ATTITUDE ESTIMATION PROCESS OF THE SENSING REMOTE SATELLITE CBERS-2 WITH UNSCENTED KALMAN FILTER AND QUATERNION INCREMENTAL, USING REAL DATA

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ABSTRACT

The aim of this paper is to study the influence of real data in the attitude estimation process when the estimator is the Unscented Kalman Filter. The importance of this study is the fact that the use of real data from satellite's on-board attitude sensors can introduce difficulties like mismatch of sizes, misalignments, unforeseen systematic errors, and post launch calibration errors.

The attitude estimation results get by the Unscented Kalman Filter (UKF) and the Extended Kalman Filter (EKF) are compared when the attitude is represented by the error quaternion. In this study, the attitude of the remote sensing satellite CBERS-2 (China Brazil Earth Resources Satellite) is estimated, simulating real time conditions using real data supplied by gyros, Earth sensors and Sun sensors that are on board of the satellite.

The attitude of the satellite represents how the satellite is oriented in the space. The importance of the attitude determination is not only related to the performance of the attitude control system, but also to the correct interpretation of information obtained from payloads on board of the satellite.

To determine the attitude of a satellite, the choice of the method depends on the type of application, of the mission, and on the requirements to be satisfied, such as the real time processing and the precision. However, independent of the method chosen, a minimum set of measurements supplied by sensors on-board the satellite are needed. Among estimations methods applied for nonlinear problems, the EKF is traditionally picked out for attitude estimation. However the EKF operates by approximating the state distribution as a gaussian random variable and then propagating it through the first-order linearization of nonlinear system. This estimator is a suboptimal nonlinear filter due to the truncation of the higher-order terms when linearizing the system. The loss of the higher-order terms can be avoided in the propagation of the state of the system by using the full nonlinear equations. To solve this problem the UKF, by means of the unscented transformation, uses a carefully selected set of sample points, the sigma points, to more accurately map the probability distribution of the phenomenon. Therefore, instead of the linearization commonly used in the EKF, this approach leads to faster and robust convergence from inaccurate initial conditions in attitude estimation problems. The UKF method is able to carry out the processing of sensor measurements

(e.g. horizon and sun sensors) in real time, its formulation accounts for the dynamical noise on the states, and allows a kinematic attitude determination, using additionally the gyro measurements.

Several parameterizations can be used to represent the satellite attitude, but the quaternion parameterization was chosen for several practical reasons: the prediction equations are treated linearly, the representation is free from singularities, and the attitude matrix is algebraic in the quaternion components. However the use of the quaternion as the attitude state presents some difficulty in the application of the filter equation. This difficulty is due to the lack of independence of the four quaternion components, which are related by the constraint that the quaternion have unit norm. This constraint results in the singularity of the covariance matrix of the quaternion state. To avoid such problems, it was used the quaternion incremental. The quaternion incremental is expressed not as the arithmetic difference between the true and the estimated quaternion but as the quaternion which must be composed with the estimated quaternion in order to obtain the true quaternion. Since this quaternion incremental corresponds almost certainly to a small rotation, the fourth component will be close to unity and, hence, all the attitude information of interest is contained in the three vector component. Therefore, the six-component object defined by the vector components of the quaternion incremental and the gyro bias vector will provide a representation of the state.

For the simulation, the measurements were collected by the Satellite Control Centre of INPE (Brazilian Institute for Space Research) and the data consisted of batches of around 10-15 minutes of sensor telemetries recorded every pass over a Brazilian ground station. The results obtained by the UKF and EKF with quaternion incremental parameterization are compared and show the behavior of each component of the estimated state vector, the error associated with measurements, as well as the estimated covariance. It is observed that, although the EKF and UKF have roughly the same accuracy, the UKF leads to a convergence of the state vector faster than the EKF. This fact was expected, since the UKF prevents the linearizations needed for EKF, when the system has some nonlinearity in their equations.