AA575: Satellite Navigation

Homework 3: Measurements, the Ionosphere and the Troposphere

Assigned:
Due: Friday, November 4, 2011

Problem 1 (40 Percent): Two files of data, collected from satellite PRN 13 at the Boulder, CO CORS (Continuously Operating Reference Stations [1]) site, on November 4, 2002, are provided in: 'rawdata.sv13' and 'orbit.sv13'.

The columns of 'rawdata.sv13' contain the following measurements, obtained by tracking satellite PRN 3.

1. GPS Time (sec)
2. L1 Pseudorange (meters)
3. L2 Pseudorange (meters)
4. L1 Carrier Phase (cycles)
5. L2 Carrier Phase (cycles)
6. L1 Doppler frequency (Hz)
7. L2 Doppler frequency (Hz)

The satellite clock bias has already been removed from these data. The columns of 'orbit.sv13' provide the position of satellite PRN 13, computed at the time of signal transmission, for each time that a measurement in 'rawdata.sv13' is made. It's columns are:

1. GPS Time of signal reception (sec)
2. X (meters)
3. Y (meters)
4. Z (meters)

The location of the Boulder, CO, CORS station, in Earth-centered Earth-fixed coordinates is:

$$\begin{aligned} X &= -1288337.0539\text{m} \\ Y &= -4721990.4483\text{m} \\ Z &= 4078321.6617\text{m} \end{aligned}$$

1. Compute the ionosphere-free pseudorange, carrier phase, and the Doppler frequency from these measurements. Convert each to an equivalent range, or range-rate, measurement in meters or meters/sec. Compute the true range and range rate from the provided satellite data, and plot them on the same plot as the corresponding GPS measurement. Explain the discrepancies between the GPS measurement and the "true" geometric quantity.
2. Estimate the oscillator frequency bias in both the L1 and L2 Doppler measurements. Convert this bias to an equivalent line-of-sight velocity bias (in m/s). Is the value for the L1 bias compatible with the value your found for L2 ?
3. Estimate the receiver clock bias, and it's rate from the ionosphere-free pseudorange measurement. Compare your estimate of clock bias rate with the frequency bias found in step 2.
4. Similarly, estimate the receiver clock bias and rate from the ionosphere-free carrier phase measurement. Compare these estimates to those from steps 3 and 2.

[1] http://www.ngs.noaa.gov/CORS/cors-data.html

5. Any receiver must estimate for the clock and frequency biases as unknowns in the position and velocity solution. This avoids the unreasonable complication and expense in synchronizing the receiver clock with GPS time, and calibrating the frequency against the GPS standard. A measurement of the quality of an oscillator is it's **stability**, or how well it can maintain a fixed frequency.

   To illustrate the oscillator stability, compute the range rate from each of the three GPS measurements above (pseudorange, carrier phase, and Doppler). Then compute the frequency error **at each time step**for each of these three measurements. Plot all three against GPS time on the same plot. Make sure that a consistent set of units is used, so that you can compare all 3 measurements.

   What can you say about the oscillator behavior ? Do all 3 measurements give the same results ?

6. Last, we want to illustrate the use of carrier phase to smooth the pseudorange measurement. As you recall from class, the carrier measurement is much more precise, but suffers from an unknown integer ambiguity. However, as long as this ambiguity does not change (no cycle slips) the change in phase between two time steps, and the change in pseudorange between two time steps, will both be unambiguous estimates of the change in geometric range between those two times. However, the error in the carrier phase difference would be much lower.

$$\frac{\lambda}{2\pi}(\phi(t_2) - \phi(t_1)) = (\rho(t_2) - \rho(t_1)) = r(t_2) - r(t_1)$$

   (Carrier phase ϕ in radians)

   One approach to combining these two measurements, for some set of data starting at time t_0, is to generate an accurate estimate of the pseudorange at the start of the data set, $\hat{\rho}_k(t_0)$, by averaging all data up to time t_k. Then a smoothed pseudorange at time t_k would be formed from

$$\bar{\rho}(t_k) = \hat{\rho}_k(t_0) + \frac{\lambda}{2\pi}[\phi(t_k) - \phi(t_0)]$$

   The estimate of $\hat{\rho}_k(t_0)$ can be found, by averaging the pseudorange measurements available up to time t_k, after they have been corrected to the value at time t_0 using the phase measurement:

$$\hat{\rho}_k(t_0) = \frac{1}{k}\sum_{i=0}^{k} \rho(t_i) - \lambda[\phi(t_i) - \phi(t_0)]$$

   Generate the estimate, $\hat{\rho}_k(t_0)$, for the provided data set, using both the ionosphere-free values of ρ and ϕ, and the L1 only values. Plot these two estimates vs. the number of measurements processed (k). Explain what this shows about "smoothing" of the pseudorange, or how the phase measurements can reduce the error in the pseudorange measurement. Explain the difference between the L1-only case, and the ionosphere-free case, and how this illustrates code-carrier divergence.

Problem 2 (20 Percent): You are given a file of dual frequency GPS data collected from satellite PRN 1 at the CORS site in Boulder, Colorado on November 4, 2002 (dualfreq.sv1 on the course web page) The columns of this file are:

1. GPS Time (sec)
2. Satellite Azimuth (deg).
3. Satellite Elevation (deg).
4. L1 Pseudorange (meters)
5. L2 Pseudorange (meters)
6. L1 Carrier Phase (cycles)
7. L2 Carrier Phase (cycles)

The $\{\alpha_n\}$ and $\{\beta_n\}$ coefficients broadcast in the GPS data message on that same day are given in the following table

α_0	α_1	α_2	α_3
0.028 E-6	-0.007 E-6	-0.119 E-6	0.119 E-6
β_0	β_1	β_2	β_3
137.0 E3	-49.0 E3	-131.0 E3	-262.0 E3

The location of this site is given in problem .
Apply the Klobuchar model to compute the predicted delay on L1 as a result of the ionosphere.

Problem 3 (5 Percent): From this same data set, compute the ionospheric delay at the L1 frequency from the pseudorange measurements at L1 and L2.

Problem 4 (25 Percent): Using the meteorological data recorded at the Durmid Hill GPS station (DH010600.MET) predict the wet and dry zenith tropospheric delay using the Saastamoinen model and the Hopfield model. Plot the predictions of these two models as functions of time.

The station is located at

$$\begin{aligned} \phi &= 33.390 \text{ deg. N} \\ \lambda &= 115.79 \text{ deg. W} \\ h &= -82.94 \text{ meters} \end{aligned}$$

The columns of DHO10600.MET are

1. Year (2 digit)
2. Month
3. Day
4. Hour (GPS time)
5. Minute (GPS time)
6. Second (GPS time)
7. Surface atmospheric pressure (mbar)
8. Surface atmospheric temperature (^{o}C)
9. Relative Humidity (percent)

Problem 5 (10 Percent): Make a comparison between the simple flat-Earth mapping function ($1/sin(EL)$), the mapping function of equation (4.42) in *Misra and Enge*

$$\frac{1}{\sqrt{1-(\cos E/1.001)^2}}$$

and the *Chao* mapping functions by applying each of them to the zenith delays predicted in the previous problem. Compare the total tropospheric delay for elevations of 5^o, 15^o, 45^o and 85^o for the data collected during that day.