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An unified approach for DTC design using interactive tools

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ABSTRACT

This paper presents an interactive tool for dead-time compensator design. The tool is based on an unified dead-time compensator and considers models commonly used in industrial process control. The main contribution of this work is that the proposed tool and controller are simple to analyze and tune as they are based on an unique modified structure of the Smith predictor valid for every type of dead-time process (including integrating and unstable systems). Simple frequency analysis and block diagram transformations are used together with simulations to illustrate the main problems associated to the control of dead-time processes. Several examples of typical processes are presented to illustrate the fundamental concepts associated to the control of these systems. The interactive tool is not only useful for designing and analyzing but also for training and educational purposes.

1. Introduction

Dead times are present in most industrial processes. These dead times may be intrinsic to the process (such as in chemical and biological processes, distillation columns, etc.) or caused by the processing time of sensors, control algorithms requiring high computational burden, remote control tasks, or communication networks (Normey-Rico & Camacho, 2007). The main cause of dead times is the time needed to transport mass, energy, or information; but it can be also caused by the accumulation of time lags. From a control point of view, dead times produce an increase in the system phase lag, a decrease of the phase and gain margins and therefore a limitation in the controller gains and closed-loop response speed of the system (system bandwidth) (Palmor, 1996).

Many dead-time compensators (DTC) (strategies which include a model of the process in the structure of the controller in order to cope with dead times) have been widely studied in literature (Normey-Rico & Camacho, 2007; Palmor, 1996). The Smith predictor (SP) (Smith, 1957) is the best known and most used algorithm for dead-time compensation in industry and education. The main advantage of the Smith predictor method is that the dead time is eliminated from the characteristic equation of the closed-loop system. However, it has some drawbacks and, over the last 25 years, numerous extensions and modifications have been proposed to improve the regulatory capabilities of the SP; to allow its use with integrative (Chien, Peng, & Liu, 2002; Garcia & Albertos, 2008; Hang, Wang, & Yang, 2003; Kaya, 2003; Kwak, Whan, & Lee, 2001; Mataušek & Micić, 1999), to deal with unstable plants (Garcia, Albertos, & Hägglund, 2006; Kwak, Sung, Lee, & Park, 1999; Liu, Zhang, & Gu, 2005; Lu, Yang, Wang, & Zheng, 2005; Rao & Chidambaram, 2007; Tan, Marquez, & Chen, 2005); or to improve the robustness (Normey-Rico, Bordons, & Camacho, 1997; Zhong & Mirkin, 2002; Zhong & Normey-Rico, 2002). See (Normey-Rico & Camacho, 2008; Palmor, 1996) for a review of the SP and its modifications.

From an educational point of view, it would very useful to have an unique control solution to cope with these different kinds of models (stable, integrative, and unstable models), instead of using different control strategies as described in literature. This paper is focused on this idea, where its main objective is to present an interactive tool and a teaching methodology based on the filtered SP (FSP) (Normey-Rico & Camacho, 2007) as unique control algorithm to show the advantages and drawbacks of the SP and proposing solutions to the problems mentioned above. The developed tool allows working with a simple PI, the SP, and FSP control algorithms, compare them, and study the different problems related with stability, performance, and robustness in an interactive way. The unified approach, the simplicity of the controller, and the more intuitive interpretation of the tuning parameters are the main advantages of the new proposed controller and the interactive tool when compared to recent works dedicated to the same subject (Guzmán et al., 2008).

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The term interactivity is becoming common in the field of Automatic Control. Interactivity is associated with a set of graphical representations, elements, and parameters interconnecting each others, in such way that if some element is modified, the rest are updated immediately and only spending a short interval of time (Dormido, 2004). Interactivity provides new possibilities in researching and teaching, making it possible to study problems at different complexity levels and using a new interactive philosophy relatively difficult some years ago (Dormido, Gordillo, Dormido Canto, & Aracil, 2002; Guzmán, Berenguel, & Dormido, 2005, 2008b; Johansson, Gäfvert, & Åström, 1998; Wittenmark, Hägglund, & Johansson, 1998). This new generation of software packages is based on objects that admit a direct graphic manipulation and are automatically updated, so that the relationship among them is continuously maintained.

The power of the interactive tools sometimes induces the user to play around with different dynamic objets while forgetting the real meaning of such graphical elements. Thus, users must understand that interactive tools are abstractions of theoretical concepts, and the full learning must be completed as a mixture of both. For this reason, interactive tools are recommended as support to consolidated theoretical books or lessons looking for this combination between theory and practice. A good example is the Interactive Learning Modules project (Guzmán et al., 2008a, 2008b), which is a set of interactive tools developed as support to the well-know book *Advanced PID Control* (Aström & Hägglund, 2005). Therefore, and following this idea, the interactive tool presented in this paper has been developed as complement to the book *Control of Dead-time Processes* (Normey-Rico & Camacho, 2007), which presents an useful guide for practitioners to design dead-time compensators.

Special examples, extracted from this book, are presented to relate the results with the control theory and express better the interactive capabilities of the developed tool.

The next section presents the interactive tool and Section 3 revises the basic ideas of the dead-time process control using the interactive capabilities of the tool. Section 4 is dedicated to present several case studies and interactive examples. Finally some conclusions are summarized.

2. Describing the interactive tool

This section briefly describes the main features of the developed tool. The tool is focused on understanding control ideas for dead-time processes and uses the unified scheme described in the next section. This tool has been implemented in Sysquake, a Matlab-like language with fast execution and excellent facilities for interactive graphics (Piguet, 2004). The tool is freely available through (Normey-Rico, Guzmán, Dormido, Camacho, & Berenguel, 2008). One consideration that must be kept in mind is that the tool's main feature–interactivity–cannot be easily illustrated in a written text. Nevertheless, some of the advantages of the application are shown below. The reader is cordially invited to experience the interactive features of the tool.

When developing a tool of this kind, one of the most important things that the developer has to have in mind is the organization of the main windows and menus of the tool to facilitate the user the understanding of the control technique (Dormido, 2004; Guzmán, 2006). The main window of the tool is divided into several sections represented in Fig. 1 (basic screen of the developed interactive tool) which are described as follows:

- *Time-domain graphics*: Two graphical elements on the right side of the screen, which represent the system output (Process Output) and the controller output (Process Input). The graphics show the simulation results of the control algorithm selected for a step change in set-point and load disturbance (in the

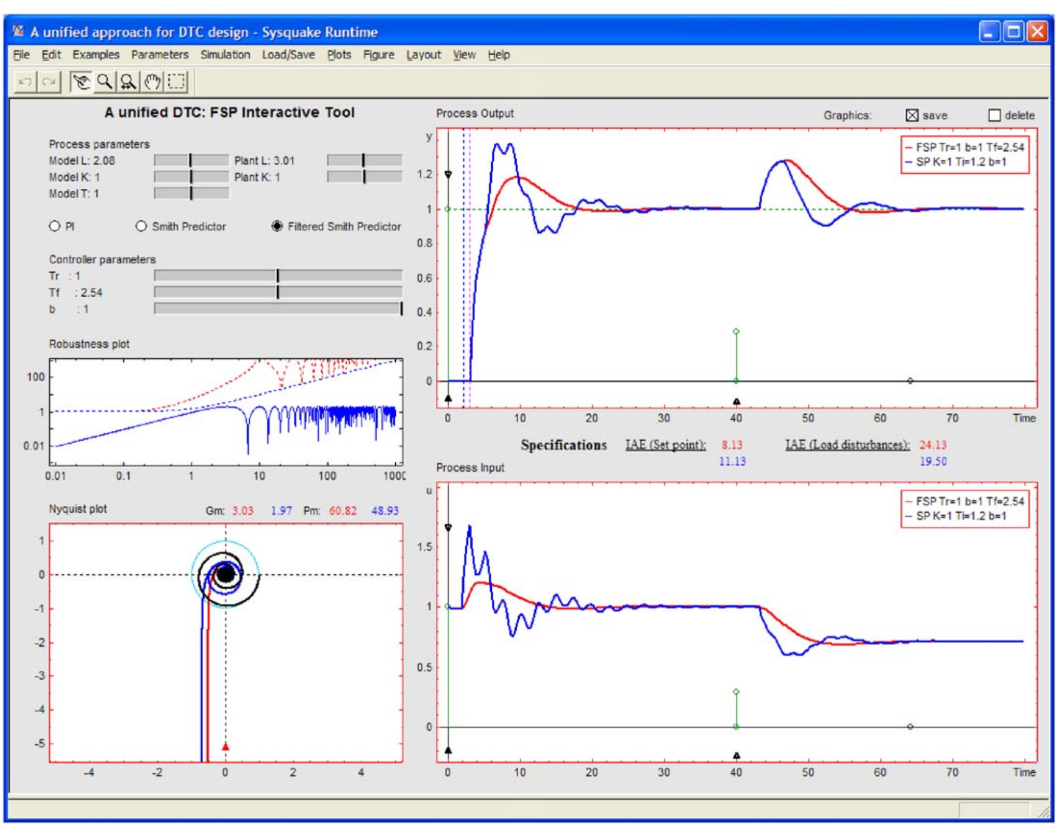

Fig. 1. Interactive tool user interface.