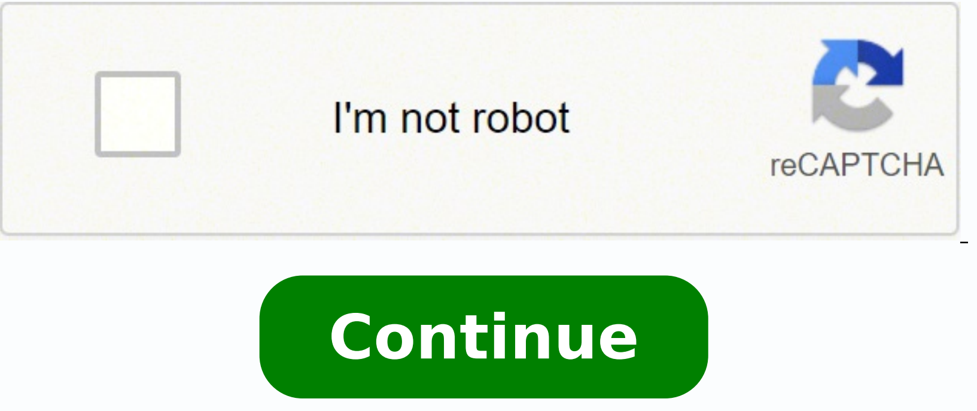

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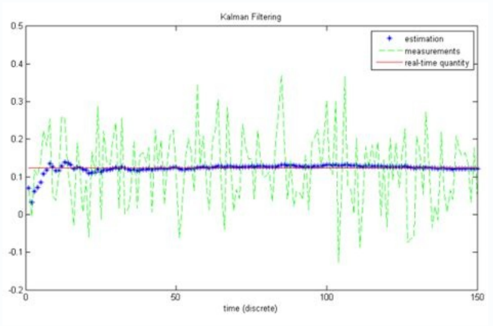

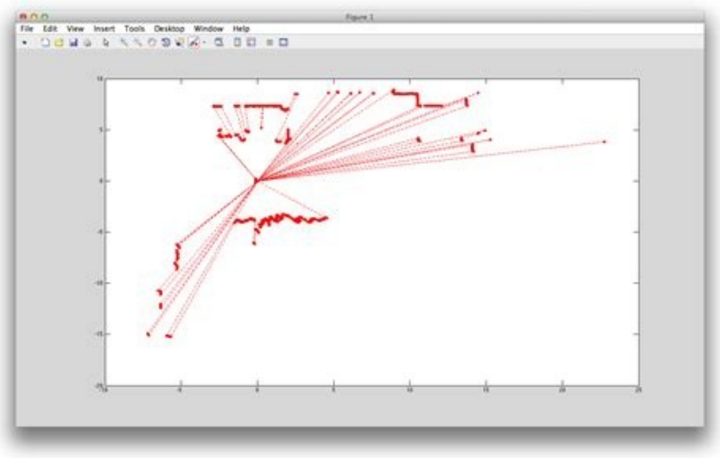

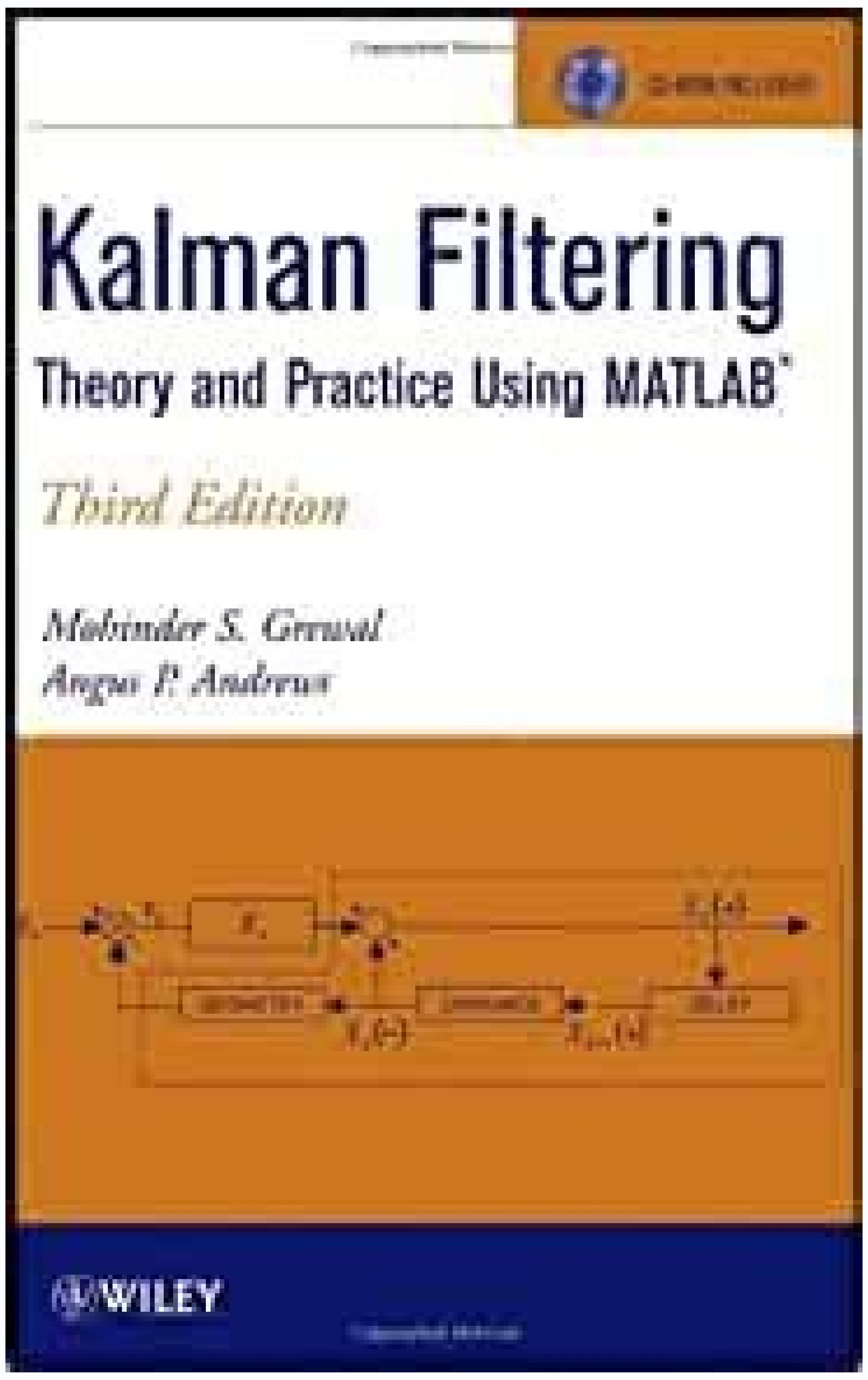

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The ensemble Kalman filter is an ABC algorithm

David J. Nott · Lucy Marshall · Tran Minh Ngoc

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Abstract The ensemble Kalman filter is the method of choice for many difficult high-dimensional filtering problems in meteorology, oceanography, hydrology and other fields. In this note we show that a common variant of the ensemble Kalman filter is an approximate Bayesian computation (ABC) algorithm. This is of interest for a number of reasons. First, the ensemble Kalman filter is an example of an ABC algorithm that predates the development of ABC algorithms. Second, the ensemble Kalman filter is used for very high-dimensional problems, whereas ABC methods are normally applied only in very low-dimensional problems. Third, recent state of the art extensions of the ensemble Kalman filter can also be understood within the ABC framework.

Keywords Approximate Bayesian computation · Data assimilation · Ensemble Kalman filter · Regression adjustment

1 Introduction

The ensemble Kalman filter (Evensen 1994, 2007) is perhaps the most widely used approach in very high-dimensional filtering problems in areas such as meteorology, oceanography and hydrology. In this note we show that the ensemble Kalman filter updates are an example of the regression adjustment ABC algorithm of Beaumont et al. (2002). This is interesting as the ensemble Kalman filter predates the development of ABC algorithms and is effective in very high dimensions, whereas ABC algorithms are used mostly in low-dimensional problems. Furthermore, a recent state of the art extension of the ensemble Kalman filter due to Lei and Bickel (2011) also corresponds to an ABC algorithm, namely the heteroscedastic nonlinear regression adjustment of Blum and François (2010). The regression perspective on the ensemble Kalman filter noted in Lei and Bickel (2011) and also discussed in the meteorological literature by Anderson (2003) is effectively the same as the method of Beaumont et al. (2002) applied to the filtering problem, although there has been no previous explicit link made with ABC methods. Lei and Bickel (2011) contains a number of other important innovations including some analysis of theoretical properties of their method and dimension reduction by localization, a very important issue in high-dimensional applications in the geosciences. There has been some recent interest in using ABC methods for filtering problems (Jasra et al. 2011) but there has been no study of regression adjustment methods in this context as far as we are aware. An anonymous referee has pointed out to us, however, that the convolution particle filter (Campillo and Rossi 2009) is in essence a regression approach to the filtering problem based on kernel conditional density estimation and simulation from a forward model. The purpose of this note is to make explicit the links between the method of Beaumont et al. (2002) and the ensemble Kalman filter, and between the method of Blum and François (2010) and that of Lei and Bickel (2011).

In Sect. 2 we briefly describe the regression adjustment ABC methods of Beaumont et al. (2002) and Blum and François (2010). Section 3 introduces the ensemble

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D.J. Nott (✉) · T.M. Ngoc
Department of Statistics and Applied Probability,
National University of Singapore, Singapore 117546, Singapore
e-mail: standj@nus.edu.sg

L. Marshall
Department of Land Resources and Environmental Sciences,
Montana State University, 334 Leon Johnson Hall,
PO Box 173120, Bozeman, MT 59717-3120, USA

So the pendulum model almost acts linearly. We assumed perfect knowledge of the system model, and processed at noise covariance matrices Q and R. Therefore, for small angles we can linearize this equation and write that on this form. We'll expect the sensor readings to have some noise, which we'll simulate using this noise block. As we mentioned before, we're interested in estimating theta through a Kalman Filter, because the measurement of theta is noisy. Now, we have the actual and measured values of theta. Note that there is a nonlinear term associated with the angular position. Although we can measure theta, our measurements will be noisy. But since we're assuming that the process noise acts on the angular acceleration only, we entered associated term noted in the covariance matrix as 0. Recall that the first state is the change in the unemployment rate, and the second state helps build the first.figure plot(dates((end-fh+1):end),[unrateF(:,1) y((end-fh+1):end)]); xlabel('Period') ylabel('Change in the unemployment rate') title('Filtered Change in the Unemployment Rate') We can also look at these in the mechanics explorer. Also, note that you can specify the covariance matrices as time variant by unchecking the box next to them. So the process noise covariance is a 2 by 2 matrix. The pendulum block's output is the angular position, which is assumed to be measured with a sensor. The second input is the process noise. But in case you don't know the system parameters, or the sensor characteristics exactly, then this simulation gives you an opportunity to play with your model parameters, as well as noise covariance matrices, and observe and improve your state estimation. And when we let it go, it starts to swing back and forth. We set the initial conditions for the states by double clicking the pendulum block. In this system, we're interested in observing the angular position theta. Here, we modeled the pendulum by connecting a fixed pivot with a link through a revolute joint. If you look at the plot of the function, we see that for small values of theta, this function almost acts linearly. One thing to note is that the pendulum model used in this block includes the nonlinear term sine of theta. Here, for estimating the angular position of the pendulum, we will use Simulink. This is because for larger values of theta, the pendulum model acts nonlinearly. Next, we want to estimate theta using the Kalman Filter. It uses the system model and the measurement and solves for the Kalman gain by minimizing the error covariance p, and outputs the optimal state estimates. And we output the joint position, theta, through the revolute joint block. In these blocks, we define dimensions, mass, and inertial properties of the bodies. As we discussed in the previous video, this problem can be addressed by using an extended Kalman Filter. The cross covariance matrix, n, is used to capture the correlation between the process and measurement noise. Imagine that the pendulum is connected to a rigid rod and we initiate it at an angle. Predictors=Z(T-fh+j,:),Beta=estParams(end-1:end)); currentState = unrateF(j,:)'; currentStateCov = unrateCovF{j}; endPlot the estimated, filtered states. In the next video, we will use the same pendulum model and demonstrate how you can use an extended Kalman Filter in Simulink. This estimate shows us that Kalman Filter filters out the noise. Next, we run the script and the Simulink model and look at this negative theta through the Kalman Filter. In the pendulum model, we use an initial conditional pi over 18 radius for the angular position. 'Beta0',[0.1 0.2],'lb',[-Inf,-Inf,0,-Inf,-Inf]);Method: Maximum likelihood (fmincon) Sample size: 51 Logarithmic likelihood: -87.2409 Akaike info criterion: 184.482 Bayesian info criterion: 194.141 | Coeff Std Err t Stat Prob -- c(1) | -0.31780 0.37357 -0.85071 0.39494 c(2) | 1.21242 0.82223 1.47455 0.14034 c(3) | 0.45583 1.32970 0.34281 0.73174 y

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