Beyond the EKF

Introduction and Application of Advanced Nonlinear Filtering Techniques

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Description:

Since the development of the Kalman Filter, it has become one of the most famous and widely used sensor fusion algorithms. However, the underlying assumption of linear dynamics is not satisfied by most real-world systems. Thus, linearization of system and measurement models is performed in order to make consideration of nonlinear systems possible which is known as the extended Kalman filter (EKF).

The last two decades have witnessed a rapid development of novel nonlinear filtering techniques that are inherently better suitable for consideration of nonlinear system dynamics. This is done at two levels. First, consideration of nonlinear system and measurement models can be improved, e.g., by making use of deterministic sampling based nonlinear filtering techniques that do not require the computation of derivatives (thus, they are sometimes referred to as derivative-free filters). This involves approaches such as the Unscented Kalman Filter (UKF), the Gauss-Hermite Kalman Filter, or the Smart Sampling Kalman Filter (S^2KF). Second, a sound consideration of nonlinear underlying state spaces is possible by making use of probability distributions that are defined on these state spaces. This is made possible by making use of directional statistics, which is a subfield of statistics that considers directional quantities such as angles or orientations.

Sensor fusion applications can benefit from using these novel approaches in several ways. First, they make stochastic filtering possible in scenarios where computation of derivatives is infeasible or overly burdensome. Second, the error made within computation of integrals within one filtering step may be bounded to a desired predefined level. Finally, they make consideration of high uncertainties on nonlinear domains possible as errors from falsely assuming linearity are avoided.

The goal of this tutorial is to provide better understanding of nonlinear filtering techniques. It will discuss the problems and conceptual limitations of the extended Kalman filter and propose alternatives. This discussion will mostly focus on filters that are based on deterministic approaches, such as the Unscented Kalman Filter, the Gauss-Hermite Kalman Filter, and the Smart Sampling Kalman Filter. Furthermore, we will address special consideration of nonlinear domains by giving an introduction to directional statistics and some filters that correctly consider the nonlinearity of the underlying domain. This will involve estimation of orientation and angles in the presence of high uncertainties. A combination of both ideas will be discussed in order to address the problem of handling complicated system and measurement models on nonlinear domains.