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

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Motivation

- Limited space and computational power along with a 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.

Contribution

- Magnetic disturbance on Smallsats should be modelled and considered as an external torque instead of considering it as standard white noise.
- Main source of Magnetic perturbation is satellite's own RMM, which should thus be modelled and determined in real time
- Most of current research considers RMM to be a predetermined constant or piece-wise constant parameter.
- Main contribution of this work is to model the satellite RMM using a Random Walk model.
- Magnetic torque due to this time varying RMM is computed and considered as an external disturbance.
- This poster proposes a body referenced EKF to estimate the satellite's RMM in real-time along with the satellite's attitude and angular velocity using only magnetometer.

Body Referenced EKF

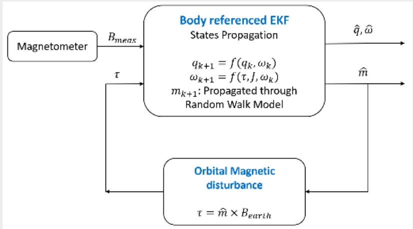
- If the satellite states are simply attitude quaternion $\bar{q}$ and angular velocity ω, the covariance matrix can turn out to be singular.
- A body referenced EKF makes use of a lower dimension state vector to avoid singularity.
- The state perturbation for body referenced representation is
- $\Delta\tilde{x} = \begin{bmatrix} \delta q \\ \Delta\omega \end{bmatrix}$
- $\delta\,\dot{q} = -\omega^{\times}\delta q + \frac{1}{2}\Delta\omega$
- $\Delta\,\dot{\omega} = J^{-1}[(J\omega)^{\times} - \omega^{\times}J]\Delta\omega$
- The only sensor used for this study is a magnetometer.
- This EKF also does not consider magnetic perturbation separately.

Random Walk Model

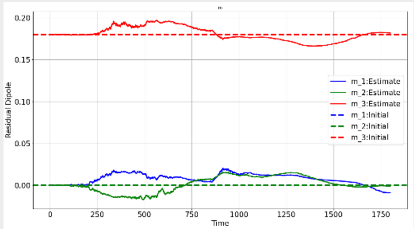
- If the standard white Gaussian noise $D(k)$ in a state equation needs to be estimated, it can be expressed as a random walk model.
- The state and disturbance are propagated as
- $\begin{bmatrix} X(k+1) \\ D(k+1) \end{bmatrix} = \begin{bmatrix} F\big(X(k),U(k),D(k)\big) \\ D(k+1) \end{bmatrix} + \begin{bmatrix} 0 \\ I \end{bmatrix} w_d(k)$

RMM Estimation & Modified EKF

- Error in RMM is augmented in the state vector as $\Delta\,\tilde{x} = \begin{bmatrix} \delta q \\ \Delta\omega \\ \Delta m \end{bmatrix}$
- Modified state perturbation differential equations are thus
- $\delta\dot{q} = -\omega^{\times}\delta q + \frac{1}{2}\Delta\omega$
- $\Delta\,\dot{\omega} = J^{-1}[\Delta m \times B] + J^{-1}[(J\omega)^{\times} - \omega^{\times}J]\Delta\omega$
- RMM and its differential (error in RMM) are propagated as per Random Walk Model
- $\dot{m} = \eta$
- $\Delta\dot{m} = 0$
- The flow of the estimation algorithm can be explained by the following figure.

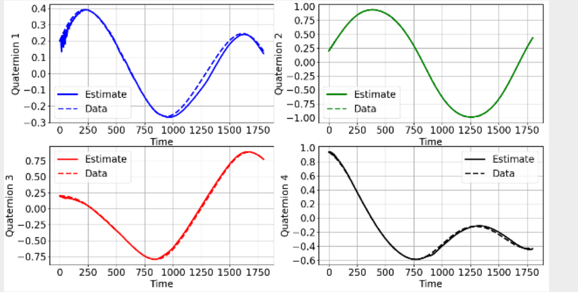


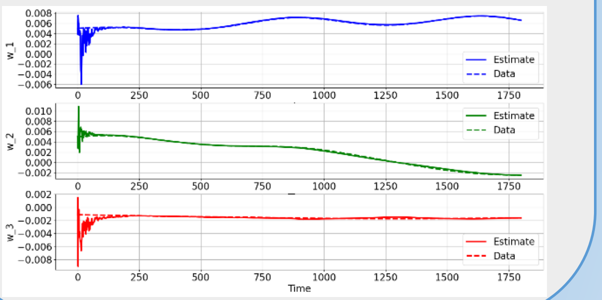
- The result in following figure shows time-varying estimates of RMM as opposed to constant predetermined value.
- This proves our proposed hypothesis that RMM should be estimated for better estimation accuracy.



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.