Three Benchmarks Addressing Open Challenges in Nonlinear System Identification

Maarten Schoukens (VUB)
Jean-Philippe Noël (ULg)
Benchmarks on nonlinear system identification

Raise interest in selected challenges

Compare methods

Interaction between identification communities

  Mechanical
  Systems & Control
  Machine Learning

...
Outline

Benchmarks
  What? Why? How?

Challenges in nonlinear sys. id.

Three benchmarks
  Bouc-Wen
  Wiener-Hammerstein
  Cascaded Tanks
Benchmarks: What?

- Clear Objective
- Open Access
- Challenging Problem

Benchmark
Benchmarks: Why?

- Raise Interest
- Compare Methods
- Increase Interaction
Benchmarks: How?

- System
- Simulation or Measurement
- System Information
- Data Record
- Format
Benchmarks: How?

System
Simulation or Measurement
System Information
Data Record
Format

3 ≠ Systems
Simulation & Measurement
Full System Disclosure
Open & Fixed Measurements
Workshop / Invited Tracks
Nonlinear Sys Id: Challenges

- Dynamical Nonlinearity
- Process Noise
- Short Data Records
- Inaccessible Nonlinearity
- Combined Hard + Soft Nonlinearity
### Three Benchmarks

<table>
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Bouc-Wen Hysteretic System
Bouc-Wen Hysteretic System

Nonlinear differential equations:

\[ m_L \ddot{y}(t) + r(y, \dot{y}) + z(y, \dot{y}) = u(t) \]

\[ r(y, \dot{y}) = k_L y + c_L \dot{y} \]

\[ \dot{z}(y, \dot{y}) = \alpha \dot{y} - \beta (\gamma |\dot{y}| z + \delta |\dot{y}| z) \]

Nonlinearity with memory
Bouc-Wen Hysteretic System

What do we provide?

Matlab simulation package

Signal design by participants

As much data as you want

Available on benchmark website
Bouc-Wen Hysteretic System

Challenges:

- Nonlinearity with memory
- Nonlinearity governed by internal variable
- Nonlinearity is not differentiable

\[
\begin{align*}
  m_L \ddot{y}(t) + r(y, \dot{y}) + z(y, \dot{y}) &= u(t) \\
  r(y, \dot{y}) &= k_L y + c_L \dot{y} \\
  \dot{z}(y, \dot{y}) &= \alpha \dot{y} - \beta (\gamma |\dot{y}|z + \delta |\dot{y}|z)
\end{align*}
\]
Wiener-Hammerstein + Process Noise

\[ u(t) \xrightarrow{R(s)} x(t) \xrightarrow{f(x)} r(t) \xrightarrow{S(s)} y(t) \]

\[ e_x(t) \]

\[ e_u(t) \]

\[ u(t) \]

\[ e_y(t) \]

\[ y(t) \]

\[ u(t) \]

\[ y(t) \]

\[ e_u(t) \]

\[ u(t) \]

\[ y(t) \]

\[ e_y(t) \]
Wiener-Hammerstein + Process Noise

dominant noise source

e_x(t)

R(s) → \( x(t) \) → \( f(x) \) → \( r(t) \) → \( S(s) \) → \( y(t) \)

e_u(t)

\( u(t) \)

\( e_y(t) \)

\( y_m(t) \)

\( u_m(t) \)

small noise sources
Wiener-Hammerstein + Process Noise

difficult to invert
Wiener-Hammerstein + Process Noise
Wiener-Hammerstein + Process Noise

Open measurement campaigns:

Setup @ VUB, Brussels

Signal design by participants

Measurements performed by me

As much data as you want*

All data available to all participants

* Terms and conditions may apply ;}
Wiener-Hammerstein + Process Noise

Challenges:

- Process noise in nonlinear system
- Nonlinearity not accessible from measurements
- Output dynamics are difficult to invert
Cascaded Tanks: Short Data Record

Nonlinear system dynamics:

\[
\begin{align*}
\dot{x}_1(t) &= -k_1 \sqrt{x_1(t)} + k_4 u(t) + w_1(t), \\
\dot{x}_2(t) &= k_2 \sqrt{x_1(t)} - k_3 \sqrt{x_2(t)} + w_2(t), \\
y(t) &= x_2(t) + e(t),
\end{align*}
\]

Overflow not included!
Cascaded Tanks: Short Data Record

Fixed data records:
- 1024 points
- 60 frequencies excited
- Unknown initial states
- Small information content
Cascaded Tanks: Short Data Record

Challenges:

- Small information content
- Combination of soft and hard nonlinearity
- Overflow
- Unknown initial states
Benchmarks Website

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