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COMPARISON OF EKF AND UKF FOR ROBOTIC MISSIONS TO MARS

Abstract

The most commonly used filtering process in orbit determination, the batched Kalman filter, works well for a wide variety of mission scenarios, but does have some notable deficiencies. First and foremost, the Kalman filter requires linearity or a linearized approximation in the underlying dynamical system. For the classical Kalman filter, this linearization is assumed to remain valid for the duration of the orbit determination arc, often necessitating segmenting trajectories based on propagation time or events introducing highly non-linear effects, such as gravity-assist flybys. Furthermore, the Kalman filter relies on the computation of partial derivatives for all measurements and parameters used in the filter, a non-trivial task even when analytical derivations are possible. To address these limitations, many extensions and modifications to the linear Kalman filter have been proposed over the years since Kalman's initial publication.

Our investigation examines two popular variants of the Kalman filter, namely the Extended Kalman Filter (EKF) and Unscented Kalman Filter (UKF), within the context of spacecraft missions to Mars. The EKF relies on the same mathematical basis as the classic version of the filter, however it sequentially updates the linearization as the filtering process is conducted. In contrast, the UKF is built upon the unscented transform which samples the nearby solution space and numerically propagates perturbed trajectories as part of the update / estimation process. This approach better captures the true perturbed dynamics of the system, while still assuming Gaussian distributions like other versions of the Kalman filter. These differing approaches to the filtering process offer different advantages and drawbacks which can have important implications for upcoming Mars mission architectures. While near-term applications for Mars focus on robotic missions of increasing autonomy, eventual human missions will also require robust and efficient orbit determination processes. Thus, we assess the performance of differing filtering algorithms under a variety of mission scenarios with the goal of establishing clear decision criteria for which implementation to use under differing circumstances.