Global Positioning System
Theory and Practice

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What is GPS?
Worldwide Space-based Navigation System

Funded, Controlled, and Maintained by
U.S. Department of Defense
Operated by U.S. Air Force

Original Objective
• Determine position of all military forces continuously worldwide.
• Accurately deploy nuclear missiles from subs.

Components of GPS

1. Space segment
   - Satellites
   - Ground control segment
   - User equipment

2. Control segment
   - Monitor satellite health
   - Time synchronization
   - Ephemeris updates
Components of GPS
(1: Space Segment)

- 28 satellites in 6 nearly-circular orbits (4-5).
- Orbital paths are 20,200 km MSL with a 55° angle of inclination and 60° horizontal separation (360).
- Global coverage 4-10 observable satellites simultaneously w/ 15° elevational mask.

Satellites (Space Vehicles [SVs])

NAVSTAR

- Block II Class (Block IIA, Block IIR, Block IIF)
- Weigh ca. 2000 kg, launched from KSC using Delta II rockets or placed in orbit using the Space Shuttle, life = 7.5 years, and cost $50 million each.
- Each contains 2 rubidium and 2 cesium atomic clocks or hydrogen masers (i.e., use atoms as their metronome).

Components of GPS
(2: Control Segment)

- Master Control Station
- 5 Monitor Stations
- 3 Ground-based Uplink Antennas

Monitor
Errors in
Satellite
Position & Clocks

Transmit Corrections
Components of GPS
(3: User)

GPS Receivers
Computes
3-Dimensional Location
3-4 Satellites

Primary Uses of GPS
(1: Navigation)

Primary Uses of GPS
(2: Surveying/Mapping)
Primary Uses of GPS
(2: GIS Mapping: Natural Resources)

Five Steps of GPS
(3-Dimensional Location)

1. Geometric positioning (trilateration) of satellites
2. Measure satellite-specific distance
3. Correct clock errors
4. Correct ephemeris (orbit) errors
5. Correct atmospheric errors

Trilateration: Satellites 1 and 2

Located within the Intersection of 2 Spheres

18,000 km
(18,000 km)
(19,000 km)
Trilateration: Satellites 1-4

2 Possible Locations at Intersection of 3 spheres

(18,000 km) (19,000 km)
(20,000 km) (21,000 km)

Usually can reject 1 of 2 locations; however, 4th satellite needed for time correction.

Geometric Configuration of Satellites
(Geometric Dilution of Precision [GDOP])

1 per quadrant, >15° elevation

Position Dilution of Precision (PDOP)
  - Horizontal Dilution of Precision (HDOP)
  - Vertical Dilution of Precision (VDOP)

PDOP < 6

SatView Demonstration: DOP
(http://www.trimble.com/planningsoftware.html)

Sample when satellites are positioned optimally!!
Their locations are known.

Free Trimble Software

02/25/99: Lubbock, TX
1400-1800 hrs: CDT
1400-2300 hrs: CDT
2. Measuring Distance to Satellites

Distance = Velocity \times Time

Distance must be accurate

V = c or 300,000 km/sec

\( t = \) “Micro-seconds” of travel (0.06)

Difficulty in measuring time

Synchronized Radio Frequencies

- Code-Phase
- Carrier-Phase

“On” and “Off” Pulses 1000x Faster

Psuedo-random Code

12:00

Receiver

Satellite

PRC

Satellite Unique

3. Measuring Accurate Time

(Atomic vs. Quartz Clocks)

Accuracy: 10^{-10} seconds
(10 nanoseconds)

$100,000 each (4/satellite)

Accuracy: 10^{-3} seconds
(300 km error)

$50 each (1/receiver)

Satellite and Receiver Codes Must be Generated Simultaneously

Receiver Calculates Time Correction and Calibrates Itself to Universal Time and Perfect Synchrony

4. Determining Satellite Position

(Ephemeris: Satellite Orbit)

High Altitude Orbits

- Extremely Stable
- No Atmospheric Drag
- Maximize Coverage of Earth
- Enhance Satellite Survivability

Orbit Errors

- Gravitational Pull (Moon & Sun)
- Pressure from Solar Radiation

Monitored by Ground Control & Errors Transmitted
Determining Satellite Position (Correcting Ephemeris Errors)

- Monitor Stations
  - Colorado Springs
  - Hawaii
  - Ascension
  - Diego Garcia
  - Kwajalein

- Ground Antennas

- Master Control

GPS Signal
- Pseudo-random Code
- Navigation Message

Correcting Atmospheric Delays (Ionospheric and Tropospheric Errors)

**Ionosphere**
Region of the atmosphere (50-300 km MSL) containing ionized particles that reflects radio waves.

Ionospheric errors can be modeled and are incorporated as temporal-specific algorithms in GPS receivers.

**Troposphere**
Region of the atmosphere (0-20 km MSL) containing water vapor, various gases, and temperature decrease with altitude.

Errors are minimal; nonetheless, tropospheric errors are modeled with ionospheric errors for “typical” meteorological conditions.
**Additional Non-Intentional Errors**

- **Receiver Noise**
  - Innate Receiver Error (i.e., technological limitations)
  - Carrier-phase < Code-phase

- **Multipath**
  - Signal Bounce or Reflection (i.e., same signal arrives >1 path)
  - Signal Rejection Techniques

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**Government-Induced Error (Selective Availability)**

Error intentionally introduced randomly into satellite-specific clock data by the U.S. Department of Defense

Intention of DOD is to limit accuracy of non-U.S. military and government users for national security

SA can increase error in location by 20x (100 m)

No Longer Activated!

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**Differentially Corrected GPS (DGPS)**

- Real-time DGPS
- Corrections Transmitted via FM Radio Link
- U.S Coast Guard
- OmniStar, Inc.
- $300
  - 150 Broadcast Antennas
  - FM Receiver & Antenna
  - <100 km from Antenna

Not good for mountainous sites

http://www.omnistar.com/
Differentially Corrected GPS (DGPS)

Post-processing DGPS

Roving/Field Unit
Reference/Base Station Unit

Receive Same Errors

< 300 km apart

PathFinder Office Software

Correction

X Y Z

Rover

X Y Z

Base Station

Regional Community Base Stations

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

White = 100 km
Tan = 200 km

PSCC: Pellissippi State College
FRKN: Franklin, NC

Use Pathfinder Software

Augmented GPS

Federal Aviation Administration (FAA)

Wide Area Augmentation System (WAAS)
Local Area Augmentation System (LAAS)

Transmit Correction Message

25 Stations Closest is Atlanta
### Accuracy and Cost of GPS Receivers

<table>
<thead>
<tr>
<th>Receiver</th>
<th>Accuracy</th>
<th>Cost</th>
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<tbody>
<tr>
<td>Garmin Rino</td>
<td>10 m</td>
<td>$250</td>
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<tr>
<td>GeoExplorer XM</td>
<td>2.5 m</td>
<td>$2500</td>
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<tr>
<td>PathFinder Pro XR</td>
<td>≤ 1 m</td>
<td>$10000</td>
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Ephemeris Ionosphere Troposphere Noise Multipath Clock 3D

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<tr>
<th>Type</th>
<th>2.5</th>
<th>5</th>
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<th>0.3</th>
<th>0.6</th>
<th>1.5</th>
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<td>0.6</td>
<td>0</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Good PDOP!

### Helpful GPS Websites & References

**GPS Overview**
http://www.trimble.com/gps/

**Community Base Stations**
http://www.ngs.noaa.gov/CORS/Maps.html

**WAAS Enabled**
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