Identification of unstable, nonlinear systems working under feedback

Roger Larsson, Martin Enqvist

Background

The flight characteristics of modern fighter aircraft vary from stable to unstable, from linear to nonlinear, and the flight control system needs to deal with all combinations of these. Also, the process noise characteristics for atmospheric flight is colored, which adds to the system identification complexity. This gives rise to some:

Challenges:

- Nonlinear system
- Closed-loop data
- Partially unknown disturbance characteristics

Engineering constraints:

- Accuracy
- Scalability
- User-independent system identification results

Theory

Flight dynamics can, in general, be described as

$$x_{k+1} = F(\,x_k,\, u_k,\, w_k) \tag{1a}$$

$$y_k = H(\,x_k,\, u_k,\, v_k) \tag{1b}$$

where F describes the nonlinear dynamics of flight and H is the measurement equation. For the aircraft application the measurement is $y_k = x_k + v_k$.

A prediction-error method (PEM) is used for the system identification:

$$\hat{x}_{k+1}(\theta) = F_m(\hat{x}_k(\theta),\, u_k, \theta) + K_k(\theta)(y_k - \hat{x}_k(\theta)) \tag{2}$$

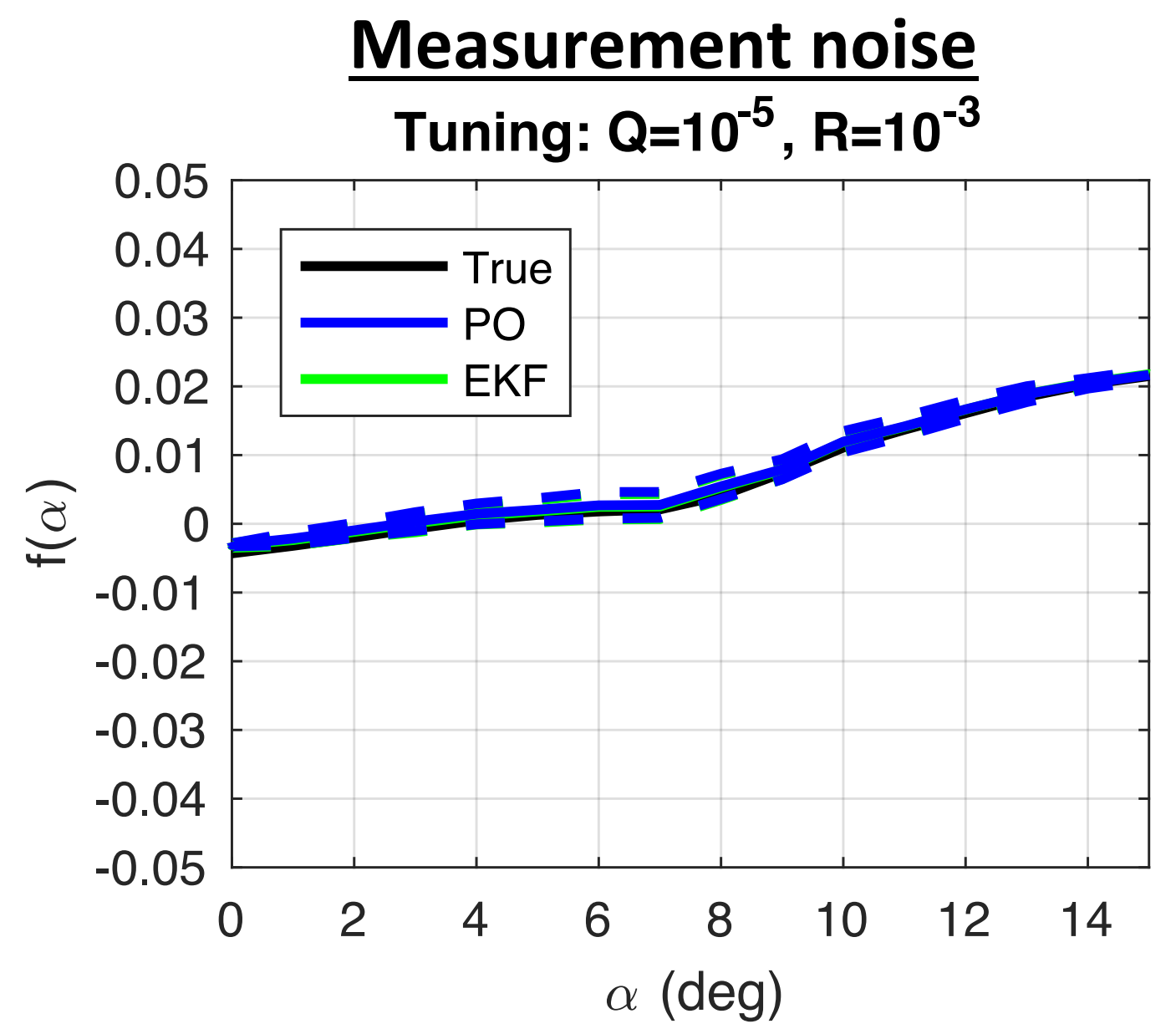
In the Parameterized Observer (PO) approach the observer gain $K_k(\theta)$ is a parameter to be defined by optimization.

$$\theta = \left[\theta_f^T\ \theta_K^T\right]^T \tag{3}$$

The PO approach has been compared to four other methods, Extended Kalman filter (EKF), Unscented Kalman filter (UKF), Augmented states (AUG), Constrained Levenberg-Marquardt optimization (CLM).

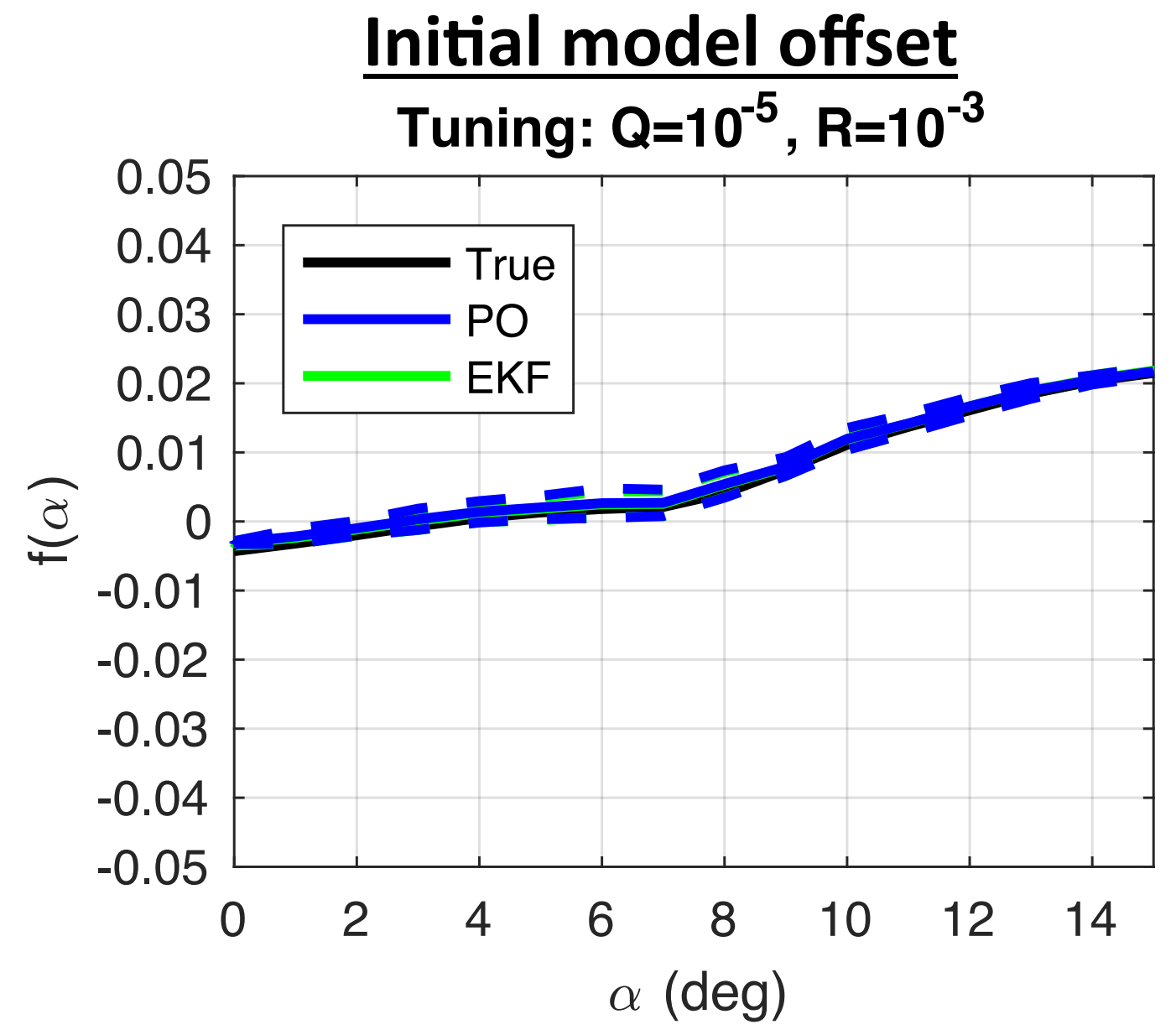
Results

Three sensitivity investigations have been carried out. These have been focused on initial model offset, measurement and process noise. Several Signal-to-noise ratios have been checked. Here, only the comparison between the PO and EKF methods is shown. In addition, the methods have been used on real flight test data.



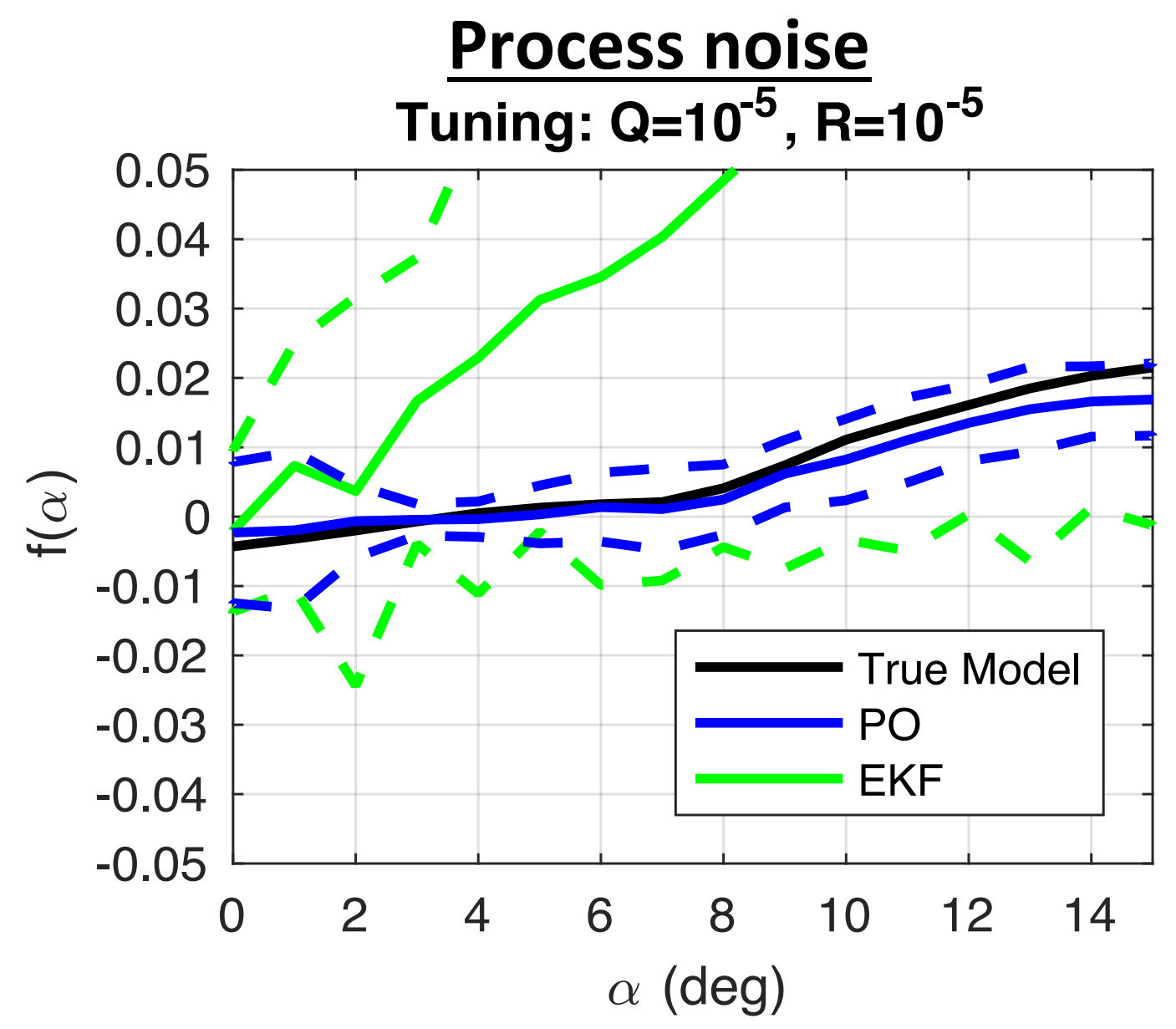
Measurement noise

Tuning: $Q=10^{-5}$, $R=10^{-3}$



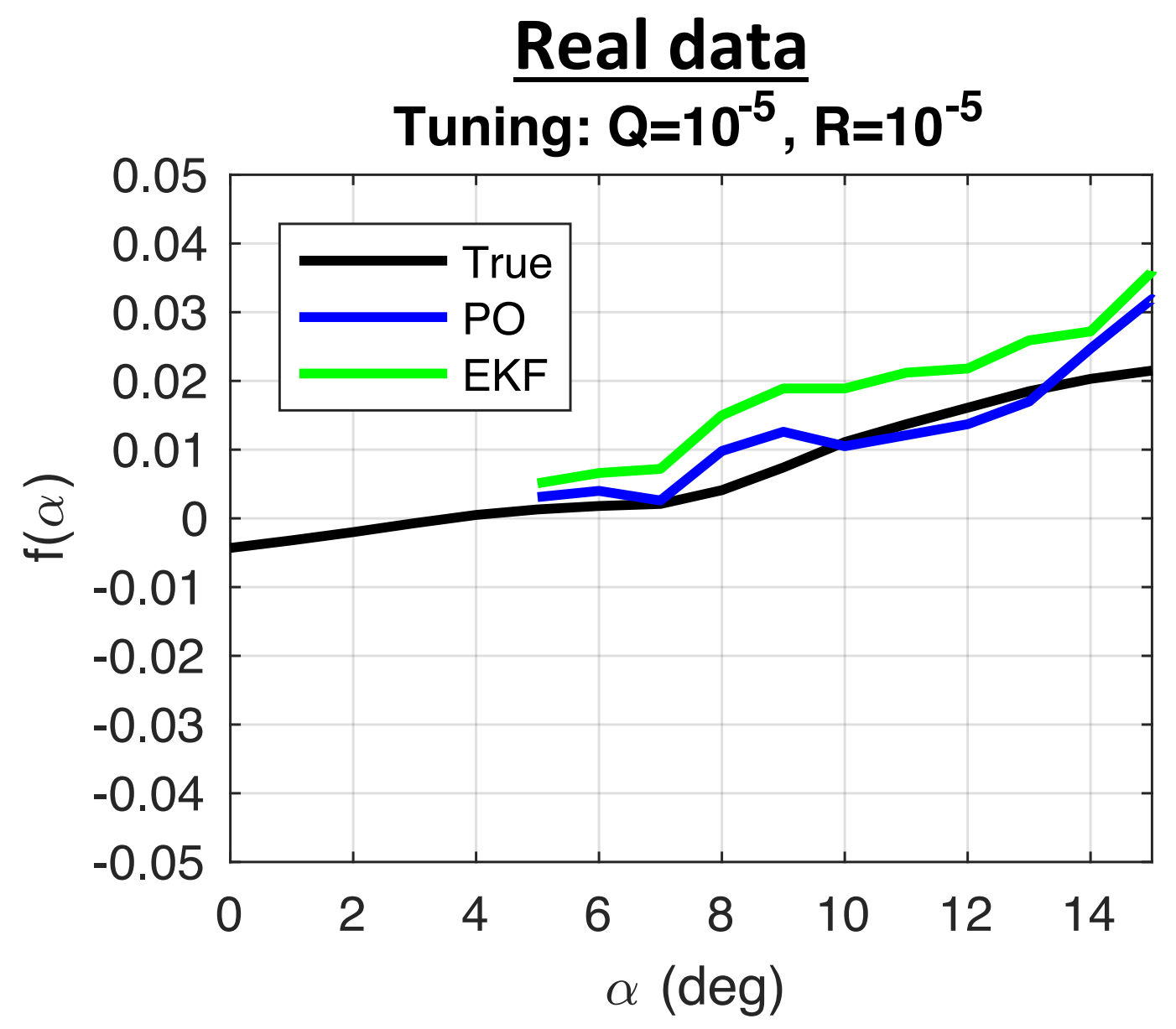
Initial model offset

Tuning: $Q=10^{-5}$, $R=10^{-3}$



Process noise

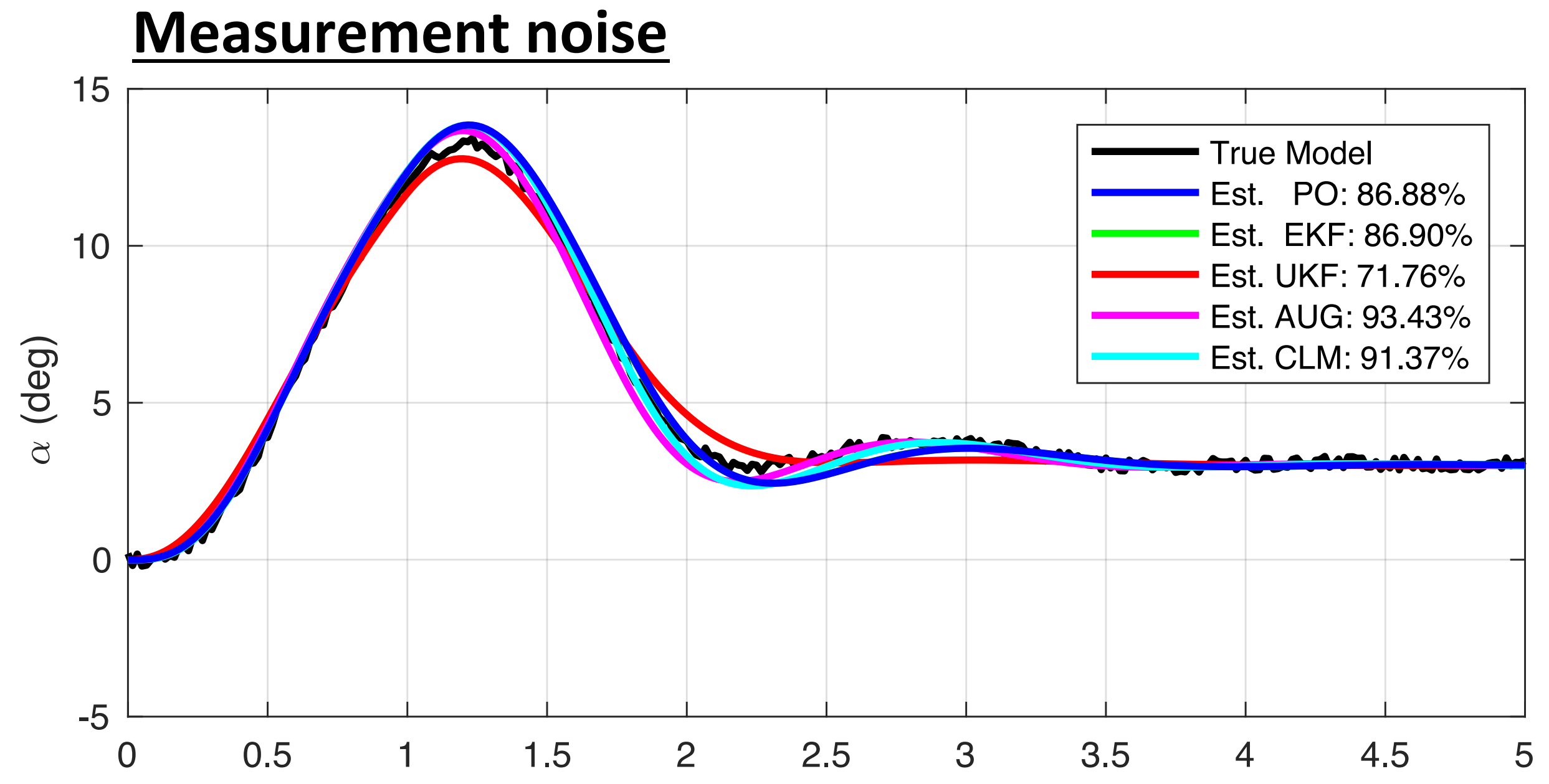
Tuning: $Q=10^{-5}$, $R=10^{-5}$



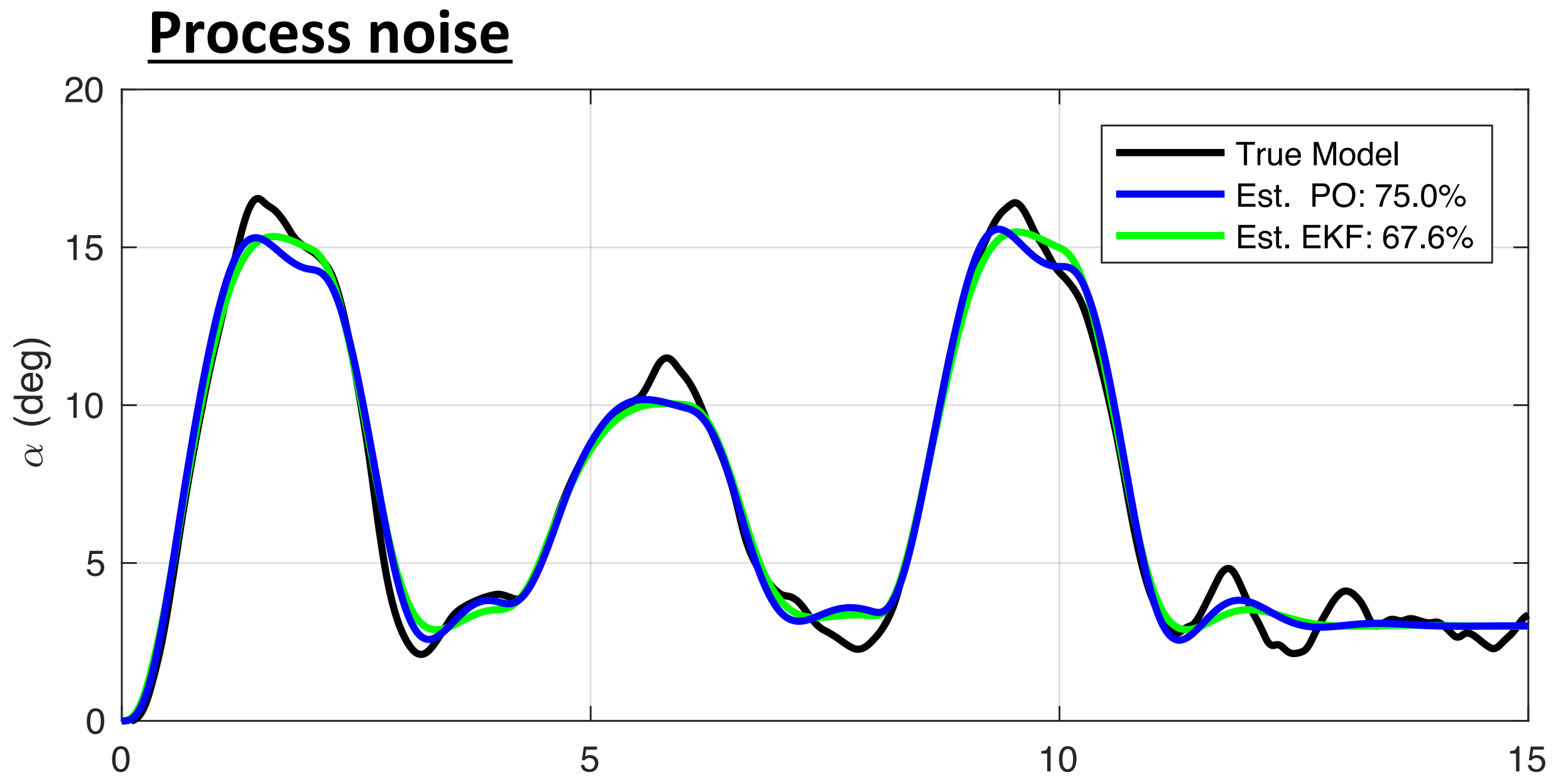
Real data

Tuning: $Q=10^{-5}$, $R=10^{-5}$

Apart from the figure above, one result is that both the UKF and AUG methods can give very good and/or bad results depending on SNR and the setting of tuning parameters. Another result is that the CLM method is biased for the process noise case since the constraints used cannot handle this. For the measurement and process noise cases, model validation has been performed. In the measurement case all methods are included while only the PO and EKF methods are validated for the process noise case.



Measurement noise



Process noise

Conclusion

The PO method is simple and robust, which are desired properties from an engineering point of view.

Acknowledgements

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