Energy-SmartOps Integrated Control and Operation of Process, Rotating Machinery and Electrical Equipment

Dynamic control and analysis of uncertain systems

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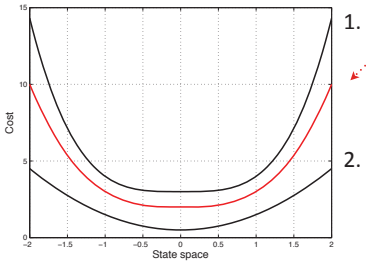
Focus of the work

We focus on **robust control** formulations for which we try to tackle two problems:

1. *synthesis* of near-optimal controllers,
2. *analysis* of suboptimality of controllers.



Motivation from electrical drives

Find a control policy (switching pattern) that is a trade-off between:

1. Tracking performance, robust against
   - grid and
   - motor-load variability
2. Energy consumption, consisting of
   - conduction and
   - switching losses

Abstraction

Consider a **infinite horizon** problem :

$$V_\infty(x) := \inf_\pi \mathbb{E}\left[\sum_{t=0}^{\infty} \beta^t \left(\mathbf{x}_t^T Q \mathbf{x}_t + \mathbf{u}_t^T R \mathbf{u}_t\right)\right]$$

subject to:

$$\mathbf{x}_{t+1} = A\mathbf{x}_t + B\mathbf{u}_t + G\mathbf{w}_t,$$
$$(\mathbf{x}_t, \mathbf{u}_t) \in Z, \ \mathbf{x_0} = x$$

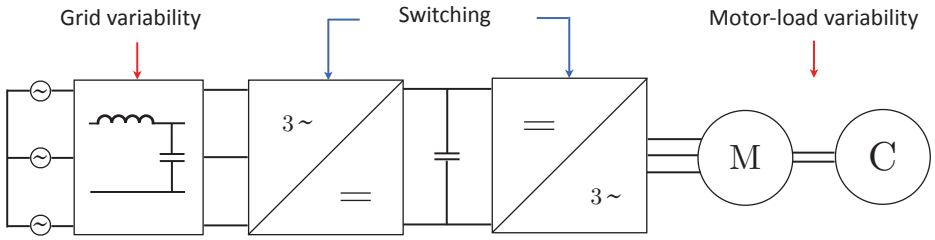
The *robustness* model :

- **Additive noise**, known moments and support,
- worst-case constraint satisfaction.

The *cost* model :

- discounted **quadratic** stage cost.

INTRACTABLE



Mathematical idea via analogy

synthesis ⟷ duality ⟷ analysis

1. Synthesis, affine *primal* restriction

$$p := \inf \ \langle c, u\rangle, \ u : \text{affine}$$
$$\text{st} \ \ Au = b, \ u \in \mathcal{K}$$

2. Analysis, affine *dual* restriction

$$d := \sup \ \langle y, b\rangle, \ (y, s): \text{affine}$$
$$\text{st} \ \ A^\star y + s = c, \ s \in \mathcal{K}^\star$$

where $p \geq d$.

Both synthesis and analysis are **computationally tractable.**

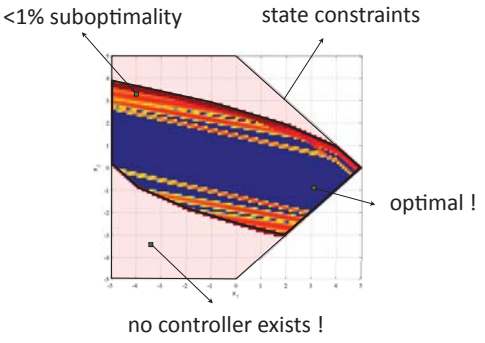
Double integrator example

State space respresentation

$$\mathbf{x}_{t+1} = \begin{pmatrix} 1 & 1 \\ 0 & 1 \end{pmatrix} \mathbf{x}_t + \begin{pmatrix} 0.2 \\ 1 \end{pmatrix} \mathbf{u}_t + \begin{pmatrix} 0.1 \\ 0.1 \end{pmatrix} \mathbf{w}_t$$

$$|\mathbf{u}_t| \leq 5, \ |\mathbf{w}_t| \leq 1$$

- *synthesis* : **Affine control** policies
- *analysis* : Affine dual control policies



Publications

- B. Van Parys, P. Goulart, M. Morari, "Infinite-horizon performance bounds for uncertain constrained systems", *IEEE-TAC* [submitted].
- B. Van Parys, P. Goulart, M. Morari, "Performance bounds for min-max uncertain constrained systems", *IFAC NMPC conf.*, Aug, 2012.
- B. Van Parys, P. Goulart, M. Morari, "Infinite-horizon performance bounds for uncertain constrained systems", *IEEE-CDC*, Dec, 2012.

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