Engineering Risk Analysis Group
Prof. Dr Daniel Straub

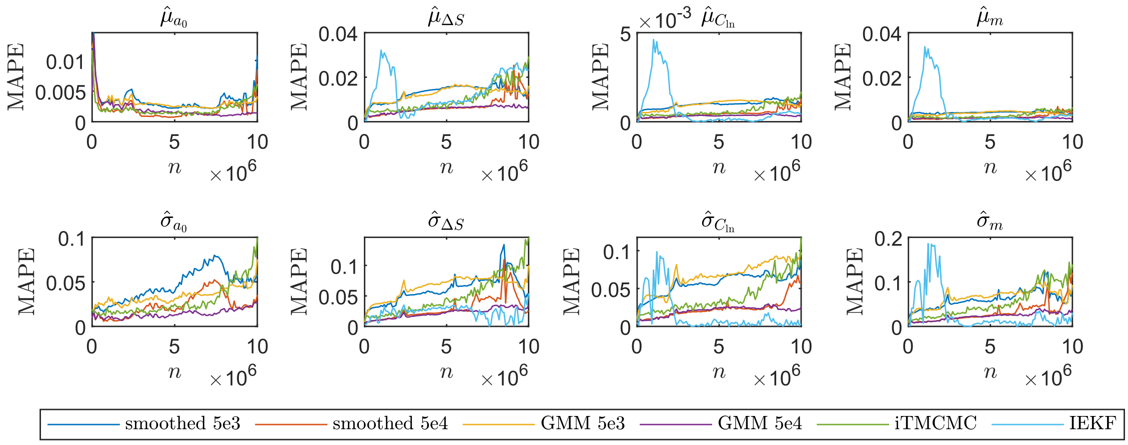
MSc thesis

Bayesian Filtering for Joint State and Parameter Estimation of Structural Deterioration

Luca Sardi, April 2021

Background

Technological advancements in sensor technology and non-destructive testing will lead to a further increase in data collection for civil engineering structures in the coming years. The motivation for this data collection is the inference of the state of the structural system with the goal of optimizing life-cycle maintenance decisions. Different Bayesian inference tools are already available and can be utilized to reduce the uncertainty of the current and future state of the structures based on the collected data. The focus of this work is specifically on recursive (online) filtering algorithms in the context of joint state and parameter estimation.



Mean absolute percentage error (MAPE) of the estimates of the mean and standard deviation of the model parameters for the fatigue crack growth model without process noise. For both the particle filter methods (5000 and 50000 particles) and the iTMCMC 50 runs are used to obtain the MAPE. The results of the iTMCMC and the iterated extended Kalman filter (IEKF) are obtained by offline estimation. The MAPE of the different methods is obtained by comparing the results to a reference solution created with rejection sampling.

Methodology

The classical Kalman filter, some nonlinear variations of it, and the general formulation of the particle filter are recapitulated. To solve the sample impoverishment problem when using the particle filter, two solution strategies are presented. The first solution is based on kernel smoothing, while the second idea relies on an approximation of the particles by a Gaussian mixture model throughout the resampling process. The filters are tested using a power function model and a fatigue crack growth model. In case that there is process noise in the model, the state vector consists of what normally would be referred to as state, i.e., the deterioration, and the time-invariant parameters. In case that there is no process noise, the state vector consists only of the time-invariant parameters (i.e., parameter estimation only).

Conclusion

The two presented resampling methods, especially the one using the GMM approximation, solve the sample impoverishment problem effectively. The solution of the particle filter in the case of parameter estimation only is also compared to the results of an offline estimation method called iTMCMC. In the given example, the particle filter shows to be a qualitatively competitive and computationally cheap alternative, especially if a real-time estimation of the parameters is required.

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