Nonlinear Measurement Combinations for Optimal Operation

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Competition, rising energy prices and environmental demands make it increasingly necessary to operate chemical processes as close to optimality as possible. In order to avoid suboptimal performance in presence of disturbances, mainly two approaches are considered for control [3]: On-line and off-line optimization based control.

The first approach implies computing the optimal setpoints of the controlled variables online and updating their values at certain time intervals based on the newest available measurements. Setting up, solving and maintaining an RTO system can be complex and very time-consuming, as uncertainty in the model and the parameters can have a severe impact on the performance and the new setpoints have to be available at a given time instant.

The second approach is to move these considerations and calculations off-line and to find self-optimizing control variables (optimally invariant measurement combinations). Controlling these variables keeps the process at or close to the optimal operating point in presence of disturbances without the need to re-optimize. Once these variables are obtained and the control structure is set up, the conventional RTO optimization problem can be reduced significantly and may even be completely replaced.

To the authors knowledge, optimal measurement invariants have been considered systematically only for unconstrained linear plants with quadratic cost functions e. g. [1]. This work extends the ideas to polynomial and rational systems using the elimination property of Gröbner bases. The concept is introduced by the special case of a quadratic programming example and then extended to systems described by polynomial equations, where the invariants are polynomials in the measurements.

For polynomial or rational systems the measurement polynomial is invariant throughout the active set. Other nonlinear systems can be approximated by a higher order Taylor series to operate in a larger disturbance space, while still being close to optimal.

The method is tested on a model of an isothermal CSTR model [4] with four components and two reactions. This process has three operational regions which are determined by the set of active constraints. The measurements are the two feed flow rates, one outlet concentration and the heat applied to the jacket. The process has one unknown reaction constant as a disturbance.

Using the Computer Algebra package 'Singular' [2], a polynomial self-optimizing variable is found for each of the regions of active constraints. Controlling these measurement polynomials to zero yields optimal operation in the region. Moreover in this case-study it is found that the self-optimizing variables of the neighboring regions can be used for determining the switching point between the active sets. This shows that it is unnecessary to track the necessary conditions of optimality (NCO) for this system by more complicated methods.

Designing a control structure using optimally invariant measurement combinations might require more efforts in advance, but is straightforward to implement and to maintain in practice. Once the control structure is obtained and implemented, there is no longer need to invest in expensive real-time equipment in order to obtain optimal operation.

References

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