Huzaifa Mustafa Unjhawala

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Summary

I am a Ph.D. candidate in Mechanical Engineering with a deep focus on developing high-performance, physics-based simulation engines for robotics and autonomous systems. My background includes a master's in computer science and extensive experience in C++, CUDA, and SYCL for GPU-accelerated computing. As a core developer of Project Chrono's Chrono::FSI module and a contributor to Drake's collision engine at Toyota Research Institute (TRI), I have hands-on experience building and optimizing the foundational components of large-scale simulation tools. My work involves creating scalable solutions for complex challenges in multibody dynamics, terramechanics, and collision detection, directly aligning with the core problems in autonomy simulation.

Education

University of Wisconsin-Madison — May 2026 (Expected)
Ph.D. Mechanical Engineering, Minor in Mathematics, Advisor: Dan Negrut — *Current GPA: 3.93/4.0*

University of Wisconsin-Madison — Dec 2024 (Completed)
MS Computer Science — *GPA: 3.9/4.0*

Relevant Coursework

High Performance Computing, Scientific Computing, Applied Mathematics, Kinematics and Dynamics of Machine Systems, Vehicle Dynamics, Continuum Mechanics, Nonlinear Finite Elements, Non-Linear Optimization, Machine Learning, Foundation Models, Probabilistic Machine Learning, Stochastic Computational Methods.
Awards: Baden-Württemberg Stipendium

Skills

Languages: C/C++, `CUDA`, SYCL, Python (incl. JAX, PyTorch), Matlab, LaTeX
Tools: Git, Linux (Arch, Ubuntu), Docker, CMake, Shell (Bash, Zsh), SWIG, PyBind11
Robotics Middleware: Drake, Project Chrono

Work Experience

Toyota Research Institute | *Robotics Intern - Dynamics and Simulation, Boston, MA* — May 2025 – Present

- Developing a GPU-based collision detection engine for Drake's Hydroelastic contact model, a robotics middleware used for autonomy research.
- Using SYCL to achieve cross-platform parallelization on NVIDIA, Intel, and AMD GPUs.
- Implementing a custom sort-sweep and prune with spatial grids for the broad phase to obtain efficient parallelization for large-scale scenes.
- Follow my progress here on Github.

National Renewable Energy Laboratory | *Graduate Engineering Intern, Golden, CO* — Jul. 2023 – Sep. 2023

- Developer of HydroChrono – a C++ library enabling potential flow-based wave simulations for Wave Energy Converters (WECs) within the Project Chrono physics engine.
- Established a comprehensive testing infrastructure and CI/CD pipeline to ensure software reliability and robustness.

Research

GPU Solvers for Granular Terrain Dynamics with SPH | *UW–Madison* — May 2024 – Present

- Core developer of the Chrono::FSI solver, a Fluid-Structure Interaction module within the Project Chrono physics engine.
- Incorporating granular material physics into the Smoothed Particle Hydrodynamics (SPH) solver for high-fidelity simulation of robotic excavation and off-road mobility.
- Achieved a **10× speedup** by optimizing memory layouts and data movement for proximity search, a primary bottleneck in SPH.
- Contributions to the open source codebase and a related paper under review.

Simulator for Low-Fidelity Vehicle Dynamic Models | *U*W–Madison — Jan. 2022 – May 2023

- Developed a `C++` library of vehicle dynamics models capable of running **1000×** faster than real-time on a single CPU core.

- Engineered and parallelized the models using `CUDA`, enabling large-scale simulation of over **300,000 autonomous vehicles in real-time**.
- Utilized Bayesian Optimization to tune model parameters against high-fidelity Chrono models and real-world data, ensuring predictive accuracy for vehicles of various scales.
- Wrapped the C++ CPU and CUDA GPU models with `SWIG` for seamless integration with Python-based workflows.
- Open source code can be found here with related papers in the Publications section.

DEM Simulations for Autonomous Loading | *UW-Madison* Aug. 2024 – Present
- Generating large-scale Discrete Element Method (DEM) simulation data using the DEM-Engine, a dual-GPU DEM library.
- The resulting simulation data is used as a training source for Komatsu's autonomous excavation and loading machinery, improving robotic perception and control algorithms.
- Early simulation results can be found here.

Machine Learning for Constrained Multibody Dynamics systems | *UW Madison* Aug. 2023 – Mar. 2024
- Contributed to MBD-NODE, a physics-informed neural network for learning the dynamics of constrained multibody systems.
- The model achieved **state-of-the-art** performance in generalizing to out-of-distribution (OOD) scenarios, a critical challenge in robotics simulation.
- See Publication below for more details.

SAE Baja Racing

Team Lead 2019-2020
- Led a 30-member team in overall vehicle design, manufacturing strategy, and system integration for an off-road racing vehicle.
- Achieved a **top 5 finish (out of 150)** in *SAE Baja India 2020* and secured multiple podiums at *Enduro Student India 2020*.

Publications

- **H. M. Unjhawala**, L. Bakke, H. Zhang, M. Taylor, G. Arivoli, R. Serban, and D. Negrut, "A Physics-Based Continuum Model for Versatile, Scalable, and Fast Terramechanics Simulation," Manuscript submitted to *Journal of Terramechanics*, 2025. https://uwmadison.box.com/s/wb822liputgrca6iz444ofo7s2391zgm
- Hu, W., Li, P., **Unjhawala, H.M.**, Serban, R., & Negrut, D. (2023). Calibration of an expeditious terramechanics model using a higher-fidelity model, Bayesian inference, and a virtual bevameter test. *Journal of Field Robotics*, 1–20. https://doi.org/10.1002/rob.22276
- **Unjhawala, H. M.**, Zhang, R., Hu, W., Wu, J., Serban, R., & Negrut, D. (2023). Using a Bayesian-Inference Approach to Calibrating Models for Simulation in Robotics. *ASME Journal of Computational and Nonlinear Dynamics*, 18(6), 061004. https://doi.org/10.1115/1.4062199
- **Unjhawala, H. M.** et al. (2024). An Expeditious and Expressive Vehicle Dynamics Model for Applications in Controls and Reinforcement Learning. *IEEE Access*. https://doi.org/10.1109/ACCESS.2024.3368874
- **Unjhawala, H. M.** et al. (2024). A Library of Lower Fidelity Dynamics Models (LFDMs) For On-Road Vehicle Dynamics Targeting Faster Than Real-Time Applications. *Journal of Open Source Software*, 9(99), 6548. https://doi.org/10.21105/joss.06548
- Wang, J., Wang, S., **Unjhawala, H.M.** et al. (2024). MBD-NODE: Physics-Informed Data-Driven Modeling and Simulation of Constrained Multibody Systems. *Multibody System Dynamics*. https://doi.org/10.1007/s11044-024-10012-6
- Zhou, Z., **Unjhawala, H. M.**, Kamaraj, A., Kissel, A., Lee, J., Serban, R., & Negrut, D. A Chrono-Based Framework for Large-Scale Traffic Simulation with Human-In-The-Loop. *IEEE Journal of Intelligent Vehicles*.
- Zhang, H., **Unjhawala, H.**, Young, A., Ruiz, A., Bakke, L., Serban, R., & Negrut, D. Using simulation in the design and evaluation of path following control policies for autonomous ground robots. *Simulation Modelling Practice and Theory*
- Mahajan, I., **Unjhawala, H. M.**, Zhang, H., Zhou, Z., Young, A., Ruiz, A., Caldararu, S., Batagoda, N., Ashokkumar, S., & Negrut, D. (2024). Quantifying the Sim2real gap for GPS and IMU sensors. arXiv. https://arxiv.org/abs/2403.11000
- Wang, J., Zhang, H., **Unjhawala, H. M.**, Negrut, P., Wang, S., Slaton, K., Serban, R., Wu, J.-L., & Negrut, D. (2024). SimBench: A rule-based multi-turn interaction benchmark for evaluating an LLM's ability to generate digital twins. arXiv. https://arxiv.org/abs/2408.11987
- Zhang, H., Caldararu, S., Young, A., Ruiz, A., **Unjhawala, H. M.**, Mahajan, I., Ashokkumar, S., Batagoda, N., Zhou, Z., Bakke, L., & Negrut, D. (2024). A study on the use of simulation in synthesizing path-following control policies for autonomous ground robots. arXiv. https://arxiv.org/abs/2403.18021