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An application software for visualization and control configuration selection of interconnected processes ☆

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ABSTRACT

This paper presents a new application software for control configuration selection of interconnected industrial processes, called ProMoVis. Moreover, ProMoVis is able to visualize process models and process layout at the physical level together with the control system dynamics. The software consists of a builder part where the visual representation of the interconnected process is created and an analyzer part where the process is analyzed using different control configuration selection tools.

The conceptual idea of the software is presented and the subsequent design and implementation of ProMoVis are discussed. The implemented analysis methods are briefly described including their usage and implementation aspects. The use of ProMoVis is demonstrated by an application study on the stock preparation process at SCA Obbola AB, Sweden. The results of this study are compared with the currently used control strategy.

The study indicates that ProMoVis introduces a systematic and comprehensive way to perform control configuration selection. ProMoVis has been released under the Apache Open Source license.

1. Introduction

Continuity is an important aspect of industrial process plants. It means that the industrial plant has a certain level of availability for production and evolves with maintenance and optimization efforts. Nowadays, availability of production plants needs to be very high and the production quality needs to be well aligned with customers' requirements (El-Halwagi, 2006). In turn, the requirements on performance of processes, their control and maintenance are high, and any changes in hardware should lead to adaptations in the control systems more or less right away.

However, these industrial process plants are interconnected systems where hundreds or even thousands of variables are connected through dynamic systems, resulting in a so-called topological complexity (Jiang, Zhou, Xu, & Yuan, 2007). These connections can be physical connections between components, plant-wide access of information by the control system, or control actions by the control system on a plant-wide scale. Examples of physical interconnections are material flows and reflows, like discarded material which is returned to a previous process step and thus gives rise to large recycle loops.

A consequence of this topological complexity is that adding control loops to a process in an ad hoc manner may result in a system with obscure causality and unforeseen dynamics. Understanding of such systems becomes a challenge which makes the control configuration task very difficult. Remember, control configuration selection (CCS) addresses the problem of finding a low complexity structure for a controller for an industrial process that has the potential to render a control system with desirable performance. It does not involve the parametrization of the controller.

The first methods date back more than four decades, initiated by the work published in Bristol (1966) and Rijnsdorp (1965) where small scale multivariable problems were addressed. Since then, the host of methods has increased largely and can now be used to determine feasible control configurations for problems of larger scale. This has also led to the introduction of the control structure selection problem which contains the I/O selection problem and the control configuration selection problem as subproblems. A good overview of the topic and available methods is given in van de Wal and de Jager (2001), Skogestad and Postlethwaite (2005) and Khaki-Sedigh and Moaveni (2009). It is also important to mention that these methods are not viable on a plant-wide scale, where the total number of inputs and outputs exceeds a few dozen.

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Despite the vast host of proposed methods for CCS, there are no up-to-date toolboxes available for industrial use of the methods. To the knowledge of the authors, the only toolbox reported in the literature is by Nistazakis and Karcanias (2004), but it does not seem to be widely available.

As indicated in Rohrer (2000), visualization is important both from a collaborative perspective as well as to provide a comprehensive understanding of processes. Within the areas of construction, manufacturing, or production management, visualization is recognized as an important tool, see Bouchlaghem, Shang, Whyte, and Ganah (2005) and Browning and Ramasesh (2007), but when it comes to the design and maintenance of control systems in process industries, the use of visualization is still very limited. Available software that can be used for visualization focuses mainly on simulation of the process dynamics, such as ChemCAD, MATLAB/Simulink, LabView, Extend, or Dymola, the latter based on the generic modeling language Modelica. However, there is a lack of user-friendly toolboxes or software aiming at control configuration selection.

The aim of this paper is to propose a new application software, called ProMoVis, that combines a graphical representation of a process plant and a control system with analysis of the dynamic interconnections for control configuration selection. The underlying mathematical framework is the directed graph which is a highly abstract way of representing topological complexity in various applications.

Based on this mathematical framework a set of selected control configuration methods is implemented and can be used to analyze interconnected processes. Thereby, even mathematically complex methods become available for industrial use. Obviously, analyses performed by ProMoVis have the same limitations as the implemented control configuration methods, which means that the user has to select at most a few dozen variables for an individual analysis. These variables do not need to belong to the same part of the process plant, may be selected on a plant-wide scale, and may include variables in the control system, like e.g. estimated variables. It should be noted that ProMoVis is not limited to the selected set of methods, and other analysis methods for interconnected systems can be added. The software is currently in use at several industry partners of the SCOPE consortium within ProcessIT Innovations (2012), and is made available by the open-source project ProMoVis at Sourceforge, (OProVAT EF, 2012).

The paper is arranged as follows. First, the interface for modeling and visualization is discussed and some necessary notation is introduced. Thereafter, the implemented CCS methods are shortly summarized including their usage, properties, and limitations. Then the stock preparation process of SCA Obbola AB is introduced as a case study. It is shown how the stock preparation process can be represented in ProMoVis and how the CCS task is performed. Finally, the results from the CCS are compared with the currently implemented control strategy and are discussed. The paper is concluded with some final remarks.

2. Application software ProMoVis

Selection of a control configuration for processes with many interconnections is facilitated by a systematic approach, which is based on process knowledge in terms of dynamic models of the interconnected process. To the knowledge of the authors there is no software available which can visualize process variables including their dynamic interconnections and control configuration analysis results in a comprehensive way. For this end, we now propose the software ProMoVis (*Pro*cess *Mo*deling and *Vis*ualization).

From a practical perspective, selection and assessment of a control strategy would require the following actions by a practitioner:

1. Derive a dynamic model for the process.
2. Select a set of manipulated and controlled variables (I/O selection).
3. Determine a controller configuration.
4. Design of the individual controllers according to the configuration.
5. Implementation of the controllers.
6. Assessment of the control performance.

For all actions, besides action three, there exist software tools that support the control engineer. For modeling of processes and control design, toolboxes in MATLAB, (The Mathworks, Inc., 2012), or multivariate analysis and modeling tools from MKS Umetrics AB, Sweden (2012), are available. For the selection of I/O sets with manipulated and controlled variables the tools from MKS Umetrics AB, Sweden (2012) can be used from a multivariate perspective, whereas the methods proposed in Skogestad (2000) address the problem from a feedback control perspective. For the implementation of controllers in the control system there are tools proposed that support the automatic generation of control system code (Estévez, Marcos, & Orive, 2007; Vyatkin, 2012). Additionally, control systems provide standard blocks for certain types of controllers, for example the PID. Further, many industrial control systems possess online tools to monitor the performance of control loops as part of the control system. The remaining gap is action three, where ProMoVis aims at providing support for CCS.

2.1. Software concept

In this section the required mathematical framework and the notation are introduced and based on that the software concept is explained.

The signal flow graph (SFG) was proposed by Mason (1953) to represent interconnected dynamic linear systems, where the nodes represent the signals and the edges elementary linear dynamic systems, and will be used as the mathematical framework for the application software. Thus, the modeling task in ProMoVis reduces to the effort of collecting and combining information on the process plant and its control system. We will now state the algebraic form of the signal flow graph as given in Johansson (2010).

Let x_i, $i=1,\dots,p$ represent all exogenous signals, i.e. those variables that are not affected by any other variables in the interconnected system and let z_i, $i=1,\dots,n$ be all other variables of interest. The models are assumed to be formulated as

$$z_i=\Phi_{i1}z_1+\cdots+\Phi_{in}z_n+\Gamma_{i1}x_1+\cdots+\Gamma_{ip}x_p \tag{1}$$

for $i=1,\dots,n$ where Φ_{ij} and Γ_{ij} are linear dynamic systems that may represent process model interconnections as well as controllers. The set of exogenous signals may include e.g. external disturbances and manipulated variables but also set points. When a control loop is closed using a manipulated variable x_i and a variable z_j, then x_i will become an element in z and the associated set point variable will be introduced in x. Now, let us associate each signal x_i and z_i with a node, each $\Phi_{ij}\neq 0$ with an edge from z_j to z_i, and each $\Gamma_{ij}\neq 0$ with and edge from x_j to z_i. Then the SFG is obtained as a graphical representation of the model interconnections. Moreover, by collecting the signals x_i and z_i into vectors x and z and defining the multivariable, dynamic systems Φ and Γ whose i,j th element are Φ_{ij} and Γ_{ij} respectively, the signal flow