GPS (GLOBAL POSITIONING SYSTEM) BASICS AND APPLICATIONS

Paul Ayers
Professor and Extension Agricultural Engineer
Department of Chemical and Bioresource Engineering
Colorado State University
Fort Collins, Colorado

INTRODUCTION

The Global Positioning System (GPS) was developed by the Department of Defense as a satellite navigation system to provide accurate and continuous navigation and position service. The system utilizes the NAVSTAR (NAVigation Satellite Timing And Ranging) satellites developed by Rockwell International. Positional and navigation information is obtained using triangulation of the NAVSTAR satellites.

GPS ELEMENTS

The NAVSTAR Global Position System consists of three elements. The control segment is located in Colorado Springs. This element uses stations located around the world to monitor the position of the satellites and transmit updates to the satellite. The space segment consists of the NAVSTAR satellites developed by Rockwell International, and the user segment encompasses the GPS receivers that are used for positioning and navigation. This includes commercial, recreational, and military application.

NAVSTAR SATELLITES

There are 24 satellites in the final NAVSTAR constellation. Deployment of the last satellite to complete the constellation occurred in November 1994. Of the 24 satellites, 21 are operational and 3 are reserved as spares. The satellites orbit at an altitude of 11,000 miles to maintain coverage and survivability. Four satellites are in each of the six orbital planes and are spaced 55 degrees apart. This provides a 24-hour, all weather, worldwide coverage with 6 to 12 satellites in view at all times.

POSITION DETERMINATION

GPS receivers utilize triangulation to determine their location on the surface of the earth. Knowing the distance from the receiver to at least three satellites as well as the position of those satellites, the position of the receiver can be calculated. The location of the satellites is transmitted directly to the GPS receiver. The distance from the GPS receiver to the satellite (also called pseudorange) is determined by measuring the time it takes for a signal to travel from the satellite to the receiver. This is done by measuring the time offset between when the receiver acquires the satellite signal and when the receiver generates that same signal. This is done only after the GPS receiver and satellite are synchronized to generate the same signal at exactly the same time. Very accurate clocks are needed to accomplish this task. Once the time for the signal to travel from the satellite to the receiver is known, the distance can be found using the speed of light (186,000 miles/second). Because the satellites are in an orbit of 11,000 miles, the signal takes about 0.06 seconds to reach the receiver.

SATELLITE OUTPUT

The NAVSTAR satellites are transmitting signals on two carrier frequencies referred to as L1 and L2. The L1 frequency (1575.42 MHz) carries the coarse acquisition (C/A) code. This is the code that is used in civilian applications. An encrypted Precise (P) code also is sent on the L1 frequency, but a special military GPS receiver is needed to decipher. The L2 frequency (1227.60 MHz) contains only the encrypted P code. The two carrier frequencies can be used to obtain more accurate positions. The ephemeris (or satellite position) information also is sent on the carrier frequencies.

GPS RECEIVER CALCULATIONS

The GPS receiver can use triangulation from the satellite to determine its position and is usually expressed as latitude (N/S) and longitude (E/W). Other usable information that is determined is altitude, bearing (direction of travel), speed, and time. The output from the receiver can either be displayed, stored, or sent out to another device. The storage and transfer of GPS information is done either using the NMEA 0183 format or a proprietary format.

GPS POSITIONAL ERRORS

The errors in the distance measurement from the satellite to the receivers (pseudorange) will produce inaccuracies in the GPS information. These errors can come from clock inaccuracies, satellite position inaccuracies, atmospheric delays, multipathing (reflectance of signal), and selective availability (SA). Remember, with GPS, time is distance. SA is an intentional error used by the Department of Defense to control access to the full accuracy of the NAVSTAR system. Alone, errors resulting from SA can result in inaccuracies of up to 100 feet. Satellite geometry can reduce the positional accuracies resulting from the pseudorange (distance) errors. For example, satellites that are grouped close together create more opportunity for error than satellites spread across the sky. This increase in uncertainty is called Dilution of Precision or DOP. Because of these errors, single GPS receivers have inaccuracies ranging up to 300 feet.

DIFFERENTIAL GPS

Because inaccuracies of the single GPS receivers can be up to 300 feet, differential GPS was developed to improve the positional accuracies. This technique uses two GPS receivers, a base station, and a rover. The base station is established at a known location. The base station utilizes its known location to determine the pseudorange (distance) errors to each of the satellites. The pseudorange errors for each satellite are then transmitted to the roving (moving) GPS receiver so that a more accurate position of the rover can be determined. The format for this transmission is RTCM 104 for compatible receivers. Using this technology, positional accuracies of 10 to 15 feet, or better, can be obtained. This accuracy enhancement procedure can either be done in real-time or at a later date (post processing). Post processing DGPS requires that the base station and rover receivers store the pertinent data and that special post processing software be utilized. Real-time DGPS requires a communication link between the base station and rover receivers. Real-time DGPS can be accomplished using two receivers and a radio link or by using a Wide Area Differential GPS Network. This network is used to broadcast differential correction information using either an FM broadcast or satellite transmissions. Satellite transmissions of differential correction information is worldwide but also is expensive. FM broadcasts are subjected to signal degradation if the rover is a significant distance from the broadcast location. Both require a subscription to acquire the signal as well as a hardware purchase to obtain the decoder and antenna.

CARRIER-AIDED TECHNOLOGY

By utilizing both the code and carrier frequency of the NAVSTAR satellite transmissions, better positional accuracies can be obtained. Kinematic (on-the-go) DGPS accuracies of less than 3 feet have been reported. If a dual frequency static DGPS technology is used, accuracies are less than 1 inch. However, the better the accuracy, the more expensive and less flexible the system becomes.

PURCHASING A GPS RECEIVER

When purchasing a GPS receiver, the cost and accuracy required is the first consideration. Other considerations include:

- Power supply (Is the receiver battery powered or does it need 12 volts?)
- Display (Can the position be displayed?),
- Output compatibility (Does the receiver use NMEA 0183 format for output?),

- Capable of differential correction (Can it receive RTCM 104 format?),

- Number of channels (Can the receiver lock on to enough satellites?), and

- Waypoint Identifier (Can the GPS receiver help you get home?).

FUTURE CONSIDERATIONS FOR GPS

GPS technology is changing rapidly. Costs are decreasing, and receivers are becoming more accurate. Wide area differential correction transmission using FM broadcast is becoming more widespread. The Department of Transportation is considering a public, no fee, broadcast of differential correction signals. Congress is putting pressure on the Department of Defense to turn off SA (differential correction may not be necessary). The Russians have nearly completed their own positioning system called GLONASS, and dual system receivers are being marketed (NAVSTAR may not be necessary). Some companies are planning private positioning satellite systems. Regardless of the change in GPS technology, expect to see GPS, of some sort, quickly become a part of our everyday lives, whether we know it or not.

Glossary of GPS terms

Almanac Data Satellite constellation information (including location, velocity, and health of satellites) that is transmitted to the receiver from every GPS satellite. Almanac data must be acquired before GPS navigation can begin.

Anywhere Fix The ability of a receiver to start position calculations without being given an approximate location and approximate time.

Bandwidth The range of frequencies in a signal.

Base Station GPS receiver placed at benchmark transmitting differential corrections.

Bearing The compass direction from the position to a destination, usually expressed as degrees (clockwise) from north.

Benchmark Location of known position to place base station.

C/A Code The standard (Coarse/Acquisition) GPS code—a sequence of 1023 pseudo-random binary, biphase modulations on the GPS carrier at a chip rate of 1.023 MHz. Also known as the "civilian code."

Carrier A steady transmitted RF signal whose amplitude, frequency or phase can be modulated to carry information.

Carrier-aided Tracking A signal processing strategy that uses the GPS carrier signal to achieve an exact lock on the pseudo-random code.

Carrier Frequency The frequency of the unmodulated fundamental output of a radio transmitter.

Carrier Phase GPS GPS measurements based on the L1 or L2 carrier signal.

Channel A channel of a GPS receiver consists of the circuitry necessary to receive the signal from a single GPS satellite.

Circular Error Probable (CEP) The radius of a circle that contains 50 percent of the position measurements.

Clock Bias The difference between the clock's indicated time and true universal time.

Coarse Acquisition (C/A) Code A sequence code used by commercial GPS receivers to determine the range to the transmitting GPS satellite.

Code Phase GPS GPS measurements based on the C/A code.

Control Segment A world-wide network of GPS monitor and control stations that ensure the accuracy of satellite positions and their clocks.

Course Made Good The bearing from a starting point to present position.

Crosstrack Error The distance off a desired course in either direction.

Cycle Slip A discontinuity in the measured carrier beat phase resulting from a temporary loss-of-lock in the carrier tracking loop of a GPS receiver.

Data Message A message included in the GPS signal that reports the satellite's location, clock corrections, and health. Included is rough information on the other satellites in the constellation.

Dead Reckoning (DR) To determine the position using the last known position and a computer position vector (i.e., course, velocity, and time).

Desired Track The compass course between the "from" and "to" waypoints.

Differential GPS (DGPS) A technique to improve GPS accuracy using pseudorange errors to measure at a known location to adjust the measurements made by other GPS receivers.

Dilution of Precision The multiplicative factor that modifies ranging error. It is caused solely by the geometry between the user and the current set of satellites. Known as DOP or GDOP.

Dithering — The introduction of digital noise. This is the process the DoD uses to add inaccuracy to GPS signals to induce Selective Availability.

Doppler-aiding — A signal processing strategy that uses a measured doppler shift to help the receiver smoothly track the GPS signal. Allows more precise velocity and position measurement.

Doppler Shift — The apparent change in the frequency of a signal caused by the relative motion of the transmitter and receiver.

Ephemeris — A set of satellite orbit parameters used by the GPS receiver to calculate current satellite position and velocities that are transmitted to the user in the data message.

Estimated Time of Arrival (ETA) — The time of day of arrival at a destination.

Estimated Time Enroute (ETE) — The time left to destination at present speed.

***Fast-switching* channel** — A single channel that rapidly samples a number of satellite ranges. "Fast" means that the switching time is sufficiently fast (2 to 5 milliseconds) to recover the data message.

Frequency Band — A particular range of frequencies.

Frequency Spectrum — The distribution of signal amplitudes as a function of frequency.

Geodetic Datum — The reference ellipsoid surface that defines the coordinate system.

Geoid — The shape of the earth considered as a sea level surface and perpendicular to the force of gravity.

Geometric Dilution of Precision (GDOP) — See Dilution of Precision.

GPS — Global Positioning System—a satellite-based radio positioning system.

Grid — A coordinate system that projects the earth on a flat surface, using square zones for position measurements.

Ground Speed — The travelling velocity relative to a ground position.

Handover Word — The word in the GPS message that contains synchronization information for the transfer of tracking from the C/A to P code.

Heading — The direction of travel at any instant. Usually expressed s degrees clockwise from north.

Ionosphere — The band of charged particles 80 to 120 miles above the earth's surface.

Ionospheric Refraction — The change in the propagation speed of a signal as it passes through the ionosphere.

Latitude — A north/south measurement of position perpendicular to the earth's polar axis.

L1 Frequency — The 1575.42 MHz GPS carrier frequency that contains the C/A code used by commercial receivers. This frequency also carries the encrypted P-code.

L2 Frequency — The 1227.60 MHz GPS carrier frequency containing only the encrypted P-code. This frequency can be used to calculate signal delays caused by the ionosphere.

Longitude — An east/west measurement of position in relation to the Prime Meridian, an imaginary circle that passes through the north and south poles.

Mask Angle — Angle above the horizon desired before satellites will be used for positioning.

Multipath Error — Errors caused by the interference of a signal that has reached the receiver antenna by two or more different paths. Usually caused by one path being bounced or reflected.

Multi-channel Receiver — A GPS receiver that can simultaneously track more than one satellite signal.

Multiplexing Channel A channel of a GPS receiver that can be sequenced through a number of satellite signals.

NAVSTAR *NA*V*igation* *S*ystem ***and*** *T*iming *a*nd *R*anging.

NMEA 0183 Standard format for GPS receiver outputs (National Marine Electronics Association).

Obscuration Periods of time in which the line of sight between the satellite and GPS receiver is lost.

P-code The precise code—a very long sequence of pseudo-random binary biphase modulations on the GPS carrier at a chip rate of 10.23 MHz which repeats about every 267 days. Each one week segment of this code is unique to one GPS satellite and is reset each week. Primarily used by the military.

Position An exact, unique location based on a geographic coordinate system.

Precise Positioning Service (PPS) The most accurate dynamic positioning possible with standard GPS, based on the dual frequency P-code and no SA. Authorized by the U.S. Department of Defense.

Pseudolite A ground-based differential GPS receiver that transmits a signal like that of an actual GPS satellite and can be used for ranging.

Pseudorandom Code A signal with random, noise-like properties. It is a very complicated but repeated pattern of 1's and 0's.

Pseudorandom Number (PRN) The identity of the GPS satellite based on their pseudorandom noise codes.

Pseudorange A distance measurement based on the correlation of a satellite transmitted code and the local receiver's reference code, that has not been corrected for errors in synchronization between the transmitter's clock and the receiver's clock.

Receiver Channels A GPS receiver specification that indicates the number of independent hardware signal processing channels. These channels receive the signals transmitted by the satellites.

Route A planned course of travel.

Rover GPS receiver (moving or stationary) that utilizes differential corrections to more accurately determine position.

RTCM 104 Standard format for receiving and transmitting differential correction data (Radio Technical Commission for Maritime—Special Committee 104).

S/A (Selective Availability) Intentional timing error introduced by the Department of Defense to control access to full GPS accuracy.

Satellite Constellation The arrangement in space of a set of satellites.

Satellite Elevation The angle of the satellite above the horizon.

Sequential Receiver A GPS receiver in which the number of satellites tracked exceeds the number of available channels. Satellite signals are then periodically assigned to channels.

Slow Switching Channel A sequencing GPS receiver channel that switches too slowly to allow the continuous recovery of the data message.

Space Segment The part of the whole GPS system that is in space, i.e., the satellites.

Spheroid or Ellipsoid A mathematical figure that very closely approximated the geoid—the surface of reference used in geodetic surveys.

Standard Positioning Service (SPS) The normal civilian positioning accuracy obtained by using the single frequency C/A code

Static Positioning	**Location determination when the receiver's antenna is presumed to be stationary in the earth. This allows the use of various averaging techniques that improve accuracy by factors of over 1000.**
SV	**Space vehicle (satellite) number (similar to PRN).**
Time to Fix	**Time required by a GPS receiver to acquire satellites and determine location.**
Track	**The direction of movement relative to a ground position.**
Undulation	**The distance of the geoid above or below the spheroid. Also known as the geodial height.**
Universal Time Coordinated (UTC)	**The time system used in GPS output sentences. The same time zone as Greenwich Mean Time (GMT).**
Universal Transverse Mercator (UTM)	**A grid coordinate system that projects global sections onto a flat surface to measure position in specific zones.**
Update Rate	**The position solution rate for the GPS receiver.**
User Interface	**The way a receiver conveys information to the person using it—the controls and displays.**
User Segment	**The part of the whole GPS system that includes the receivers of GPS signals.**
Velocity Made Good	**The speed at which closing in on a destination along a desired course.**
Waypoints	**A geographic point identified with latitude and longitude.**
WGS-84	**World Geodetic System 1984—a spheroid that closely approximates the shape of the earth on a worldwide basis. Used as the center of the GPS reference frame.**