Automated identification of grey-box control models for monitored buildings with JModelica.org

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Optimal control of thermal systems in buildings using Modelica
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From data to models

Data

From:
- monitored buildings
- simulation

Automation of data-driven low-order building modelling
- Data exploration
- Model specification
- Parameter estimation
- Model validation

Models

Use:
- Model Predictive Control (MPC)
- Forecasting
- Large-scale simulations with reduced-order models
- Fault detection and diagnostics (FDD)
Grey-box buildings toolbox

FastBuildings (Modelica library)

Modelica + Optimica

GreyBox

Measurement data

greybox (python module)

JModelica.org

.simulation

.optimization

.compilation
Toolbox functionality and work flow
Data handling

- Loading dataset
- Resampling / interpolation
- Selection of training and validation sets
- Visualization
  - Time series
  - Scatter plots
  - (lagged) cross-correlation
Model selection

- Select a model from FastBuildings library
- Set fix and to-be-estimated parameters (.mop)
Initialization

- Initial value for parameter vector
  - Educated guess
  - From a prior *case*
- Initial simulation
  - Initial trajectories for all variables
  - Automatic scaling
- Visual check (optional)
- Latin hypercube sampling
Latin Hypercube Sampling

Beta distribution based on initial guess, min and max for each parameter
Parameter estimation

minimize $\int_{t_0}^{t_f} e(t)^T \cdot Q \cdot e(t) \, dt$,

with respect to $\dot{x}, x, w, u, p$,

subject to $F(t, \dot{x}(t), x(t), w(t), u(t), p) = 0$,

$x(t_0) = x_0$,

$\forall t \in [t_0, t_f]$.

- $e(t) = w_{meas}(t) - w_{mod}(t)$
- $F()$ needs to be twice continuously differentiable except towards time
- $x_0$ included in parameters to be estimated $p$
- $u(t)$ (disturbances or inputs) can be included in $e(t)$ in order to obtain an 'errors-in-variables' method
Parameter estimation

minimize \( \int_{t_0}^{t_f} e(t)^T \cdot Q \cdot e(t) \, dt \),

with respect to \( \dot{x}, x, w, u, p, \)

subject to \( F(t, \dot{x}(t), x(t), w(t), u(t), p) = 0, \)
\( x(t_0) = x_0, \)
\( \forall t \in [t_0, t_f]. \)

JModelica.org
- Compilation, simulation and optimization
- Direct collocation with automatic differentiation (with CasADi).
- Resulting NLP solved with IPOPT
Collocation method

\[ \begin{align*}
\text{min. } & \sum_{i=1}^{n_e} \left( h_i \sum_{k=1}^{n_c} \omega_k e_{i,k}^T Q e_{i,k} \right), \\
\text{w.r.t. } & \dot{x}_{i,k}, x_{i,l}, w_{i,k}, u_{i,k}, p, \\
\text{s.t. } & F(t_{i,k}, \dot{x}_{i,k}, x_{i,k}, w_{i,k}, u_{i,k}, p) = 0, \\
& x_{1,0} = x_0, \\
& x_{n,n_c} = x_{n+1,0}, \quad \forall n \in [1..n_e - 1], \\
& \dot{x}_{i,k} = \frac{1}{h_i} \sum_{j=0}^{n_c} \alpha_{j,k} \cdot x_{i,j}, \\
& \forall i \in [1..n_e], \quad \forall k \in [1..n_c], \quad \forall l \in [0..n_c].
\end{align*} \]
Validation

- Based on post-simulation
- In- and out-of-sample
- Numerical and visual
- Automation:
  - Set of tests (cap ratio, confidence intervals, heatflux, ...)
  - Pass all tests $\Rightarrow$ accepted

back to initial guess, model selection or data handling
Case study twin house
Case study twin house
Model selection
Model selection

![Graph showing RMSE on T_{zon} vs. Number of estimated parameters for different values of n: n=1, n=2, n=3, n=4.](image)

- **RMSE on T_{zon} [K]**
  - 2.5
  - 2.0
  - 1.5
  - 1.0
  - 0.5
  - 0.0

- **Number of estimated parameters**
  - 0
  - 2
  - 4
  - 6
  - 8
  - 10
  - 12
  - 14

- **Symbols**:
  - n=1: Square
  - n=2: Circle
  - n=3: Triangle
  - n=4: Diamond
Validation
Validation

Auto-validation

![Graph showing measured and simulated $T_{Zon}$ temperatures from 24/08/13 to 09/09/13. The graph compares measured ($T_{Zon}$ (measured)) and simulated ($T_{Zon}$ (simulated)) temperatures, with a clear decrease over time.]

- **Start** → **Data handling** → **Model selection** → **Initial guess**
- **Parameter estimation** → **Validation** → **Forecasting/MPC**
Validation

Cross-validation (≡ open loop simulation)
Validation

Selected model (not self-containing for MPC)
Experiment 2

Data
Model selection

- First attempt: two single zone models
- Temperature in other zone as boundary condition
Validation

Zone 1, 95% confidence
Zone 2, 95% confidence

Normalized confidence interval

Start → Data handling → Model selection → Initial guess

Parameter estimation → Validation → Forecasting/MPC
Model selection

- Two-zone model
- Objective = $\text{RMSE}(T_{\text{zon1}}) + \text{RMSE}(T_{\text{zon2}})$
Validation

Auto-validation

- $T_{Zon1}$ (measured)
- $T_{Zon1}$ (simulated)
- $T_{Zon2}$ (measured)
- $T_{Zon2}$ (simulated)
Validation

Cross-validation (= open loop simulation)
## Validation

RMSE for both single zone models

<table>
<thead>
<tr>
<th></th>
<th>$RMSE_{auto}$</th>
<th>$RMSE_{cross}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>0.27 K</td>
<td>0.51 K</td>
</tr>
<tr>
<td>Zone 2</td>
<td>0.07 K</td>
<td>0.65 K</td>
</tr>
<tr>
<td>SE</td>
<td>0.34 K</td>
<td>1.16 K</td>
</tr>
</tbody>
</table>

RMSE for two-zone model

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</tr>
<tr>
<td>Zone 2</td>
<td>0.10 K</td>
<td>1.14 K</td>
</tr>
<tr>
<td>SE</td>
<td>0.33 K</td>
<td>1.65 K</td>
</tr>
</tbody>
</table>
Summary

- Python tool chain for parameter estimation of non-linear Modelica models
- Interactive and scripting/automation
- JModelica.org for compilation, simulation and optimization
- Latin hypercube sampling for search space coverage
- Application to monitored dwelling with good results except if insufficient excitation in identification data
- License: free with GPL-like license for non-commercial use.
Thank you for your attention!

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Backup slides
FastBuildings library
FastBuildings library
Partial_SZ
Identical interface as IDEAS.Interfaces.BaseClasses.Structure
FastBuildings library

Partial_SZ_Zon
FastBuildings library

SZ_ZonWalEmbInt_B
FastBuildings library
A building model