Bayesian filtering of state-space models with unknown covariance matrices

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Motivation

Bayesian filtering is used in many applications in various fields, such as target tracking, stock exchange, or bioprocesses. It is still limited by a few complications, such as:

- Necessaty to know the noise covariance matrices
- Inability to combine information from multiple sensors

Problem statement

Given a network of collaborating agents (e.g., sensors) that can communicate with it nearest neighbors They observe a real process (target locations, stock price, bio values...) and aim to learn a convenient model that mimics the process and allows to predict values of interest (e.g., forecasts).

Our goal: Make this possible even under a severely underspecified model.

Methods

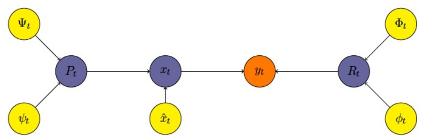
Our approach is based upon the following methods:

- Variational inference
- Message passing

We have used those methods to develop a collaborative variational Kalman filtering approach with information diffusion to solve the proposed problem.

$$x_t = A_t x_{t-1} + B_t u_t + \omega_t,$$
$$y_{i,t} = H_t x_t + \epsilon_{i,t}.$$

Used linear state-space model



Graphical model of message passing algorithm

Results

All tests were run on simulated 2-D trajectories

Comparison with standard Kalman filter:

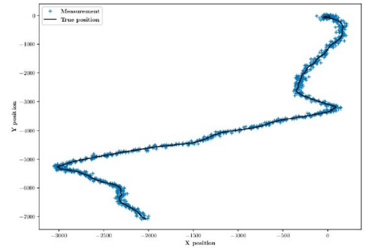
- Only single agent
- Two different settings of forgetting for variational filter
- Performance very close to the standard Kalman filter

Distributed estimation with constant measurement noise covariance matrix:

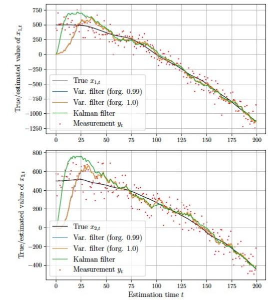
- Four different variants compared
- Excellent performance comparable to the filters with known cov. matrices

Distributed estimation with variance measurement noise covariance matrix:

- Four different variants compared
- Covariance matrix varies throughout the trajectory
- Good performance assuming an appropriate setting of forgetting



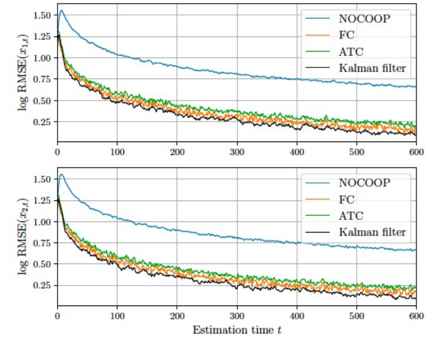
Example of the generated trajectory



Single-agent performance comparison

Conclusions

- The proposed method provides filtering under severely underspecified models.
- Straightforward representation and explainability.
- Low number of tunable parameters



Constant noise covariance matrix performance comparison

References

- K. Dedecius and O. Tichý, “Collaborative sequential state estimation under unknown heterogeneous noise covariance matrices”.
- Y. Huang, Y. Zhang, Z. Wu, N. Li, and J. Chambers, “A novel adaptive Kalman filter with inaccurate process and measurement noise covariance matrices”.