Shrenik Zinage

Contact information

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Research background

Physics Informed Machine Learning/Scientific Machine Learning, Uncertainty Quantification, Digital Twins, Causal AI, Inverse Problems, Bayesian Statistics, Stochastic Modeling, Control, Information Field Theory, Gaussian Processes, Recurrent Neural Networks, Graph Neural Networks and Reinforcement Learning

Summary

Driven final year Ph.D. candidate in mechanical engineering with a research background in the above areas. I have hands on experience applying a variety of techniques from my research to real world systems such as internal combustion engines, hypersonic vehicles, refrigeration systems, and geodetic satellite missions. I am especially interested in how mathematics and machine learning can work together to solve real world engineering problems.

Education

Purdue University, West Lafayette, USA — GPA: 3.88 / 4.0
Ph.D. in Mechanical Engineering — Jan 2023 - May 2026 (Expected)
Purdue University, West Lafayette, USA — GPA: 3.34 / 4.0
MS (Thesis) in Mechanical Engineering — Aug 2021 - Dec 2022
Indian Institute of Technology Madras, Chennai, India — GPA: 8.7 / 10
Bachelor of Technology in Naval Architecture and Marine Engineering — Aug 2017 - Jul 2021

Skills

Programming Languages: Python, Julia, MATLAB/Simulink, C, Java, R, Fortran
Programming Environments: Git, LaTeX, ROS, Docker, Slurm
Software/Libraries: JAX, PyTorch, TensorFlow, Keras, GPJax/GPyTorch, Flax, Equinox, Jraph, Diffrax, Optax, Pyro, PyMC, SALib, SciML.jl, DeepXDE, Neuromancer, ModelingToolkit.jl, Turing.jl, Langchain, Langgraph, n8n
Computer-Aided Design Software: AutoCAD, Fusion 360, Ansys, OpenFOAM, InkScape

Internship Experience

Mitsubishi Electric Research Laboratories, Cambridge, MA, USA — May 2025 - Aug 2025
Estimation and Calibration of Multi-Physical Systems using Experiments Intern

- Estimated and calibrated large scale first principles dynamic models of vapor compression cycles in Julia for robust control and fault detection applications.
- Due to MERL confidentiality policy, no more information can be provided.

RTX Technology Research Center, East Hartford, CT, USA — May 2024 - Aug 2024
Physics Informed Machine Learning Intern

- Introduced a scalable deep kernel using Kolmogorov Arnold networks as an effective alternative to deep kernel learning using multi-layer perceptrons.
- Developed an information field theoretic approach for learning partial differential equations using neural operators.
- Conducted research towards pretrained foundational models for physics and engineering.

Mazagon Dock Shipbuilders Limited, Mumbai, India May 2019 - Jun 2019
Industrial Intern

- Worked in productive and workflow processes.
- Collaborated with public sector entities to implement quality control measures followed in MDL.

Research Experience

Purdue University, West Lafayette, USA Aug 2021 - Present
Graduate Research Assistant

- Developing a novel scalable Bayesian approach to causal discovery using observational data and prior beliefs.
- Proposed a Bayesian calibration framework combining Gaussian processes with approximate Bayesian computation to build transferable probabilistic models for engine-out NOx.
- Utilized graph neural networks to model and predict engine-out NOx with a causal graph-enhanced Gaussian process.
- Developed an innovative multiscale model combining atomistic simulations and machine learning to predict alloy behavior under high strain rate loads.
- Integrated transformers with model predictive path integral control to improve efficiency, reduce samples, and optimize autonomous navigation performance.
- Built a stable linear control oriented model for predicting engine-out NOx using deep Koopman operator.
- Leveraged gated recurrent units for iterative online precise attitude control for geodetic missions.
- Outperformed RNNs by 10% in learning engineered dynamics from noisy data using liquid time-constant networks.
- Built a predictive linear control oriented turbocharger turbine model using the Koopman operator approach.

Indian Institute of Technology Madras, Chennai, India Aug 2018 - Jul 2021
Undergraduate Research Assistant

- Optimized payload stability on KCS ship under variable sea conditions through comparative analysis of control strategies.
- Implemented control strategies including PD, MPC, LQI, SMC, data-driven, and RL-based control.
- Assessed these controllers against benchmarks for heave compensation, offset tracking, disturbance rejection, and noise attenuation.

Research Projects

Causal Digital Twins for Real-Time Decision Making and Fault Detection Sep 2024 - Present

- Developing a novel scalable Bayesian approach to causal discovery using observational data and prior beliefs.
- Developing AI agents for automating end to end causal inference.
- Evaluating the real world applicability and effectiveness of our proposed approach to fault detection in a real world engineering scenario.

Probabilistic System Modeling and Adaptability for Engine-out NOx Jan 2023 - Present

- Developed a predictive probabilistic model for modeling engine-out NOx using Gaussian process regression.
- Incorporated physical laws in the deep kernel with a causal graph derived via graph convolutional networks.
- Quantified the epistemic and aleatory uncertainty in NOx predictions.
- Assessed the performance of the model on various quantitative and qualitative metrics.
- Proposed a Bayesian calibration framework combining Gaussian processes with approximate Bayesian computation to build transferable probabilistic models for engine-out NOx.

Multiscale Models for the Mechanical Response of FCC Alloys under High Strain Rates and Complex Triaxial Loads Aug 2022 - Present

- Created an innovative multiscale model for predicting metallic alloys response to high strain rate loads.
- Merged large scale atomistic simulations with machine learning for optimal model development.
- Achieved improved results, capturing various deformation mechanisms under extreme conditions.

TransformerMPPI: Accelerated Model Predictive Path Integral Control with Transformer-Initialized Control Sequences Sep 2024 - Dec 2024

- Integrated transformers with MPPI control to improve computational efficiency.
- Used a trained transformer to produce informed mean control sequences, reducing sample requirements and accelerating convergence.
- Achieved superior performance in collision avoidance and autonomous racing, outperforming MPPI in cost, speed, and efficiency.

Leveraging Gated Recurrent Units for Iterative Online Precise Attitude Control for Geodetic Missions Jan 2024 - Aug 2024

- Integrated GRU-based disturbance prediction with PID controllers for precise satellite attitude control.
- Enhanced geodetic mission accuracy by reducing attitude error via real-time ML corrections.
- Improved traditional control systems by adding GRU-based predictive corrections.

Liquid Time Constant Networks for Engineered Systems Jan 2022 - Dec 2022

- Evaluated and demonstrated the superior performance of liquid time-constant (LTC) networks in learning dynamics from noisy data compared to traditional RNNs.
- Used synthetic, corrupted data to test the robustness of these networks under various conditions and parameter settings.
- Showcased the effectiveness of this network in modeling benchmark oscillatory systems under diverse test excitations and its ability to capture resonance effects.

Turbocharger Turbine Modeling using Koopman Operator Aug 2021 - Dec 2021

- Developed a predictive control oriented model for turbocharger turbines using the Koopman operator approach.
- Applied extended dynamic mode decomposition to approximate the action of the Koopman operator, using experimental data from a Cummins heavy duty engine, outperforming existing nonlinear autoregressive models with exogenous inputs.
- Used enhanced sensor data for more accurate modeling, addressing gaps in manufacturer provided maps, especially in wide operating regions and incorporating heat transfer effects for more comprehensive and realistic modeling.

Reinforcement Learning based Control for Heave Compensation Sep 2020 - May 2021

- Implemented deep deterministic policy gradient algorithm to capture the experience of the RL agent during training trials.
- The simulation results demonstrated up to 10 % better heave compensation performance of RL controller as compared to a tuned proportional-derivative Control.
- The performance of the proposed method was compared with respect to heave compensation, offset tracking, disturbance rejection, and noise attenuation.

Data Driven Control for Heave Compensation Aug 2020 - Nov 2020

- Performed the model identification of the winch model using long short term memory (LSTM) network.

- The network was trained using pairs of input-output data where the input was the opposite of the net heave time history of a KCS ship and output was the control input to winch placed on board the ship.
- Analyzed the ability of LSTM network in handling the hard constraints of the swash angle.

A Comparative Study of Different Heave Compensation Approaches Aug 2019 - Aug 2020

- Evaluated various control strategies (proportional-derivative, model predictive control, linear quadratic integral compensator, sliding mode control) for maintaining stability of a suspended payload on a KCS container ship under variable sea conditions.
- Conducted simulations in MATLAB/SIMULINK across three scenarios: no disturbance or measurement noise, with disturbance but no measurement noise and with measurement noise but no disturbance.

Course Projects

Probabilistic Koopman Operator Learning with Stability Guarantees, *Purdue University, USA* Jan 2024 - May 2024

- Replicated the results of the paper "Physics-Informed Probabilistic Learning of Linear Embeddings of Non-linear Dynamics With Guaranteed Stability" using JAX to implement Koopman operator models for non-linear dynamics.
- Applied mean field variational inference to quantify uncertainty in Duffing oscillator and cylinder wake flow predictions.

Bayesian Physics Informed Neural Networks, *Purdue University, USA* Aug 2022 - Dec 2022

- Leveraged B-PINNs for learning dynamics from noisy data and physics equations with unknown parameters.
- Utilized Hamiltonian Monte Carlo for posterior estimation.
- Conducted case studies on benchmark dynamics: spring-mass-damper, 1-D heat equation, and Van der Pol oscillator.

Nonlinear Feedback Control for Autonomous Vehicle, *IIT Madras, India* Sep 2020 - Dec 2020

- Implemented the paper "Composite nonlinear feedback control for path following of four-wheel independently actuated AGV".
- Investigated the path following control problem via integrated control of active front wheel steering and direct yaw moment control.
- Applied a modified composite nonlinear feedback strategy to improve performance and eliminate steady state errors.

Control of a Self Balancing Robot, *IIT Madras, India* Feb 2020 - Apr 2020

- Analyzed the kinematics and dynamics of an inverted pendulum on MATLAB and used accelerometer and gyroscope sensors output as feedback.
- Implemented integral backstepping control to accurately hold the inverted pendulum at an upright position (error < 5 deg).
- The noise in the IMU data was removed using extended kalman filter.

Achievements

- **Recognized** by Purdue University for contributions to high profile projects, efficiency improvement, and departmental advancements.
- Experience in running codes on **GPU clusters** and handling **large codebases** in GitHub.
- Awarded the **Class NK-100** prize for the best thesis in Ocean Engineering at IIT Madras.
- **Second Rank Holder** in the B.Tech curriculum at the Department of Ocean Engineering, IIT Madras, among a batch of **27** students.

- **Building an Autonomous Surface Vehicle (ASV)**: Part of a group which was working on building an ASV from scratch.
- Secured All India Rank of 4500 (Top **0.025%** percentile) in JEE Advanced (for admission into IITs the top engineering institutions in India).
- Selected in the **Top 2%** in the National Physics Olympiad (2016), National Chemistry Olympiad (2016), and National Astronomy Olympiad (2015).
- National Talent Search Examination (NTSE) Scholarship awarded by National Council of Education Research and Training (NCERT), India.
- **UCMAS** (Mental Calculations): Cleared ten levels and won awards at National and International levels.

Relevant Courses

Mathematics: Introduction to Probability Theory, Linear Algebra, Differential Equations, Series and Matrices, Probability and Stochastic Processes, Advanced Mathematics for Engineers and Physicists I and II.
Machine Learning and AI: Bayesian Data Analysis, Topics in Advanced Scientific Machine Learning, Introduction to Scientific Machine Learning, Generative Models*.
Control Systems: Optimal Control, Theory and Design of Control Systems, Nonlinear Programming, Modern Control Theory, Maneuvering and Control of Marine Vehicles.
Robotics: Introduction to Robotics, Marine Robotics.
Other Engineering Topics: Advanced Thermodynamics, Intermediate Heat Transfer, Numerical Methods, Statistical Methods, Foundations of Computational Imaging*.
Online Courses: Generative AI with Large Language Models (Coursera), Data Structures and Algorithms Specialization (Coursera), Self-Driving Cars Specialization (Coursera), Introduction to IoT Specialization (Coursera), Dynamics and Control (edX), Signals and Systems (NPTEL), Advanced Linear Control Systems (NPTEL), Non-Linear Programming (NPTEL), Machine Learning (NPTEL), Introduction to Artificial Intelligence (Coursera), Robotics (NPTEL)

Journal Publications

1. **S. Zinage**, V. Dixit, A. Chakrabarty, H. Qiao, C. R. Laughman, I. Bilionis, and V. M. Deshpande. "Sequential Bayesian Model Calibration of Vapor Compression Cycles using Experiments" **to be submitted** to *International Journal of Refrigeration*.
2. C. Yuan, **S. Zinage**, E. Holbrook, C. Li, I. Bilionis, M. Koslowski, and A. Strachan (2025). "Multiscale Models for the Mechanical Response of FCC Alloys under High-Strain Rates and Complex Triaxial Loads" **to be submitted** to *Nature*. (Abstract)
3. **S. Zinage**, P. Meckl, and I. Bilionis (2025). "Bayesian Calibration of Engine-Out NOx Models for Engine-to-Engine Transferability" **submitted** to *International Journal of Engine Research*. (Link)
4. **S. Zinage**, V. Zinage, and E. Bakolas (2024). "Transformer-Based Model Predictive Path Integral Control" **submitted** to *ACM Transactions on Intelligent Systems and Technology*. (Link)
5. **S. Zinage**, I. Bilionis, and P. Meckl (2025). "A Causal Graph-Enhanced Gaussian Process Regression for Modeling Engine-out NOx" *International Journal of Engine Research*, 14680874251381460. (Link)
6. **S. Zinage** and A. Somayajula (2020). "A Comparative Study of Different Active Heave Compensation Approaches" *Ocean Systems Engineering*, 10(4), 373. (Link)

Peer Reviewed Conference Publications

1. **S. Zinage**, and I. Bilionis. "SVIDAG: A Structural Variational Inference Approach to Causal Discovery" **to be submitted** to *NeurIPS 2026*.
2. **S. Zinage**, V. Dixit, A. Chakrabarty, H. Qiao, C. R. Laughman, I. Bilionis, and V. M. Deshpande. "Sequential Model Calibration of Vapor Compression Cycles using Approximate Bayesian Computation" **submitted** to the *American Control Conference (ACC) 2026*. (Patent filing in process)

3. **S. Zinage**, S. Mondal, and S. Sarkar (2024). "DKL-KAN: Scalable Deep Kernel Learning using Kolmogorov-Arnold Networks" **to be submitted** to *Modeling, Estimation and Control Conference 2026.* (Link)
4. V. Zinage, **S. Zinage**, S. Bettadpur, and E. Bakolas (2024). "Leveraging Gated Recurrent Units for Iterative Online Precise Attitude Control for Geodetic Missions" *AIAA SciTech 2025.* (Link)
5. **S. Zinage**, S. Jadhav, Y. Zhou, I. Bilionis, and P. Meckl (2022). "Data Driven Modeling of Turbocharger Turbine using Koopman Operator" *IFAC-PapersOnLine*, 55(37), 175-180. (Link)
6. **S. Zinage** and A. Somayajula (2021). "Deep Reinforcement Learning Based Controller for Active Heave Compensation" *IFAC-PapersOnLine*, 54(16), 161-167. (Link)

References

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