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ICAC – A MATLAB TOOLBOX FOR INDUSTRIAL COMPUTER AIDED CONTROL

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Abstract: The Industrial Computer Aided Control (ICAC) toolbox for MATLAB/SIMULINK™ is especially aimed at industrial users like process engineers or commissioners who are not necessarily specialist in control system design. In this paper the integration of industrial control system design functionality into a blockoriented simulation environment by means of the ICAC toolbox is described. For SIMULINK™, i.e. MATLAB™'s simulation environment, ICAC CD (control design) blocks have been programmed, which can be handled intuitively like other SIMULINK™ function blocks supporting a guided tour to control system design based on the simplified use of advanced control design methods and an ergonomically designed graphical user interface (GUI). The ICAC toolbox composes the control system from industrially available function blocks such as PID controllers and typical nonlinear control schemes.

Keywords: Control System Design, User Interface, Industrial Engineering, Process Industry.

1. Introduction

In the process industry 90% of the control systems are realised with conventional PID controllers combined with a variety of nonlinear elements which take care for changes in the process behaviour due to external influences or setpoint changes. Nowadays the design of complex control systems for the process industry (which in many cases can be characterised as multivariable and nonlinear) is still based on experience and trial and error. For a systematic control design several CACSD (Computer Aided Control System Design) tools are available which preferably are developed in or for an academic environment. These tools serve mostly as testbeds for newly developed control methods providing a confusing variety of methods and high degrees of freedom for the use of various methods and the extensive tuning of control systems.

In the process industry controller design tasks have nevertheless to be solved for complex multiple-input multiple-output (MIMO) processes by the process engineers. Using academic CACSD tools these design tasks will lead in general to mathematically complex process models and to the use of powerful theoretical controller design methods which, however, can be understood and handled only by academic control experts - even if the CACSD program is equipped with a sophisticated user guidance system (Meier zu Farwig and Unbehauen, 1991). Moreover, most of the user interfaces of academic CACSD tools were designed to enable extensive tests of various algorithms and methods but do not support efficiently the solution of complex but nevertheless standard industrial controller design tasks.

This paper presents the MATLAB™ toolbox ICAC (Industrial Computer Aided Control) as part of an industrial CACSD (ICACSD) scheme which is tailored to the needs of the engineers in the process industry. First an outline of the ICAC Toolbox as part of the ICACSD scheme is described. Then the functionality of the ICAC Toolbox and the use of the ICAC CD (control design) blocks is outlined.

2. ICAC Toolbox and the ICACSD scheme

The ICAC toolbox is part of a general framework for a simplified CAE approach to the design of complex control systems that can be used by non-expert engineers in industry. The ICACSD (Industrial Computer Aided Control System Design) scheme has been developed to allow the design of PID based control structures for linear and nonlinear SISO (Single Input Single Output) and MIMO (Multiple Input Multiple Output) processes that are as simple as possible and as good as required (Schumann et al., 1996). A key element of the ICACSD scheme is the modelling of process models by a restricted set of standard model structures used in a simple model evolution scheme, see Figure 1.

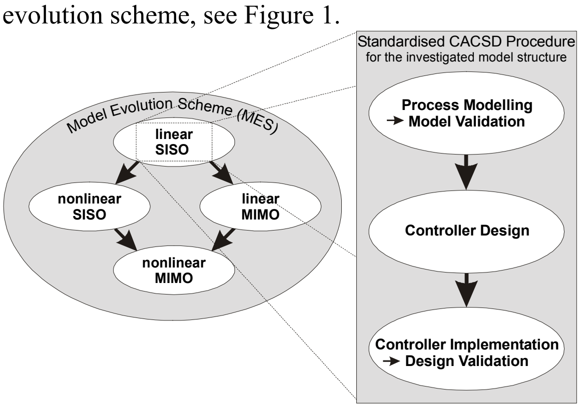

Figure 1. Industrial CACSD model evolution scheme and standardised CACSD procedure

A prototype realisation of the ICACSD scheme was developed within the MATLAB/SIMULINK™ environment and comprises several toolboxes for the generation (CAE) of process models and the design (CAE) of control systems, see Figure 2.

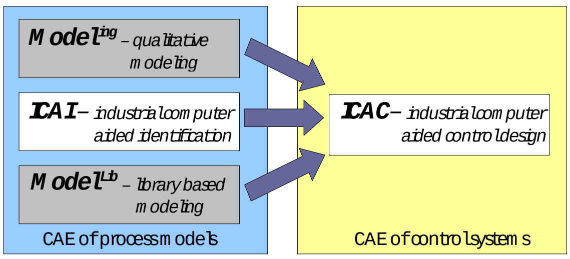

Figure 2. Industrial CACSD modules

For the process modelling three toolboxes are available which are shortly explained in the following:

- The Model^{ing} toolbox has been developed for the qualitative design of process models using the process knowledge of the industrial user (Strickrodt et al, 1996).
- The MATLAB™ toolbox ICAI develops structured linear and nonlinear single- and multivariable process models from measurement data of the process (Körner et al, 1997).
- The planned Model^{Lib} toolbox generates process models from a catalogue of the plant components.

In the ICACSD scheme the process models are preferably produced by the MATLAB toolbox ICAI which generates standardised model structures composed from linear dynamic SISO blocks and, if necessary, nonlinear static SISO blocks possibly resulting in simplified Wiener or Hammerstein type models for SISO and MIMO processes. The ICAC toolbox develops complementary control systems within the ICACSD scheme, from linear SISO to nonlinear MIMO control systems depending on the complexity of the process model and the required control performance.

The ICACSD scheme has been designed to address the industrial user's needs with limited control expertise. So the graphical user interface of all integrated toolboxes provides in the simplest case for every step of the systematic control system design procedure just one default preparametrised design method yielding usable results reliably (Syska et al, 1999).

3. ICAC Toolbox Description

The requirements for an industrial identification tool which were formulated by Körner and Schumann (1998) and realised in the ICAI Toolbox (Körner, 1999), are also requirements of the ICAC Toolbox for the reliable support of inexperienced users during the control system design procedure. The main requirements are:

- Integration of the control system design task into a block oriented simulation environment, such that the user does not have to change between different programs for the individual design tasks of identification, control system design and simulation.
- Only a few, however, robust control system design procedures are available
- Support of complex control system design tasks up to nonlinear MIMO control through standardised procedures.

MATLAB™ was chosen as software environment for the ICAC Toolbox because it became the quasi-standard base for computer aided control system design software. MATLAB™ provides a block oriented simulation environment with SIMULINK™ and also an extensive library of mathematical routines.

The ICAC Toolbox contains a SIMULINK™ blockset comprising CD (control design) blocks for the design of structured SISO and MIMO control systems (Figure 3).

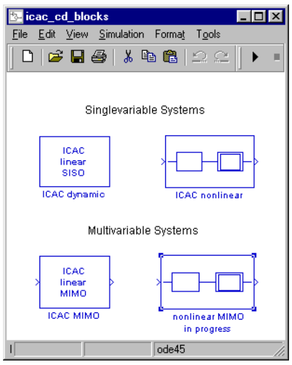

Figure 3. ICAC CD block library

The user-friendly graphical user interface (GUI) includes three user levels (plant personnel - area engineer - control expert) that provides different degrees of freedom. The *plant personnel* user level restricts the degrees of freedom for users with limited control expertise such that complicated methods are hidden, and the presentation of the simulation results is only in time domain. On the *area engineer* level additional degrees of freedom are available for the user (free choice of the ICAC CD blocks, parameterisation of the design methods, etc.). The *control expert* level allows access to the complete ICAC functionality including the unrestricted but integrated use of other control tuning and optimisation toolboxes.

The design of a control system with the ICAC toolbox is carried out in 3 steps that are described in the following:

Step1: Model Pre-processing

The prerequisite for the use of ICAC CD blocks is the availability of structured process models as produced by the MATLAB^{TM} toolbox ICAI. Thus, before designing the control system a general (Simulink™) process model may be pre-processed by applying the MATLAB™ Toolbox ICAI (Körner, 1999) to create a specifically structured linear or nonlinear SISO or MIMO process model. Original and pre-processed model are compared by simulation.

Step 2: Control system structuring by I/O-signal association

In the MIMO case the user has to associate every process (model) output to be controlled with a primary process input from which it should be controlled preferably. Thus a control system structure is organised defining preference pairs of I/O signals.

Step3: Control Design in the ICAC CD blocks

Depending upon the chosen user level ICAC offers different functionality for the control system design. The control design itself is done within the ICAC CD blocks. The design procedure is completely predefined on the *plant personnel* level and makes use of standard design methods such that the user has to make only few basic design decisions. At the end of the design procedure the user decides if the simulated step response of the closed loop simulation is satisfying or more modifications are necessary. The resulting control scheme consists in every case of linear PID control blocks possibly combined with nonlinear static blocks.

3.1 Control System Design with the ICAC Toolbox

The ICAC CD blocks are an extension of the SIMULINK™ blocks, they are handled in the same way as standard SIMULINK™ blocks. The ICAC CD blocks are identifiable from the standard SIMULINK™ blocks by their colour (blue), such that they can be distinguished even in large projects.

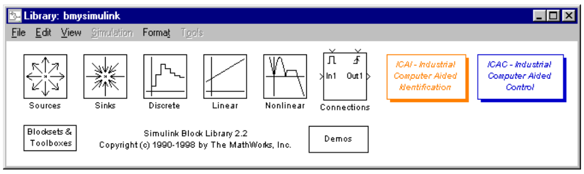

Figure 4. Expanded SIMULINK ™ standard block library

With a double-click on the ICAC block in the extended SIMULINK™ standard block library (Figure 4) the graphical user interface of the ICAC toolbox starts which guides the user through the control system design procedure.

First of all the user has to place the selected ICAC process model for which a control system is to be designed into the ICAC project window. The ICAC toolbox inherits all important data of the ICAI process model, e.g. the type of process model - SISO/MIMO, linear/non-linear -, and proposes a complementary ICAC CD block. This ICAC CD block is placed into the ICAC project window by the user. In case of a multivariable process the user has to define preferable I/O pairs of controlled and manipulated variables. After that the actual control system design starts. On the *plant personnel* level the ICAC toolbox develops a control system, which is completely complementarily to the process model (Figure 5).

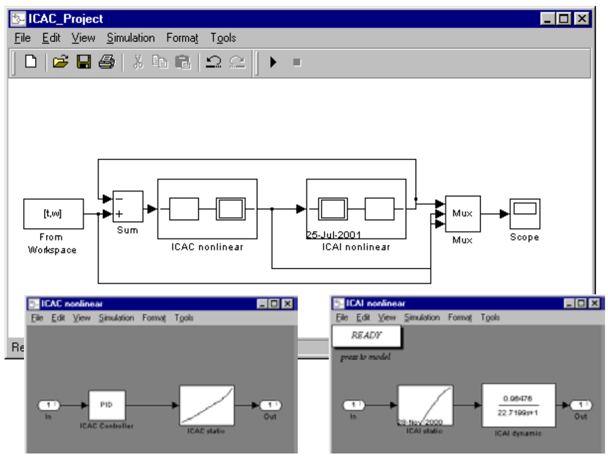

Figure 5. Process model with complementary control system

On this level the user can only modify the control performance using the sliders for stronger or weaker control action in the simulated closed-loop control system (Figure 6).

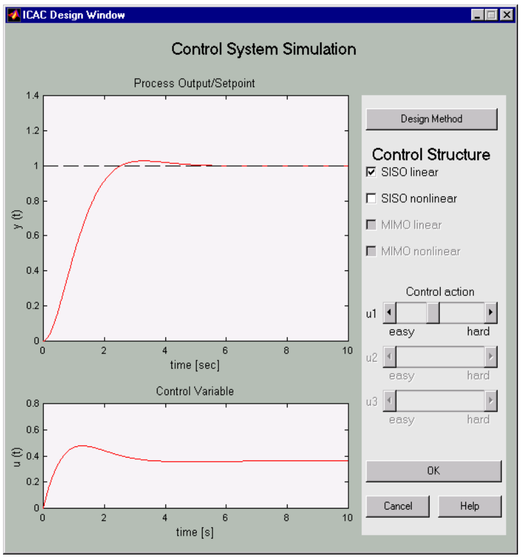

Figure 6. ICAC Design Window

On the *area engineer level* the user can choose a different control system structure and is able to parameterise the optimisation procedure. On the *control expert* level the user can choose in addition external toolboxes for the optimisation of the control system.

3.2 Control System Structures of the ICAC Toolbox

The MATLAB™ ICAI Toolbox generates four kinds of process models: linear dynamic SISO, nonlinear SISO, linear dynamic MIMO and nonlinear MIMO. All process models consist of nonlinear static blocks (static characteristics) and linear dynamic blocks. The control systems, which are designed with the MATLAB™ ICAC Toolbox to use them within conventional process control systems, are correspondingly simple and complementary to the ICAI process models and can be described as follows:

Linear Dynamic SISO CD Block
This ICAC CD block represents a single variable linear PID controller complementary to the ICAI single variable linear process model (linear dynamic SISO) (Figure 7).

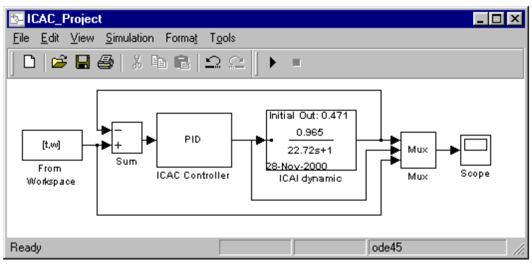

Figure 7. ICAI Linear SISO process model with linear ICAC PID controller

Nonlinear SISO CD block
The Nonlinear SISO CD block includes an inverse characteristic for the compensation of the nonlinear static portion and a linear dynamic PID controller for the control of the linear dynamic part ICAI nonlinear SISO process model (Figure 5).

Linear Dynamic MIMO CD Block
The Linear Dynamic MIMO CD block supports the design of a control system for the linear multivariable process model of the ICAI Toolbox (linear dynamic MIMO), and is composed from linear dynamic PID main controllers and PID decoupling blocks (Figure 8).

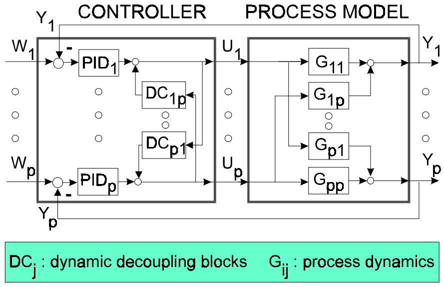

Figure 8. Linear dynamic MIMO process model with linear dynamic control system

Nonlinear MIMO CD block
The Nonlinear MIMO CD block is a combination of the Linear Dynamic MIMO CD block with nonlinear SISO CD blocks and supports the design of a control system complementary to the nonlinear MIMO ICAI process model. It includes all control system blocks realisable with ICAC (linear dynamic PID controllers, decoupling blocks and inverse static characteristic) (Figure 9).

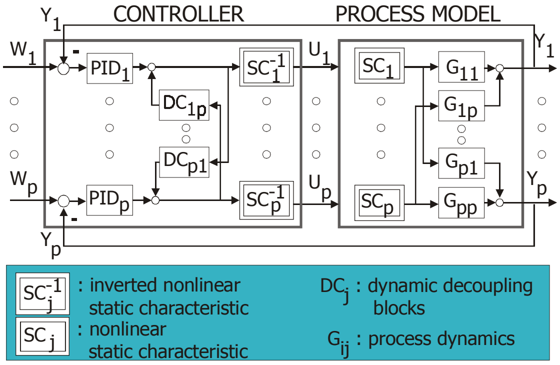

Figure 9. Nonlinear MIMO process model with complementary nonlinear MIMO control system

4. Conclusion

Theoretical control system design can be extensive and expensive and is very often not applicable for industrial control system design. This calls for the development of user friendly and efficient engineering tools which allow a rapid and useful control system design also for complex industrial processes. For inexperienced users standard control system solutions must be provided which are as simple and robust as possible.

The described ICAC Toolbox was developed as a component of an industrial CACSD environment which designs control systems for nonlinear single- and multivariable processes. The developed control systems have a simple structure and consist of standard elements like nonlinear characteristics and linear dynamics and can be implemented in industrial process control system with standard function blocks. The transfer of the designed control system to the process control system can simply be carried out by hand or by means of an OPC interface which is within ICAC currently under development .

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