High-Dimensional State Estimation with Commercial Process Simulators Using a Variant of the Unscented Kalman Filter

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Abstract: Multiphase flow plays a central role in oil and gas transportation, particularly during hydrocarbon extraction from reservoirs. Knowledge of the flow rates of each phase is valuable for process operations, monitoring, and planning. However, direct measurement of these flow rates can be expensive, intrusive, and uncertain, making virtual flow metering an attractive alternative. Virtual flow metering relies on models of multiphase flow, which can be time-consuming and costly to develop. For this reason, commercial process simulators, such as LedaFlow, may provide a practical basis for model-based flow rate estimation. Although such simulators may be based on first-principles modelling, they can appear as black-box models from the user's perspective, since the underlying model equations are not necessarily accessible. This presents a challenge for state inference, as many state estimators require explicit model information. For example, the Extended Kalman Filter is a widely used state estimator that relies on the model Jacobian. Unless the simulator is configured to provide Jacobian evaluations, these must typically be approximated using finite differences. A recent development in state estimation is the High-Dimensional Unscented Transformation, a variant of the Unscented Transformation that enables the transformation of an arbitrary number of variables, where previous formulations were limited by assumptions on the underlying probability distribution. In this work, we explore the combination of the High-Dimensional Unscented Transformation with the Unscented Kalman Filter, resulting in a novel approach for estimating unmeasured dynamic variables using only model evaluations. This makes the method relevant for state inference and virtual flow metering with commercial process simulators whose internal model equations are not directly accessible. The approach is implemented and examined on a multiphase flow case in LedaFlow.

Keywords: Nonlinear observers and filters, Estimation and filtering, Kalman filtering, Large-scale complex systems, Digital twins for cyber physical systems.