Operability Analysis and Fault-Tolerant Control of Input-Affine Systems via Moving Horizon Virtual Actuators

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Abstract

In recent years, autonomous operation in Process Systems Engineering (PSE) has received increasing attention in both academia and industry (Gamer et al., 2020; Baldea et al., 2025). In this context, modern processes are expected not only to be fully automated, but also to operate with limited or no human intervention while simultaneously addressing economic objectives and safety constraints. This evolution, however, also introduces new challenges in preserving reliable and safe operation. Therefore, ensuring that systems can effectively manage faults and mitigate their consequences is therefore of great importance. As a result, fault-tolerant control (FTC) systems (Ding, 2021) are expected to become a fundamental part of industrial control architectures in the transition toward fully autonomous chemical plants. In this work, a novel reconfigurable control approach based on virtual actuators (VA) is introduced, representing an active fault-tolerant control (AFTC) strategy capable of restoring system stability and performance without modifying the nominal control system. The proposed method extends the moving horizon virtual actuator (MHVA) framework described in Costa et al. (2021) and applies it to input-affine nonlinear systems with actuator faults. First, operability analysis (Gazzaneo et al., 2019) is used to evaluate performance limitations and delineate the feasible operating region of the process under actuator fault conditions. Subsequently, the proposed approach is used to recover the system's closed-loop behavior, aligning it as closely as possible with nominal operation. Validation through simulation scenarios demonstrates partial or complete recovery of nominal behavior under fault conditions. The results indicate that the proposed approach supports proper process operation in accordance with redesign objectives without manual intervention, underscoring its potential to facilitate autonomous operation in chemical processes.

Keywords: Fault-tolerant control, Autonomous systems, Virtual actuators, Process operability.

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