"Control the real physics, not just a comfortable model of it"

SIGICONTROL

www.sigicontrol.com

Innovative Nonlinear Control Solutions

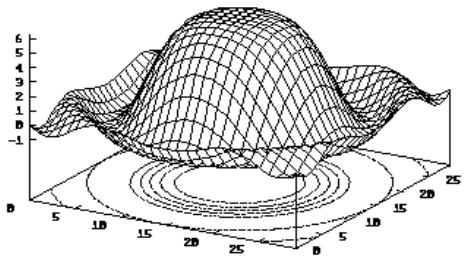
Nonlinear Control that revolutionizes the way to design controls

State Of The Art Control Approach & Issues

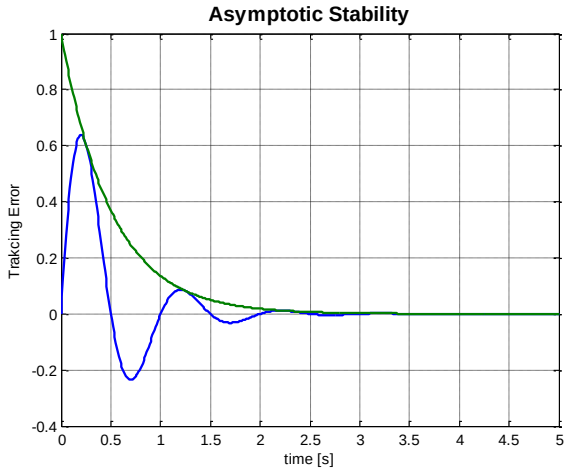
- Controls are based on mathematical descriptions **of inherently nonlinear systems**.
- **Today's system modeling is driven by known linear control tools**: easy to solve linear equations.
- **Linearization for wider operational range** leads to **long model validation**, tedious gain scheduling and requires smoothing functions.
- **Model Predictive Control (MPC) computationally expensive**, based on linear convex system models. Nonlinear-MPC not mature yet.
- Uncertainties and disturbances difficult to handle and force a **compromise between performance and stability**.

How To Approach The Challenges?

- **Use of full nonlinear system description** which allows to **include uncertainties and unknown disturbances**.



- Application of nonlinear **tools adapted to the new system description guarantee full range stability and asymptotic tracking convergence**.



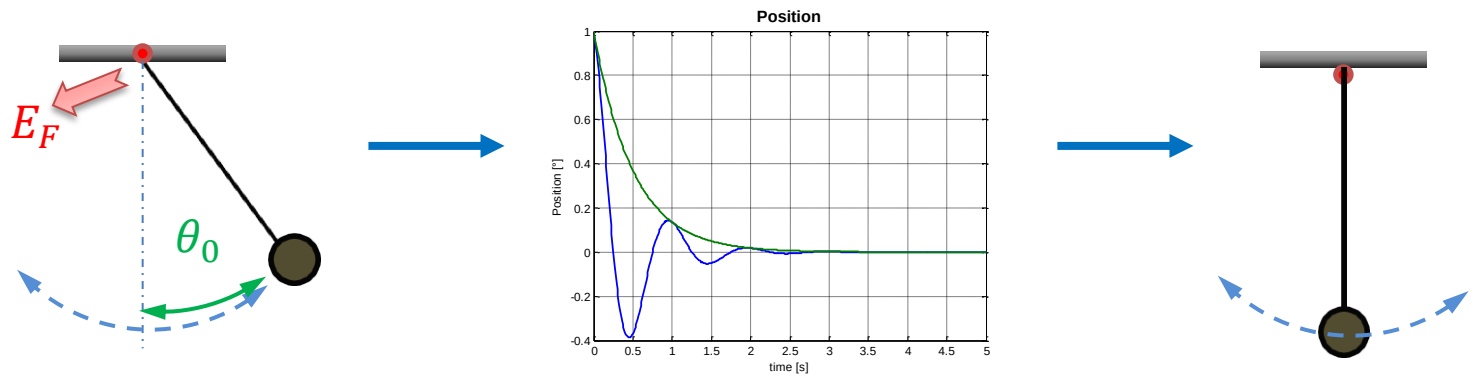
SIGICONTROL: Lyapunov Theorem

SIGICONTROL's nonlinear control solutions are based on Lyapunov's stability theorem:

"A constant withdraw of energy from a system will bring it to a state of equilibrium."

Example: Simple Pendulum

The constant energy withdraw due to friction in the hinge, causes the pendulum to stop from its initial position in an equilibrium state of rest.



SIGICONTROL: General Lyapunov Control

Lyapunov's stability analysis on an energy-like function, with the tracking error and nonlinear system dynamics included in its derivative, allows to:

- Develop a control input that constantly decreases the energy related to the error and drives the tracking error to zero.
- Find a solution to the nonlinear differential system equations with no need to solve it directly, while ensuring full range stability.

Use an appropriate error energy function and develop its control input that continuously withdraws energy.

SIGICONTROL: General Lyapunov Control

Example (Sliding Mode Control)

Assume a system described by

$$\dot{x} = \theta \sin(x(t) \cdot \alpha t)\, x(t) + u(t); \quad \theta \leq c\,; c > 0\,,$$

with $u(t), x(t), K$ as control input, system state and positive control gain respectively.

Then

$$\boxed{u(t) = Ke + \mathrm{sgn}(e)\,|x(t)|c + \dot{x}_d(t)}$$

ensures stability for every value of $x(t), \theta$ and α driving the tracking error $e = x_d - x$ to zero.

Lyapunov analysis: $V = \frac{1}{2}e^2 \;\Rightarrow\; \dot{V} = e\dot{e} = \dot{x}_d e - e\dot{x}$

$$\dot{V} = \dot{x}_d e - e(\theta \sin(x\alpha t)\, x + u(t))$$

$$\dot{V} \leq \dot{x}_d e + |e||x|c - eu(t)$$

$\dot{V} \leq -Ke^2 \leq 0$ constant error energy withdraw until state of rest.

SIGICONTROL Adapted Lyapunov Control

SIGICONTROL's Lyapunov–based nonlinear control is adapted to guarantee:

- asymptotic tracking convergence.
- full range stability.
- robustness despite model uncertainties and unknown disturbances.

The **developed solutions <u>outperform</u> known nonlinear control methods like**:

- *<u>Exact Model Knowledge (EMK)</u>*

  Drawback: System dynamics need to be exactly known, thus weak robustness.

- *<u>Sliding Mode Control (SMC)</u>*

  Drawback: Requires infinite fast control input and shows chattering, thus non suitable.

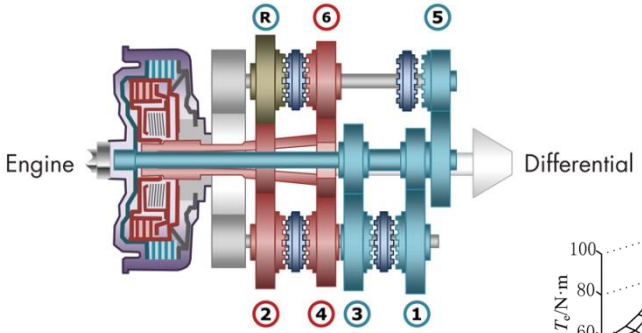
- *<u>Robust Control</u>*

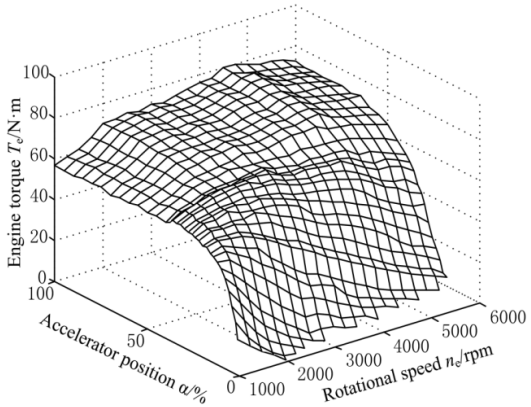
  Drawback: Doesn't result in asymptotic tracking convergence, despite high bandwidth.

Automotive Applications

- Vehicle dynamics control:
  - Active steering and suspension (link)
  - Yaw -, Roll- , Pitch- , Long.-, Lat.- control
  - Cornering, Torque Vectoring, ESC, TC
  - Active Aerodynamics

- Limit handling and safety
- Powertrain control:
  - Gearbox control
  - Engine Control





- Nonlinear estimation (link)
- …..

Advantages of SIGICONTROL Approach

Following advantages of SIGICONTROL's Lyapunov-based nonlinear control:

- Guarantee of **full range stability** and **asymptotic tracking despite model uncertainties and unknown disturbances**.
- **Reduction of development time and costs**.
- No need of model linearization, thus **shorter model validation time**.
- **No need of gain-scheduling** and gain-set tuning.
- **Increased control performance** and operational range.
- Innovative solution and technological **advantages towards competitors**.

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“The ones who follow never come in first.”

Michelangelo Buonarotti

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