GPS & Maps
The **Global Positioning System (GPS)**

- Many Advantages:
  - *Ease of use*
  - *Low cost*
  - *Coverage over large areas*
  - *Relatively high-speed data collection*
  - *Ability to collect 2-D and 3-D data*
  - *Ability to provide velocity data*
  - *Ability to provide accurate time information*
Global Positioning System (GPS)

• GPS receivers give absolute position
• GPS data are often used in GIS
• GIS data have two components:
  – A spatial component, called a feature
  – Attributes – describes a characteristic or characteristics of the feature
Technologies used to determine position

- **LORAN (Long Range Navigation)**
- **LORAN** has **shortcomings** such as:
  - Limited accuracy
  - Radio interference
  - Susceptibility of the signals to be affected by the geography of the area
- **NAVSTAR (Navigation System with Time and Ranging)** Global Positioning System
GPS Components

• **GPS** consists of:
  – A space segment
  – A control segment
  – A user segment
GPS Components
Space Segment
Control Segment

• The **control segment** of the GPS is the set of ground monitoring stations that track the location and the health of each satellite which includes conditions such as:
  – Clock error
  – Satellite malfunctions
Control Segment

• **ephemeris** *(which describes the positions of each of the satellites at all times)*

• These updates from the ground stations also synchronize the highly precise atomic clocks on board the satellites to within a **few nanoseconds** of each other
User Segment

• The user segment is the GPS receiver
• The receiver clock is not nearly as accurate as the satellite clocks, so that is taken into account when refining the GPS position
• GPS receivers typically have 12 to 20 channels which allow them to monitor many satellites at the same time
Selective Availability

• DoD intended to prevent hostile forces from fully utilizing the capabilities of GPS by introducing random errors that would cause positions to be off by as much as 100 meters

• This intentional degradation of the GPS signals is called selective availability (SA)
Selective Availability
GPS systems in use or proposed

- **GLONASS** – Russian Global Navigation Satellite System
  - Completed in 1995 with 24 satellites
  - Only 14 operational in 2006

- **Galileo** – the European Union is developing a 30-satellite system
GPS systems in use or proposed

• China is proposing is **Compass** system
• India is developing the **IRNSS** (Indian Regional Navigational Satellite System)
• The US has plans to launch the next generation of NAVSTAR satellites called **GPS III**
How GPS Works – The Big Picture

• Each GPS satellite transmit information about its **location and the current time**
• All the GPS satellites are **synchronized** so the satellite signals are transmitted at the same instant
• The **control segment** ground stations precisely collect this information as the satellites orbit the earth
How GPS Works – The Big Picture

• When the receiver estimates the distance to at least four GPS satellites, it can accurately calculate its position in three dimensions through space trilateration.

• The accuracy of a GPS determined position depends on the receiver and the field conditions:
  – Location characteristics
  – Length of time at the location
  – Arrangement of the satellites in the sky
How GPS Works – The Big Picture

• Other receivers can use a method called **differential GPS (DGPS)** for much higher accuracy

• **DGPS** requires one receiver fixed at a known ground location and one mobile receiver that is used in the field

• The mobile receiver uses the information from the fixed receiver to correct **its GPS positions** to obtain **accuracy** to less than 1 meter
How GPS Works – The Details

Satellite position

• Each satellite’s *orbital period* is approximately 23 hours and 56 minutes

• The satellites are in the same position in the sky about 4 minutes earlier each day

• The orbit of each satellite *drifts* -0.03 degrees per day
How GPS Works – The Details

• For times when you want the highest possible accuracy, the ability to predict the satellites’ locations can help in mission planning
Space Trilateration

• The basis of GPS positioning is **3-dimensional trilateration** from satellites call **space trilateration**

• Trilateration is a method of determining relative positions using the geometry of triangles
Space Trilateration

- By **ranging** *(finding distance from one location to another)* from three satellites, we can narrow our position to only two points.
- One of the two points is a position too far from the earth, so we can decide immediately to **reject it** leaving the one point that is our GPS fix.
Space Trilateration

• Using the distance from a fourth satellite, we can eliminate the ambiguity, if we have accurate receiver clocks synchronized to GPS time (the time recorded by the GPS satellites)
Triangulation

One measurement narrows down our position to the surface of a sphere.

We are somewhere on the surface of this sphere.
Triangulation

Second measurement narrows it down to the intersection of two spheres.

Intersection of two spheres is a circle.
Triangulation

*Third measurement narrows to just two points.*
Triangulation

Fourth measurement will decide between the two points.

Fourth measurement will go through only one of the two points.
Elevation Determination

• GPS position is based in the WGS 84 ellipsoid, which is actually a mathematical model representing the earth’s nearly spherical surface

• GPS receivers give us height relative to the surface of the ellipsoid based on the distance from the center of the earth to the point
Elevation Determination

- **Mean sea level** is based on the **geoid**, the gravity surface based on mean sea level.
- And since **GPS heights** are based on an ellipsoidal approximation of the earth’s shape, they do not have the same underlying geometrical model of the earth as the elevation we really want to know – height relative to **mean sea level**.
GPS Accuracy

• Added together, these errors can cause a deviation of anywhere from a few centimeters to more than a few meters from the actual GPS receiver position

• Sources of error maybe either random or systematic
GPS Accuracy

• GPS error, called **bias**, can be attributed to three primary sources:
  – The satellites, which can be affected by clock and orbital errors related to the ephemeris
  – The GPS signal, which can be affected by ionospheric and tropospheric refraction
  – The receiver, which can be affected by:
    • *the calibration of GPS antenna*
    • *GPS signal reflection*
    • *The receiver’s own clock bias*
Random error

- **Random error** is called **range noise** or noise in the distance measurement.
- This is primarily attributed to **observation noise** (random white noise in the GPS signal partially associated with ionospheric influences).
- Plus the **random parts of multipath error** from the reflection of the satellite signal off other objects before it reaches the GPS receiver.
Systematic error

- **Systematic error** can be attributed to:
  - Atmospheric effects
  - Receiver bias
  - Clock bias
  - Multipath error
## The Error Budget

<table>
<thead>
<tr>
<th>Source of error</th>
<th>Uncorrected error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionosphere</td>
<td>Up to 30 meters (100 feet)</td>
</tr>
<tr>
<td>Troposphere</td>
<td>Up to 30 meters</td>
</tr>
<tr>
<td>Signal noise</td>
<td>Up to 10 meters (30 feet)</td>
</tr>
<tr>
<td>Ephemeris data</td>
<td>1-5 meters (3-15 feet)</td>
</tr>
<tr>
<td>Clock drift</td>
<td>Up to 1.5 meters (4.5 feet)</td>
</tr>
<tr>
<td>Multipath</td>
<td>Up to 1 meter (3 feet)</td>
</tr>
</tbody>
</table>
Systematic Error

- The **systematic error** is coded in the signal from the GPS satellite
- This includes information about its own error:
  - Clock
  - Atmosphere
  - Position
Sources of Error
Time

• Most often, quartz crystal clocks are used in GPS receivers because
  – they are compact
  – inexpensive
  – have a long life span
  – require little power to operate
Multipath Error
Multipath Error

• Causes of multipath error include;
  – Topography
  – Tall buildings
  – Vehicles
  – Rock cliffs
  – Tree canopies
  – Other obstructions to your line of sight to the satellites
Dilution of Precision

• The effect of alignment, or geometry, of the satellite constellation on the accuracy of a GPS position is called dilution of precision (DOP)

• DOP is sometimes referred to as geometric dilution of precision (GDOP)
Dilution of Precision

• The components of DOP include:
  – **Position dilution of precision (PDOP)** which relates to 3-D determination of the position. Made up of:
    • **Horizontal dilution of precision (HDOP)** which relates to the determination of latitude and longitude
    • **Vertical dilution of precision (VDOP)** which relates to the determination of height
  – **Time dilution of precision (TDOP)** relates to timing of the GPS signal
DOP

• A value of 1 means that the highest confidence can be given to the GPS determination, but this is rare
• There are military and other applications that demand this highest possible precision at all times
• A range of 2-3 is excellent, and position determination can be considered as meeting the accuracy specification of the receiver in use
• A range of 4-6 is good and is often used for vehicle navigation or resource management data collection
HDOP

The area of uncertainty becomes larger as satellites get closer together.
HDOP

• The greater the angle between the satellites, the lower the HDOP, and the better the measurement

• However, when the satellites are positioned overhead, the VDOP values will improve
Good VDOP
Poor VDOP
Geometric Dilution of Precision (GDOP)

Relative position of satellites can affect error

Idealized situation
Geometric Dilution of Precision (GDOP)

Real situation - fuzzy circles

Point representing position is really a box
Geometric Dilution of Precision (GDOP)

Even worse at some angles

Box gets bigger if satellites are closer together
Geometric Dilution of Precision (GDOP)
PDOP: HDOP & VDOP

• Since PDOP is a combination of HDOP and VDOP, PDOP values are best if at least one satellite is positioned vertically above the receiver and at least three others are evenly distributed closer to the horizon in different sectors of the sky.
Elevation Accuracy

• GPS receivers give us an *elevation relative to the surface of the ellipsoid* based on the distance from the center of the earth to the point

• Usually this error is about double the horizontal error

• a horizontal position accurate to within 10 meters will be accurate to within 20 meters vertically
High-Accuracy Positioning

- to obtain the highest accuracy using GPS, you have to have a clear view of the sky at all times and the GPS signal has to be able to avoid trees, buildings and other obstructions that could cause the GPS signal to be blocked or reflected or cause multipath errors
High-Accuracy Positioning

• There are two other ways you can improve the accuracy:
  – More expensive GPS units that are able to use higher-frequency carrier phase signals
  – GPS augmentation which is less expensive
GPS Augmentation

• More precision using other navigation signals
• GPS augmentation involves using external information, often integrated into the calculation process, to improve the accuracy, availability or reliability of the satellite signal
Differential GPS (DGPS)

- Can be used to achieve horizontal accuracy of 1 to 5 meters, or even better
- **Differential correction** requires a second GPS receiver called a base station
Differential GPS (DGPS)
Differential GPS (DGPS)

• This differential signal can come from a variety of sources:
  – GPS base station
  – Free signals from beacons or transmitters that are administered by:
    • The Coast Guard
    • Dept of Transportation
    • Army Corps of Engineers
  – Commercial FM signals from:
    • DCI
    • Accupoint
    • Raycal
    • Omnistar
Post-processing

• **Post-processing** is lower in cost and does not require a sophisticated receiver

• Post-processing can be used for any GPS data that are collected with time tags to tell precisely when each fix was recorded

• Post-processing requires base station data for a location near where the mobile receiver collected its positions
Inertial Navigation Systems (INS)

• Because the two systems (GPS and INS) are complementary, they are often used together.
• The combined systems are becoming more popular for use in car navigation systems so that travel through tunnels and on streets lines with tall buildings does not interrupt positioning.
Wide Area Augmentation System

• Even without selective availability, GPS by itself does not have:
  – an adequate level of reliability,
  – integrity,
  – accuracy,
  – availability to support a nationwide autonomous aviation navigation system
Wide Area Augmentation System

• WAAS originally consisted of 25 wide-area reference stations (WRS) – ground-based facilities that gather GPS data used for WAAS corrections

• And a number of geostationary satellites broadcasting a radio signal in the same band as the GPS satellite signals
Wide Area Augmentation Systems (WAAS)

Accuracy
15m - typical handheld GPS accuracy without corrections
3-5m - typical DGPS accuracy
<3m - typical WAAS accuracy

http://www.ae.utexas.edu/~shep/
3 Classes of GPS Receivers

Mapping

- capable of sub-meter accuracy (<2 meters accuracy)
- lightweight, portable, less expensive
- resource mapping and navigation applications

Navigation

- capable of 12 meter accuracy
- lightweight, cheap!
- navigation applications such as surveying, geodetics