Optimization Methods Applied to Observability Analysis in Industrial Processes

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ABSTRACT

Observability is a fundamental requirement for the safe operation of industrial processes and is defined as the ability to infer the system variables of interest from available measurements. This property depends directly on the process instrumentation configuration, which determines the set of effectively measured variables. However, in real systems, the availability of such measurements may be compromised by sensor failures, altering the information set available for variable inference. Therefore, the analysis of observability associated with measurement selection constitutes a relevant problem from both design and operational perspectives. In this work, the optimal sensor placement (OSP) problem is formulated as a combinatorial optimization problem under structural observability constraints, aiming at minimizing the number of measurements. Additionally, the enumeration of equivalent optimal solutions is performed, allowing the identification of different instrumentation configurations that ensure system observability. The problem is solved using a unified optimization model implemented in OR-Tools and addressed through two exact/combinatorial strategies – CP-SAT and MPSolver with SCIP backend – as well as an alternative Monte Carlo–based approach, employed for comparative performance analysis under different operational conditions. The methodology is first evaluated on a multivariable linear system and subsequently applied to a Sulfate Removal Unit (SRU), representative of a real industrial process. Different operational scenarios are considered, including conditions without instrumentation, operation with available measurements, and situations involving sensor failures. Furthermore, the analysis of optimal solutions enables the assessment of variable relevance within the system, contributing to their classification in terms of observability. The results indicate that the methods exhibit similar performance in lower-complexity scenarios. However, significant differences arise under more challenging conditions, particularly in the presence of sensor failures, where the CP-SAT approach stands out due to its superior computational performance. In contrast, the Monte Carlo–based approach presents a high computational cost, highlighting its limitations for large-scale applications. Overall, the results demonstrate that the choice of optimization method directly impacts the computational feasibility of observability analysis, especially in more complex scenarios. Thus, the proposed approach contributes to the integration of observability analysis and sensor placement, providing support for real-time monitoring and decision-making in industrial processes.

Keywords: Observability, Optimal Sensor Placement, Combinatorial Optimization, Industrial Processes.

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