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# Enhanced predictive ratio control of interacting systems

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ABSTRACT

Ratio control for two interacting processes is proposed with a PID feedforward design based on model predictive control (MPC) scheme. At each sampling instant, the MPC control action minimizes a state-dependent performance index associated with a PID-type state vector, thus yielding a PID-type control structure. Compared to the standard MPC formulations with separated single-variable control, such a control action allows one to take into account the non-uniformity of the two process outputs. After reformulating the MPC control law as a PID control law, we provide conditions for prediction horizon and weighting matrices so that the closed-loop control is asymptotically stable, and show the effectiveness of the approach with simulation and experiment results.



## 1. Introduction

Ratio control has become a demanding task in industrial processes involving combustion systems or blending operations. Ratio control methods are used to maintain the flow rate of one stream in the process at a specified proportion relative to that of another (the *wild flow*). Besides the traditional series and parallel control, an alternative architecture, called Blend station, was proposed [1] as auto-tuning and later improved in [2] for the choice of setpoint weighting. While ratio control of decoupled processes is well established, the problems become significantly complex for interacting processes. In this context, model predictive controllers (MPCs) have been recently applied to deal with ratio control, such as engine air–fuel and fuel–gas ratio control [3–5].

Among the various classes of MPCs, Generalized Predictive Control (GPC) is a potential method which overcome many pitfalls of other schemes when dealing with open loop unstable, non-minimum phase, or delayed systems [6,7]. Moreover, GPC can be used with multivariable systems just by an order-augmented modification, even when constraints are considered. These advantages have been reviewed in [8,9]. Despite its efficiency, the computing burden discourages the widespread use of GPC compared to PID regulators in process industry. Compared with a true GPC method, PID control uses present and past data but not future information; moreover, its coefficients are limited to lower order polynomials than those of GPC law. To address GPC computational issues, several PID tuning procedures incorporating GPC were proposed so that they could achieve model-based control performance with a simpler structure. The idea of matching the GPC and PID control law structure was presented in [10–12]. These papers showed that, by using a first/second-order system model, it is possible to simplify the GPC law as PID control law. A PID predictive controller was proposed in [13] where the author, rather than looking for the match of GPC and PID laws, considered a number of parallel PID controllers corresponding to the prediction horizon of GPC. In another context, the work in [14] developed a GPC-based PID controller by bringing PID error state into GPC performance index.

To bring these predictive PID design closer to the original ratio control problem, a previous work from [15] achieved composition control by changing setpoint when the output ratio is out of a predetermined threshold, without considering time delays. However, this setpoint variation method modifies control input through feedforward term outside MPC, so it easily upsets the input constraint. In addition, when the dead-time factor is included, especially different dead-times for individual processes, the information of future output ratio is demanded and the solution becomes more complicated. Thus the question is how to deal with a normal delayed process, as in [1,2].

In this paper, a PID feed-forward design based on predictive control concept is presented. It can be used for ratio control of two-input two-output (TITO) with inconsistent input delays. The solution for the delay case is solved by using equivalent control in MPC formula. Moreover, it incorporates ratio control into the performance index of GPC, so that no setpoint variation is required. The control law is still obtained as a feed-forward PID structure,

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