Improved Estimator Insensitivity to Outliers, Measurement Drift, and Noise

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Three common problems that are encountered with industrial data include outliers, measurement drift, and measurement noise. Gross error detection is commonly used to eliminate outliers while estimators are commonly employed to reconstruct actual process values from noisy or drift-prone measurements. Common approaches include filtered bias updates, Kalman filtering, adaptive observers, inferential calculations for predicted values, and Moving Horizon Estimation (MHE). Problems with many of these approaches are that state and parameter values change with corrupted data. The focus of this paper is to design a novel MHE estimator and Nonlinear Model Predictive Controller (NMPC) framework that is less sensitive to the three classes of corrupt data described above (outliers, drift, and noise).

This novel formulation is a modified ℓ1-norm objective for estimation and control with a simultaneous optimization approach. The advantage of this ℓ1-norm over conventional ℓ1-norm, squared-error, or ℓ2-norm objectives is that it includes dead-band which improves outlier rejection, measurement drift insensitivity, and noise rejection that suppresses unnecessary state or parameter adjustments. The solution method attributed to the proposed ℓ1-norm includes this innovative form with inequality constraints and slack variables to apply ℓ1-norm in nonlinear optimization based controllers and estimators.

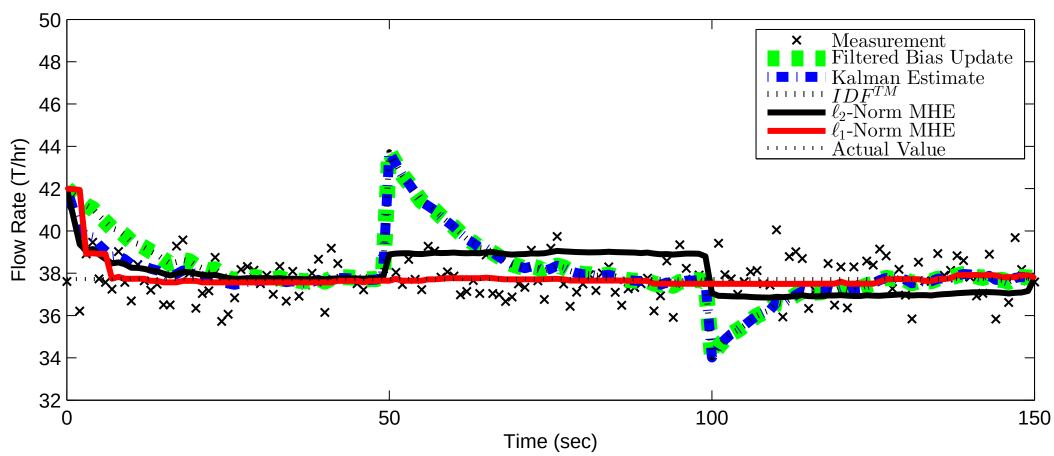

Figure 1. Comparison of various estimators in the presence of outliers at 50 and 100 seconds [1].

Additionally, this paper offers details on the simultaneous optimization of objective function and model equations for solving nonlinear parameter estimation and control problems.

Simultaneous optimization decreases the computational time by several orders of magnitudes for some problems with moderate sized models but with a relatively large number of decision variables [2-5]. Sequential optimization approaches, where the model and objective function are solved separately in a series of iterations, may be better suited for large-scale models such as those that result from distributed parameter systems such as partial differential and algebraic equation models [6]. Depending on the size of model and number of decision variables, either may be more suitable for solving complex, large-scale industrial problems that include multiple variables and require rapid convergence.

A typical industrial distillation problem is illustrated, and is solved using the two techniques. The first is with the proposed simultaneous method with a deadband and second using sequential shooting optimization approach. The ℓ_1-norm, ℓ_2-norm, Kalman filter, and other estimators are also compared to demonstrate improved insensitivity to outliers, noise, and measurement drift (see Figure 1). The computational time is compared for both cases to demonstrate the trade-offs with the proposed approaches.

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