



LinksPoint White Paper

How GPS Works



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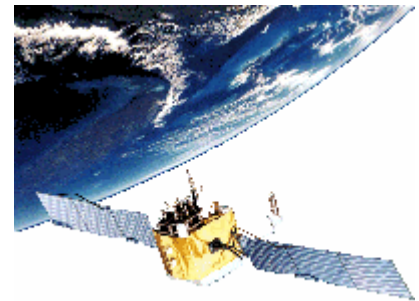
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How GPS Works: An Introduction to the Global Positioning System

The Global Positioning System, or GPS, is a satellite-based navigation system. It was developed by the United States Department of Defense (DOD) for military and government use, but the information it provides is available free for civilian and commercial uses.

From satellite-guided bombs used in the war against terrorism to handheld receivers carried by hikers, GPS offers a wide range of applications and uses. Between these two ends of the spectrum, GPS technology can provide GIS professionals with a wide range of valuable data.

The first GPS satellite was launched in 1978. The full constellation of 24 satellites was in place in 1994 and the system was declared fully operational in 1995. Another key date in GPS history is May 1, 2000, the day “Selective Availability” was discontinued, significantly increasing the accuracy of GPS signals.



Source: National Telecommunications and Information Administration

In simple terms, GPS is a broadcasting system in which satellites transmit information toward Earth. GPS receivers take the transmitted information and use a form of triangulation to calculate the user’s exact location. The basic premise of the technology is that the GPS receiver compares signal transmission time with the signal reception time, and then uses the time difference and the propagation speed to deduce the distance from each of the visible satellites.

Of course, it isn’t that simple – GPS really is “rocket science.” The best place to start a review of the Global Positioning System is with the three segments that make it up:

- The Space Segment, consisting of the GPS satellites orbiting the earth
- The Control Segment, consisting of a system of tracking stations located around the world
- The User Segment, consisting of GPS receivers and the user community.

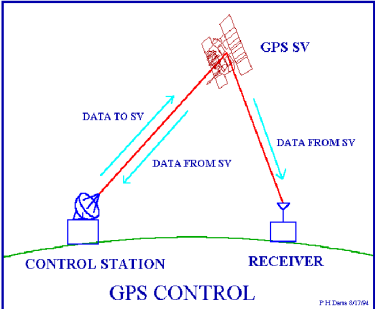
Space Segment

The Space Segment consists of a minimum of 24 satellites (sometimes referred to as space vehicles, or SVs) orbiting 12,600 miles above the earth. Because each satellite lasts about ten years, there are often extra satellites already in orbit to replace the failing older satellites (right now there are 26). Each satellite travels at about 7,000 miles per hour, enabling them to orbit the earth in just under twelve hours; the altitude and orbital inclination are such that each satellite repeats the same ground track in each twelve-hour

orbit. The satellites are arranged in six orbital planes, spaced equally at 60 degrees apart, and each inclined at about fifty-five degrees with respect to the equatorial plane. This spacing is intended to ensure that the required four satellites are viewable at any given time from any spot on Earth, however there are often eight and up to twelve satellites visible. Each satellite weighs approximately 2,000 pounds, is approximately 17 feet across, and uses solar panels to power its electronics and transmit the GPS signal. It's worth noting that at 50 watts or less, the GPS signal is at approximately the same level as the background noise of the universe by the time it reaches Earth.

Control Segment

The Control Segment consists of a network of monitor stations located around the world used to track the “health” of all of the satellites, as well as one master control facility located at Schriever Air Force Base in Colorado Springs. The orbital models for each satellite describes the degree to which each SV is on its proper flight path; the monitor stations measure certain signals from the satellites, determine to what degree each satellite is off course, and compute new orbital data and clock corrections. The monitor stations then send the new orbital information (known as ephemeris data) and the clock corrections to the master control station, which then relays the information to the satellites.



Source: P.H. Dana

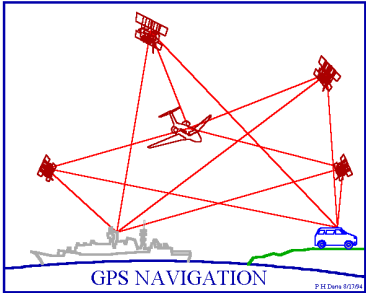
User Segment

The User Segment consists of the GPS receivers in the hands of the community of GPS users. GPS receivers convert satellite signals into position and time estimates, and often use this information to calculate other information such as velocity and heading. GPS receivers make positioning, navigation, and time dissemination possible. This information is then used for recreational, educational, commercial, research, and many other applications. The receivers in the user segment are often used for aviation, marine, and terrestrial vehicular and non-vehicular navigation.

GPS Navigation

Tracking Code Phase

In standard GPS navigation, each GPS receiver produces “replicas” of the code transmitted by the various satellites. These replicas represent the code the receiver expects to receive from any given satellite. A satellite is located and verified when a replica of the code matches up with the code received (a process known as code phase tracking). At the beginning of each individual signal is a sort of time

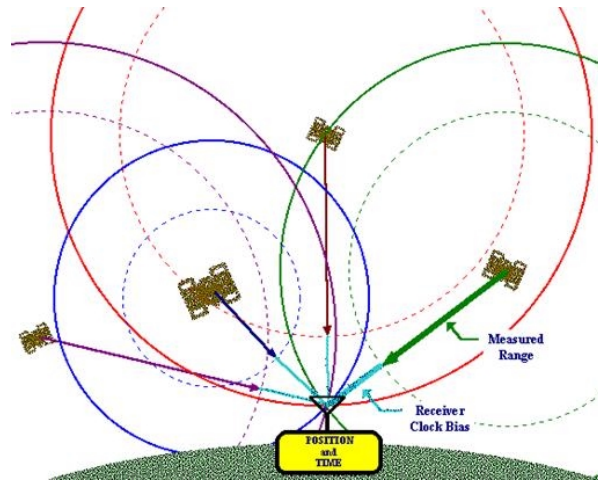


Source: P.H. Dana

stamp. When the two signals are examined by the receiver (called “correlation”), the time stamps of the two signals are compared and a time difference is ascertained. Given this time difference and the rate of propagation of the signal, the GPS receiver uses the simple formula of Rate times Time equals Distance ($R \cdot T = D$) to compute the distance to each satellite. Due to the uncertainties introduced by the many variables this distance to each satellite is only an estimate, and is known as the pseudo-range.

Pseudo-Range Navigation

The pseudo-range from each satellite can be seen as a radius of a large sphere, and the location of the GPS receiver is one point on that sphere. When several pseudo-ranges from several satellites are used in conjunction, the position of the receiver is simply the intersection of these spheres at a given time. The position is first determined in what is known as the Earth-Centered, Earth-Fixed (ECEF) coordinate system, which describes the receiver’s position relative to the center of the earth. From this ECEF location the receiver then easily deduces the latitude, longitude, and altitude, which of course describes the receiver’s position on the surface of the earth.



Source: P.H. Dana

In solving for the ECEF position the receiver needs to examine four variables (three dimensions and time), and a minimum of four satellites is required. In the event that only three satellites are available, a two-dimensional fix can be calculated by assuming a certain altitude. The greater the number of satellites visible to the receiver the greater the level of GPS accuracy, as five or more satellites can provide position, time and redundancy.

GPS Errors

Types of GPS Errors

GPS accuracy is diluted by errors that can be introduced by a number of sources. GPS errors can be any combination of noise, bias, and blunders.

Noise errors combine the electronic noise from the space segment and the noise generated by the user’s device.

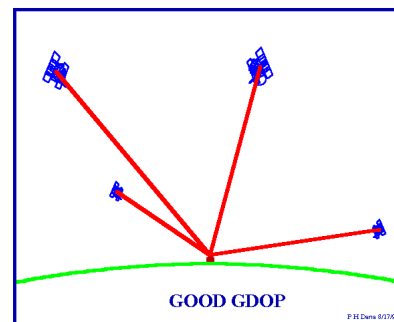
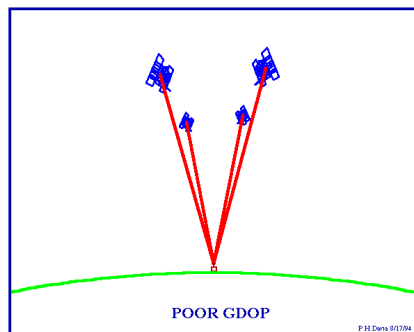
Bias errors were historically a result of the intentional degradation of GPS accuracy by the DOD known as Selective Availability, but this source of bias error is no longer active. However, bias errors can also be due to several other factors including:

Bias Error Type	Possible Errors up to...
Receiver Clock Error	1 meter
Ephemeris data errors	1 meter
Tropospheric (atmospheric water vapor) signal refraction	1 meter
Ionospheric (atmospheric electron content) signal refraction	10 meters
Multipath (reflection of signal) Errors	10 meters

Blunders are errors that occur in the user segment, result in either operator error or a malfunction of the GPS receiver. Blunders can be the most devastating errors, resulting in errors from 1 meter to several kilometers. Even without blunder errors, however, noise and bias errors can occasionally combine to result in the ranging errors of up to 15 meters.

Dilution of Precision and Visibility

Another factor that helps determine the level of accuracy of GPS data is known as the Dilution Of Precision, or DOP. The most general form of DOP is the Geometric DOP (GDOP); its components consist of the following DOP measurements: Positional (PDOP), Horizontal (HDOP), Vertical (VDOP), and Time (TDOP). GDOP is a measure of how the position information is affected by calculation errors, and is dependent upon the range vector difference between the user's receiver and the space segment (see figure below). The volume of the shape described by the unit-vectors from the receiver to the SVs used in a position fix is inversely proportional to GDOP. Simply put, a good GDOP (and accurate position information) results when the angles from the satellites are large, and a bad GDOP results when the satellites lie in or close to the same plane. Ranging errors from the SV signals are multiplied by various DOP measurements and estimates, and are used to estimate the resulting error in position or time.



Source: P.H. Dana

GPS Accuracy Defined

Regulated GPS Levels of Precision

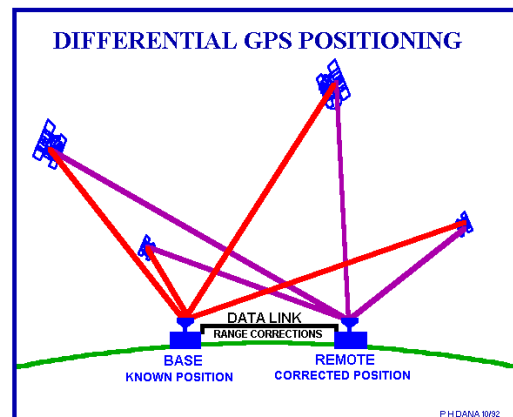
There are presently two levels of GPS precision available: the Precise Positioning Service (PPS) and the Standard Positioning Service (SPS). Each requires a user segment consisting of a specific set of equipment, and each carries with it a well defined guaranteed minimum level of accuracy.

PPS requires dual-frequency receivers that must be equipped with cryptographic keys to decode the PPS signal. PPS is used by the US and allied military, certain US government agencies, and by specially approved civilians. PPS is listed as having 22 meter horizontal accuracy, 27.7 meter vertical accuracy, and 200 nanosecond time (UTC) accuracy. These figures are the specifications for minimum accuracy in "worst case" conditions as published in the Federal Radionavigation Plan. Actual accuracy in the field for PPS receivers can be in the sub-centimeter range.

SPS only requires single frequency receivers and is available for use for free the world over, and as a result almost every receiver that we see on the internet or in stores uses the SPS. Until May of 2000 the SPS was intentionally degraded by the DOD under what was known as Selective Availability (SA). SPS with SA was listed as having 100 meter horizontal accuracy, 156 meter vertical accuracy, and 340 nanoseconds time accuracy; without SA SPS is listed as having 36 meter horizontal accuracy, 77 meter vertical accuracy, and 40 nanoseconds time accuracy. As with the PPS numbers, these numbers represent the minimum accuracy to be expected, with real-world accuracy in the 5 meter or below range for uncorrected GPS data.

Differential GPS

There are many means of improving the accuracy and precision of Global Positioning System data. The most common method of improving position information is known as Differential GPS, or DGPS. DGPS is predicated on the concept that for two receivers positioned reasonably close to each other, several of the errors will be common to both devices, and can therefore be subtracted from the navigation solution. Errors common to both receivers are known as common-mode errors, and do not include multipath errors or errors due to noise in the user segment. Specifically, DGPS requires that one receiver is stationary at a known location, and that it sends corrected signals to a roving station; the roving station then incorporates the new information into the range corrections for each satellite. The best DGPS corrections for the roving station occur when the common-mode errors are most similar, or when the receivers are 100 km or closer to each other.



Source: P H Dana

DGPS corrections can be broadcast from the stationary receiver to the roving receiver in many ways. If a user does not or cannot set up a reliable stationary receiver for use with a roving receiver, there are several stationary receivers already in place. There exist several locations in the world where data is acquired, and when matched with the time of the rover's location information can be used to process its location information at a later time, known as post processing. Post-processing can significantly increase the accuracy of GPS data collected with even inexpensive receivers. This is especially useful and cost effective in instances where position information is not needed in real-time.

DGPS can also be performed in real time using freely broadcast DGPS signals from either the Radio Technical Commission for Maritime Services(RTCM) or the Wide Area Augmentation System (WAAS). There also exist private DPGS services; for real-time applications these often use satellite links or private radio-beacons.

Differential Code Corrections

One method of DGPS is to apply the two-receiver differential techniques to the actual code transmitted by the satellites. Applying DGPS using code corrections is used primarily for navigation, and can yield differential position accuracies of 1-10 meters.

Differential Carrier Phase Corrections

Another method of DGPS is to apply differential techniques to the carrier phase of the signals transmitted by the satellites. Both receivers used must track carrier phase at the same time, and both must be close enough to each other to ensure that the ionospheric delay is less than one carrier wavelength, or within about 30 kilometers of each other. Commercial user segment receivers rarely employ this technique, as it is quite expensive and special software is required to process the carrier-phase measurements. Improvements are constantly being made to this; techniques such as Real Time Kinematic (RTK) processing can provide centimeter accuracy.

Differential Time Synchronization

For applications such as the synchronization of power grids, accurate time is essential to operation. Using differential techniques, time can be synchronized to an accuracy of ten parts per billion over distances as long as 2000 kilometers.

Costs of Various GPS Projects

Receiver costs vary depending on capabilities. Small civil SPS receivers can be purchased for under \$200, some can accept differential corrections. Receivers that can store files for post-processing with base station files cost more (\$2000-5000). Receivers that can act as DGPS reference receivers (computing and providing correction data) and carrier phase tracking receivers (and two are often required) can cost many thousands of dollars (\$5,000 to \$40,000). Military PPS are not available for consumer and civilian use. Other costs include the cost of multiple receivers when needed, post-processing software, and the cost of specially trained personnel. Project tasks can often be categorized by required accuracies, which will determine equipment cost. The chart below, adapted from the Australian Antarctic Division, outlines the approximate costs for varying levels of GPS accuracy.

Scenario	Desired Accuracy	Required Occupation Time	Initial Cost
A	< 1 meter	1 second	\$18,700
B	< 1 meter	600 seconds	\$10,900
C	2 meters	180 seconds	\$8,600
D	5 meters	1 second	\$8,600
E	3 meters	10 seconds	\$1,800

Source: <http://www.aad.gov.au/> and LinksPoint.

Conclusion

The Global Positioning System provides untold value to people, governments and enterprises around the world. It offers the prospect of adding accurate position information that can improve the quality of everything from asset management to field workforce operations. While GPS is "rocket science," it is based on a number of simple principles that can be easily grasped.

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Note: Certain images were created by Peter H. Dana, The Geographer's Craft Project, Department of Geography, The University of Colorado at Boulder. © 1999 Peter H. Dana.

About LinksPoint

LinksPoint provides Location Powered Solutions built around three enabling technologies – Global Positioning System (GPS), Geographic Information Systems (GIS) and Mobile Computing. LinksPoint helps enterprises work more efficiently with solutions for vehicle tracking, navigation and field data collection. LinksPoint's products are used by transportation companies, utilities and government agencies. LinksPoint technology was used by the FDNY at Ground Zero, an application that won the 2002 Exemplary System in Government Award from the Urban and Regional Information System Association (URISA).

Products & Services: LinksPoint tools make mobile workers more productive including, *GlobalPoint RouteTrak™*, *GlobalPoint AVL™*, *Field Data Collector™* and *Destinator™*. The company also manufactures the *GlobalPoint GPS™* line of specialized GPS receivers for mobile computing devices and ruggedized handheld computers.

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