Adaptive Kalman Filter Simulation Platform with Application to Marine GPS/SINS Integrated Navigation System Based on Scilab

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Abstract

Presently, Global positioning system (GPS) and Inertial navigation system (INS) are two major navigation systems now widely used for marine application around the world. INS and GPS have very complementary error characteristics. Short-term position errors from the INS are relatively small, but they degrade without bound over time. GPS position errors, on the other hand, are not as good over the short term, but they do not degrade with time. Additionally, the GPS data updating rate (that is, between 1 Hz and 10 Hz) is comparatively low comparing with the INS high data updating rate (that is 100 Hz).

Kalman filter is the most frequently used algorithm in the integrated navigation system since it is capable of taking advantage of these error characteristics to provide a common, integrated navigation implementation with performance superior to that of either subsystem (GPS or INS). A key function performed in the Kalman filter is to estimate error parameters of the inertial components by using the statistical information of GPS and INS. As a result, it can enhance INS accuracy when GPS signals are available.

However, the Kalman filter requires the accurate noise statistic properties of the dynamic and observation models. Commonly, as limited knowledge about the system, this priori statistical information is not accurate determined. If such a priori information is not accurate to represent the real statistic noise levels of the system, Kalman estimation is not optimal and may cause to an unreliable result, sometimes even leads to filtering divergence (Mohamed and Schwarz 1999). For marine integrated navigation application, marine dynamics have a strong influence on GPS and INS performance and there sudden acceleration or deceleration and sudden change of the directions are impossible to predict. Therefore it is difficult to design a system with constant noise variances that will satisfy all situations.

From this point of view, many different adaptive schemes of Kalman filter have been proposed to overcome the conventional Kalman filter's problems (that requires the accurate noise statistic properties beforehand). In the past few years, three major approaches have been proposed for adaptive Kalman filtering (AKF) were covariance scaling, multiple-model-based adaptive estimation and adaptive stochastic modeling. The covariance scaling method improves the filter stability and convergent performance by introducing a multiplication factor to the state covariance matrix. The calculation of the scaling factor can either be fully empirical or based on some criteria derived from filter innovations (Hu, Chen et al. 2003; Yang and Xu 2003; Yang and Gao 2005; Yang and Gao 2006). In the multiple-model-based adaptive estimation (MMAE) a bank of Kalman filters runs in parallel under different models for the filter's statistical information. The output of MMAE is the weighted sum of each individual filter's output, and the weighting factor can be calculated using the residual probability function (Brown and Hwang 1997; Hide, Moore et al. 2004). Adaptive stochastic modeling includes innovation-based adaptive estimation (IAE) (Mohamed and Schwarz 1999) and residual-based adaptive estimation (RAE) (Wang, Stewart et al. 1999). It is well known that the innovation and residual sequences of the Kalman filter are a reliable indicator of the

Kalman filter performance. For an optimal filter, the innovation and residual sequences are white Gaussian noise (Brown and Hwang 1997). By online monitoring of the innovation or residual sequence, IAE or RAE can estimate directly the covariance matrices of process noise and measurement errors, and tunes them in real-time. The adaptation is done directly to the statistical information matrices R and/or Q based on the changes in the innovation or residual sequence. Recently, many researchers introduce fuzzy logic control (FLC) method into IAE algorithm, and accordingly propose various adaptive Kalman filtering (Sasiadek, Wang et al. 2000; Loebis, Sutton et al. 2004; Jwo and Chang 2007; Jwo and Wang 2007).

Simulation platform, as the foundation of research on GPS/SINS Integrated Navigation System, can be used to verify the different variations of Kalman filter for using in integrated navigation system. So it is necessary to design and implement an effective and flexible Kalman Filter simulation platform for Integrated Navigation System. As open source software, Scilab is powerful for scientific computation widely used by many scientists and engineers in many fields. In this paper, based on Scilab, a novel adaptive Kalman filter simulation platform is implemented with Application to Marine GPS/SINS Integrated Navigation System. The superior merit of the implemented simulation platform is that it contains the three major approaches for adaptive Kalman filtering (AKF), namely, covariance scaling, multiple-model-based adaptive estimation and adaptive stochastic modeling.

Key words: INS, GPS, Integrated navigation, Adaptive Kalman Filter, Simulation Platform, Covariance Scaling, Multiple-model-based Adaptive Estimation, Adaptive Stochastic Modeling