Attitude and In-orbit Residual Magnetic Moment Estimation of Small Satellites Using only Magnetometer

Raunak Srivastava, Roshan Sah & Kaushik Das

TCS Research, Bangalore, India

srivastava.raunak@tcs.com

35th Annual Small Satellite Conference

SSC-21-P2-11

Motivation

• Limited space and computational power along with low budget leading to lack of high precision sensors limits attitude estimation accuracy of small satellites.
• Estimation accuracy is also more sensitive to magnetic orbital disturbances.
• Satellite’s Residual Magnetic Moment (RMM) should be determined in real time in order to model the magnetic disturbance while estimating attitude.

Body Referenced EKF

• If the satellite states are simply attitude quaternion \( \hat{q} \) and angular velocity \( \omega \), the covariance matrix can turn out to be singular.
• A body referenced EKF makes use of a lower dimension state vector to avoid singularity.
• The state perturbation for body referenced representation is

\[
\Delta \hat{x} = \begin{bmatrix} \delta q \\ \Delta \omega \end{bmatrix}
\]

\[
\delta \hat{q} = -\omega^* \delta \hat{q} + \frac{1}{2} \Delta \omega
\]

\[
\Delta \omega = J^{-1} (\omega^* - \omega) \Delta \omega
\]

The only sensor used for this study is a magnetometer.
• This EKF also does not consider magnetic perturbation separately.

Random Walk Model

• If the standard white Gaussian noise \( D(k) \) in a state equation needs to be estimated, it can be expressed as a random walk model.
• The state and disturbance are propagated as

\[
X(k+1) = F(X(k), U(k), D(k)) + [0] \nu_w(k)
\]

RMM Estimation & Modified EKF

• Error in RMM is augmented in the state vector as \( \Delta \hat{x} = \begin{bmatrix} \delta q \\ \Delta m \end{bmatrix} \)
• Modified state perturbation differential equations are thus

\[
\delta \hat{q} = -\omega^* \delta \hat{q} + \frac{1}{2} \Delta \omega
\]

\[
\Delta \omega = J^{-1} (\omega^* - \omega) \Delta \omega
\]

• RMM and its differential (error in RMM) are propagated as per Random Walk Model

\[
\nu_R = \nu \eta
\]

\[
\Delta \nu_R = 0
\]

• The flow of the estimation algorithm can be explained by the following figure.

![Diagram showing the flow of the estimation algorithm]

Results

• RMM augmented estimator is efficiently able to estimate the attitude quaternion and angular velocity despite the presence of magnetic disturbance.

Conclusion

• Satellite attitude was estimated using only magnetometer as the sensor.
• Magnetic perturbation on satellite was modelled as function of time varying RMM.
• Resulting attitude estimates were better than those estimated by standard state of the art EKF.