Siddharth Hari Nair

Curriculum Vitae

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Research Interests

Model Predictive Control, Numerical Optimal Control, Robust Optimization, Machine Learning

Education

UC Berkeley.

2018-Present *PhD: Mechanical Engineering*, *Advisor*: Prof. Francesco Borrelli.

Major: Control, *Minors*: Optimization, Machine Learning.

IIT Bombay .

2013–2018 *B.Tech+M.Tech: Aerospace Engineering*, *Minor: Systems and Control Engineering*.

Awards Received the *Institute Silver Medal* for graduating with the highest GPA in Aerospace Engineering.

Received *Undergraduate Research Awards 1 & 2* for Bachelor's thesis and research.

Projects

UC Berkeley

Theme: Learning for Efficient, Robust Nonlinear Model Predictive Control

Title *Learning for Solving Parametric Mixed Integer Linear Programs Online with Optimality Certificates*

Fa'22–

- Contribution: Developed a supervised learning framework for fast online solutions of multi-parametric Mixed Integer Linear Programs (mp-MILPs) for MPC, with sub-optimality quantification for verifying the quality of the predictions.
- Key idea: Proposed a strategy mapping that captures the parametric optimality certificates for mp-MILPs from which lower bounds and upper bounds on the optimal objective can be obtained efficiently (akin to Strong duality in convex optimization) without Branch-and-Bound (BnB).
- Approach: Collected a dataset of strategies by extracting the BnB solution tree from various MILP instances for MPC, and trained a Deep Neural Network using Pytorch to predict the optimal strategy. The online computation is then reduced to a parallel solution of LPs.
- Result: Our approach shows favourable performance compared to state-of-the-art MILP solvers (Gurobi, Mosek, SCIP, GLPK) for real-time mixed-integer MPC.

Title *Collision Avoidance for Autonomous Driving with Uncertain, Multi-Modal Predictions* [Experiment Video]

Fa'21–

- Contribution: Proposed Stochastic, Robust, and Distributionally Robust MPC formulations for autonomous driving which incorporates multi-modal predictions of surrounding vehicles within the collision avoidance constraints.
- Key idea: Proposed novel, multi-modal feedback policy parameterizations, designed to effectively handle the uncertainty in the predictions to enhance the feasibility of the MPC optimization problem.
- Approach: Formulated convex SMPC, RMPC, DRMPC formulations to obtain the optimal policies online. The controller is tested in closed-loop on the CARLA simulator and on a full-scale vehicle using with the multi-modal predictions being generated using Multipath.
- Result: Our approach shows marked improvement over prevailing approaches along axes of mobility, comfort, conservatism and computational efficiency.

Title *Robust Output-lifted Learning Model Predictive Control* [Experiment Video]

Sp'20–Sp'21

- Contribution: Developed a computationally efficient approach to use historical data for synthesizing MPC policies for flat nonlinear systems.
- Key idea: Construct convex approximations of the value function of the optimal control problem on a convex, lifted space of virtual output sequences. This reformulates the Learning MPC problem as a nonlinear program (NLP) as opposed to an MINLP.
- Approach: Collected historical data for various flat nonlinear systems to construct their value function approximations for our MPC algorithm. The MPC optimization problems were modelled using Casadi and solved using IPOPT. The algorithm was also demonstrated on a 1/10 scale vehicle.
- Result: Our approach guarantees iterative performance improvement, constraint satisfaction, and asymptotic convergence to the desired goal, along with reduced computational effort.

Title *Data-driven Modelling and Control with State-dependent Uncertainty*

Sp'19–Fa'19

- Contribution: Proposed a non-parametric technique for modelling systems with Lipschitz/Lur'e nonlinear dynamics using semi-definite programming and set membership
- Key idea: Use system trajectory traces to approximate the graph of the dynamics function using incremental quadratic constraints.
- Approach: Statistically estimate the system constants using Extreme Value theory to characterize the nonlinearity. Use the system trajectory data and the incremental quadratic constraints to approximate the graph of the dynamics using the S-procedure.
- Result: Our approach is demonstrated for: (i) computation of tractable bounds for unmodelled dynamics, (ii) approximation of positive invariant sets, and (iii) an Adaptive MPC framework for linear systems with additive state-dependent uncertainty.

Title *Learning to Race on Hyundai G90* [Experiment Video]

Fa'18

- Contribution: (i) Implemented the Learning Model Predictive Control (LMPC) scheme on a full-scale vehicle on ROS for improving lap times around a track, (ii) Implemented a kernel-based local regression scheme for system identification, (iii) Modelled and estimated actuation delays from vehicle data.
- Result: The G90 iteratively improves lap times, and operates near cornering regimes at the end.

IIT Bombay

Theme: Geometric Optimal Control for Mechanical Systems

Title *Discrete Optimal Control for Interconnected Mechanical Systems* *Master's Thesis*

- Developed variational integrators for mechanical systems on Lie groups, to formulate a discrete optimal control problem and the necessary conditions that characterise optimal trajectories.

Title *Control Strategies for Load Carrying Drones* *Bachelor's Thesis*

- Formulated a novel problem in cooperative control of quadrotors - a group of quadrotors carrying a ball and plate system slung via inextensible tethers. Using tools from geometric nonlinear control, synthesized feedback policies for the quadrotors to stabilize the underactuated payload.

Publications

2023 Russo*, L., **Nair*, S.H.**, Glielmo, L., Borrelli, F., "Learning for Online Mixed-Integer MPC with Parametric Optimality Certificates", *IEEE Control Systems Letters* (pdf) **(Invited Paper)**

2023 Oliveira, R., **Nair, S.H.**, Wahlberg, B. "Interaction and Decision Making-aware Motion Planning using Branch Model Predictive Control ", *IEEE Intelligent Vehicles Symposium* (pdf)

2022 **Nair, S.H.**, Tseng, E.H., Borrelli, F., "Collision Avoidance for Dynamic Obstacles with Uncertain Predictions using Model Predictive Control", IEEE Conference on Decision and Control (CDC) 2022 (pdf)

2022 **Nair, S.H.**, Govindarajan, V., Lin, T.,Wang, Y., Tseng, E.H., Borrelli, F., "Stochastic MPC with Dual Control for Autonomous Driving with Multi-Modal Interaction-Aware Predictions", International Symposium on Advanced Vehicle Control (AVEC) 2022 (pdf)

2022 **Nair*, S.H.**, Govindarajan*, V., Lin, T., Meissen, C., Tseng, E.H., Borrelli, F., "Stochastic MPC with Multi-modal Predictions for Traffic Intersections", International Conference on Intelligent Transportation Systems (ITSC) 2022 (pdf)

2021 **Nair, S.H.**, Rosolia, U., Borrelli, F., "Output-Lifted Learning Model Predictive Control", IFAC Conference on Nonlinear Model Preditive Control (NMPC) 2021 (pdf) **(Keynote Talk)**

2020 **Nair, S.H.**, Bujarbaruah, M., Borrelli, F., "Modeling of Dynamical Systems via Successive Graph Approximations", IFAC World Congress 2020 (pdf)

2020 Bujarbaruah*, M., **Nair*, S.H.**, Borrelli, F., "A Semi-Definite Programming Approach to Robust Adaptive MPC under State Dependent Uncertainty", European Control Conference (ECC) 2020 (pdf)

2019 **Nair, S.H.**, Banavar, R.N., "Discrete Optimal Control of Interconnected Mechanical Systems", IFAC Symposium on Nonlinear Control Systems (NOLCOS) 2019 (pdf)

2019 **Nair, S.H.**, Banavar, R.N., Maithripala, D.H.S., "Control Synthesis for an Underactuated Cable Suspended System Using Dynamic Decoupling", American Control Conference (ACC) 2019 (pdf)

2017 **Nair, S.H.**, Sinha, A., Vachhani, L., "Hilbert's Space-filling Curve for Regions with Holes", IEEE Conference on Decision and Control (CDC) 2017 (pdf)

2017 **Nair, S.H.**, Subbarao, K., "Attitude Control of Spacecraft Formations subject to Distributed Communication Delays", AAS/AIAA Space Flight Mechanics Meeting 2017 (pdf)

Preprints/Reports

2023 **Nair, S.H.**, Borrelli, F., "Robust Output-Lifted Learning Model Predictive Control", *submitted to IEEE Transactions on Automatic Control* (pdf)

2022 **Nair, S.H.**, Stüerz, Y. "Control of Uncertain PWA systems using DC Decompositions" (pdf)

2019 Byun*, J., Jain*, K.P., **Nair*, S.H.,** Xu*, H., Zha*, J., "Predictive Control for Chasing a Ground Vehicle using a UAV" (pdf)

Working Papers

Nair*, S.H., Lee*, H., Joa*, E., Lin, T., Wang, Y., Tseng, E.H., Borrelli, F., "Stochastic MPC with Multi-modal Predictions for Autonomous Driving: Theory and Experiments"

Nair, S.H., Russo, L., Glielmo, L., Borrelli, F., "End-to-End Learning for Rapid Mixed-Integer Model Predictive Control with Parametric Optimality Certificates"

Key Courses

Control

- Optimal Contol, Model Predictive Control
- Adaptive, Sliding Mode Control
- Flight Dynamics, Navigation and Guidance
- Nonlinear, Hybrid and Stochastic Systems
- Differential Geometric Methods in Control
- Control for Legged Robots

Optimization

- Linear, Nonlinear Programming
- Convex and Robust Optimization

Mathematics

- Numerical Analysis, Numerical Integration
- Real Analysis, Point-Set Topology
- Advanced Matrix Computations
- Measure Theory, Functional Analysis

Machine Learning

- Theoretical Statistics
- Deep Reinforcement Learning

Skills

Programming Python, C++, Julia

Tools Matlab, ROS, Casadi, Pytorch

References

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Chancellor's Professor
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