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Estimating performance enhancement with alternate control strategies for multiloop control systems☆

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Abstract

A filter based methodology, studied earlier for SISO systems, is extended to MIMO systems. The presented approach facilitates the calculation of best achievable performance for proportional-integral (PI) controller and the optimal multiloop (ML) PI settings for stochastic disturbance rejection in ML control systems. The filter based approach is further extended to answer some of the key questions for ML control systems such as: (a) performance enhancement possible with the alternate pairing scheme, (b) benefits that will accrue through the employment of decouplers and (c) the performance achievable with the use of multivariable controller (as opposed to an ML controller). Further, the trade-off curve between output variance and control effort is generated for the various control configurations within PI controller domain.

Keywords: Control loop performance monitoring; PI achievable performance; Loop pairing; Decouplers; Multiloop control; Multivariable control; Input–output variance trade-off

1. Introduction

Chemical industries rely on advances in control and instrumentation technologies to ensure economic viability in an increasingly competitive global marketplace. One of the major challenges is to keep the product variance at the levels governed by the consumer specifications. The performance of control loops plays a vital role in keeping the product variability within acceptable limits in a cost effective way. Traditionally, control loop performance was assessed primarily on the basis of the variance of the controlled variable and attributes such as rise time, settling time, overshoot, decay ratio and offset following a step change in set point. Though these measures are representative indicators for the loop performance, new approaches are needed. Methods that can provide performance measures in a non-intrusive manner using only minimal process knowledge are particularly useful in the chemical process industry where a typical plant has several thousand control loops.

The solution to the problem of performance assessment without any design information about the loop was initiated by Åström (1970) who advocated using autocorrelation plots obtained from closed loop output data for performance monitoring. Later, spectral dispersion and spectral methods were used for MIMO performance assessment (deVries and Wu, 1978). A major breakthrough was achieved when Harris (1989) employed simple time series analysis to extract the controller invariant part of variance from the routine operating data and used this minimum variance controller (MVC) as a benchmark for control loop performance assessment. Stanfelj et al. (1993) used cross correlation analysis for feedforward plus feedback control systems to diagnose the root cause of poor loop performance. Later works (Desborough and Harris, 1993; Vishnubhotla et al., 1997) used analysis of variance (ANOVA) for performance assessment of feedforward plus feedback control systems of SISO processes. MVC based performance monitoring has also been extended to multivariable processes (Huang et al., 1997; Harris et al., 1996). Since then, a lot of successful industrial case studies have been reported based on the MVC benchmark (Kozub, 1997; Thornhill et al., 1999; Haarsma and Nikolaou, 2000). Excellent overviews of the research in the area of control

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loop performance monitoring based on MVC and other benchmarks such as LQG can be found in review articles (Harris et al., 1999; Hoo et al., 2003; Qin, 1998) and textbooks (Huang and Shah, 1999). Ko and Edgar (2000) established the basis of performance assessment of the series cascade control strategy while Chen et al. (2005) presented a procedure to compute the proportional-integral (PI) achievable performance for the parallel cascade control strategy. Lakshminarayanan et al. (2006) estimate the variance reduction opportunities if a control loop is upgraded from simple feedback to series cascade control configuration.

Apart from the performance assessment based on the MVC benchmark, few other approaches are also described in the literature. Kendra and Cinar (1997) proposed a frequency domain approach for control loop performance monitoring. A method based on likelihood ratios has also been described in Tyler and Morari (1995). Rengaswamy et al. (2001) introduced a qualitative shape analysis formalism for detecting and diagnosing different kinds of oscillations in control loops.

Even though great strides have been made in the assessment of control loop performance using the MVC benchmark, this yardstick does not reflect the true performance of the industrial controllers as 95% of the industrial controllers belong to the proportional-integral-derivative (PID) controller family. The performance index of an industrial controller must really be based on the best performance obtainable from this class of controllers (controllers of reduced/restricted complexity). Further, as most of the industrial control loops utilize PI controller as opposed to PID controller, PI achievable performance is a more suitable benchmark in performance assessment of industrial controllers. The main and important attraction of the MVC benchmark is that only routine closed loop data and knowledge of process time delay (or delay structure) are sufficient to quantify the performance of the control system. For more specific benchmarks (such as the one discussed later in this paper), the requirement in terms of data or process knowledge increases.

The MVC benchmark does not account for controller structure limitation or the control effort—therefore other more useful benchmarks have been proposed and used in the industry. Measures such as bandwidth, normalized peak error, etc. have been employed to characterize the performance of the PID type controllers (Åström, 1991). Swanda and Seborg (1999) used set point response data to derive two normalized performance indices: (i) the normalized settling time (actual settling time divided by the apparent time delay) and (ii) the normalized integral absolute error (IAE) (IAE divided by the product of the apparent time delay and size of the set point change) for assessing the performance of PID type controllers. Eriksson and Isaksson (1994) analyzed the limitations of the minimum variance benchmark and recommended the use of PI achievable performance as the benchmark for control loops regulated by PI controllers. The need to incorporate the information on control effort in the computation of the performance index was also emphasized in their work. Ko and Edgar (1998) outlined a technique termed approximate stochastic disturbance model realizations (ASDR) to determine the PI achievable performance using known open loop process model and routine closed loop data. If plant and disturbance models are available, one could use the criteria developed by Grimble (2002) to assess the performance of PID type controllers and optimally tune them. In the absence of such models, Agrawal and Lakshminarayanan (2003) showed that closed loop experimental data can be used to obtain the PI achievable performance. Recently, Hugo (2006) demonstrated that a process model is not required for calculating the PI achievable performance if the process is assumed to be first order plus time delay. There has been an increasing interest in determining the PI achievable performance of process control loops.

The unique feature of this study is the development of an unified framework that helps in the estimation of performance benefits for various control configurations *without* their actual implementation. Starting with a given ML control configuration, we estimate output variance reduction opportunities for various scenarios: (i) alternate input–output pairing (ii) use of decouplers in conjunction with current input–output pairing and (iii) full multivariable control. The methodology can also be easily extended to partial decoupling control strategy. We also take into consideration the control effort in addition to the output variance—the result is the derivation of a variance trade-off curve that can be very useful in controller tuning. To the best of our knowledge, our work is the first attempt at the generation of the variance trade-off curve using limited experimental data *only*.

The organization of the paper is as follows. Section 2 starts with the review of performance monitoring using the MVC benchmark. Section 3 provides a brief overview of the various existing methods for PI achievable performance calculation. A new filter based method is introduced for MIMO control systems in Section 4 for estimation of the PI achievable performance. This section also covers the extension of the filter based method to estimate the probable benefits that would result with various control loop performance enhancement strategies. Section 5 addresses input–output variance trade-off issues. This benchmark considers both controller structure limitation as well as control effort in assessing a controller's performance. Several simulation examples are presented in Section 6 to demonstrate the utility of the developed methodology followed by the conclusions.

2. Performance assessment with minimum variance benchmark

The most fundamental limitation to the controller's performance is the process delay, which characterizes the controller invariant part of output variance. This controller invariant part of output variance is referred as minimum variance—the variance that would result if we employ the theoretically "best" linear controller, i.e. an MVC. The minimum variance is the global lower bound on the output variance, hence it can be used as a benchmark to assess any controller's performance by comparing the present variance with the minimum variance. Harris (1989) established that the minimum variance bound can be estimated using time series modeling with routine closed loop operating data and knowledge of process delay.