Global Positioning System
(GPS)

The space age dawned with the launch of Sputnik 1, Earth's first artificial satellite, in 1957.

The Global Positioning System (GPS) is a satellite-based system that can be used to locate positions anywhere on the earth. Operated by the U.S. Department of Defense (DoD), NAVSTAR (NAVigation Satellite Timing and Ranging) GPS provides continuous (24 hours/day), real-time, 3-dimensional positioning, navigation and timing worldwide. Any person with a GPS receiver can access the system, and it can be used for any application that requires location coordinates.

The GPS system consists of three segments: 1) The space segment: the GPS satellites themselves, 2) The control system, operated by the U.S. military, and 3) The user segment, which includes both military and civilian users and their GPS equipment.

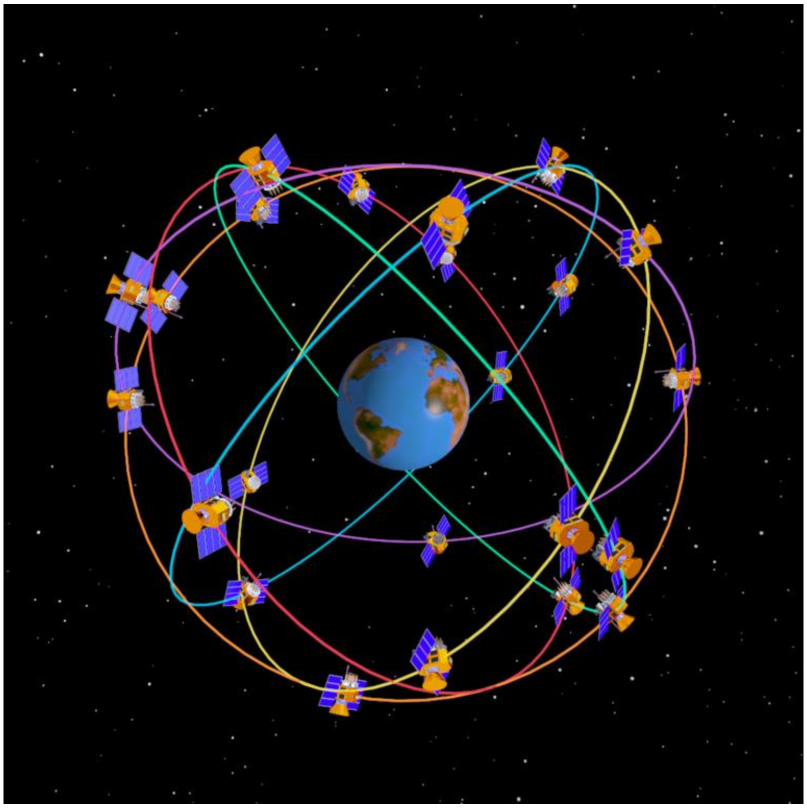
Space Segment: The GPS Constellation

The first GPS satellite was launched by the U.S. Air Force in early 1978. This full system has a total of 28 GPS satellites in orbit about the earth, although four are prototypes not used in the main constellation. There are now at least 24 satellites orbiting the earth at an altitude of about 20200km. The high altitude insures that the satellite orbits are stable, precise and predictable, and that the satellites' motion through space is not affected by atmospheric drag. Full operational capability was declared by NAVSTAR in April 1995.

The GPS satellites are solar powered with nickel-cadmium batteries providing secondary power. On board each GPS satellite are four atomic clocks(two rubidium & two caesium)only one of which is in use at a time. These highly accurate atomic clocks enable GPS to provide the most accurate timing system that exists.

SatelliteOrbits

There are four satellites in each of 6 orbital planes. Each plane is inclined 55 degrees relative to the equator, which means that satellites cross the equator tilted at a 55 degree angle. The system is designed to maintain full operational capability even if two of the 24 satellites fail. This deposition ensures that at least four satellites can be observed from any point on the earth.



GPS satellites complete an orbit in approximately 12 hours, which means that they pass over any point on the earth about twice a day. The satellites rise (and set) about four minutes earlier each day.

SatelliteSignals

GPS satellites continuously broadcast satellite position and timing data via radio signals on two frequencies (L1 and L2). The radio signals travel at the speed of light (186,000 miles per second) and take approximately 6/100ths of a second to reach the earth.

Two kinds of code are broadcast on the L1 frequency (C/A code and P code) along with data message giving information about the satellite location within the constellation, clock corrections and system status. C/A (Coarse Acquisition) code is available to civilian GPS users and provides Standard Positioning Service (SPS).L2 is modulated with P (Precise) code and data message. P code, used for the Precise Positioning Service (PPS) is available only to the military. Using P code on both frequencies, a military receiver can achieve better accuracy than civilian receivers. Each satellite has a unique C/A and P-code for its identification

GLONASS

The Russian government has developed a system, similar to GPS, called GLONASS (Global Navigation Satellite system). The first GLONASS satellite launch was in October 1982 and was declared operational in January 1996. The full constellation consists of 24 satellites in 3 orbit planes at an altitude of 19100Km inclined at 64.8 degree to the earth's equator. Each satellite orbit the earth every 11h 15min and ensures that 5 satellites are always visible. GLONASS uses the same code for each satellite and many frequencies, whereas GPS which uses two frequencies and a different code for each satellite. Some GPS receiver manufacturers have incorporated the capability to receive both GPS and GLONASS signals. This increases the availability of satellites and the integrity of combined system.

IRNSS: Indian regional Navigation Satellite System

Galileo: Developed by European Union, joined by China, Israel, India, Morocco, Saudi Arabia, South Korea and Ukraine.

QZZ (Quasi-Zenith Satellite System): Developed by Japanese

Control Segment: U.S. DoD Monitoring

The U.S. Department of Defense maintains a master control station at Falcon Air Force Base in Colorado Springs, CO. There are four other monitor stations located in Hawaii, Ascension Island, Diego Garcia and Kwajalein. Master control station is responsible for collecting tracking data from the monitoring stations and calculating satellite orbits and clock parameters. Each satellite databank is updated every hour by the control station.

User Segment: Military and Civilian GPS Users

The U.S. military uses GPS for navigation, reconnaissance, and missile guidance systems. Civilian use of GPS developed at the same time as military uses were being established, and has expanded far beyond original expectations. There are civilian applications for GPS in almost every field, from surveying to transportation to natural resource management to agriculture. Most civilian uses of GPS, however, fall into one of four categories: navigation, surveying, mapping and timing.

How can GPS be used?

GPS Applications in Agriculture

More and more producers today are using precision farming techniques that can help increase profits and protect the environment. Precision, or site-specific farming involves applying fertilizer, pesticides and other inputs only where they are needed. GPS-guided equipment is often used for variable rate application of fertilizer (based on soil tests) or pesticides (based on pest survey). GPS can also be used to develop the initial reference maps upon which variable rate applications are based. A GPS system on a combine with a yield monitor can be used to develop an on-the-go yield map or can be used to map weed locations from the combine when harvesting. Mounted in an airplane, GPS can be used to guide aerial spraying operations.

GPS can be used to locate weed, insect or diseases infestations and monitor their spread. It can also be used to navigate back to previously mapped infestations to apply controls. A field map can be created using GPS to record the coordinates of field borders, fence lines, canals, pipelines, and point locations such as wells, buildings, and landscape features. The resulting field map might be the first layer a producer would develop for an on-farm GIS (Geographic Information System). Additional layers showing crop damage from hail or drought, and riparian areas or wetlands could be mapped using GPS. Ranchers could use GPS to develop rangeland utilization maps and to navigate back to previously mapped areas or monitoring sites.

GPS Navigation: Land, Sea and Air

GPS is being used for emergency response (fire, ambulance, police), search and rescue, fleet management (trucking, delivery vehicles, and public transportation) and for automobile guidance systems. Recreational uses of GPS include navigation while hiking, hunting, or skiing. GPS is even used on golf courses to track golf carts, and to let players know how far it is to the center of the greens.

On our nation's waterways, GPS is being used for recreational sailing and fishing and for commercial shipping fleet management. Assisted steering, risk assessment and hazard warning systems for marine navigation are being developed using GPS.

In the air, GPS is being used for en-route navigation (helicopter, airplane, hot-air balloon), aircraft landing, and air-collision avoidance systems.

GPS Applications: Mapping and Surveying

GPS applications in natural resource management include inventory and mapping of soils, vegetation types, threatened and endangered species, lake and stream boundaries and wildlife habitat. GPS has been used to aid in damage assessment after natural disasters such as fires, floods and earthquakes. GPS has also been used to map archaeological sites and for infrastructure (streets, highways and utilities) mapping, management, and planning for future growth. Engineers use GPS for surveying when building roads, bridges and other structures.

Other GPS Applications: The Possibilities are Endless

Other uses of GPS include real estate valuation and taxation assessment, air quality studies, environmental protection, demographic analysis including marketing studies, atmospheric studies, oil and gas exploration, and scientific exploration. There are many additional current and possible uses for GPS. Any application where location information is needed is a possible candidate for GPS.

How does GPS work?

Calculating a Position

1: GPS satellites circle the earth twice a day in a very precise orbit and transmit signal information to earth.

2: GPS receivers use this information and triangulation to calculate the user's exact location.

3: Essentially, the GPS receiver compares the time a signal was transmitted by a satellite with the time it was received. The time difference tells the GPS receiver how far away the satellite is.

4: Now, with distance measurements from a few more satellites, the receiver can determine the user's position and display it on the unit's electronic map.

MeasuringDistance

The first step in measuring the distance between the GPS receiver and a satellite requires measuring the *time* it takes for the signal to travel from the satellite to the receiver. Once the receiver knows how much time has elapsed, it multiplies the travel time of the signal times the *speed of light* (because the satellite signals travel at the speed of light, approximately 186,000 miles per second) to compute the distance. Distance measurements to four satellites are required to compute a 3-dimensional (latitude, longitude and altitude) position. A GPS receiver must be locked on to the signal of at least three satellites to calculate a 2D position (latitude and longitude) and track movement.

In order to measure the travel time of the satellite signal, the receiver has to know when the signal left the satellite and when the signal reached the receiver. Knowing when the signal reaches the receiver is easy, the GPS receiver just "checks" its internal clock when the signal arrives to see what time it is. But how does it "know" when the signal left the satellite? All GPS receivers are synchronized with the satellites so they generate the same digital code at the same time. When the GPS receiver receives a code from a satellite, it can look back in its memory bank and "remember" when it emitted the same code. This little "trick" allows the GPS receiver to determine when the signal left the satellite.

Principle of GPS

The principle on which the working of GPS is based, deals with a simple formula used for calculation of distance. So, the velocity (V) is going to be the speed of light or roughly 186,000 miles per second. The distance this signal travels is given as (S). $S = V \times t$

GPS Error

Ionosphere and troposphere delays — The satellite signal slows as it passes through the atmosphere. The GPS system uses a built-in model that calculates an average amount of delay to partially correct for this type of error.

Signal multipath — This occurs when the GPS signal is reflected off objects such as tall buildings or large rock surfaces before it reaches the receiver. This increases the travel time of the signal thereby causing errors.

Receiver clock errors — A receiver's built-in clock is not as accurate as the atomic clocks onboard the GPS satellites. Therefore it may have very slight timing errors Therefore, it may have very slight timing errors.

Orbital errors — Also known as ephemeris errors, these are inaccuracies of the satellite's reported location.

Number of satellites visible — The more satellites a GPS receiver can "see," the better the accuracy. Buildings, terrain, electronic interferenceor sometimes even dense foliage can block signal reception, causing position errors or possibly no position reading at all. GPS units typically will not work indoors, underwater or underground.

Satellite geometry/ Geometric Dilution of Precision (GDOP) — This refers to the relative position of the satellites at any given time. Ideal satellite geometry exists when the satellites are located at wide angles relative to each other Poor geometry results when the wide angles relative to each other. Poor geometry results when the satellites are located in a line or in a tight grouping.

Intentional degradation of the satellite signal — Two modification system called Selective Availability (SA) is an intentional degradation of the signal once imposed by the U.S. Department of Defense. SA was intended to prevent military adversaries from using the highly accurate GPS signals. First, the process of SA-dither is adopted whereby some of the satellite clock are placed out of phase by amounts known only to the military. Second SA-epsilon is applied so that the satellites returns an incorrect position for itself. The government turned off SA in May 2000, which significantly improved the accuracy of civilian GPS receivers

Table 1. GPS Error Budget

Error source	**Potential error**	**Typical error**
Ionosphere	5.0 meters	0.4 meters
Troposphere	0.5 meters	0.2 meters
Ephemeris data	2.5 meters	0 meters
Satellite clock drift	1.5 meters	0 meters
Multipath	0.6 meters	0.6 meters
Measurement noise	0.3 meters	0.3 meters
Total	~ 15 meters	~ 10 meters

Reduce GPS Error

DIFFERENTIAL GPS

The Earth's atmosphere slows the electromagnetic energy down somewhat, particularly as it goes through the ionosphere and troposphere creating errors. Differential GPS (DGPS) helps correct these errors. The basic idea is to gauge GPS inaccuracy at a stationary receiver station with a known location. Since the DGPS hardware at the station already knows its own position, it can easily calculate its receiver's inaccuracy. The station then broadcasts a radio signal to all DGPS-equipped receivers in the area, providing signal correction information for that area. In general, access to this correction information makes DGPS receivers much more accurate than ordinary receivers.