On the Optimization of hard and soft sensing via Symbolic Regression for Enhanced Fault Detection in Feedback Control Systems

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Detecting faults in closed-loop control systems is inherently challenging, as feedback mechanisms may obscure or delay the observation of fault effects. Advanced and robust fault detection tools are critical for ensuring safety and reliability in engineering systems. To address this challenge, we propose a physics-informed data-driven framework for designing informative inferential sensors. Using symbolic regression, a genetic programming (GP) approach generates mathematical expressions that effectively represent system parameters, even with limited training datasets. These expressions are optimized using statistical estimation theory, specifically the D-optimality criterion, to achieve enhanced sensitivity to faults. To validate the proposed approach, we integrate an extended Kalman filter (EKF) for fault estimation within a closed-loop dynamic model of a plate-fin cross-flow heat exchanger. The system is evaluated under varying levels of parameter uncertainty and measurement noise variance. The effectiveness and robustness of the developed methodology are demonstrated by comparing the EKF performance, with and without the inclusion of inferential sensor data alongside physical sensor measurements. The results demonstrate that the inferential sensor significantly enhances fault detection accuracy and reliability.