Development of Advanced Control Methods and Their Successful Incorporation in the Industry

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1. Abstract

The main objective of this paper is to point out the development of advance control methods and their applications in the industry. Multi-producers and multi-vendors market environment dealing with the control systems is today's reality. In many European companies, control systems are built up stepwise in a non-homogeneous way. In such an environment the final system integration requires a considerable effort and diverse specific knowledge of all system components. The objective of this paper is to analyse the individual control methods and the possibility to their successful incorporation into integrate complex control systems.

Keywords: control methods, complex systems, integration, PID control, predictive control, adaptive control, information technologies

2. Introduction

Automatic control system are today pervasive. They appear practically everywhere in our homes, in industry, in communications, information technologies, etc.. Process control continues to be a vital, important field with significant unresolved research problems and challenging industrial applications. The present trends in the process control design demand an increasing degree of integration. Any effort to maintain the optimal operation results in a requirement of increased flexibility in control layers. Furthermore, increasing problems with interactions, process non-linearity's, operating constraints, time delay, uncertainties, and significant dead-times consequently lead to the necessity to develop more sophisticated control strategies capable to be incorporated into the software package following the present software engineering lines.

Control systems design is currently undergoing an interesting phase of development and implementation in industrial plants. The driving force of it is the drastically increased computation ability offered by the digital computers and highly powerful 16bite and 32bite microprocessors. Process control methods can be classified according to the level and degree use in industry. We distinguish:

A. Conventional Control Methods and Algorithms

1. Manual Control
2. PID Control
3. Cascade Control
4. Ratio Control
5. Feedforward Control

Most of the used industrial controllers are of standard PID type (in continuous and/or digital form). For practical implementation, only 10-12 basic algorithms are used being modified according to the used processor type, plant dynamics, time delays, etc. Moreover, in typical control processes (e.g. thermal processes, chemical processes, power plants, etc.) it is often necessary to modify the mentioned classical methods of tuning taking into consideration the time delays, unmodelled dynamics, change of working conditions and disturbances. The improvement of classical methods is possible under the assumption that the original issuing control algorithm is extendable with respect to the changes in process parameters, yields stability of the closed loop even in the presence of large time delay and is applicable in the real-time control. The emphasize is being placed on generalized discrete controllers designed as dead-beat controllers of classical type and/or algebraic polynomial controllers. The algebraic approach allows to design controllers with robust properties modifiable by IMC filters (with a feed-forward and a feedback structure as well).

B. Advanced Control – Classical Methods

1. Gain scheduling
2. Time delay compensation
3. Decoupling Control
4. Selective/Override Controllers

C. Advanced Control I

1. Model predictive Control (MPC)
2. Statistical Quality Control (SQC)
3. Internal Model Control (IMC)
4. Adaptive and Self-tuning Control Methods (AC and STC)

The MPC is based on the process model, which approximates the control systems dynamics. As such, the model is crucial part of the MPC algorithm. Not all formal models, developed e.g. for process dynamics simulation purposes, are suited for MPC scheme. Thus the family of models suited for seamless integration with the MPC optimization

Algorithms for deriving the control actions have to be specified. The objective is to specify the information, which will serve for process model derivation and parameter identification. There is always some kind of prior information, which can be supplied by the field engineer in terms of number of inputs and outputs, time constants, delays, static input-output characteristic, limits etc. Design of on-line tests providing information for model parameters identification is another objective for this phase. A distinctive characteristic of this class of methods is their ability of optimizing a measure of closed-loop behavior by taking advantage of an explicit process model, while respecting at the same time the existing operational constraints. Because of their nature they allow a more flexible integration between the control and optimization layers, when compared with the traditional schemes. This creates the possibility of using more varied performance criteria, such as economic, safety and environmental ones, equipment and product quality constraints, as direct control objectives. The objective of this task is to develop the predictive control strategies and robust control strategies for solving the tasks with constraints and without constraints and to analyze the possibility of using these control methods to control industrial processes of interest. Theoretical work on design of algorithms for control parameter tuning will then be coupled with implementing the model design techniques in software.

Nonlinear model predictive controllers (NMPC) can be designer by extending the popular MPC approach for linear models to classes of problems where the process model is nonlinear. As indicated in the many papers surveys, a wide variety of nonlinear models and problem formulations can be employed with no single model type being dominant at this time. If a general nonlinear programming problem is considered with hard inequality constraints, then a nonlinear programming (NP) problem result which must be solved on-line at each sampling period. This is a much more difficult and time-consuming task than the LP and QP calculations employed in linear MPC. For large NLP problems (>10.000 variables), interior points methods are very promising approach. An alternative approach is to update linear models as conditions change or to use a set of a set of local models (either linear or nonlinear) to accommodate different operating regimes.

NMPC methods and algorithms offers for industrial applications five NMPC vendors. At the present there are approximately about 90 industrial applications. The vast majority of these applications involved two commercial packages: Pavilion Technologies' *Multivariable Control* (MVC) product (36 applications). Both products divide the control calculations into a steady-state optimization followed by a dynamic optimization; both can accommodate hard constraints. Process Perfecter control calculations are based on a nonlinear steady-state model and a dynamic model that used gains calculated from the steady-state model. Significant reductions in plant testing time have been reported using this approach .

In the last time, many methods of robustification of classical methods have been elaborated but for a pratcical use only the *IMC (Internal Model Control)* approach proved to be suitable. The results obtained by H-inf optimization methods are too complicated and the yielded algorithms are not realizable. The adaptive forms of the PID-controllers for practical purposes use to be simple and allowing to tune the controller parameters directly from the currently measured plant parameters. Also the employed identification and control procedures are very simple (LDDIF, Takahashi form of PID-controller). In the last five years, the adaptive control methods have been more and more employed in the technical practice. The world-known producers of control systems build these algorithms into their products (Honeywell, Yokogawa, Siemens, etc.). These methods are modifiable very well with respect to changing working conditions. The adaptive controllers used in practice are of classical type (PID) and of advanced type (generalized difference equation of order greater than 2).

After a control system is installed in the plant, controller tuning is often required to determine suitable controller settings. This typically involves plant tests which are both time consuming and intrusive. Furthermore, after process conditions change, the old controller settings may not be satisfactory and thus the controller should be re-tuned. If the process characteristic change in significant and unanticipated ways, then continuous re-tuning (or *adaptive control*) may be required. The development of simple, effective methods for updating controller setting to compensate for changing process conditions would be beneficial for both model-based controllers and conventional PID controllers.

The topic of tuning single-loop PID controllers has received an inordinate amount of attention in the process control literature. Most of the academic publications have been concerned with tuning relations for the ideal PID control algorithm. But since this form is seldom used in practice , the recommended controller setting may have to be modified. Many commercial DCS control packages contain automatic tuning features (Åstrőm and Hägglung method) for a detailed comparison of commercial auto-tuning techniques.

Despite the extensive literature, there have been a number of interesting new developments in PID controller tuning in recent years. For example, modifications of the popular relay auto-tuning method and have been reported in many papers for SISO and MIMO systems and refinements to the ZN rules and tuning relations for unstable processes have been published and verified for chemical processes. A new pattern recognition, adaptive PI controller has been developed and widely used in HVAC applications

In contrast to the voluminous literature on tuning PID controllers, techniques for re-tuning model-based controllers have received relatively little attention in the literature. Two key issues include:

1. How do we decide that the controller is not performing well?
2. How do we decide whether to re-tune the controller or to update (or re-identify) the process model?

During the past 25 years, *adaptive control is* one of the advanced control techniques that have received the most attention. The basis concept is very appealing, namely, to have a control system that can automatically adjust its settings to accommodate changing process and to other unforeseen conditions. Thus the controller "adapts" to changes in the process and to other unforeseen conditions. It is convenient to classify adaptive control strategies as either being *direct methods or indirect methods.* In a direct method the controller's parameters are adjusted based on input-output data collected under closed-loop conditions. By contrast, in the indirect approach, model parameters in an assumed model structure are estimated via a recursive parameter estimation technique from the same closed-loop data. Adaptive control research has been conducted for over 40 years while commercial adaptive control systems have been available since the early 1980's. Probably the most widely used STC is the NOVATUNE controller, which was originally marketed by ASEA in Sweden about 1982. A different type of adaptive controller, the EXACT controller, was introduced by the Foxboro Company in 1984 (oil refinery processes, power systems, etc.) The EXACT is an adaptive PID controller, which is based on a proprietary pattern recognition approach.

It is difficult to make accurate assessments of industrial utilization of adaptive control methods. Åstrőm has reported that there were 100,000 adaptive control loops running in 1988 but this estimate includes "auto-tuners" which provide PID controller tuning "on-demand" basis.

It is important to note that adaptive control can also be implemented as a custom version of a specific controller, rather than as a general purpose adaptive controller. For example, in a recent application of a nonlinear control strategy to a obtain satisfactory control.

D. Advanced Control II

1. Linear Optimal control LQ, LQG
2. Nonlinear Control Methods
3. Robust Control Methods
4. Hybrid methods for discrete event dynamic system control
5. Fuzzy Control Methods
6. Neural Control
7. Expert Systems Control

The state-space methods (LQ a LQG) are the second most successfully from the viewpoint of the practical use. In comparison to the classical PID controllers, their number is considerably smaller and their applicability is reduced as not all state variables are measurable and observable. They are used in servo-systems in electrical and hydraulic drives. These methods can be even appropriately modified and robustified however, the customers do not rely on them and prefer the classical methods. From the numerical effort viewpoint, the state-space methods are difficult to use in large-scale systems requiring to solve the discrete form of the Riccatti equation.

Many European research groups and companies from various areas of engineering and science are active in the area of performance nonlinear control. There is still a gap between university research groups and the industry. Due to theoretical open problems, this approach spread out in industry only in a limited way, involving a limited number of either large groups or smaller high-tech companies. One issue consists in developing a computer-aided design of nonlinear control laws, through some case studies. This will contradict the apparent drawback, which is inherent to the nonlinear control system theory.

Introduction of expert systems, fuzzy controllers and neural networks enables to improve the performance quality under the mentioned classical controllers. However, the applications do not confirm a full applicability for the large-scale plants.

3. Advanced Information Technology and Control Engineering

Advance control methods, e.g. model predictive control and robust control, are planned to be included in advance information technologies for process control. The former approach is applicable in control of complex processes with inherent limitations, while the latter provides simple controllers for systems with uncertainties. Besides the development of new artificial neural network based methods used for modeling, optimization and control design it is necessary to modified and improve also the existing approaches and procedures and methods based on conventional PID controller design. Another important aim is the accuracy enhancement of long- term control predictors; usage of recurrent and feed-forward multi-layer neural networks with stochastic approximation methods for adaptive training.

Development and introduction of ANN into process modeling and control will provide the possibility to create new advanced technologies in various fields of industrial applications. ANN based technologies together with robust, predictive and adaptive control methods will be used for creating the engineering software systems enabling the high performance for real–time control. The project will be focused to speed up the introduction of advanced control methods based on ANN in industrial applications. The individual methods of modeling and control using ANN will be incorporate in complex information systems.

For applications of this method it is necessary

- development of artificial neural network based technologies and engineering software in modeling and control of industrial and production systems
- development of software packages for adaptive and robust real-time control systems for high-quality , safe and energy saving control in industrial applications
- incorporation of software packages of ANN in complex information systems for industrial applications in steel industry.

The higher control levels in the present complex systems require to handle the intrinsic relations of the system events. It is necessary to cope with the problems of event concurrency, synchronization, conflict, mutual exclusion, forbidden events avoidance and other. Such situation can be encountered in the transportation systems, flexible manufacturing systems, telecommunication systems, local and global computer networks etc. First of all suitable and effective models of the discrete event dynamic systems (DEDS) must be available. This task will contribute to the development of the models based on Petri nets, flow-charts and function blocks. The developed models will be utilized for the solution of the system control on the considered control levels according to the main objectives of the project. The event and logic control methods will be developed for the process level and the supervisory control, reachability control and dead-lock avoidance methods will be solved at the higher levels of control where adaptation, coordination and production planning is dominating.

4. Multilevel Distributed Control System Design

At present day is the information and control system of this plant realised on principle of client-server architecture with local aggregate control. But it is controlled and monitored without global integration of information technologies linking together processes on various process levels of the controlled process.

The proposed advanced integrated information system will have data artery based on fibre optics connecting all production aggregates, laboratories, dispatching centre and management workstations. To simplify the user interaction with the system it will use the Internet/Intranet technologies with user-friendly environment and simple data exchange possibilities.

The advanced control system is represented in multilevel information system with 4 basic levels:

1. Processes level – At this level are controllers, which directly control the technological aggregates, frequency transducers, motors, etc. They are mainly realised as PLC controllers with continuous control function blocks.
2. Information and monitoring level – This level consists of OO-SCADA (Object Oriented Supervisory Control And Data Acquisition) system, blocks of advanced control methods and loop parameters optimisation, etc. Furthermore are here generated production reviews, summaries and other information for higher levels.
3. Planning and scheduling level – Here are created operating plans for plant.
4. Top-management level – This is the highest level – the level of factory management.

Table 1: Overview of implementation od different controller types

CONTROLLER TYPE	PRACTICAL IMPLEMENTA-TATION [%]	POSSIBILITY OF THE REALIZATION AS DDC CONTROL	IMPLEMEN-TATION IN INDUSTRY	POSIBILITY OF IMPROVE- MENT
PID continuous type discrete type	**85-92** 10 75-82	YES	**all types of plants** (chemical plants, power plants, oil industry, gas industry, servosystems)	YES Robustification - only by IMC approach
STATE SPACE LQ LQG	**25-3.4** 3-5 0.2	NO (YES)	Servosystems: - electrical - hydraulical	YES Robustification by H_2, H_{inf} approach

CONTROLLER TYPE	PRACTICAL IMPLEMENTATION [%]	POSSIBILITY OF THE REALIZATION AS DDC CONTROL	IMPLEMENTATION IN INDUSTRY	POSIBILITY OF IMPROVE- MENT
ADAPTIVE AND SELFTUNING **Clasical type** : **tuning PID parameters** Direct Indirect **Advanced type** Generalized discrete adaptive controller	**2.1-2.8** 2-2.45 0.2 0.1 0.05	YES YES YES (NO) YES YES	**all types of plants** (chemical plants, power plants, oil industry, gas industry (slow dynamics sampling time 0.1-60s) Servosystems **all types of plants**	YES Robustification of identification procedures Robustification of control algorithm Robustification of identification procedures
GENERALIZED DISCRETE Classical deadbeat Algebraic polynomial Pole assignment	**0.7-1.1** 0.25 0.05 0.9	YES YES YES YES	**all types of plants** Servosystems	Robustification of control algorithms by H_2 ,IMC approach
NONLINEAR CONTROLLER	**0.4**	YES	Thermal plants, chemical plants	Robustification by QFT approach
ROBUST CONTROLLER Continuous form Digital form	**0.2** 0.1 0.1	NO(YES)	Navigation systems, ship control, fly control, chemical plants	H_2 , H_{inf} and QFT techniques
INTELLIGENT CONTROLLER PID - Controller Assessment - Control Design Fuzzy controller Neural Network	**1.1** 0.5 0.03 0.02	YES YES YES YES	Simple plants, Cement kilns	Heuristic rules, Ziegler Nichols rules Knowledge-based control

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