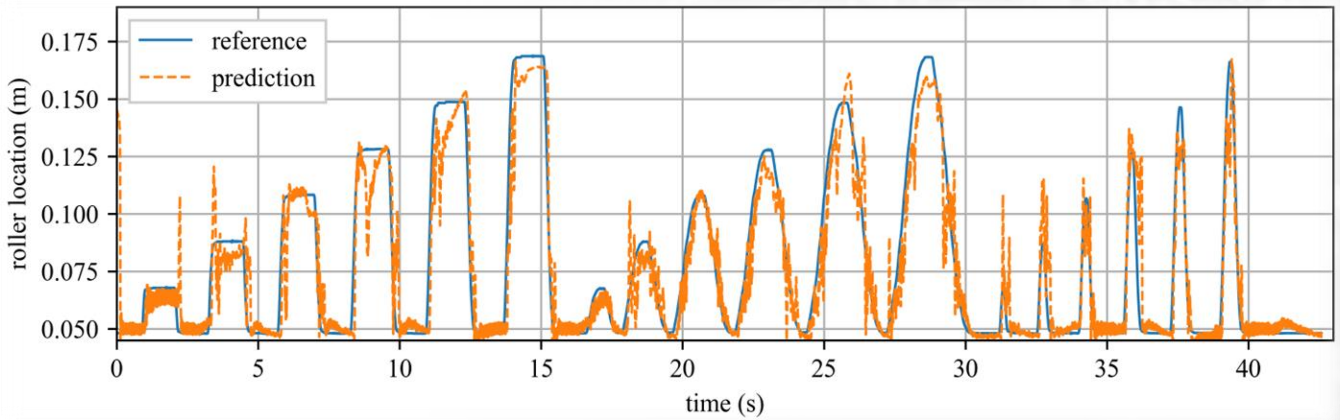
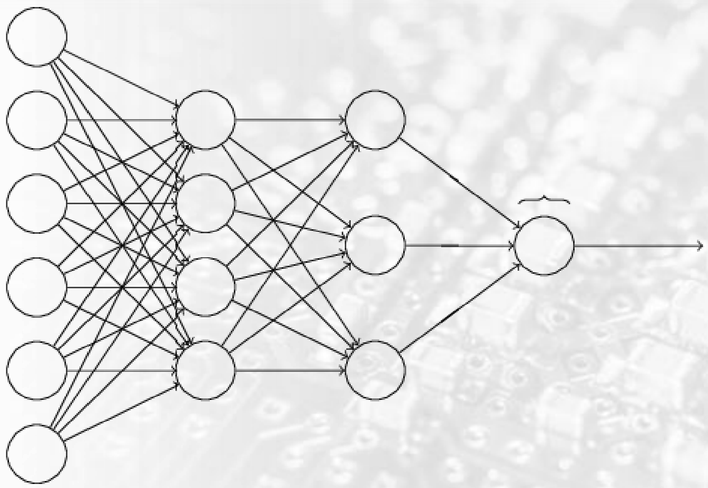
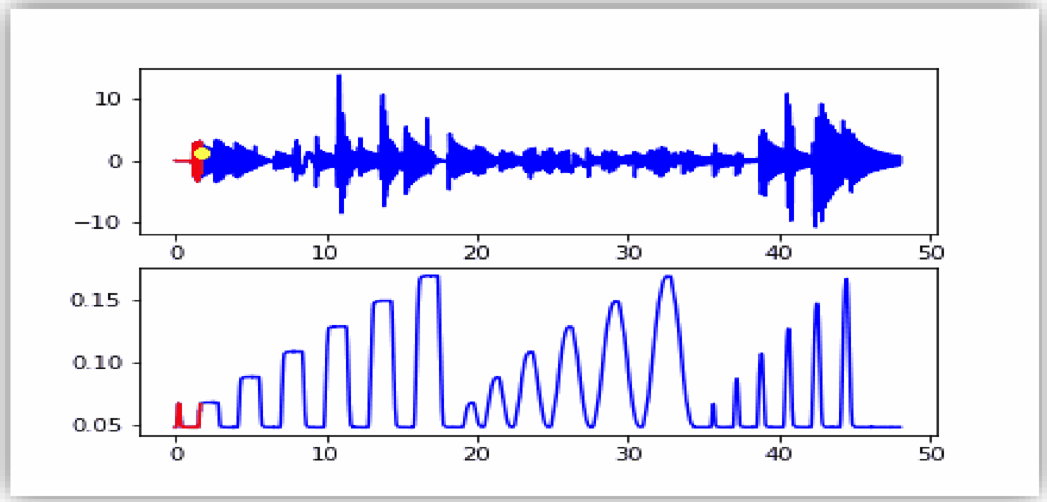


Future work will revolve around:

- Enhance prediction accuracy by altering training method.
- Increase model throughput and minimize hardware latency.





Thank you
Questions?

The ARTS-Lab
University of South Carolina
Progress towards data-driven high-rate structural state estimation on edge computing devices

https://github.com/ARTS-Laboratory/Paper-Progress-towards-data-driven-high-rate-structural-state-estimation-on-edge-computing-devices