Challenging Ourselves: Three Benchmarks for Nonlinear System Identification

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Benchmark on nonlinear system identification

Raise interest in selected challenges

Compare methods

Interaction between identification communities

Mechanical
Systems & Control
Machine Learning

Benchmark Workshop, Spring 2016
Outline

Benchmarks
  What? Why? How?
Challenges in nonlinear sys. id.
Three benchmarks
  Bouc-Wen
  Wiener-Hammerstein
  Cascaded Tanks
Benchmark meeting: practicalities
Benchmarks: What?

- Challenging Problem
- Clear Objective
- Open Access
Benchmarks: Why?

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

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

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

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

- **Bouc-Wen**
  - Hysteresis

- **Wiener-Hammerstein**
  - Process Noise

- **Cascaded Tanks**
  - Short Data Record
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
  Noiseless validation
Bouc-Wen Hysteretic System

Challenges:

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

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

\[
\begin{array}{ccc}
R(s) & f(x) & S(s) \\
\downarrow & \downarrow & \downarrow \\
e_x(t) & x(t) & r(t) \\
\downarrow & \downarrow & \downarrow \\
e_u(t) & u(t) & u_m(t) \\
\end{array}
\]
Wiener-Hammerstein + Process Noise

dominant noise source

\[ R(s) \quad f(x) \quad S(s) \]

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
Noiseless validation

* 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

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

input signal

output signal
Cascaded Tanks: Short Data Record

Challenges:

Small information content
Combination of soft and hard nonlinearity
Overflow
Unknown initial states
Benchmark on nonlinear system identification

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Benchmark Workshop, Spring 2016
Benchmark: Practicalities

When: 25/04/2016 – 27/04/2016
Where: Brussels, Belgium
Who: Mechanical, Systems & Control and Machine Learning Community
What: Plenary sessions / discussions
Contributions: 1-page abstracts
Benchmark on nonlinear system identification

25/04/2016 – 27/04/2016

You are all invited to participate