557d Control Loop Pairing Using Dynamic Performance

Tom E. Marlin and Yongsong Cai

Control loop paring is important for designs using single-loop algorithms, e.g., PI, and for the base level controls below a centralized (e.g., MPC) controller. In spite of the decades of research and practice, we do not have a systematic method for designing multiloop controllers. This research combines several screening techniques for evaluating all possible loop pairings and finding one (or a few) viable designs.

First, the best achievable control is determined using an open-loop calculation that includes actuator saturation. If acceptable control performance cannot be achieved, the engineer must modify the process or reduce disturbances.

Second, short-cut metrics are used in eliminating many candidates. The relative gain is used in evaluating system integrity; the designer can specify the maximum number of possible pairings on negative relative gains. The relative disturbance gain is used for an easily evaluated lower bound on controlled variable performance; very poor performing designs can be rejected, while other designs must be retained for further evaluation.

Third, the remaining designs are evaluated using the dynamic response of the controlled and manipulated variables. The integer pairing decisions are managed using a branch and bound (B&B) approach. The evaluation of the performance at each B&B node can challenging when the integer variables are relaxed at each node. With the relaxation approach at each node, all controllers must be tuned, which requires a non-linear, non-convex optimization. For example, a 5x5 problem at the first level will have one integer decision (one loop paired) and the remaining 4x4 system involving 16 PI controllers. Thus, a total of 17 controllers must be tuned.

To overcome the intractability of the conventional formulation, a novel formulation is used at each node that does not use a straightforward relaxation of the integer variables. All unpaired inputs and outputs are represented by a centralized controller, whose performance can be evaluated by a quadratic program. For example, a 5x5 problem at the first level will have one integer decision (one loop paired) and the remaining 4x4 system represented by a 4x4 open-loop quadratic programming problem. Thus, at the first level a total of 1 controller must be tuned with this formulation.

This novel approach provides a valid lower bound that discriminates between good and poor structures and gives computing times that are orders of magnitude faster than the typical relaxation problem. The performance of the resulting designs and computation results will be provided to demonstrate the importance of closed-loop dynamics and the substantial reduction in computing times.

Examples will come from the Tennessee Eastman Problem, Rosenbrock fired heater, and Fluidized Catalytic Cracker. Solutions will be presented that are superior to previously published results. Results will again demonstrate the importance of well-defined scenarios, including disturbances, noise and model mismatch.

Extensions for non-square control systems will also be described. When the number of manipulated variables exceed the number of controlled variables, the values (e.g., valve openings) of the manipulated variables not used for control can also be optimized to give the best nominal operation. When the number of manipulated variables is less than the number of controlled variables, the measurements selected for control will give the best performance for all controlled variables.