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Unified approach for minimal output dead time compensation in MIMO processes

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ABSTRACT

This paper presents the development of a unified dead-time compensator for multiple-input and multiple-output (MIMO) $n \times n$ processes with multiple delays. The proposed structure is a generalization of the single-input and single-output (SISO) filtered Smith predictor (FSP) controller, therefore, as in the SISO case it can be used to control stable, integrating, and unstable dead-time processes. MIMO-FSP compensates the minimal output dead time and its tuning is simple and can be performed considering a trade-off between performance and robustness. Several simulation case studies are used in the paper to illustrate the use of the unified approach and also to compare the obtained solutions with some recent published results. Practical experiments using a neonatal intensive care unit prototype are also presented.

1. Introduction

Most industrial processes exhibit dead times (or time delays) in their dynamics. Dead times are caused mainly by the time required to transport mass, energy or information, but they can also be caused by processing time or by the accumulation of time lags in a number of simple dynamic systems connected in series [1].

Processes with delay are difficult to control using traditional controllers mainly because of the following [2]: (i) the effect of the disturbances is not felt until a considerable time has elapsed, (ii) the effect of the control action takes some time to be felt in the controlled variable, and (iii) the control action that is applied based on the actual error tries to correct a situation that originated some time before.

Dead-time compensators (DTC) can be used to improve the closed-loop performance of classical controllers for processes with dead time [1]. The first dead-time compensation algorithm proposed in the literature considers the single-input and single-output (SISO) processes case and its objective was to eliminate the delay from the characteristic equation [3]. This control algorithm, which became known as the Smith predictor (SP), can be used only with stable processes and cannot be tuned to speed up the disturbance rejection response [2,1]. Because of these drawbacks, in the last 30 years, several authors have proposed special tuning procedures or modified versions of the SP with the aim of: (i) improving the regulatory properties under measurable and nonmeasurable disturbances; (ii) controlling integrating or unstable plants; and (iii) improving robustness properties or facilitating the tuning. A review of many of these control techniques, which in general are more complex than the original SP and are specially proposed for one type of process, can be found in [2,4]. More recently, a unified approach for SISO DTC design has been proposed [5]. This controller, called filtered Smith predictor (FSP), can be used to control stable, integrating, and unstable dead-time processes and its design and tuning can be performed in a unified manner.

In a general multivariable (multiple-input and multiple-output (MIMO)) system, dead times may appear in the input actions, in the measurement paths, and also in the interconnection between internal variables. Therefore, each signal path between outputs and inputs may show a different delay [6]. These multiple delays together with the interactions increase the complexity of the control design procedure [7]. Thus, dead-time compensator structures should be used to obtain efficient solutions [1]. Several papers have analyzed the extension of the SP to MIMO stable processes. In [8] the SP was extended to MIMO processes with a single delay and in [7,9] to the case of multiple delays. [10] have proposed a decoupling internal model control to improve the performance of MIMO-SP. In [11] MIMO-SP was extended to multivariable nonsquare stable systems with multiple time delays. In [12] an optimal decoupled MIMO-SP is analyzed, while [13] extended the robustness and performance analysis of the classical SP for the case of uncertain systems with multiple delays. Decoupling techniques have also been proposed [5,7,13–15] to use the SISO-DTC design for each loop. In any case, the main drawback of all of these methods is the use of the full model of the plant to predict the non-delayed output. Thus, they cannot be used to control unstable MIMO time-delay

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