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Estimation of time varying system parameters from ambient response using improved Particle-Kalman filter with correlated noise

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Although Kalman filter (KF) was originally proposed for system control i.e. steering a system as desired by monitoring the system states, its application for parameter estimation problems is widespread because of the excellent similarity between these two apparently different problem types in state space description.

In standard Kalman filter, system dynamics is described through the dynamics of certain internal variable, termed as states, evolving over time as defined by an assumed process model, while a measurement model maps these states to measurements. In some parameter estimation problems, the system is replaced by a state space formulation of the dynamic model with parameters appended in the unobserved states and collectively observed through the response measurements. Filtering based parameter estimation problems are thus inherently nonlinear due to the required nonlinear mapping of parameters to the corresponding observations.

Being a linear estimator, Kalman Filter (KF) cannot be employed for such nonlinear system estimation and alternative filtering algorithms (eg. Particle filter) are therefore generally used. However, being model based, these filters optimally estimate the parameters of a quasi-static model of the real dynamic system. Consequently, any time variation in the system dynamics may completely diverge the estimation yielding a false or infeasible solution. By decoupling the estimation of system states and parameters, and applying concurrent filtering strategy that attempts conditional estimation of states based on parameters and vice versa, time varying systems can be estimated.

This article attempts to combine KF with Particle filter (PF) and apply them for estimation of states and system parameters respectively on a system with correlated noise in process and measurement. The idea is to nest a bank of linear KFs for state estimation within a PF environment that estimates the parameters. This facilitates employing relatively less expensive linear KF for linear state estimation problem while costly PF is employed only for parameter estimation. Additionally, the proposed algorithm also takes care of those systems for which system and measurement noises are not uncorrelated as it is commonly idealized in standard filtering algorithms.

As an example, for mechanical systems under ambient vibration it happens when acceleration response is considered as measurement. Thus the process and measurement noise in these system descriptions are obviously correlated. For this, an improved description for the Kalman gain is developed. Further, to enhance the consistency of particle filtering based parameter estimation involving high dimensional parameter space, a new temporal evolution strategy for the particles is defined. This strategy aims at restricting the solution from diverging (up to the point of no return) because of an isolated event of infeasible estimation which is very much likely especially when dealing with high dimensional parameter space.