Abstract

Successful navigation of any vehicle requires accurate knowledge of position and velocity. Conventional means of position and velocity estimation include offline-processing techniques like Least Square Method and online/real time sequential processing techniques such as Kalman Filter. These algorithms use measurements from the Inertial Navigation System (INS) or from GPS or from both. The main disadvantage of INS is that the use of motion sensors is prohibitive in terms of cost, weight and unacceptable drift during long period of operations. In this thesis, an alternative method of estimating position and velocity using Global Positioning System (GPS) is presented. A low speed Miniature Air Vehicle (MAV) is taken as a test platform to prove the effectiveness of the proposed technique. An important virtue that makes GPS based systems attractive is their long time stability and relative accuracy (in the order of tens of meters). Also, their small size makes them the most suitable candidate for MAV navigation.

GPS based navigation requires the knowledge of position of visible satellites and criterion for selection of at least four GPS satellites for determining the GPS receiver (or MAV) position. The navigation and observation data at fixed epochs are stored in Receiver Independent Navigation Exchange (RINEX) format. The navigation data contains satellite identification number (PRN) and respective orbital parameters. The observation data set has GPS satellite PRNs and corresponding pseudo ranges from GPS satellites to master receiver at Colorado Springs USA and also to standard receivers (say, one at Indian Institute of Science (IISc), Bangalore). At a given time and receiver location, four or more satellites will be visible. The Chapter 2 studies visibility of GPS satellites from the user receiver using the data stored in RINEX format with the mask angles of 5°, 15°, and 30°.
For a given user position and time, it is possible to identify the available GPS satellites from the visibility study and determine their position and velocity vectors using the orbit propagation from the fixed epoch recorded in RINEX format. The estimation of user/receiver position vector is an inverse problem in which the pseudo range from user to the identified GPS satellites and GPS position vector are used as input parameters. Since the relation between the user position vector (or latitude, longitude, altitude) and pseudo ranges is nonlinear, an iterative algorithm based on Least Squares or quadratic cost is used in Chapter 3. Computation of user/receiver position is, therefore, based on synthetic data (which includes intentionally added noise in generating pseudo range) owing to non-availability of the flight derived data from GPS receiver in real time. The iterative algorithm requires approximate knowledge of the user position as an initial guess. The search algorithm is used in Chapter 3 to arrive at the near optimal solution. In order to check robust convergence of the point-positioning algorithm of Chapter 3, a number of initial guesses for latitude and longitudes for the receiver are used. For example, the iterative algorithm converges to 13°022' latitude, and 77°57' longitude of IISc receiver starting from faraway initial guesses of, say, 1) 5°1889' latitude and 62°065' longitude (which is the mean value of eight visible GPS satellites at the time of computation), 2) 12° latitude and 75° longitude (to list two out of the six initial guesses). For these two cases, time of computation using MATLAB 6.1 on a PC with AMD Athlon 1.8 GHz Processor, are 1.14 seconds and 1.38 seconds respectively.

The iterative point-positioning algorithm is not suitable for real-time navigation of a mobile platform like MAV. It cannot remove bias and low frequency noise in the measurements. The algorithm does not use the previous estimate to determine the current estimate and knowledge of the system dynamics/kinematics. The sequential algorithms like Extended Kalman Filter (EKF) are better suited for such applications. The EKF algorithm used in Chapter 4 employs MAV kinematics rather than MAV dynamics since then the time varying inertia, aerodynamics, propulsion, gravity and control parameters...
are not needed. It is assumed that the MAV flies in closed elliptical trajectory (other closed trajectories can be special cases, and are not considered in this thesis).

The present study does not use the flight measured navigational data for the MAV. Instead, synthetic data is generated for the assumed trajectory with realistic noise and disturbance terms for the best four visible satellites (based on Geometric Dilution of Precision (GDOP)). The duration of synthetic flight is 380 sec and hence all the four satellites are visible throughout the flight. True and estimated position and velocity components in ECEF frame of reference are computed and the results show that the estimated values converge to the true values in ~10 seconds with a typical error of 10 m in position estimation and 10 m/sec in velocity estimation. The error components are quite small in the ECEF frame of reference. The Cramer-Rao Bounds (CRB) are calculated for both position and velocity estimates (1σ) and the simulation results show that more than two-thirds of the estimated signals fall in CRB in the present case. The measured and estimated range and range rates for the four satellites are also presented for the sake of completeness. The innovation for range and range rate estimates are shown to fall inside the 3σ levels of 30 m and 15 m/sec. To quantitatively prove the effectiveness of the estimation technique, $R^2$ estimates of different states are calculated. For position estimation, the $R^2$ estimate is found to be in the range of 0.98 – 0.99 and for velocity estimation, $R^2$ estimate is calculated to be between 0.73 – 0.98.

To summarize, the use of GPS based systems coupled with estimation techniques like EKF is shown to be an effective means for precise position and velocity estimation that is essential for superior navigation requirements.