Modelling and Optimal Control of a Sewer Network

C.1 Hydraulic application (6.9.2012)

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Overview

Case study
- The system that is analyzed and controlled

Modelling and calibration
- Use of different model types
- What are the models
- Model calibration & comparison

Model predictive control
- MPC Principals
- Objectives of MPC underlying optimization
- Results based on simulation

Implementation issues

Conclusions
The studied sewer system

Artificial Lake, mainly used for drinking water
Combined sewer network to drain to central WWTP
24 controllable CSOTs
• 8 are in operation now
Mix of pressured and free flow pipes

<table>
<thead>
<tr>
<th>Summer 2010</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Population equivalents</td>
<td>3869</td>
</tr>
<tr>
<td>Impervious surface</td>
<td>80 ha</td>
</tr>
<tr>
<td>CSOT</td>
<td>8</td>
</tr>
<tr>
<td>Total CSOT volume</td>
<td>1600 m³</td>
</tr>
<tr>
<td>PS</td>
<td>4</td>
</tr>
<tr>
<td>Total transport sewer length</td>
<td>19.7 km</td>
</tr>
<tr>
<td>Pressure conduits</td>
<td>4.1 km</td>
</tr>
</tbody>
</table>
Modelling and calibration

Use of different model types

Hydrodynamic model
- Planing, case studies, network analysis
- In the context of the research project and the project planning
- Creates data for the calibration of the other models (offline virtual reality)

Simple time-delayed model
- Used inside to the model predictive control
- Implemented in Matlab for offline simulations and Python for the MPC pilot implementation

Hydrological model
- Used for long time simulations and as virtual reality for testing the MPC approach
- Integrated Control Sewer & WWTP (PhD)
Modelling and calibration

Flow time and profile test

Test design and properties

- dry weather situation
- Impounding of the dry weather flow in CSOTs
- Release of the throttled volumes in a given temporal sequence for each CSOT

Test goal

- Allocation of the Qin_{WWTP} pattern to Q_{out_{CSOT,i}}
- Identification of individual flow times from each CSOT to the WWTP
- Validation of the hydrodynamic model
- Evaluation of the other models
Modelling and calibration

Result and discussion

- Hydrodynamic model fits quite good to the monitored flows.
- NL hydrological model much less detailed compared to the HD-Model but is able to reproduced most of the dynamics.
- Translation Model gets the timing of the waves good enough for the use in the MPC context.
Model predictive control

used principals

System
- Measurements
- Historic data
- Controllable aggregates

Optimizer
- Input forecasting
- Model based output prediction
- Objective-function
- Optimization over prediction horizon

Control loop
- Apply control for $u(k+1)$
- Run the optimization in real time ($\Delta t$)
- Update to current system state
Model predictive control
for the proposed sewer systems

Multi-Objective function

\[
\text{minimize} \quad J = \sum_{n=t}^{t+H_p} \lambda \varphi_1(n) + \beta \varphi_2(n) + \alpha \varphi_3(n)
\]

subject to
\[
c_i(x) = 0 \quad i \in E \\
c_i(x) \geq 0 \quad i \in I
\]

- Homogenous distribution of the storage

\[
\varphi_1(n) = \sum_{i=1}^{N} \left[ V_i(n) - \frac{V_{i\max}}{\sum_{i=1}^{N} V_{i\max}} \sum_{i=1}^{N} V_i(n) \right]^2
\]

- Constant inflow to the WWTP

\[
\varphi_2(n) = \left[ y_{ref}(n) - \sum_{i=1}^{N^*} \text{Out}_i(n-d_i) \right]^2
\]

- Minimum overflow

\[
\varphi_3(n) = \sum_{i=1}^{N} \left[ Ov_i(n) - NL \right]^2
\]
Model predictive control

some results
Model predictive control
some results

Reduction of overflow volume...

Compared to a static control

<table>
<thead>
<tr>
<th></th>
<th>Static</th>
<th>Theoretical</th>
<th>GPC forecasting sensitivity</th>
<th>GPC weighting sensitivity</th>
<th>GPC Qwwtp_ref sensitivity</th>
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</thead>
<tbody>
<tr>
<td>Ref</td>
<td>-24%</td>
<td>-5%</td>
<td>-12%</td>
<td>-9%</td>
<td>-19%</td>
</tr>
<tr>
<td>Theoretical</td>
<td>-5%</td>
<td>-5%</td>
<td>-5%</td>
<td>-9%</td>
<td>-5%</td>
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<td>Qwwtp_ref sensitivity</td>
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physically possible
0% 20% 80% 100%
Implementation

PLS – SCADA
- Centralize all network variables
- Via real-time bus
- User and Admin interface for the GPC

OPC interface
- Industrial standard
- Exists for most SCADA hardware
- Software libraries available in FOSS

Global Predictive Control implementation
- Matlab → Python
- End-User system feedback / training / issues
- Fall-back strategies

Weighted sub-goals
- $\alpha$: Minimize overflow
- $\beta$: Constant WWTP-inflow
- $\lambda$: Homogeneous storage use

Convex Optimization
Conclusions

Different models used in different phases of the project

Virtual reality

• important to demonstrate the possible gains of the GPC approach
• important to analyze different control approaches
• validate the effective gains of the controlled system after implementation

Simple sewer model (time delayed / plug flow)

• linear, robust model
• calibration towards the real network affordable
• convex optimization

Further works

• Integrate a global quality component in the simple model
• Handling structural network modifications in the GPC approach