Satellite and Inertial Attitude and Positioning System

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Abstract

Inertial navigation systems (INS) can provide sensitive and fast updates in real-time for precision navigation. Recent advances in fabrication methods allow inertial sensors to be built using micro electromechanical systems (MEMS) which reduce the cost of an INS. A drawback of MEMS sensors is that they are prone to significant sources of error which include white noise and a random sensor bias. These will cause a spinning motion in the processed attitude information and an estimated position that rapidly deviates from the vehicle's true position. These errors can be mitigated by combining INS and GPS measurements with a Kalman filter.

Due to the nonlinearity of the INS error sources a nonlinear Kalman filter must be employed. The goal of this project is to implement and test an Unscented Kalman filter (UKF) to achieve real-time estimates of the position, velocity, and attitude of the vehicle.

Project Goals

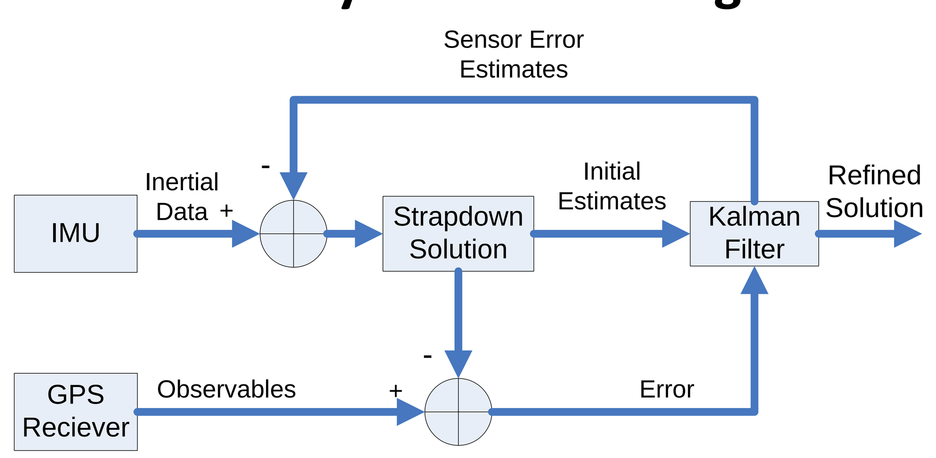
- Model system error sources
- Integration of IMU and GPS
- Implementation of navigation algorithm in software

- **Create a low cost and robust navigation system**

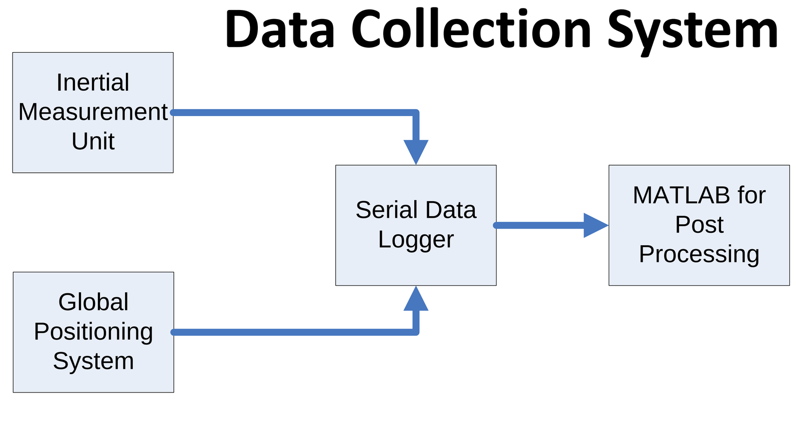
System Overview

The combined solution will be a closed-loop system. The GPS and INS solution will be differenced, generating an error signal. The error will be processed by the Kalman filter to estimate the IMU biases so they can be corrected.

Overall System Block diagram



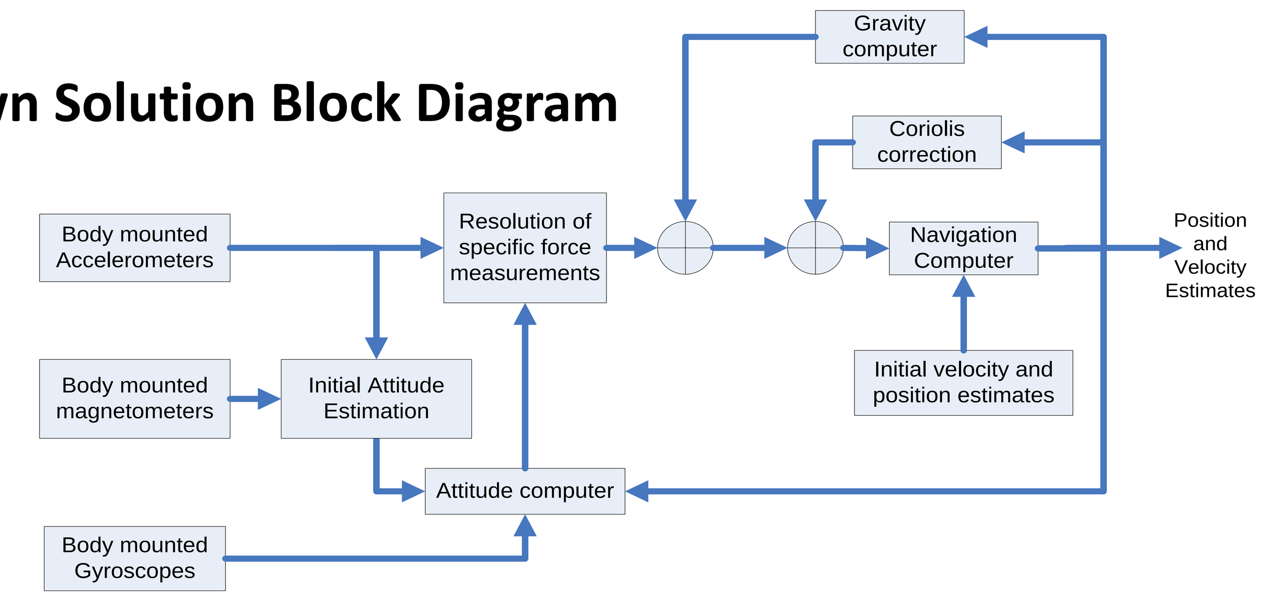
Data Collection System



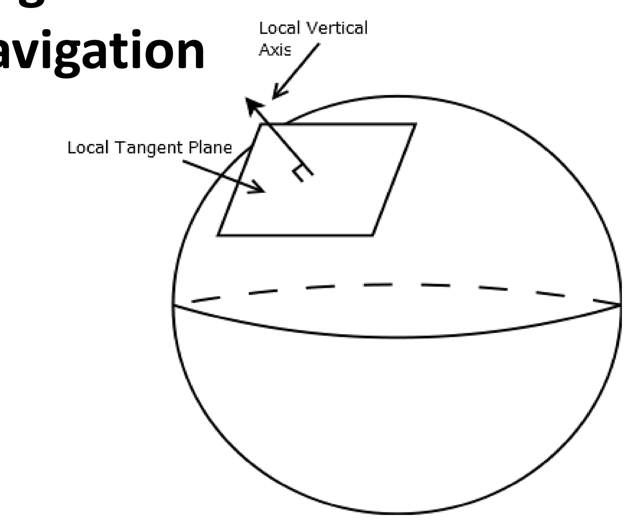
Inertial Navigation

The inertial system estimates its navigation solution with a dead-reckoning/control algorithm called the strapdown solution. The algorithm is so-named because the inertial sensors are rigidly attached to the vehicle of interest so that the sensors and vehicle experience identical forces and rotations. For intuitive simplicity, the solution is computed with respect to a local tangent plane to the earth's surface.

Strapdown Solution Block Diagram



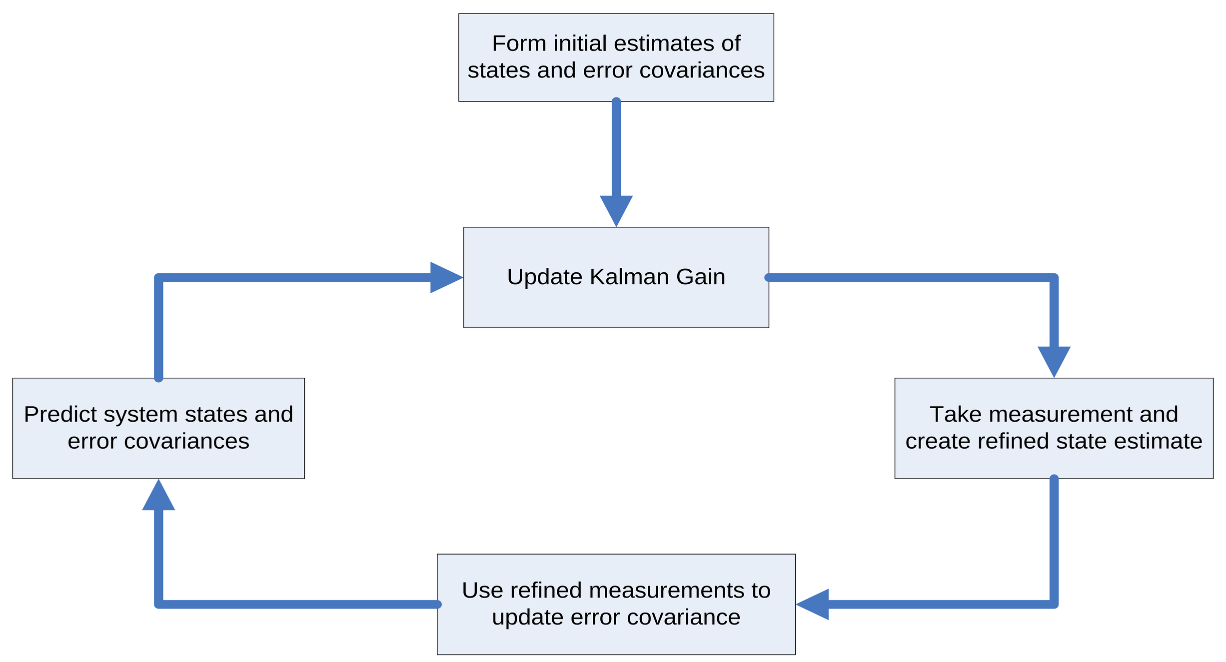
Local Tangent Plane Navigation



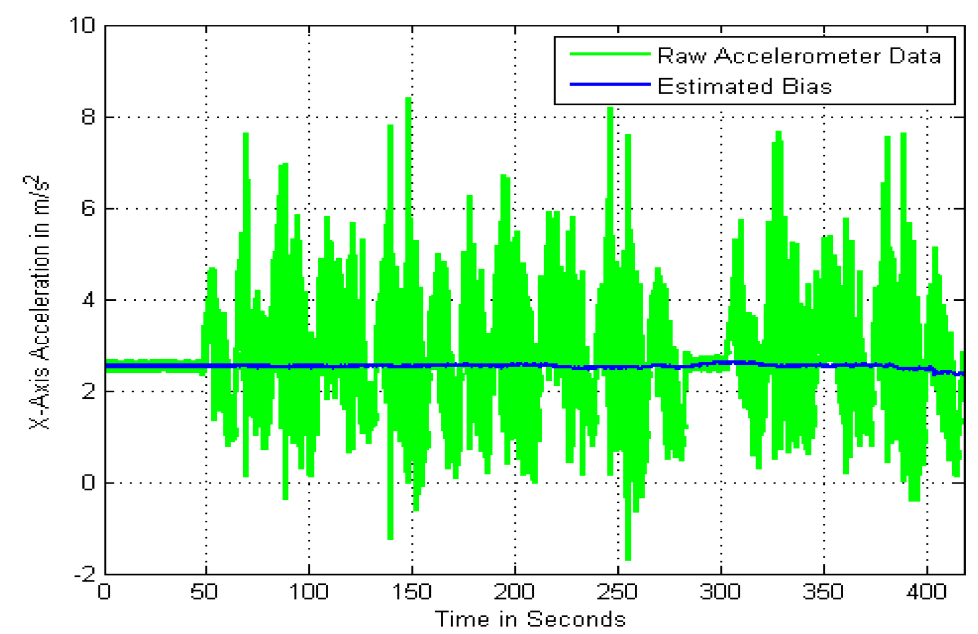
The Kalman Filter

A statistical model of the inertial navigation system was created that allows the Kalman filter to estimate each inertial sensor's bias and noise in the system. Using this information, the filter can correct for these sources of error to produce more accurate estimates of position and velocity

Kalman Filter Mechanization

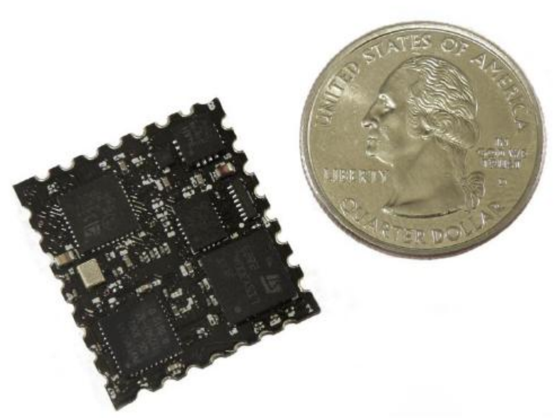


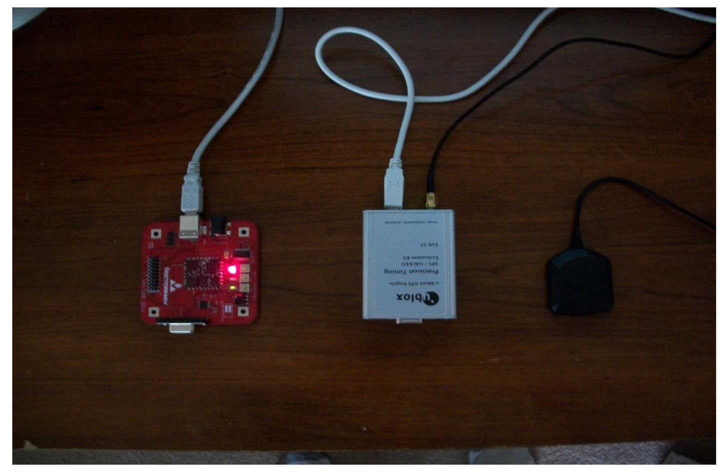
Accelerometer Data With Estimated Bias



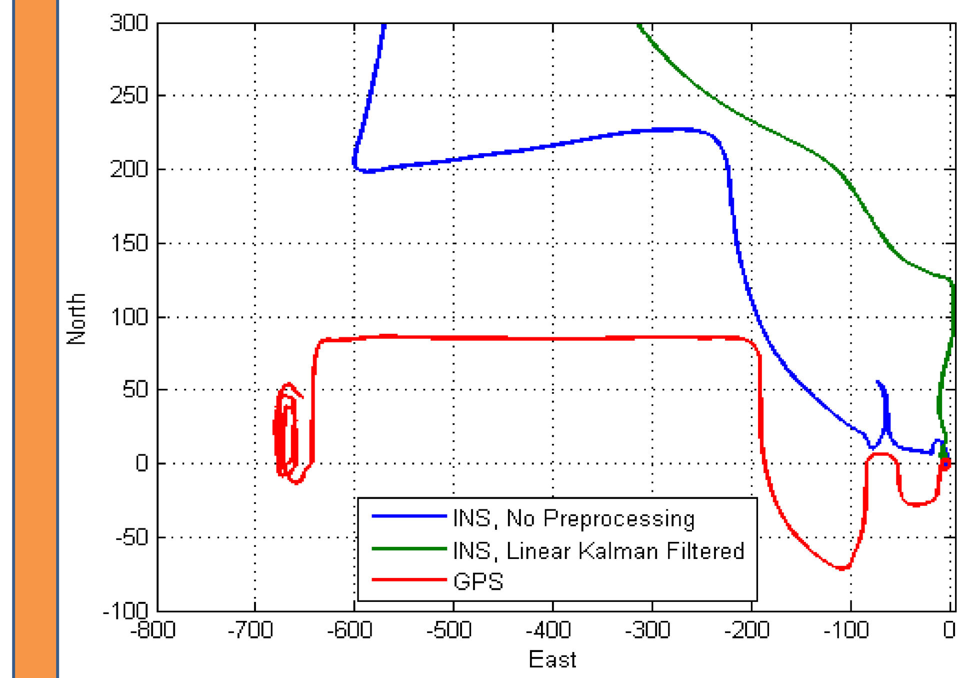
Equipment and Experimental Setup

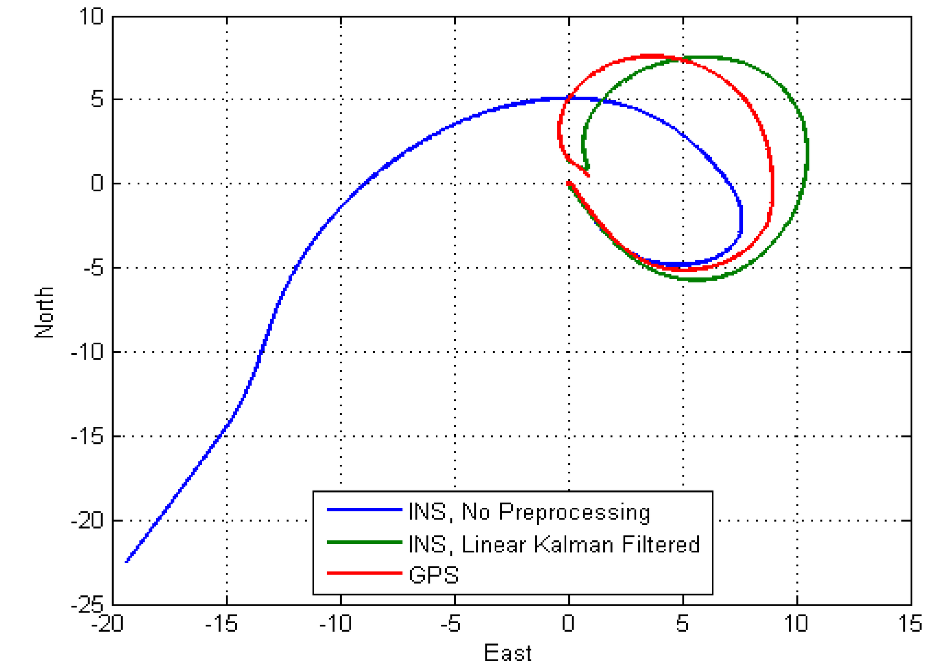
Both sensors are connected to the laptop via USB cables. To take driving data, the sensors are securely placed in the vehicle near the center of gravity. The GPS antenna is placed on the outside of the vehicle. In the future, a platform will be constructed to hold the sensors.



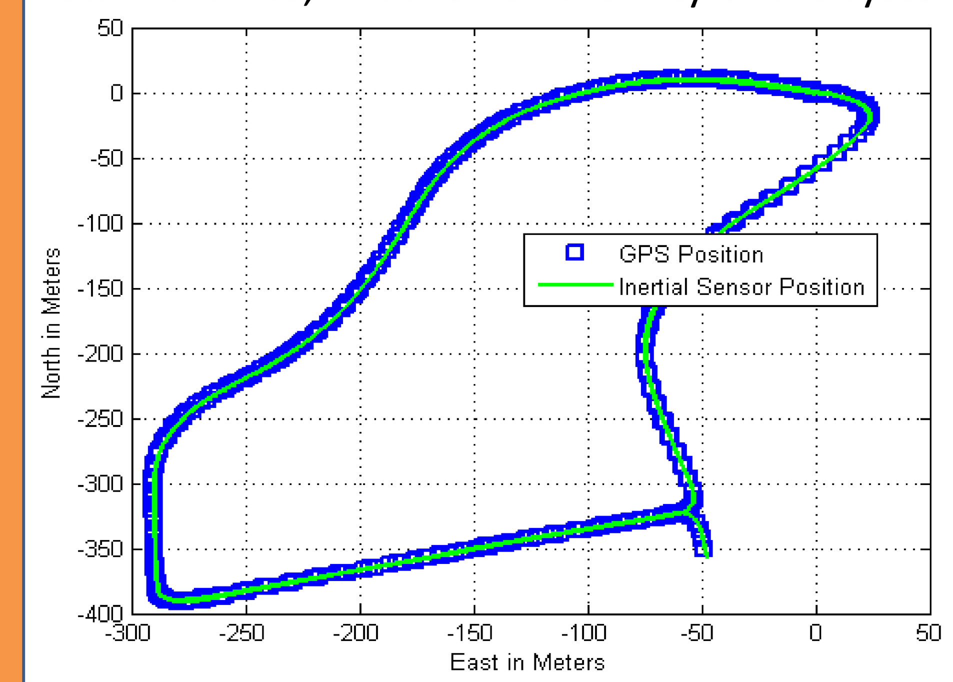


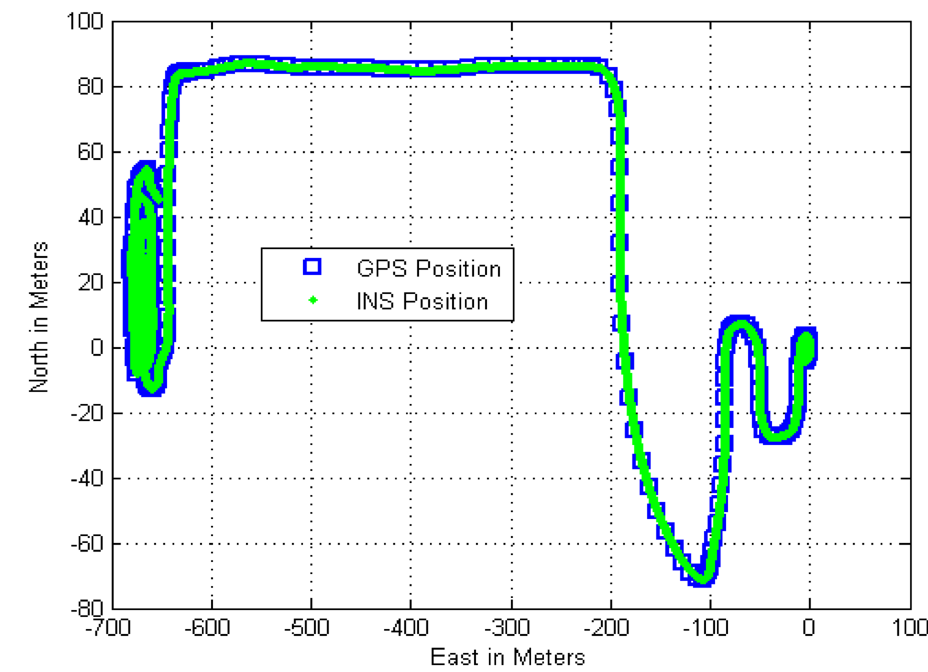
Results

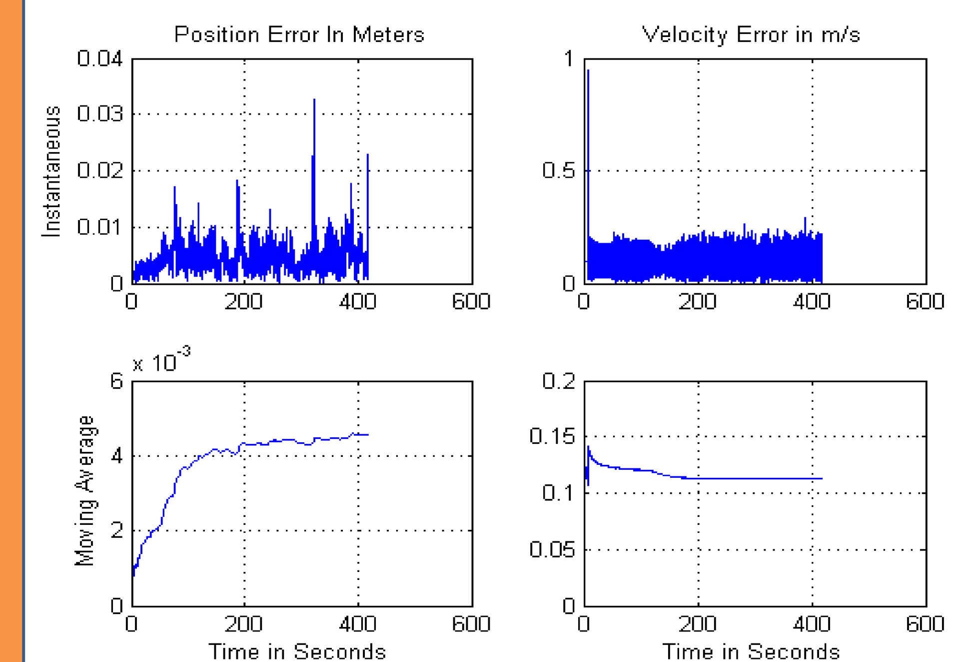




With much manual tuning, the linear Kalman filter can find a more accurate solution than the standard INS, but the nonlinearity of the syster







The unscented Kalman filter consistently finds an accurate estimate of the GPS solution for a single parameter set. The position is accurate up to within a few millimeters of the GPS and the velocity is accurate up to just over 10 centimeters of the GPS velocity.

References

[1] D.H. Titterton and J.L. Weston, Strapdown Inertial Navigation Technology, 2nd Edition, The Institution of Electrical Engineers, 2004.

[2] J.L. Crassidis, "Sigma-point Kalman filtering for integrated GPS and inertial navigation," IEEE Transactions on Aerospace and Electronic Systems, vol. 42, pp 750-755, Dec. 2006.

[3] D. Simon, Optimal State Estimation. Hoboken, NJ: John Wiley & Sons, 2006.