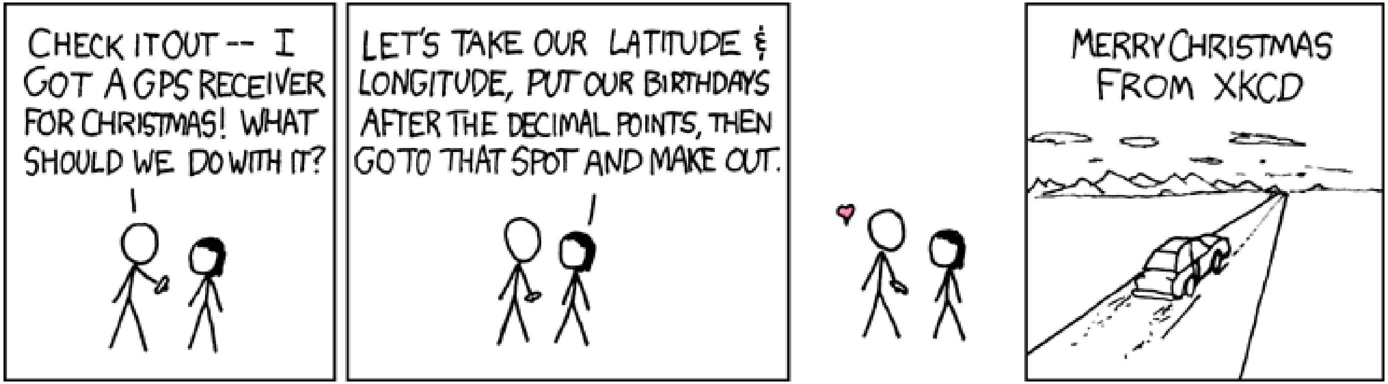
Global Positioning Systems (GPS)



Source: https://xkcd.com/407/ ; https://xkcd.com/license.html

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GPS History (from Wikipedia)

https://en.wikipedia.org/wiki/Global_Positioning_System#History

"Genesis of Satellite Navigation" by William H. Guier and George C. Weiffenbach:
http://www.jhuapl.edu/techdigest/td/td1901/guier.pdf

Source: https://www.uwgb.edu/dutchs/CosmosNotes/sputnik.htm

How GPS is administered?

US Department of Defense initiated GPS in 1960s as Navigation Satellite Timing and Ranging System (**NAVSTAR**). In 1970s first satellites were launched into space and now it has about 30 active satellites orbit the earth in a distance of 20,200 km.

GLONASS is a radio-based satellite navigation system, developed by the former Soviet Union in 1976 and now operated for the Russian government by the Russian Space Forces. It is an alternative and complementary to the United States' Global Positioning System (GPS), the Chinese COMPASS Navigation System, and the planned Galileo positioning system of the European Union (EU).

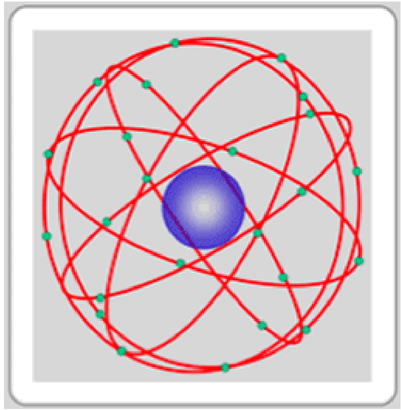
GLONASS (Russian: ГЛОНАСС, abbreviation of ГЛОбальная НАвигационная Спутниковая Система; translation: GLObal'naya NAvigatsionnaya Sputnikovaya Sistema; OR "GLObal NAvigation Satellite System" in English)

Definition of GPS

GPS (Global Positioning System) is a radio-based navigation system that uses GPS receivers to compute accurate locations on the Earth's surface from a series of orbiting satellites. With a small, inexpensive, hand-held GPS receiver (see below), you can determine your location usually within about three meters. Using two GPS receivers simultaneously (called Differential GPS or DGPS) or using a Wide Area Augmentation System (WAAS)-enabled GPS receiver, which uses satellites and ground stations that provide GPS signal corrections, you can get sub-meter accuracy.

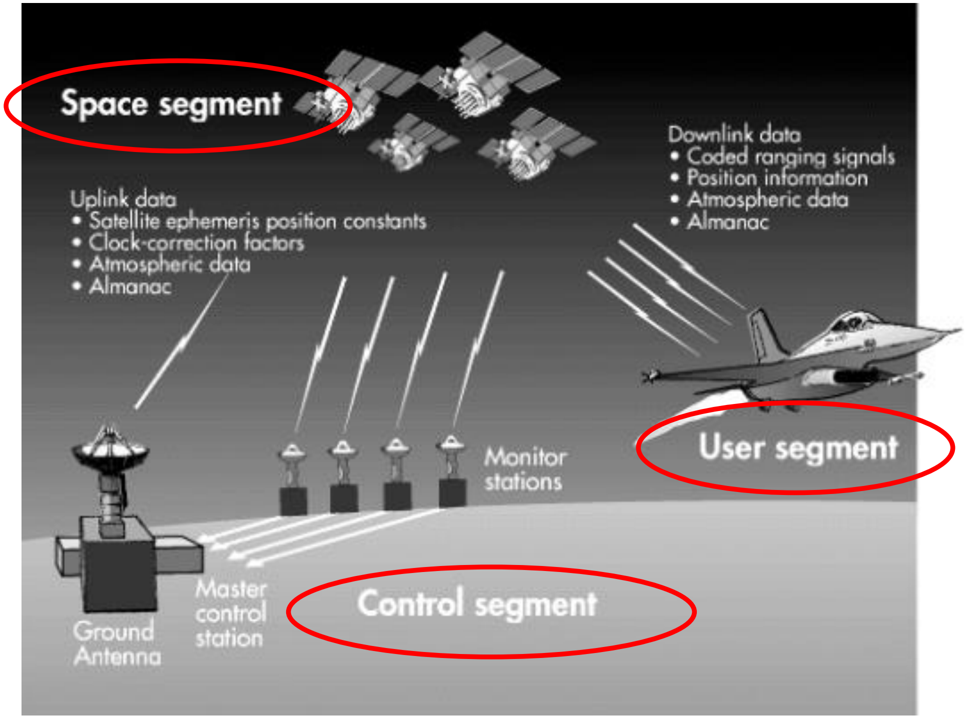
Typical low-end GPS device.

Global Navigation Satellite System (GNSS)



How does GPS work? https://youtu.be/qadHYkbmIAs

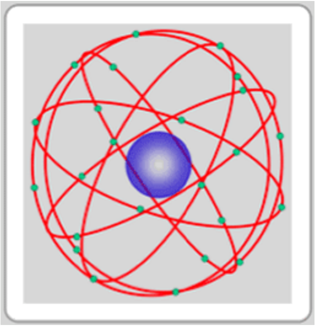
In general, GPS structure can be described as Space Segment, Control Segment and User Segment.



Space Segment (Source: http://www.gps.gov/systems/gps/space/)

The U.S. GPS network has at least 24 satellites that orbit in six planes around the Earth (see below). The network's configuration secures at least four satellites—the minimum number of satellites needed to capture location data—above the horizon for every point on Earth.

Almanac and Ephemeris:



Almanac data is course orbital parameters for ALL satellite vehicles (SV); it is not very precise and is considered valid for up to several months.

Ephemeris data is very precise orbital and clock correction for EACH SV and is necessary for precise positioning. This data is only considered valid for about 30 minutes.

Atomic Clock: Speed of light approx. 300,000 km/sec. Considering the distance from satellites to the Earth is 20,000 km, the time required for signal to reach the Earth is 0.0666 sec. To measure such a miniscule time satellites have atomic clock which is based on cesium atom oscillations (9,192,631,770 cycles per second). Measuring these oscillations allows to deal with accuracies within 10^{-9} sec.

ALMANAC DATA (an example):

PRN number for data 1

Health of SV 0

Reference Week of Almanac 797

Eccentricity 0.00346661

Corr: inclination angle (rad) ... 0.00388718

Mean Anomaly @ ref time (rad) ... 2.79387

Argument of Perigee (rad) .... -1.31888

Rate right ascension (rad/sec) .. -8.01176E-09

Right ascension @ ref time (rad) -0.296182

Sqrt semi-major axis (m^1/2) 5153.58

Clock correction term 1 .... 0.000148773

Clock correction term 2 .... 7.63976E-11

Reference time almanac 466944

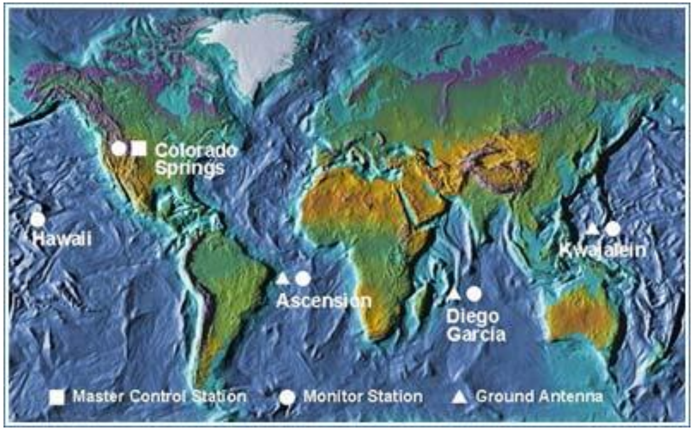
Semi-Major Axis (meters) .... 2.65594E+07

Corrected Mean Motion (rad/sec) . 0.000145862

Inclination angle (rad) 0.95469

Control Segment: (Source: http://www.gps.gov/systems/gps/control/)

The U.S. Department of Defense (DoD) developed and controls NAVSTAR, and DoD can turn the whole system off, as they briefly did immediately following the terrorist attacks of September 11, 2001. DoD monitors and tracks the satellites (which are equipped with radio transmitter/receivers and a set of atomic clocks) from five stations across the globe where they compute precise satellite orbital and clock corrections. These corrections are transmitted from the master control station at Schriever Air Force Base in Colorado to the satellites, which make the adjustments.



User Segment (Source: http://www.gps.gov/applications/)

GPS is an essential element of the global information infrastructure. The free, open, and dependable nature of GPS has led to the development of hundreds of applications affecting every aspect of modern life.

GPS technology is now in everything from cell phones and wristwatches to bulldozers, shipping containers, and ATM's

User Segment:

GPS receivers tuned to two microwave bands:

L1, 1575.42 MHz - coarse acquisition (CA) code & P (precise) code

L2, 1227.42 MHz - measures ionospheric delay, P code

Recreational GPS mostly get L1 and professional GPS units receive both, L1 and L2 bands.

User Segment:

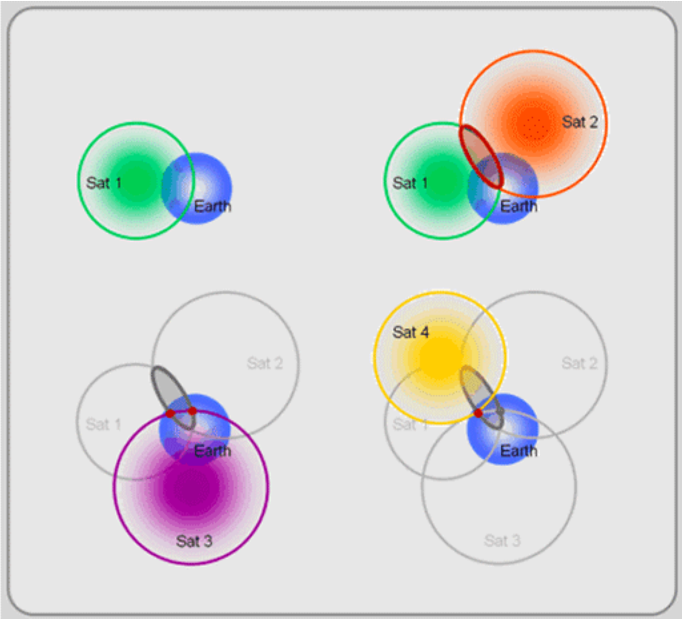
Selective Availability (SA) – the intentional alteration of the timing and position information transmitted by a GPS satellite.

"The decision to discontinue Selective Availability is the latest measure in an ongoing effort to make GPS more responsive to civil and commercial users worldwide…This increase in accuracy will allow new GPS applications to emerge and continue to enhance the lives of people around the world."

President Bill Clinton

May 1, 2000

The Core of GPS functionality: Trilateration Concept



All of the satellite's locations are precisely known, and by knowing their exact locations, we can determine the location of every point on Earth with a GPS receiver. This is possible because each satellite transmits a unique radio signal, which can be received by GPS receivers. Using this signal, your GPS receiver calculates the distance to each of the four satellites it is tracking by the amount of time it takes for the signals to travel from the satellites to your receiver. This is a high-tech version of triangulation called trilateration. The first satellite locates you somewhere on a sphere (top left of figure). The second satellite narrows your location to a circle created by the intersection of the two satellite spheres (top right). The third satellite reduces the choice to two possible points (bottom left). Finally, the forth satellite helps calculate a timing and location correction and selects one of the remaining two points as your position (bottom right).

Trilateration Exercise:

Source: http://www.gps.gov/multimedia/tutorials/trilateration/

How accurate is GPS?

Source: http://www.gps.gov/systems/gps/performance/accuracy/

Small errors in the receiver's clock, variations in the satellite's orbit, atmospheric conditions that slow radio waves, and radio signals that bounce (called "multipath" or "ghosting") off buildings and cliffs are some possible distortions. In addition, GPS has difficulty penetrating thick forests and urban canyons created by tall buildings.

Another source of error is Geometric Dilution of Precision (GDOP). This is the spatial relationship between the GPS receiver and each of the potential satellites. In general, the fewer the satellites available, and the closer they are clustered, the less accurate your readings. GPS receivers try to avoid GDOP by selecting the set of satellites that provide the least error. It chooses satellites that are well above the horizon, minimizing atmospheric thickness and interference from buildings, yet not so high that they are clustered together.

How accurate is GPS?

	Garmin eTrex	Garmin eMap/GA-27C
RMS error	3.8 m	3.9 m
Mean error	3.0 m	3.2 m
CEP (50%)	2.7 m	2.7 m
95%	6.7 m	6.9 m
Mean no. sat.	6.82	6.87
Mean HDOP	1.41	1.38
RMS HDOP	1.48	1.1.44
Notes	Internal antenna	Garmin GA-27C External antenna
	One simultaneous 48 hour session	

Adapted from: http://users.erols.com/dlwilson/gpsacc.htm

How Accurate is GPS?

GPS satellites move constantly, therefore the accuracy changes correspondingly.

Factors influencing accuracy:

1. Satellite position (art of the Dilution of Precision, **DOP**)
2. Atmospheric condition
3. User environment
4. **Multipath (signal bouncing off surrounding obstacles) and equipment quality**
5. Occupation time, i.e. the length of time taken to record GPS position
6. Number of readings recorded by GPS at one location

Dilution of Precision (DOP):

The DOP is a mathematical function involving the relative coordinates of the receiver and the satellite and can be easily computed for a particular satellite arrangement. It is geometric factor. The more spread out the satellites are in the sky, the smaller the DOP value. A typical value for the *horizontal dilution of precision* (HDOP), assuming that a receiver is processing the signals of 4 satellites only, is 2.0. **Source:** Langley, R. B. (1997), The GPS error budget. GPS World , Vol. 8, No. 3, pp. 51-56.

However, if satellites are too close to horizon they send signal that travels through more atmosphere thus contributing more timing errors. ***Elevation angle*** is a parameter that can be set in GPS to eliminate these satellites.

List of DOPs:

- PDOP: Positional Dilution of Precision, measure of overall positional accuracy
- VDOP: Vertical Dilution of Precision
- HDOP: Horizontal Dilution of Precision
- TDOP: Timing Dilution of Precision
- GDOP: Geometric Dilution of Precision, measure of satellite geometry

Notes:

1. The records of PDOP, etc can provide a document for legal case.
2. Too many restrictions on PDOP values, elevation angles, etc. can make GPS survey long and sometimes impossible.

Methods of increasing accuracy:

- Differential GPS (DGPS): differential correction of the signal using Continuously Operating Reference Stations (CORS).

- Wide Area Augmentation System (WAAS) aka Satellite Based Augmentation Systems (SBAS)

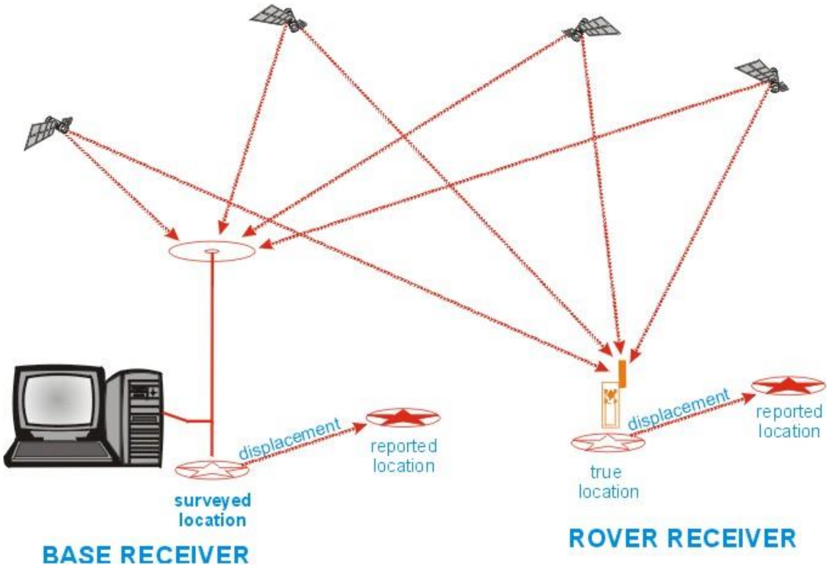
GPS Augmentation Systems Overview:

http://www.gps.gov/systems/augmentations/

DIFFERENTIAL CORRECTION

Differential correction serves as a tool to improve accuracy of GPS data to sub-inch or sub-cm level.

Errors in positions collected by the rover receiver can be removed because the location of the base unit is already known and errors collected by the base and rover receivers will be identical for any given moment in time.



GPS Error Budget

Langley, R. B. (1997), The GPS error budget. GPS World, Vol. 8, No. 3, pp. 51-56.

http://seismo.berkeley.edu/~battag/GAMITwrkshp/lecturenotes/unit1/unit1.html

Source	Effect
Satellite	Clock bias
	Orbital errors
Signal propagation	Ionospheric refraction
	Tropospheric refraction
Receiver	Antenna phase center variation
	Clock bias
	Multipath

(After Hoffmann-Wellenhof et al. (1997),
GPS: Theory and Practice, 4 th Ed., Springer.)

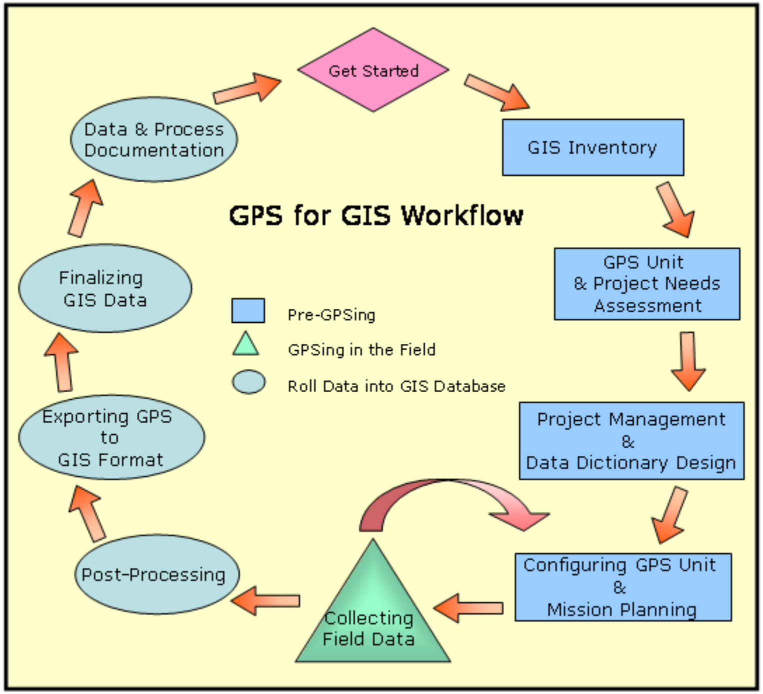
GPS can be linked to GIS data

GPS is a major data input tool for GIS. Most receivers, even inexpensive units, contain a hard-drive where you can log your positions. Each logged position is called a waypoint, and together, waypoints depict the location and extent of the features you enter in the field. They can be downloaded from GPS receivers (sometimes with the help of a separate software program) and imported into many GIS programs.

Some of the more expensive GPS units have “feature lists” that streamline the data entry process. Feature lists are databases that you define to contain a list of the possible features you will locate. These lists have associated attributes for each feature type, and drop down lists of common attribute values can also be predetermined for each attribute to save time in the field. Both the feature locations and their associated attributes can be downloaded into your GIS.

GPS and GIS Workflow

Source: http://www.nps.gov/gis/gps/gps4gis/



GPS Modernization:

http://www.gps.gov/systems/gps/modernization/

Additional Resources:

Trimble Tutorial: http://www.trimble.com/gps_tutorial/

Attribution Information for some material used in lecture:

https://www.merlot.org/merlot/viewMaterial.htm?id=514304&showThanks=true

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