Global Positioning System

SOIL 4213

http://npk.okstate.edu/documentation/various/index.htm

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GPS

• Three Segments:
  – Space
  – Control
  – User
Space Segment

• Satellite constellation consisting of approximately 31 satellites in 6 orbital planes (currently 30 operational).
• The satellites are identified by space vehicle number (SVN) or pseudo random noise (PRN).
• With the constellation geometry, 4-10 satellites can be seen anywhere in the world with an elevation of at least 10°.
• Have an orbital altitude of about 12500 miles.
• Clear of the atmosphere so they will orbit according to very simple mathematics.
• Space segment provides ranging signals and data messages to user equipment.
• The satellites have a nominal orbital period of ~12 hours.
Control Segment

- Consists of three parts: Monitor Stations, Ground Antennas, and the Master Control Station.
- Monitor stations are remotely operated. They track and monitor the GPS satellites, checking both their operational health and their exact position in space. There are five such stations: Hawaii, Ascension Island, Diego Garcia, Kwajalein, and Colorado Springs.
- Positions are precisely known and stations are equipped with dual frequency receivers logging both L1 and L2 signals.
- The master ground station transmits corrections for the satellites ephemeris constants and clock offsets back to the satellites themselves. The satellites can then incorporate these updates in the signals they send to GPS receivers.
- Errors in orbit are measured, corrected for, and sent back to the satellite by the DOD to increase the accuracy.
User Segment (Receivers)

• Provides navigation, guidance, surveying, tracking, etc.
• On the ground all GPS receivers have an almanac programmed into their computers that gives them real-time satellite location.
GPS Signals

• GPS measurements contain errors and biases, which can be removed or minimized by combining various GPS observables (signals).

• The signal structure comes in the form of a microwave radio signal composed of two carrier frequencies (sine waves). Using two signals (different frequencies) allows correction for ionospheric delays.
GPS Signals

- The Pseudo Random Noise/Code (PRN or PRC) is a fundamental part of GPS. It is a complicated sequence of “on” and “off” pulses. This signal is so complicated that it almost looks like random electrical noise.

- The complex pattern helps ensure the receiver doesn’t accidentally sync to another signal.

- Since each satellite has its own unique PRN the complexity guarantees that the receiver will not accidentally pick up another satellite’s signal, so all of the satellites can use the same frequency without jamming each other.

- The other reason for the complexity of the PRC, is that it’s crucial to making GPS economical. The codes make it possible to use “information theory” to amplify the signal, thus the receivers do not require large dishes to receive the signal.
GPS Signals-Carriers

• The L1 carrier is 1575.42 MHz and carries both the status message and a pseudo-random code for timing. It has a wavelength of 19 cm (7.5 inches).

• The L2 carrier is 1227.60 MHz and is used for the more precise military pseudo-random code. It has a wavelength of 24.4 cm (9.6 inches).
GPS Signals-PRC

• There are two types of PRC. This first is called the C/A (Coarse Acquisition) code. It modulates the L1 carrier. It repeats every 1023 bits and modulates at a 1.023 MHz rate (Mbps). The C/A code is the basis for civilian GPS use.

• The second PRC is called the P (Precise) code. It repeats on a 7-day cycle and modulates both the L1 and L2 carriers (P1 and P2) at a 10.23 MHz rate. This code is intended for military users and can be encrypted (Y code).
GPS Signals-Navigation Message

- There is a low frequency signal added to the L1 codes that gives information about the satellite’s orbits, their clock corrections and other system status.
- Transmission of the complete message takes 12.5 minutes.
GPS Signals-Pseudo range Measurements

• Pseudorange is a measure of the range between the satellite and receiver.
• These ranges are used to locate the receiver via trilateration.
• Either P or C/A code can be used.
• It is called pseudo range because we know it contains errors and is thus not the true range.
GPS Signals: Code-Phase GPS vs. Carrier-Phase GPS

- Code-Phase and Carrier-Phase refer to the particular signal that we use for timing measurements. The primary method is code phase, but the carrier frequency can significantly improve accuracy.

- A GPS receiver determines the travel time of a signal from a satellite by comparing the “pseudo random code” it’s generating, with an identical code in the signal from the satellite.
GPS Signals: Code-Phase GPS vs. Carrier-Phase GPS

- The receiver slides its code later and later in time until it syncs up with the satellite’s code. The amount it has to adjust the code is equal to the signal’s travel time.
- The problem is that sometimes you can move a signal half a cycle and the signals would still logically match up.
- Due to this error code-phase GPS can have an error of up to 300 meters.
- Luckily receiver designers have ways to ensure the signals are almost perfectly in phase. Good machines can get within a percent or two, but that can still be around 3 to 6 meters of error.
GPS Signals: Carrier-Phase GPS

- Higher accuracy receivers beat the system by starting with pseudo random code and then move on to measurements based on the carrier frequency. The carrier frequency is much higher so its pulses are closer together thus it is more accurate.
- If we could get within one percent of perfect phase like we do with code-phase receivers then we could have 3 to 4 millimeter accuracy.
GPS Signals: Carrier-Phase Challenges

• This method is just counting the exact number of carrier cycles between the satellite and the receiver.

• This is a problem because the frequency is so uniform it is hard to count.

• Newer technology is making the receivers better at lining up the cycles.
<table>
<thead>
<tr>
<th>Typical Error in Meters (per satellite)</th>
<th>Standard GPS</th>
<th>Differential GPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite Clocks</td>
<td>1.5</td>
<td>0</td>
</tr>
<tr>
<td>Orbit Errors</td>
<td>2.5</td>
<td>0</td>
</tr>
<tr>
<td>Ionosphere</td>
<td>5.0</td>
<td>0.4</td>
</tr>
<tr>
<td>Troposphere</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>Receiver Noise</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Multipath</td>
<td>0.6</td>
<td>0.6</td>
</tr>
</tbody>
</table>
GPS Signals: Errors-Ephemeris

- Even though satellite positions are constantly monitored, slight position or ephemeris errors can occur between monitoring times.
- Orbital data are constantly being transmitted by the satellites in the Navigation Message.
- Receivers maintain an “almanac” of this data for all satellites and update their almanacs as new data comes in.
- Ephemeris errors affect all users the same regardless of where they are.
- Since the range error due to ephemeris errors is similar for users who are close to each other, they can be essentially removed through differencing observations.
GPS Signals: Errors-Clock

- Even though the satellites clock systems are very sophisticated they do account for some tiny errors in the system.
- The atomic clocks that satellites use are very, very precise but not perfect. Minute discrepancies can occur, and these translate into travel time measurement errors.
- Satellite clock error can range from 8.64 to 17.28 ns/day translating to errors of 8.5 to 17 ft.
Receiver Errors: Clock

- Receiver clock errors are a bias unique to each receiver.
- Since it would be too expensive to put atomic clocks in receivers, designers use an extra satellite measurement to increase the time accuracy.
- Four range measurements are used instead of three to increase the timing accuracy to that of an atomic clock.
- However, this means that the receiver will need four channels to perform the measurements through.
Receiver Errors: Multipath

- The signal may bounce off various local obstructions before it gets to the receiver.
- The whole concept is that the signal is being received directly from the satellites by the receiver.
- Unfortunately, in the real world the signal will also bounce around on just about everything in the local environment and get to the receiver.
- If the bounced signals are strong enough they can confuse the receiver and cause erroneous measurements.
Errors: Geometrical Locations

- A dimensionless number called “Dilution of Precision” or DOP measures the affect of satellite geometry.
- Various forms of DOP exist depending on the users need:
  - PDOP (position dilution of precision) quantifies the affect of satellite geometry on 3D position.
  - VDOP (vertical dilution of precision) is always higher than HDOP.
  - TDOP (Time dilution of precision)
  - GDOP (Geometric dilution of precision) is a combination of PDOP and TDOP.

<table>
<thead>
<tr>
<th>DOP Value</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ideal</td>
</tr>
<tr>
<td>1-2</td>
<td>Excellent</td>
</tr>
<tr>
<td>2-5</td>
<td>Good</td>
</tr>
<tr>
<td>5-10</td>
<td>Moderate</td>
</tr>
<tr>
<td>10-20</td>
<td>Fair</td>
</tr>
<tr>
<td>&gt;20</td>
<td>Poor</td>
</tr>
</tbody>
</table>
Differential GPS

- Many of the errors associated with GPS have been addressed with differential correction.
- DGPS receivers have an integrated antenna to receive a correction signal and the on-board processing to apply the correction message to the GPS signal.
- Types of DGPS:
  - WAAS
  - Coast Guard Beacon
  - GLONASS
  - OmniStar
  - StarFire
  - RTK
Wide Area Augmentation System (WAAS)

- Originally developed as an air navigation aid developed by the FAA.
- Uses a network of ground-based reference stations in North America and Hawaii to measure small variations in GPS signals, send this information to master stations, which send a corrected signal to WAAS satellites, which broadcast the corrected message back to WAAS enabled GPS receivers.
- Accuracy is 25 ft or better for both lateral and vertical measurements 95% of the time, which it typically provides better than 3 ft lateral and 5 ft vertical accuracy.
Coast Guard Beacon

- NAVCEN operates the Coast Guard Maritime DGPS Service and the developing Nationwide DGPS Service.
- Consists of two control centers and over 60 remote broadcast sites.
- Provides 10-meter accuracy in all established coverage areas with a typical error of 1 to 3 meters.
GLONASS

- Russian based system with 31 satellites in constellation (24 operational).
- Typical accuracy of about 7.38 meters.
- Adds to the integrity of receivers that are GLONASS compatible by increasing the number of available satellites in view at any given time.

- PDOP from GLONASS
OMNISTAR

- Private industry correction service.
- Worldwide coverage, 70 reference stations around the globe, and 3 network control centers.
- Based on the subscription purchased the accuracy can be between 15 cm to 1 m.
- Typically used on Trimble devices for Agricultural and Surveying needs.
- Subscriptions are around $1,000/year.
STARFIRE

- Global system
- Gives the user the ability to measure position anywhere in the world with accuracy better than 10 cm (4 inches).
- Typically used on John Deere devices for Agricultural operations.
- Subscriptions are around $1,000/year.
RTK-Real Time Kinematic

• Carrier-Phase relative positioning technique that requires two or more receivers simultaneously tracking the same satellites.
• Base station is stationary at a known point and has a radio transmitter (Two methods of base stations available).
• Rover has a radio receiver and dual frequency (typically) GPS receiver.
• Sub-inch accuracy and repeatability.
• Most accurate type of DGPS correction currently available.
Accuracy and Precision

Accuracy is the ability to closely approximate a value such as hitting specific spots on a dartboard; precision is more about measurement repeatability or the ability to hit the same spot multiple times. By combining accuracy and precision, you can hit the bulls-eye every time.
Accuracy

- To determine equipment accuracy, several factors much be taken into account:
  - Equipment precision
  - Reference system and reliability of true position
  - Transformation parameters used to determine final coordinates
Accuracy

GPS Location Error in Feet

- Error
- 95%
- 68%
- 50%
Homework

- Write a short paragraph on “Selective Availability”. Give your interpretation on what it is and how it might be similar to or different from Light Squared. Due Friday 2-17-12.