Practical Kalman Filtering using MATLAB

Summary
The Kalman filter has become arguably the most widely applied technique in modern control systems. This course will cover the theory of Kalman filters and their application to problems in guidance control and navigation. Given a linear system model and any measurements of its behavior, plus statistical models that characterize system and measurement errors, plus initial condition information, the Kalman filter describes how to process the measurement data.

Instructor
Donald L. Mackison is an Adjunct Professor of Aerospace Engineering at the University of Colorado. He has a PhD from CU in Controls and Systems, and has worked at Johns Hopkins University Applied Physics Laboratory, Ball Aerospace, and the National Oceanic and Atmospheric Administration. His 40 years of professional experience have included development work on submarine inertial and satellite navigation systems, satellite attitude control and attitude determination (gravity gradient and spin stabilized system, Orbiting Solar Observatory, Hubble Space Telescope, Upper Atmospheric Research Satellite- UARS) and several lightsats at CU. His research has included application of Linear Quadratic and Kalman Filter methods to satellite attitude control systems, including the development of “modal weighting” methods for both controllers and filters.

What You Will Learn
- Theory of the Kalman filter.
- Application to typical dynamic systems
- Matlab modeling of Kalman filters applied to typical linear and nonlinear systems.
- Extended Kalman filters.
- How to develop measurement and state noise model for the Kalman filters.
- Comparison of discrete and continuous filter models.
- What are extended Kalman filters, and how to apply them to problems with nonlinear dynamics and nonlinear measurement.
- Advantages and disadvantages of time dependent and constant gain filters.
- Two points of view- Noise models representing physical reality and noise models as tuning knobs for both constant gain and time dependent filters.
- The relation between the Kalman gain, the noise models, and time response of the filter.
- The Kalman filter as a AR filter.

Course Outline
1. Review of linear algebra and random processes. Review of the mathematics of linear algebra and random processes necessary to understand the engineering application of Kalman filters.
2. Development of the discrete Kalman Filter. Mathematical development of the discrete filter- based on a linear dynamic system driven by white noise, and linear measurements of the state corrupted by white noise. The addition of shaping filters to the model to account for non-white noise sources.
3. Development of the continuous Kalman Filter. The continuous filter is shown to be a limiting case of the discrete filter. For the constant gain (steady state) filter, the filter gains and the steady-state state error covariance matrix are derived from an eigenvector decomposition of the control Hamiltonian (Potter-MacFarlane) implemented in Matlab codes.
4. Development of the Extended Kalman Filter. The linear Kalman filter is exact, based on the linear dynamics model and the linear measurement model. For most systems, orbit determination, for example, both the dynamics and measurements are nonlinear functions of the state. In the Extended Kalman Filter (EKF) the state estimate is propagated with the full nonlinear model, and the predicted measurement is computed with the full nonlinear model. Linearized models are used to propagate the covariance, and to compute the filter gains using the state and measurement Jacobian matrices. The EKF solved much of the early problems of filter divergence.
5. Estimators for linear dynamic systems. A series of simple dynamic models will be used to focus all these ideas in a tractable problem.
6. Application to navigation systems. Modern navigation system (inertial, celestial, GPS) computations are driven by Kalman filter estimators. We will look at several of these systems in light of what we have learned about Kalman filters.
7. Application to orbit determination and attitude determination systems. Several examples will be examined including both discrete and continuous linear Kalman filters, and the Extended Kalman Filter, for various orbit measurements, and for a variety of attitude sensors.
8. Covariance analysis methods. One of the most important applications of Kalman filter methods is covariance analysis, used to predict the performance of a system using assumed system dynamics and assumed covariance models for system disturbances, measurement noise, and uncertain internal parameters of the system. This analysis allows one to specify parameters for hardware and software and schedule measurement updates.

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