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A New Adaptive MPC System

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1. INTRODUCTION

In the last two decades, model predictive control (MPC) technology has been widely applied in the refining and petrochemical industry. Dynamic models play a central role in the MPC technology. The most difficult and time consuming work during an industrial MPC project is modelling and identification (Richalet, 1993, Zhu, 1998). Besides model identification, understanding MPC control theory and tuning methods and control performance is not an easy task. Due to these technical and manpower difficulties, MPC applications in other (non-petrochemical) process industries are very limited. The MPC technology still cannot be used by non control experts. In MPC applications, it is greatly desired to reduce the technical difficulties and the cost of manpower. Another issue of the current industrial MPC technology is that its performance in disturbance reduction is low.

We will develop a new adaptive MPC control system that, for a given MPC design, can perform controller commissioning and maintenance automatically. Also a method of improving MPC control performance and robustness is proposed.

2. THE ARCHITECTURE OF THE ADAPTIVE MPC

At present, a common MPC project approach has following steps:

1) MPC controller design and benefit analysis.
2) Pre-test.
3) Identification test and model identification.
4) MPC controller tuning and simulation.
5) MPC controller commissioning.
6) MPC controller maintenance. The main task of maintenance is to re-identify the process model.

Highly skilled control engineers with many years of experience are needed to perform the tasks and each step cost considerable time and effort. Different software packages are used in different steps, which is not convenient for the user.

In Zhu *et. al.* (2008) we have developed an adaptive MPC controller. The adaptive MPC controller can automatically and efficiently perform MPC implementation and maintenance, that is, steps 2) to 6) mentioned above. The adaptive MPC controller consists of three modules: 1) an MPC Control Module, 2) an online Identification Module and 3) a control performance Monitoring Module. Figure 1 shows the block diagram of the adaptive MPC controller.

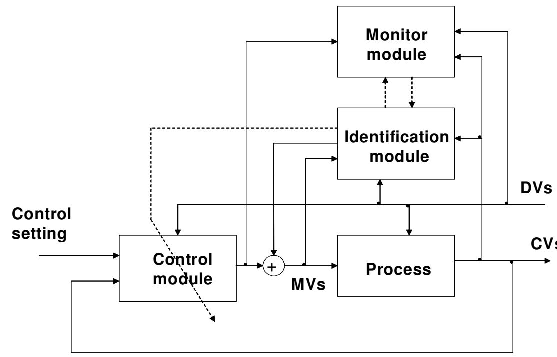

Figure 1. Block diagram of the adaptive MPC

Adaptive MPC here means automatic MPC implementation and automatic maintenance. It does not mean the sample-wise adaptation of process model as in traditional adaptive control schemes. Assume that an MPC controller design is given. During the MPC implementation, the Identification Module performs automated plant test and automatic model identification. During the plant test, when some identified models have good quality for control according to model validation, they will be used in the MPC Control Module and the corresponding manipulated variables (MV) and controlled variables (CV) will be turned on. As the test continues, more and more models will be loaded in the MPC Control Module and MVs and CVs turned on. When all expected models become good and used in the MPC Control Module, the Identification Module will stop and the MPC commissioning is finished. For an online MPC controller, the Monitor Module continuously monitors its performance. When the Monitor Module detects considerable control performance and model quality degradation, it will activate the Identification Module and plant test and model identification will start while the MPC controller is still on. During the test and identification, poor models will be gradually replaced with the new and good ones. When all the poor models are replaced, the identification module will stop and the MPC maintenance is finished.

The adaptive MPC performs plant test, model identification, control simulation and control commissioning in a parallel manner and, therefore, it can considerably reduce the cost MPC deployment. Most of the time plant tests are performed in closed-loop. Hence disturbance to process operation is reduced. Almost all steps in MPC commissioning and maintenance are done automatically and it can be used by non control experts such as operators. Hence the cost of manpower is reduced. The improvement in MPC efficiency can be shown as follows.

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

Pre-test	**Step test & model ID**	**Simulation**	**Commission**

2) With New Identification: Series steps, 3 to 4 packages

Test & model ID	**Simulation**	**Commission**

3) The Integrated MPC: Parallel procedure, 1 package

Test & model ID
Simulation
Commission

A proto type of the adaptive MPC controller has been developed which contains two modules: Control Module and Identification Module. It has been applied successfully to a PTA unit in a semi-automatic manner; see Zhu *et. al.* (2008). The development of the Monitor Module is on the way.

3. AN ADAPTIVE DISTURBANCE MODEL FOR MPC

Here a technique for improving the performance and robustness of the MPC Control Module is discussed. In industrial MPC applications for continuous process units working at stationary operating points, we have observed that the process dynamics from inputs to outputs do not change for a long period of time; but the character of unmeasured disturbances change frequently. Unmeasured disturbances are caused by variations in feed composition, in weather conditions, and in steam pressure. These variations cannot be modeled as stationary stochastic processes. In Xu *et. al.* (2010) we have developed an MPC technique that uses a fixed process model and an adaptive disturbance model. The process model is identified using externally excited input-output data. The unmeasured disturbances at the outputs are modeled as a time varying process filtered by an integrated white noise sequence; a time series ARMA model is used to describe the dynamics of the disturbances.

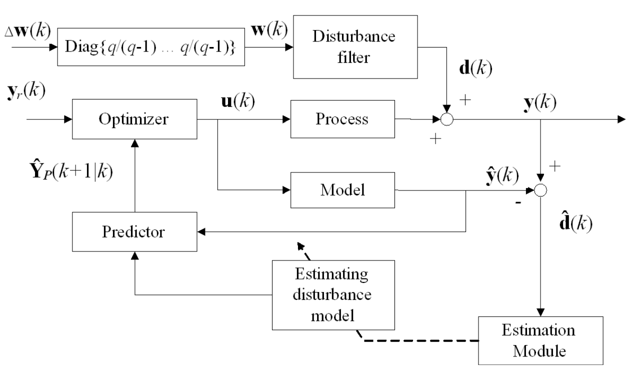

Figure 2. Schematic of the proposed MPC controller

Figure 2 shows the scheme of the MPC with adaptive disturbance model. In recursive (adaptive) disturbance model identification a multi-iteration pseudo-linear regression (MIPLR) method is proposed in order to obtain accurate and fast converging model.

Traditional adaptive MPC controllers update both process model and disturbance model sample-wise and may suffer from poor excitation conditions if no test signals are applied. For the proposed method no persistent excitation problem will occur as input signals are not used here.

The method is tested on an industrial distillation column; see Xu *et. al.* (2010). The test results show that the proposed MPC scheme can not only increase control performance, but also increase robustness against model errors.

Recent study has shown that the adaptive disturbance model is particularly useful for control during large disturbance events such as crude switches of crude units, drum switches of delayed coker and load changes of air separation units and load changes of power plants. Here a simulation study of crude switch control is presented briefly. The process is small part of an identified crude tower distillation column; studied in Zhu (1998). It has 5 MVs and 5 CVs. MV1 and MV2 are temperature setpoints, MV3 is a flow setpoint, MV4 and MV5 flow ratio setpoints. CV1 is a temperature difference, CV2 to CV5 are product qualities from online analyzers. Figure 3 shows identified step responses of the process. Disturbance source signal mimic 4 crude switches in 2 days, where each crude switch is represented as an one-hour ramp step plus random noise. The disturbance source signal is filtered using process models which resulted in 5 disturbance signals and each one acts as the unmeasured disturbance at a CV; see Figure 4. Then two MPC controllers are compared for crude switch control: the traditional DMC and the DMC using the adaptive disturbance model which will be called DMC-A. In order to test the robustness of the methods, both controllers use models that have 30% gain errors. Figure 5 shows that CV peak values during crude switches can be reduced 50% using DMC-A. Figure 6 shows that the moves of DMC-A MVs are ahead of the DMC MVs during crude switches which is due to better predictions of DMC-A.

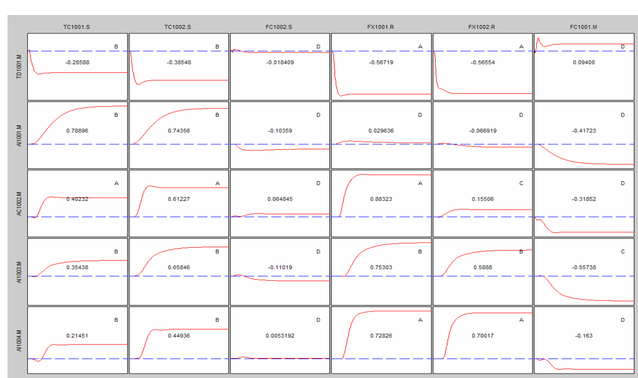

Figure 3. Step responses of the crude unit process

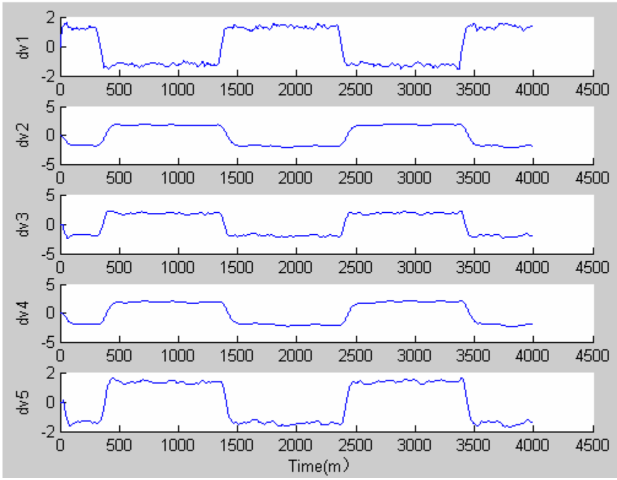

Figure 4. Crude switch disturbances at the CVs

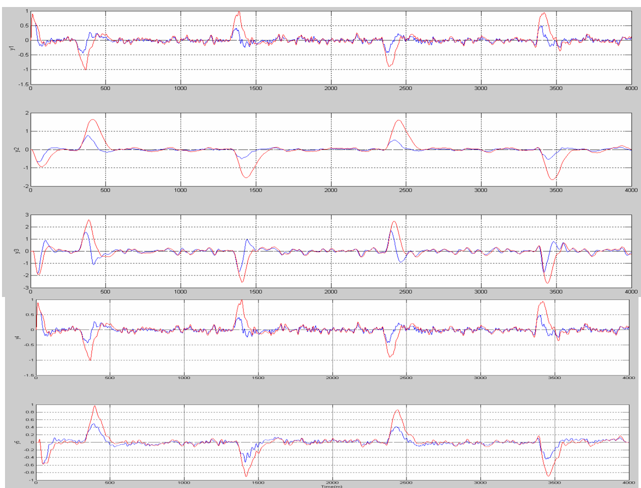

Figure 5. CVs of DMC (red lines) and of DMC-S (blue lines). CV peaks can be reduced 50% using DMC-A

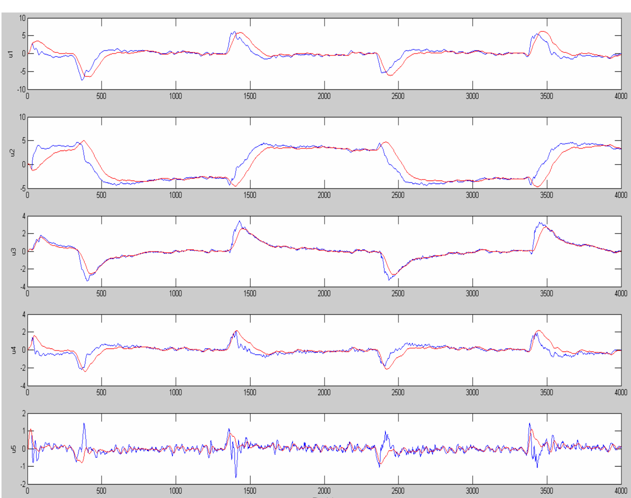

Figure 6. MVs of DMC (red lines) and of DMC-A (blue lines). DMC-A MVs are ahead of DMC MVs due to better prediction

4. CONCLUSION AND DISCUSSION

Current generation of industrial MPC technology has two main disadvantages: 1) it is very costly to implement and to maintain an MPC system; 2) the performance in disturbance reduction is low. To solve these two problems, an adaptive MPC technology is introduced. It consists of three modules, a Control Module, an Identification Module and a Monitor Module. It can perform various steps of an MPC project automatically and in a parallel manner. Thus, the efficiency of MPC commissioning and maintenance can be increased by a factor of 3 or more. In the MPC Control Module, an adaptive disturbance model is used to improve control performance and robustness. A prototype of the adaptive MPC system has been applied successfully to a PTA unit. Due to its simplicity and user friendliness, this technology may change the way MPC is applied and can make MPC feasible for all process industries, not just the refining/ petrochemical industry. Recent tests have shown that the adaptive disturbance model can increase control performance considerably.

A traditional adaptive MPC controller performs sample-wise identification and adaptation of both process models and disturbance models without monitoring the test condition and model quality. The new adaptive MPC system is very different from the traditional adaptive control: the process model is adapted on demand (when activated by the Monitor Module) where test signals are used in model identification; the disturbance model is adapted sample-wise without using test signals. We believe that this new scheme is more adequate for the control of large scale industrial processes than the traditional adaptive controller.

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