374g Optimal Actuator Placement for Transport-Reaction Process Systems Employing Spatial Controllability

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A large number of industrially important chemical processes exhibit variation of the process variables in space and can be categorized as transport-reaction processes (e.g., chemical vapor deposition and plasma etching processes). Process models can be derived from dynamic conservation equations and usually involve parabolic partial differential equation (PDE) systems. The issue of control of transport-reaction processes has received a lot of attention in the last two decades, where one research direction focuses on the development of reduced-order models based on the property of parabolic PDEs that the eigenspectrum of the spatial operator can be partitioned into a finite size set of eigenvalues that are close to the imaginary axis and an infinite size set of eigenvalues that are far in the left half plane, implying that the dominant behavior of the system can be accurately captured by a finite number of eigenmodes. The subsequent controller synthesis step is based on these reduced-order models. An important issue for the controller design methodology, is the actuator placement such that the closed-loop system is controllable.

The conventional approach to actuator placement is to select the locations based on open-loop considerations to ensure that the necessary controllability, reachability or power factor requirements are satisfied. The issue of integrating feedback control and optimal actuator placement has also been examined for linear and quasi-linear parabolic PDEs, where using quadratic performance measures, parameterized by the actuator and sensor locations, the optimal position was found as the one yielding the minimum of the optimal control measures. However, when using such performance measures, one might obtain an actuator location that in a sense is ``averaged'' over all frequencies. As a result ``optimal'' actuator locations may be identified for which however the actuator may have no authority to handle exogenous signals containing certain eigenfrequencies.

The present work deals with the optimal placement of control actuators for transport-reaction processes, mathematically modelled by linear parabolic partial differential equations. Using model decomposition to discretize the spatial coordinate, and based on the definitions of spatial and modal controllability [1], the semi-infinite optimization problem is formulated as a nonlinear optimization problem in appropriate Hilbert spaces. Standard optimal search algorithms are subsequently used to obtain the optimal locations. The proposed method is successfully applied to a representative diffusion process, modelled by a one-dimensional parabolic PDE, where the location of a single point actuator that maximizes the spatial controllability of the system subject to constraints on modal controllability and spillover effects is computed. The approach considered here differentiates fom standard methods in that it caters to specific low frequencies/modes of the system while at the same time takes into consideration medium-range frequencies often neglected in traditional model reduction techniques. The measure for actuator placement considers the enhancement of the actuator location over the dominant modes, while at the same time offers robustness with respect to the intermediate range of modes which certainly ameliorate spillover effects.

[1] D. Halim and S.O. Reza Moheimani (2003), ``An optimization approach to optimal placement of collocated piezoelectric actuators and sensors on a thin plate,'' Mechatronics, 13, 27-47.