Towards an Automated ToolChain for MPC in Multi-zone Buildings

Filip Jorissen
Lieve Helsen
KU Leuven, Belgium

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Context

- Global warming, energy prices, EU202020, …

- Building HVAC uses 20% of final energy

- Need more energy efficiency
  1. More efficient HVAC components
  2. Better control strategies
Context: MPC

- MPC: Model Predictive Control
  » White box, grey box, black box

- Key components:
  1. To be optimized control variables (heater, valves, …)
  2. Objective function
  3. Constraining equations
     - Comfort constraints
     - Technical constraints
     - System model (white box)
Context: MPC

● System model components
  » HVAC
  » Building thermal dynamics
  » Boundary conditions: weather data, occupancy, …

● System model type
  » typically reduced order
  » typically linear(ised) dynamics
Problem statement

● MPC requires custom system model for each building, resulting in high up front engineering costs.
● Unclear how to reduce model complexity.
● The same problems apply for MPC research.
Goal

- To set up a generic, scalable (semi)-automated approach for fast MPC controllers in building HVAC applications.

- Generic:
  - Applicable in simulations (presented here)
  - Re-usable in practice

- Automated:
  - No need to manually manipulate (reduced order) model, constraints, objective function
  - Easy integration in existing simulation tool

- Fast: low computation time
Case study description

- System model components
  - HVAC
    - 24 x Concrete core activation: low exergy cooling and heating
    - 24 x VAV: variable flow, with heating battery
    - 2 x AHU: free, or indirect evap., or active cooling, heating
  - Building thermal dynamics
    - 32 zones
    - Highly insulated, triple glazing, heavy building
  - Boundary conditions: weather data, occupancy, …
    - Solar irradiance, wind speed, dry bulb temperature, …
    - Occupancy, electrical load profiles
Methodology

● Outline:

1. Creating emulator model
2. Generating linear controller model
3. Generating input file
4. Post-processing
5. MPC controller configuration

● Automation based on model re-useability
Methodology: step 1

- Creating ‘emulator’ model:
  - using IDEAS² - Modelica
  - currently not automated
- 4 key components
  - Boundary conditions
  - Building envelope
  - HVAC
  - Controller
Methodology: step 2

- Generating linear controller model
  - Derived by ‘linearising’ emulator
  - Results in linear state space model
  - ‘Outputs’ for constraints and cost function

\[ \frac{dx}{dt} = A \cdot x + B \cdot u \]

\[ y = C \cdot x + D \cdot u \]

\[ A_{ineq} \cdot x + B_{ineq} \cdot u \geq 0 \]

\[ J = c_x \cdot x + c_u \cdot u \]
Methodology: step 3

- Generating input file
  - Simulates emulator
  - Store building boundary conditions
  - Store time-varying constraints
Methodology: step 4

- Post-processing of MPC-results
  - Linear MPC but non-linear HVAC -> requires reprocessing of optimisation variables

MPC Emulator

- Time
- Weather data
- Building boundary conditions
- Set points
- MPC controller
- Measurements
- Heat flow rates
- Control signals
- Low-level controller
- Measurements
- HVAC
Methodology: step 5

- Configuring of MPC-controller
  - Replace original controller by MPC controller and post-processing
  - Set MPC parameters, linear model and input file paths
  - Simulate!

- MPC block properties:
  - Single shooting
  - CasADi, CPLEX (fast)
Methodology

- Key advantages
  - Single shooting -> requires no model reduction
  - Enables hierarchical, object-oriented modeling approach
  - No manual input data handling
  - Intuitive MPC parametrisation
  - No need for co-simulation
  - Model re-use avoids model mismatch or errors
Methodology: case study

- Case study, each control interval:
  - 1330 (0) states
  - 177 optimisation variables
  - 475 model inputs
  - 542 constraints

- Initialisation: 15 minutes
- 1 MPC optimisation: 2 seconds
Conclusion

- Methodology for (semi-) automated MPC
- Fast, even for large models
- Allows the use of object-oriented, hierarchical modeling
- Automated set-up of emulator model is desirable, but may become possible in the future with BIM
