242g Fault-Tolerant Control of Nonlinear Process Systems: Performance-Based Reconfiguration and Robustness

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Modern-day chemical plants involve a complex arrangement of processing units connected, in series and/or in parallel, and highly integrated with respect to material and energy flows through recycle streams. Moreover, chemical processes need to satisfy high quality product specifications and increasingly stringent safety and environmental regulations. These more stringent operating conditions have placed new constraints on the operating flexibility of the process and made the performance requirements for process plants increasingly difficult to satisfy. The increased emphasis placed on safe and efficient plant operation dictates the need for continuous monitoring of the operation of a chemical plant and effective external intervention (automatic control) to guarantee the satisfaction of the process objectives. The design of effective process control and monitoring systems, however, requires that a host of fundamental and practical problems, which transcend the boundaries of specific applications, be adequately taken into account at the stage of controller design. Central to these issues are the problems of strong nonlinear dynamics, plant-model mismatch, external disturbances and actuator constraints. In addition, increased automation tends to increase the vulnerability of the plant to faults (e.g., defects/malfunctions in process equipment, sensors and actuators, failures in the controllers or in the control loops) potentially causing a host of economic, environmental, and safety problems that can seriously degrade the operating efficiency of the plant.

The above considerations provide a strong motivation for the development of methods and strategies for the design of advanced fault-tolerant control structures that ensure an efficient and timely response to enhance fault recovery, prevent faults from propagating or developing into total failures, and reduce the risk of safety hazards. In a previous work [1], a hybrid systems approach to fault-tolerant control was employed where upon occurrence of a fault, stability region-based reconfiguration is done to achieve fault-tolerant control. The reconfiguration in [1], however, does not incorporate performance or robustness configurations, which can lead to performance-loss or even instability for processes subject to uncertainty. Motivated by these considerations, in this work, we consider the problem of implementing fault-tolerant control to nonlinear processes with input constraints subject to control system/actuator failures, and present and demonstrate two approaches that focus on performance and robustness considerations, respectively. For the processes under consideration, a family of candidate control configurations, characterized by different manipulated inputs, is first identified. To clearly illustrate the methodology in incorporating performance considerations in fault-tolerant control, we first consider processes without uncertainty. For each control configuration, we design a Lyapunov-based predictive controller, that enforces closed-loop stability from an explicitly characterized set of initial conditions (computed using an auxiliary Lyapunov-based nonlinear controller) subject to performance specifications (for more details on the design of this controller and its stability properties, see [2]). A hierarchical switching policy is then derived, that uses stability considerations (via stability regions) first to ascertain the suitability of a candidate backup configuration and then uses performance considerations to choose between the suitable backup configurations, and guarantees closed-loop stability in the event that a failure is detected. Next, we focus on the problem of designing a robust fault-tolerant control structure, and to this end, we design a robust hybrid predictive controller for each candidate control configuration [3], that guarantees stability from an explicitly characterized set of initial conditions, subject to uncertainty and constraints. A switching policy is then derived to orchestrate the activation/deactivation of the constituent control configurations. Finally, simulation studies are presented to demonstrate the implementation and evaluate the effectiveness of the proposed fault-tolerant control method.

[1] N. H. El-Farra, A. Gani, and P. D. Christofides, Fault-tolerant control of process systems using communication networks, AIChE J., 51:1665-1682, 2005.

[2] P. Mhaskar, N. H. El-Farra, and P. D. Christofides, Predictive control of switched nonlinear systems with scheduled mode transitions, IEEE Trans. Automat. Contr., accepted for publication, 2005.

[3] P. Mhaskar, N. H. El-Farra, and P. D. Christofides, Robust hybrid predictive control of nonlinear systems, Automatica, 41:209--217, 2005.