GPS/MAGNETOMETER BASED SATELLITE NAVIGATION AND ATTITUDE DETERMINATION

Julie Deutschmann
NASA GSFC, Code 572
Greenbelt, MD 20771
julie.deutschmann@gsfc.nasa.gov

Itzhack Bar-Itzhack[*]
Sophie and William Shamban Professor of Aerospace Engineering
Faculty of Aerospace Engineering
Haifa 32000, Israel
ibaritz@tx.technion.ac.il

Rick Harman
NASA GSFC, Code 572
Greenbelt, MD 20771
rick.harman@gsfc.nasa.gov

Abstract

In recent years algorithms were developed for orbit, attitude and angular-rate determination of Low Earth Orbiting (LEO) satellites [1, 2, 3]. Those algorithms rely on measurements of magnetometers, which are standard, relatively inexpensive, sensors that are normally installed on every LEO satellite. Although magnetometers alone are sufficient for obtaining the desired information, the convergence of the algorithms to the correct values of the satellite orbital parameters, position, attitude and angular velocity is very slow. The addition of sun sensors reduces the convergence time considerably [4]. However, for many LEO satellites the sun data is not available during portions of the orbit when the spacecraft (SC) is in the earth shadow. It is here where the GPS space vehicles (SV) can provide valuable support. This is clearly demonstrated in the present paper. Although GPS measurements alone can be used to obtain SC position, velocity, attitude and angular-rate, the use of magnetometers improve the results due to the synergistic effect of sensor fusion. Moreover, it is possible to obtain these results with less than three SVs.

In this paper we introduce an estimation algorithm, which is a combination of an Extended Kalman Filter (EKF) and a Pseudo Linear Kalman Filter (PSELIKA) [5]. The measurements, which are processed by the algorithm, are the following ones:

1. Magnetometer readings,
2. GPS pseudo range,
3. GPS range-rate,
4. GPS phase measurements.

Although data from one SV only are sufficient, the improvement achieved when two SVs are used, is examined.

The incorporation of SV phase measurements for estimating the SC angular-rate requires the use of the rate-of-change of the measured phase-angle. Using the derivative approach [6], this data is obtained by differentiation; however, when the estimation approach [6] is used, there is no need to differentiate the GPS phase measurements. In this paper, both approaches for estimating the SC angular-rate are examined.

The algorithm is tested using simulated data. The test results yield the following conclusions:

1. In the absence of sun sensor data the use of GPS is essential.
2. A three-axis-magnetometer (TAM) and one SV are sufficient for obtaining good estimate of a LEO SC orbit, location, attitude and angular-rate.
3. As expected, when using two SVs, the SC orbit and location converge much faster and to smaller errors. The use of two versus one SV shortens the convergence of the attitude and the angular-rate estimates, but does not reduce their final estimation error.
4. Comparing the use of the estimation approach with the derivative approach for estimating the SC angular-rate reveals that both approaches give similar results with the estimation approach yielding angular-rate estimates, which appear less noisy, as expected.

References

1. Psiaki, M.L., Huang, L., and Fox, S.M., "Ground Tests of Magnetometer Based Autonomous Navigation (MAGNAV) for Low-Earth-Orbiting Spacecraft," *Journal of Guidance, Control, and Dynamics*, Vol. 16, No. 1 Jan.-Feb., 1993, pp. 206-214.

2. Shorshi, G. and Bar-Itzhack, I., "Satellite Autonomous Navigation Based on Magnetic Field Measurements", *Journal of Guidance, Control, and Dynamics*, Vol. 18, No. 4 July-August, 1995, pp. 843-850.

3. Deutschmann, J., and I. Bar-Itzhack, "Comprehensive Evaluation of Attitude and Orbit Estimation Using Real Earth Magnetic Field Data", *Proceedings of the 11th Annual AIAA/USU Conference on Small Satellites*, Logan, UT, September 15-18, 1997.

4. Deutschmann, J., R. Harman, and I. Bar-Itzhack, "An Innovative Method for Low Cost, Autonomous Navigation for Low Earth Orbit Satellites", *Proceedings of the AAS/AIAA Astrodynamics Specialists Conference*, Boston, MA, August 10-12, 1998.

5. R. Harman and I.Y. Bar-Itzhack, "Pseudolinear and State-Dependent Riccati Equation Filters for Angular Rate Estimation", *AIAA J. of Guidance, Control, and Dynamics*, Vol. 22, No. 5, Sept.-Oct. 1999, pp. 723-725. (Engineering Note).

6. Bar-Itzhack, I., "Classification of Algorithms for Angular Velocity Estimation", to appear in *Journal of Guidance, Dynamics, and Control*, Vol. 24, No. 2, March-April. 2001.