

# FUZZY ADAPTIVE EXTENDED KALMAN FILTER

Vasko Sazdovski, Faculty of Electrical Engineering – Skopje, [sazdo79@yahoo.com](mailto:sazdo79@yahoo.com)

**Abstract:** Kalman filtering is a method for estimating state variables of a dynamic systems recursively from noise-contaminated measurements. The filter determines the system's present state by optimally combining theoretical estimates with measurements noise characteristics based on the knowledge of the system model. This is the well known Linear Kalman filter (LKF) for state estimation of linear systems. For systems with nonlinear dynamics, a natural extension of the LKF called Extended Kalman filter (EKF) is used.

The Kalman filter represents one of the most popular estimation techniques for integrating signals from short-term high performance navigation systems (like Inertial Navigation System, INS) with reference systems exhibiting long-term stability (like Global Positioning System, GPS). For the integration of GPS and INS, because the systems are nonlinear in nature we use the EKF where the GPS errors are represented by the measurement noise covariance matrix  $R$ , and the INS errors are represented by process covariance matrix  $Q$ .

However, a significant difficulty in designing a Kalman Filter (refers to both LKF and EKF) can often be traced to incomplete *a priori* information about  $R$  and  $Q$ . In most practical applications these matrices are initially estimated or even unknown. The problem here is that the optimality of the estimation algorithm is closely connected to the quality of *a priori* information about the process and measurement noise matrices. It has been shown that insufficiently known *a priori* filter statistics can reduce the precision of the estimated filter states. In addition, incorrect *a priori* information can lead to practical divergence of the filter, resulting in a difference in the theoretical and actual behaviour of the filter. From the aforementioned it may be argued that the Kalman filter with fixed  $R$  and/or  $Q$  should be replaced by an adaptive estimation formulation.

The use of fuzzy-rule based adaptation scheme to cope with divergence problem caused by the insufficiently known *a priori* filter statistics is explored. We assume that "uncertainties" or time varying parameters exists in the measurement noise covariance matrix.

The Fuzzy Logic Adaptive Controller (FLAC) is used to detect the uncertainties, adapt the EKF with that the whole Integrated INS/GPS Navigation System on-line and prevent divergence. In the FLAC variance and the mean of residuals are used as inputs for the fuzzy inference engine while the uncertainties in measurement noise covariance matrix are used as output. Variance is a very useful statistical property for random signals because if we knew the variance of a signal that was otherwise supposed to be "constant" around some value the mean, the magnitude of the variance would give us a sense how much noise or uncertainty is in the signal.

Generally, when we have great uncertainties the variance is becoming large, and mean value is moving away from zero, the EKF is becoming unstable and divergence problems occurs. By detecting an appropriate value of the uncertainties FLAC continually adjusts the noise strengths in the filter's internal model and adapt the EKF optimally trying to keep the innovation sequence acting as zero-mean white noise.

Integrated INS/GPS Navigation System with implemented FLAC is used for navigation, guidance and control of Unmanned Aerial Vehicles (UAVs). The navigation of flying robots requires fast, accurate, on-line control algorithms with reliable navigation parameters.

The presented method has been validated in 3-D environment and is of particular importance for guidance, navigation, and control UAVs. It has been demonstrated that Integrated INS/GPS Navigation Systems with implemented FLAC gives better results (more accurate) than Integrated INS/GPS Navigation Systems without implemented FLAC.