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INVARIANT SIGMA-POINT KALMAN FILTERING ON SO(3) FOR ATTITUDE ESTIMATION OF A 3U CUBESAT

Abstract

The increasing access to space provides opportunities for student organisations and small companies to launch Nanosatellites, with a reduced sensing capability, for a variety of space missions. Many of these current Earth Observation missions place strict requirements on the pointing accuracy of the space platform of which accurate attitude estimation is a critical component. Attitude determination algorithms for CubeSats must therefore accurately estimate the satellite attitude using only gyroscope, magnetometer and sun vector measurements as inputs to the control system.

Traditionally, multiplicative forms of non-linear state estimators such as the Cubature, Extended and Unscented Kalman Filters are used to reduce the orientation state component to a minimal form however this still requires a normalisation step to ensure orthonormality. Recent work has been focussed on defining state estimation problems on manifolds, with the Special Orthogonal $SO(3)$ and Special Euclidean $SE(3)$ Lie groups describing rigid body motion most commonly used. Invariant Kalman Filters take advantage of symmetries in the matrix Lie group structure of the state and system dynamics, with the traditional linear output error used in EKF algorithms replaced with a left or right-invariant error, depending on the Lie group action taken. This approach allows for improved filter performance and stability as the error dynamics are independent of the current state estimate. These state estimators are referred to as invariant or symmetry preserving observers since, in the case of attitude estimation, the filter can preserve the normalisation property for rotation matrices and unit quaternions.

In this paper the Left and Right-Invariant Cubature and Unscented Kalman Filters are partially applied to an attitude estimation problem on $SO(3) \times \mathbb{R}^3$ to estimate the attitude and gyroscope biases for a 3U CubeSat using gyroscope and attitude vector measurements. The performance of the ICKF and IUKF algorithms are compared to traditional EKF algorithms defined in the $\mathbb{R}$ vector space. A Monte Carlo analysis is presented to demonstrate the improved performance of the invariant state estimators using both rotation matrices and quaternions as states.