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# CONSTRAINED UNSCENTED KALMAN FILTERING WITH IMPROVED RELIABILITY FOR SMALL CELESTIAL BODY RELATIVE NAVIGATION

**Abstract**

In many aerospace applications, the system state is subjected to some constraints due to physical limitations. For instance, the maximum deformation of a small celestial body flexible lander is constrained. Through integrating such physical constraints into the estimation framework, the performance of the filtering algorithm can be improved. For constrained filtering problems, the key is to ensure that the estimated state satisfies the constraints. To this end, one useful technique is to construct a constrained least square problem to restrain the estimated state within the constraint region. Moreover, for constrained unscented Kalman filter(UKF), which is applicable to many nonlinear spacecraft systems, the sigma points are also required to stay within the constraint region. In previous studies, this is usually done by introducing a scaling parameter in unscented transformation(UT) to project the sigma points to the constraint region while preserving their statistical properties. Unfortunately, the sigma points will degrade after scaling if the constrained estimation from the last step is on the boundary of the constraints. The degradation will significantly increase the error in prediction covariance, which will further lead to unreliable state estimations or even failure of the UKF with scaled UT. To address this problem, a new sigma point projection method for constrained UKF is developed in this paper. Instead of directly projecting the unconstrained sigma points to the real constraint region, a redundant term is introduced to construct a relaxed constraint boundary. Then, a non-zero scaling parameter is optimized taking into account both the new constraint boundary and limits on the scaling parameter. The optimal scaling parameter is used in the projection of the unconstrained sigma points so that degradation of the sigma points can be avoided. The proposed sigma point projection method is further incorporated into a constrained UKF to generate precise state estimates with improved reliability. Theoretical analysis is carried out to show that the statistical properties of the sigma points are still preserved. Finally, a small celestial body relative navigation scenario is simulated to verify the proposed method, where a quadratic form inequality constraint of the flexible lander is considered in the filtering process. The performance of the method under different redundant terms is evaluated, providing insights for developing an UKF under complicated constraints.