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TITLE: EnKF within the Marginalized Particle Filter and Its Application for Adaptive Estimation of Inflation Factor
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ABSTRACT BODY:

We are concerned with Bayesian approach to data assimilation. We follow the common assumptions of first order Markov process on the state variable and corresponding measurements. Many common assimilation techniques, such as Kalman filtering and particle filtering, are special cases of the approximative solution of the Bayesian equations. Both of these techniques use a single approximation for the posterior probability density function (pdf) of the state vector. In this paper we advocate the use of marginalized particle filter (MPF, also known as Rao-Blackwelized particle filter), which splits the state vector in two disjoint parts and approximates their densities differently.

Specifically, let x_t be a multidimensional state variable evolving according to a first order Markov model with unknown parameters θ_t, and $y_{1:t}=(y_1,...,y_t)$ available measurements. The task is to recursively estimate both the state variable and the parameters, forming an augmented state $\xi_t=(x_t^T,\theta_t^T)^T$. Following the Bayesian approach, we recursively evaluate posterior pdf $p(\xi_t|y_{1:t})=p(x_t,\theta_t|y_{1:t})$. This can be factorized using the chain rule as

$$p(x_t,\theta_t|y_{1:t})=p(x_t|\theta_t,y_{1:t})p(\theta_t|y_{1:t}).$$

The MPF arises when the pdf $p(\theta_t|y_{1:t})$ is approximated by an empirical pdf and conditional pdf $p(x_t|\theta_t,y_{1:t})$ is approximated by a parametric (e.g. normal) pdf. What results is a hybrid filter composed of a particle filter on θ_t, each particle of which carries an associated analytical filter on x_t. This way allows to exploit the benefits of both the methodologies. Note that this approach allows to combine an arbitrary particle filter with an arbitrary analytical filter. Moreover, the augmented state variable can be partitioned arbitrarily, i.e. the introduced partitioning is only a special case of many possibilities. In this paper we investigate the use of ensemble Kalman filter (EnKF) in place of the analytical filter and sampling-importance-resampling (SIR) filter in place of the particle filter.

As an illustrative example, we present an assimilation scenario for assessment of radiation situation on terrain after a fallout and prediction of the future evolution. The state variable x_t describes the radiation situation on terrain in terms of surface deposition in Bq/m^2. Its evolution is modeled as a superposition of two exponentials shaped by a parameter $\theta_{1,t}$. Since the variance of the evolution model is not known, we chose the EnKF which is capable to overcome this by using ensemble of states. However, EnKF has a tendency to underestimate the covariance of the posterior, which can be improved by use of the inflation factor. We consider the inflation factor to be unknown, therefore we include it into the augmented state as parameter $\theta_{2,t}$. What remains to be specified is the transition model for $\theta_t=(\theta_{1,t},\theta_{2,t})^T$. As a first guess, we chose an independent Gaussian random walk model for each of the parameters.

Simulation study was performed as a twin experiment when measurements are sampled from a twin model and perturbed. The resulting assimilation scheme proved to be robust with respect to initial conditions and the inherent adaptivity of the inflation factor accelerated convergence to the simulated values.

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