“Get the Design Right, the Rest is Automatic”
An Adaptive MPC Technology

Yucai Zhu
Tai-Ji Control
Best, The Netherlands

Contents
1. Introduction
2. The Architecture of the Adaptive MPC
3. How does it Work?
4. Software Implementation
5. Application to a PTA unit
6. Future Plans and Outlook
1. Introduction

- MPC has brought significant benefits in the refining/petrochemical industry. It has also attracted interests from other industries.
- The cost of MPC deployment and maintenance is very high due to its technical difficulties and long plant test time.
- An adaptive MPC is introduced to solve the high cost problem.
- Using the adaptive MPC, the scarce MPC expert is only needed for controller design.
- The commissioning and maintenance can be done automatically under the supervision of the operator.
- Nonlinear MPC control is achieved using multiple or LPV models.
1. Introduction (Cont.)

Traditional Project Approach to Industrial MPC

1. Controller design and benefit study (10%)
2. Pre-test (10%)
3. *Plant (step) test and model identification (40%)
4. Controller simulation and tuning (15%)
5. Controller commissioning and operator training (25%)
6. *Controller maintenance (mainly re-identification)
2. The Architecture of the Adaptive MPC

- Integration is the philosophy behind the technology — there are three modules in the adaptive MPC.

- Online automatic (open and closed-loop) identification and automatic controller tuning make the adaptation possible.

- Steps 2 to 6 can be performed automatically.
2.1 Online Identification Module

• Testing device
  - Perform automated multivariable test
  - Test can be open loop and/or closed-loop
  - Data collection

• Model ID device
  - Automated data pre-processing and model identification
  - Automated model validation and selection
  - Send good models to MPC Controller Module
2.2 MPC Controller Module

MPC parameter auto-tuning
- Dynamic control parameters can be auto-tuned
- Auto-tuning based on the model and data
- Tuning aims at good and robust control, though not optimal
- Economic optimization parameters are given in design

MPC control algorithms
- Steady state optimization: priorities, weights, IRV, LP&QP
- Dynamic optimization/control: QP, CV reference curve
- Can change model dynamically, necessary for nonlinear MPC
2.3 MPC Monitor Module

• Monitor CV variances for control performance
  - CV variances are compared to their benchmark variances
  - CV setpoint changes are excluded in the calculation
• Monitor MV/CV on/off status for control performance
• Monitor CV simulation error variances for model quality
  - Error variances are compared to their benchmarks
  - Test signal (excitation) may be used.
3. How Does the Adaptive MPC Work?

**MPC Commissioning**

Given an MPC design for a process unit:

- Set up the communication between the DCS and the PC
- Start identification test and online identification; models are created automatically at a given interval or by a mouse click
- Good quality models will be used in the MPC controller while test is ongoing
- When most (or all) expected models are with good quality, the plant test is stopped and the MPC is commissioned.
3. How Does the Adaptive MPC Work (Cont.)?

MPC Maintenance

- MPC Monitor continuously monitors the MPC performance
- When model mismatch becomes too large, the MPC Monitor will activate online identification in closed-loop
- Models are created automatically at a given interval or by a mouse click
- Good quality models will replace the old ones in the MPC controller while test is ongoing
- When most or all poor models are identified and replaced, the maintenance is done.
3. How Does the Adaptive MPC Work (Cont.)?

The **Old Way:** Series steps, 3 to 4 software packages

<table>
<thead>
<tr>
<th>Pre-test</th>
<th>Step test &amp; model ID</th>
<th>Simulation</th>
<th>Commission</th>
</tr>
</thead>
</table>

The **“New” ID:** Series steps, 3 to 4 software packages

<table>
<thead>
<tr>
<th>Test &amp; model ID</th>
<th>Simulation</th>
<th>Commission</th>
</tr>
</thead>
</table>

The **New Way:** Parallel procedure, 1 package

<table>
<thead>
<tr>
<th>Test &amp; model ID</th>
<th>Simulation</th>
<th>Commission</th>
</tr>
</thead>
</table>
4. Software Implementation

- Two modules are implemented: Controller and Identification
- Can use multi-model and LPV model for nonlinear MPC.
Configuration: Specify general items
Configuration: Specify MVs, DVs and CVs
Configuration: Specify Expectation Matrix

<table>
<thead>
<tr>
<th></th>
<th>MV1: MV1</th>
<th>MV2: MV1</th>
<th>MV3: MV1</th>
<th>DV1: DV1</th>
<th>DV2: DV2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV1:CV1</td>
<td>+</td>
<td>no</td>
<td>+</td>
<td>?</td>
<td>+</td>
</tr>
<tr>
<td>CV2:CV2</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>CV3:CV3</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>?</td>
</tr>
<tr>
<td>CV4:CV4</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>CV5:CV5</td>
<td>+</td>
<td>?</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>CV6:CV6</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>CV7:CV7</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>
ID Test, MV plots

<table>
<thead>
<tr>
<th>MV tag name</th>
<th>Testing</th>
<th>High limit</th>
<th>Average</th>
<th>Low limit</th>
<th>Amplitude</th>
<th>Next setting</th>
<th>Current MV</th>
<th>Current SP</th>
<th>Current PV</th>
<th>Current OP</th>
</tr>
</thead>
<tbody>
<tr>
<td>MV1</td>
<td>ON</td>
<td>5</td>
<td>1</td>
<td>-5</td>
<td>0.9564</td>
<td>0.5303</td>
<td>0.5303</td>
<td>0.5303</td>
<td>0.5303</td>
<td>0.5303</td>
</tr>
<tr>
<td>MV2</td>
<td>ON</td>
<td>5</td>
<td>1</td>
<td>-5</td>
<td>1.47</td>
<td>1.504</td>
<td>1.504</td>
<td>1.504</td>
<td>1.504</td>
<td>1.504</td>
</tr>
<tr>
<td>MV3</td>
<td>ON</td>
<td>5</td>
<td>1</td>
<td>-5</td>
<td>0.5144</td>
<td>0.4675</td>
<td>0.4675</td>
<td>0.4675</td>
<td>0.4675</td>
<td>0.4675</td>
</tr>
</tbody>
</table>
Model step responses
Controlled CVs: 1) ID test on; 2) ID test stopped; 3) CV1 and CV2 changed setpoints
5 Application to a PTA Unit

1) Solvent Dehydration Tower
Controller commissioned after 10 hours of test
MV Signals during plant test
Model step responses
CV responses after MPC turned on
5 Application to a PTA Unit (Cont.)

2) Reaction Section
- MPC has 16 MVs, 1 DV, 18 CVs; 3 x 10 hour tests used
- Control OK; some closed-loop test/ID can improve model quality
MPC off

MPC on
MPC off

MPC on
5. Future Plans and Outlook

• Add MPC monitor module
• Add Internet access capability
• Our vision:

An MPC controller is designed by a control expert and it can be implemented and maintained by an operator

• An adaptive MPC is justified for all process units in the refining/petrochemical industry, not just major units
• An adaptive MPC is justified for all process industries, not just the refining/petrochemical industry.