Overview of Recent Advances and Adaptive Safety for Hybrid Systems

Ricardo Sanfelice
Department Electrical and Computer Engineering
University of California

Including collaboration with Warren Dixon (UF), Matt Hale (UF), Christopher Petersen (AFRL/RV), and Sean Phillips (AFRL/RV)

CoE Review @ Zoom - April 30, 2021

Outline of Recent Results

1. Estimation

- Parameter Estimation via Hybrid Methods

  ACC 21 (3 papers); CDC 21 (2 papers submitted)

- Observers for Hybrid Systems

  CDC 20, CDC 21 (submitted), Automatica (submitted)

2. Optimization

- High Performance Optimization via Uniting Control

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  + CPSWeek Workshop w/ AFRL/RV collab.

- Adversarial Games and Distributed Optimization

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3. Safety

- Reachable Maps and Regularity

  NAHS 20, HSCC 20, CDC 20, CDC21 (submitted)

- (Necessary and Sufficient) Safety Certificates, w/ Events

  TAC 20, Automatica 21, ACC 21, TAC (submitted)

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Hybrid methods enable the following:

- **Finite-time estimation** of θ using a **hybrid algorithm** that triggers jumps in the estimates
- **Asymptotic estimation** of θ using a **hybrid algorithm** for the case when the regressor model or the dynamic model is hybrid

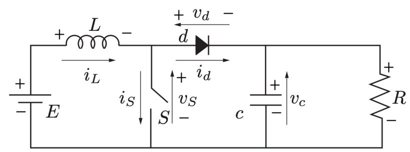
with robustness and safety, under appropriate PE conditions.

Parameter Estimation and System Identification of Hybrid Dynamical Systems

w/ Ryan Johnson

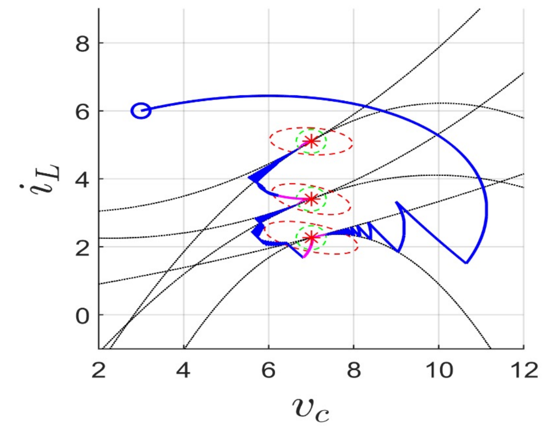
Goal

Develop generalized schemes for parameter estimation and system identification for systems with continuous and discrete dynamics, namely, hybrid dynamical systems.



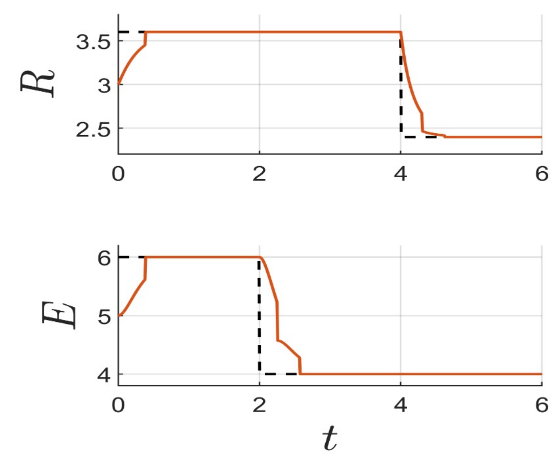
Challenges

- The values of the unknown parameters of the hybrid system may vary across the flow and jump sets.
- The flow and jump sets of the hybrid system are typically functions of the unknown parameters.
- The observability characteristics of the hybrid system may vary across the flow and jump sets.



A New Adaptive Control Scheme for a DC-DC Boost Converter with Parameter Uncertainty

- Logic-based (uniting) control scheme which switches between an asymptotically stable global algorithm and a local algorithm that maintains finite switching frequency with bounded steady-state error.
- A generalized finite-time parameter estimation scheme for switched systems which estimates the circuit input voltage and output load resistance.
- An adaptive control scheme which recomputes the controller flow and jump sets according to the circuit parameter estimates.



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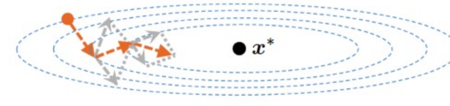
Accelerated and Robust Algorithms for Hybrid Optimization

w/ Dawn Hustig-Schultz



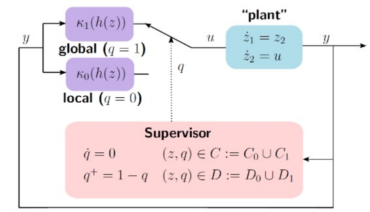
heavy-ball method

(psarkar.github.io)

Goals

- Develop algorithms, based on the heavy ball method, for optimization of a convex objective function with fast convergence, reduced oscillations, and robustness.
- Develop an algorithm for optimization of a nonconvex Morse objective function, which ensures practical global asymptotic stability of the set of minimizers with robustness.

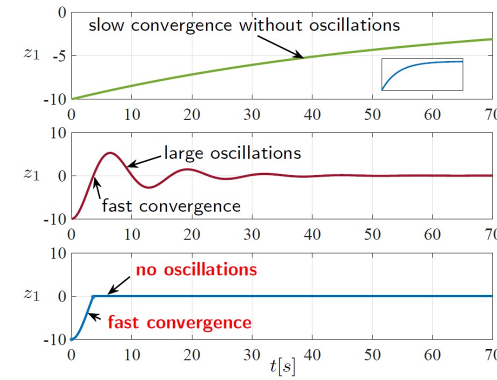
Feedback diagram of uniting algorithm



Challenges

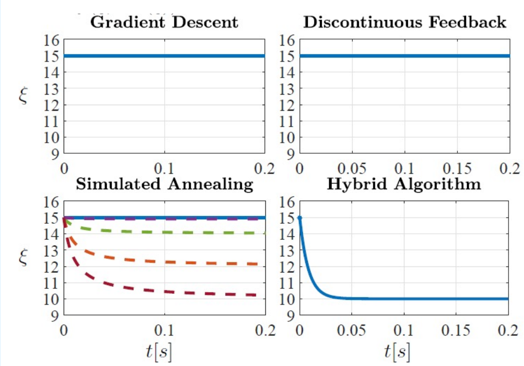
- For the heavy ball method, a large velocity coefficient converges slowly, while a small velocity coefficient results in oscillations near the minimizer.
- For existing algorithms, if the system state starts close to a local maximizer, the presence of small measurement noise in the gradient can prevent escape from that maximizer and, consequently, convergence to a local minimizer.

Performance of uniting algorithm for convex optimization, compared with local and global heavy ball algorithms.



New Algorithms for Hybrid Optimization

- Logic-based (uniting) algorithms which switch between a global heavy ball algorithm with small velocity coefficient and a local heavy ball algorithm with large velocity coefficient.
- An algorithm with switching strategy, which detects whether the state is near a critical point and ensures escape from a local maximizer, to converge to a local minimizer.
- Achieve global asymptotic stability of the set of minimizers for convex objective functions, and practical global asymptotic stability of the set of minimizers for nonconvex objective functions, with robustness.



Escape of hybrid algorithm from maximum, compared to other algorithms, when noise present in the gradient.

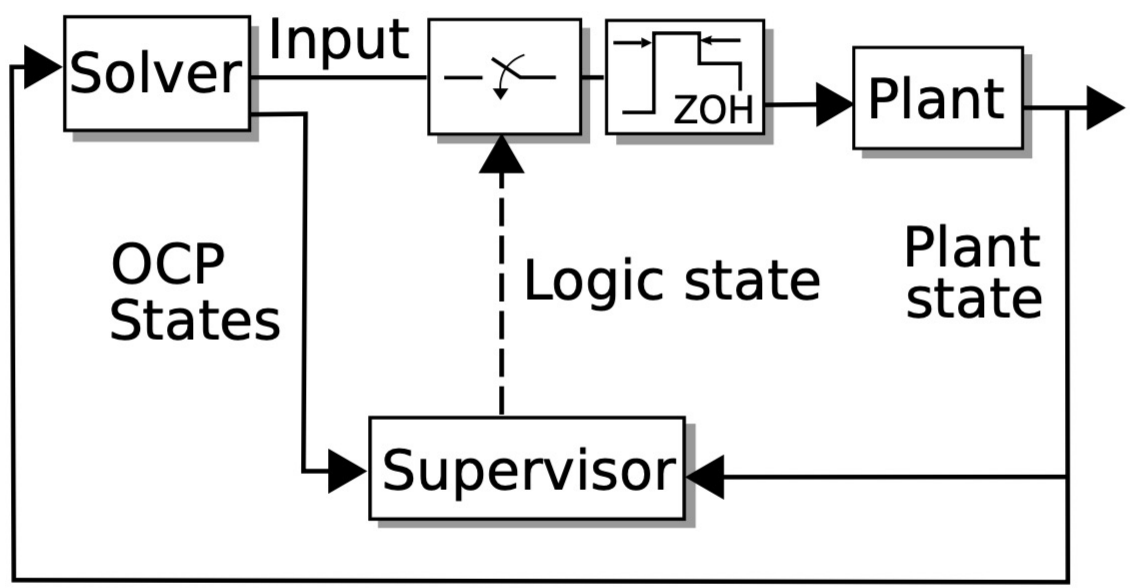
Started CoE collaboration with Matt Hale – talk by Kat Hendrickson later today

Towards Hybrid Model Predictive Control for Computationally Aware Satellite Applications

CHRISTOPHER PETERSEN and SEAN PHILLIPS, Air Force Research Laboratory, USA
DAWN HUSTIG-SCHULTZ and RICARDO SANFELICE, University of California Santa Cruz, USA

Model Predictive Control (MPC) is an optimal control method that is attractive for safe, efficient and goal based satellite operation. However, current satellite systems have limited computation and thus standard MPC approaches are limited. To overcome this, we propose a hybrid dynamical systems framework to encompass both satellite and optimizer dynamics. This enables a practical analysis of MPC and allows for user trade off between feasibility and optimality via tuneable parameters while retaining asymptotic stability.

Problem: Asymptotically stabilize the satellite to a desired set point with practical optimality taking into account the computational constraints onboard the satellite.



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Upper Bounds and Cost Evaluation in Dynamic Two-player Zero-sum Games

w/ Santiago Jimenez Leudo

Goal

To guarantee optimality in a min-max sense for constrained difference inclusions in the presence of disturbances by modeling the problem as a two-player zero-sum game.

Challenges

- When the disturbance tries to maximize a cost functional, sufficient conditions need to be stated to characterize the controller that aims to minimize it.
- Stating sufficient conditions that permit exact evaluation and upper-bounding the cost of solutions to a constrained difference inclusion.
- Cost evaluation strategies are intended to be solutions-independent. They are seek to be expressed in a point-wise structure.

$$x^+ = g(x, u, w) \qquad (x, u, w) \in D$$

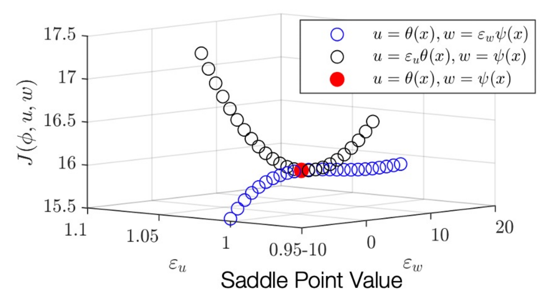
State, Control, Disturbance, Playable Set

General model of a constrained discrete-time system

Problem

$$\min_{u_\phi} \max_{w_\phi} \quad J(\xi, u_\phi, w_\phi)$$
$$\text{subject to} \quad (\phi, u_\phi, w_\phi) \in \mathcal{S}_{u,w}(\xi)$$

Cost, Initial Condition, Response, Set of Maximal Solutions



Solving the Problem as a Dynamic Two-player Zero-sum Game

- One player determines the control input, while the other player selects the disturbance allowing to attain a saddle point Nash equilibrium.
- Stating results based on cost evaluation tools allows to deal with nonquadratic nonlinear constrained systems.
- Results can be applied to bounded domain solutions.
- Basis for extension to hybrid systems.
- Connections between optimality and stability with a parallel to Hamilton-Jacobi-Isaacs results.

vs

CONTROLLER **DISTURBANCE**

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