THE UNIVERSITY OF GEORGIA
COOPERATIVE EXTENSION
Colleges of Agricultural and Environmental Sciences & Family and Consumer Sciences

Explaining GPS: The Global Positioning System

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Introduction

GPS has become a vital tool for outdoor agricultural professionals (farmers, consultants, etc.) and many other professions. GPS, or the Global Positioning System, is basically an electronic tool that provides the user with accurate position information, usually in the form of world coordinates (latitude and longitude). However, this simple concept — accurate location determination — has far-reaching implications in agriculture and natural resource management because, if the coordinates of a location are known, then you can return (navigate) to that location time and time again. This replaces the age-old method of landmark navigation with a fence post and a pine tree.

For example, suppose Farmer Joe notices a low yielding area in a field and wishes to determine "why" later in the year, after harvest. Farmer Joe could try to visually mark the "spot" by aligning the spot with some landmarks in the area, or he could mark that area with a GPS receiver and then later return to the spot as often as necessary to diagnose the problem. The same concept works for Fisherman Bill who wants to mark a favorite fishing spot in the Gulf of Mexico.

Even though GPS receivers are becoming very popular, few people have a good understanding of just how GPS works, what GPS is capable of, and what to expect when purchasing a receiver. This publication will provide you with a simple and straightforward explanation of how GPS works and how this technology can be put to work to help you in your job.

What Is GPS?

GPS is a $12+ billion navigation system made up of satellites, ground-based control, and an end-user receiver and antenna (the hardware we use). In the 1970s, after much research, the U.S. Department of Defense (DOD) developed and began deploying a satellite-based system to provide military positioning, navigation and weapons-aiming capabilities — the Global Positioning System. By 1993, the DOD had launched 24 satellites (plus three backups) to fully implement the GPS system.

While the original use of GPS was solely military, civilian use soon followed. In 1984, following the downing of Korean Airlines Flight 007, then-President Reagan announced that part of the capa-bilities of GPS would be made available to the civilian community to ensure civilian jetliners would stay on course. This technology is now available to everyone, everywhere, at any time and, best of all, at no cost. GPS operates 24 hours a day in all weather conditions, and can be used world-wide for precise navigation on land, on water and even in the air. Today, the civilian use of GPS likely equals or surpasses that of the military.

How Does GPS Work?

The basic operating principle of GPS is quite simple. Each GPS satellite broadcasts a coded radio signal (traveling at the speed of light) containing its orbit position and a very accurate time value (exact to a billionth of a second). The GPS receiver uses this data to calculate distance to the

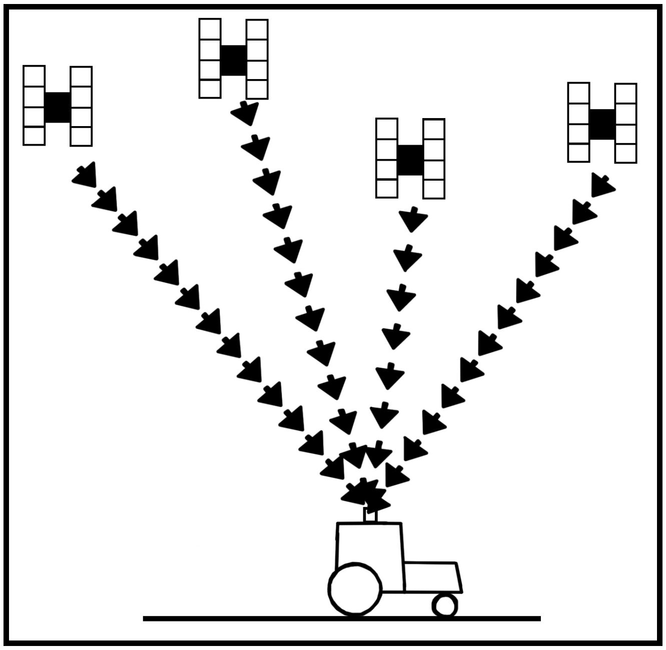

Figure 1. Four satellites are required to determine a GPS position.

satellites by determining the time it took the signal to travel from the satellites to the receiver. A GPS receiver uses this data from a minimum of four satellites (Fig 1) to calculate (via trilateration) the receiver's distance from each satellite and then its position on the earth — latitude, longitude and altitude (i.e. 3-D position).

This distance calculation (from each satellite to the receiver) must be very precise to determine position. Each satellite uses four cesium-based atomic clocks to achieve their high degree of timing accuracy, whereas consumer-oriented GPS receivers use less sophisticated and less expensive internal timing circuitry. However, the receivers continuously update their clocks from the satellite clocks thus making them far more accurate than your wristwatch.

Except for the ultra-precise "P-Code" signal (reserved for military use), every GPS satellite's current navigational message (the C/A signal) is broadcast such that it can be detected, recognized, and processed by any GPS receiver operated by any user anywhere on (or near) earth.

The 24 GPS satellites orbit the earth twice in a 24-hour period at an altitude of about 12,000 miles. DOD positioned the satellite orbits such that at least five satellites are always "visible" to a receiver anywhere on the earth. This is important since a minimum of four satellites is required to calculate a position (Fig 1). However, many newer GPS receivers are equipped to receive up to 12 satellite signals and choose the satellites with the strongest signal and best spacing to calculate position.

GPS Errors

Don't assume, however, that using a GPS receiver to determine latitude, longitude and altitude ensures absolute accuracy. Several factors can cause positional errors that affect GPS accuracy. The most common factors affecting GPS accuracy include clock errors, ephemeris errors, atmospheric delays, multipathing and satellite geometry.

Clock errors occur because the previously mentioned internal timing circuitry of GPS receivers is not as accurate as satellite clocks. Very small differences between the receiver clock and satellite clocks can cause noticeable errors in position.

Ephemeris errors are position errors caused by slight satellite orbit variations that must be periodically adjusted by ground controllers.

The earth's **atmosphere** can also affect GPS accuracy (Fig 2). Electrically charged particles in the ionosphere and water vapor in the troposphere combine to slow satellite signals as they pass through these regions. This slight slowing of the

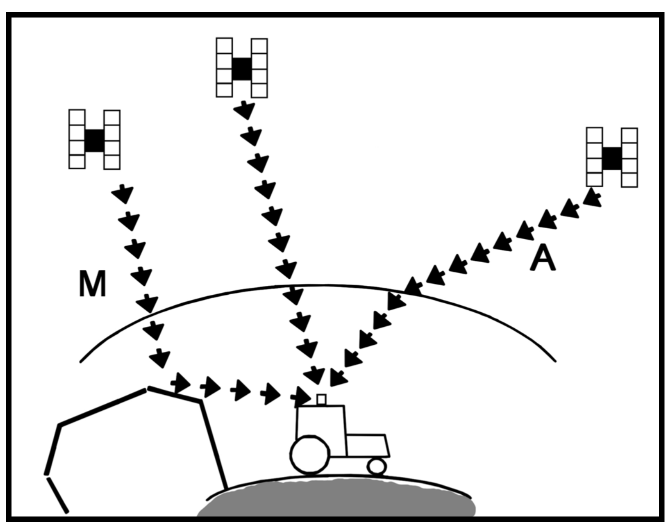

Figure 2. The atmosphere (A) and multipath (M) are two sources of GPS error.

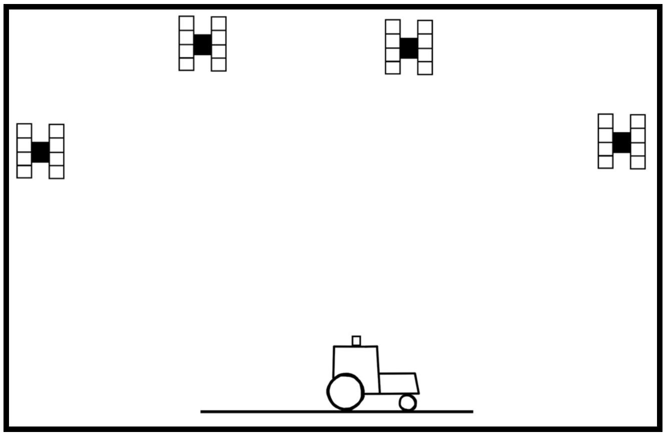

Figure 3. Example of good satellite constellation. Satellites are spaced far apart for better position calculation.

through these regions. This slight slowing of the signals can introduce considerable position errors.

Multipath errors are caused by reflected satellite signals that are received after bouncing off buildings, lakes, etc. (Fig 2). The reflected signals are not traveling directly from satellites and thus “confuse” the GPS receiver when it makes position calculations. Because it takes longer for the signal to reach the receiver, the receiver thinks it is farther away from the satellite than it actually is.

Satellite geometry can magnify positional errors due to configuration of the satellites in the sky in view of a receiver (satellite constellation). In most cases, the farther apart the satellites, the better the position calculation (Fig 3). Satellite constellation “quality” is quantified by a value called *Dilution of Precision* (DOP). For example, in Figure 4, the constellation with satellites “clumped” together would have a higher DOP than the constellation with satellites more evenly distributed in the sky (Fig 3). Many end-user GPS receivers report HDOP (horizontal DOP — or quality of the latitude/longitude) or PDOP (position DOP — or quality of the three-dimensional position data). A DOP of less than four is usually preferred for most applications.

Differential GPS

Even though the civilian market for GPS technology has grown tremendously, the primary use for GPS remains the U.S. military. The Space segment (the satellites) and the Ground Control segment (the controllers on the ground) are still exclusively maintained by the DOD. However, as mentioned earlier, each GPS satellite is configured to broadcast its navigational message on two radio frequencies (P-code signal and C/A signal). The simpler of the two, the C/A signal (C/A = coarse acquisition), is made available for non-military GPS uses worldwide.

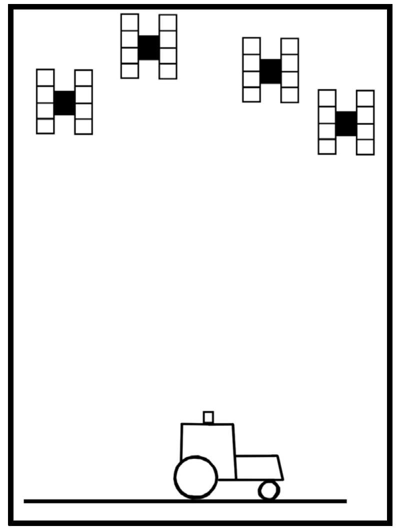

Figure 4. Example of poor satellite constellation. Satellites are spaced closely together for a poor position calculation.

The best accuracy that can be reliably expected with a stand-alone, C/A signal, non-military (ie. consumer grade) GPS receiver is about 100 feet. Obviously, this would “get you out of the woods” but would not be accurate enough for most applications in the agricultural or natural resources areas. To offset the effects of GPS errors and to increase the overall accuracy of consumer grade GPS units, a system called *Differential GPS,* or DGPS, is used. The DGPS system uses GPS receivers accurately placed at known locations (base station). Base station GPS receivers constantly calculate the error between location determined from GPS signals and its known location. This error is then relayed to a rover GPS receiver being used “in the field” for normal GPS work. That rover GPS is able to use the relayed error information to correct and improve its own GPS position calculated from C/A GPS signals. The accuracy level of the rover GPS can be improved to a range from 1.5 to 15 ft, depending on the system.

Today, users do not need to establish their own base stations to obtain DGPS. Now there are several sources for DGPS correction signals that enable DGPS-equipped receivers to function over wide areas. The differences in these sources lie in the delivery methods and reliability of the DGPS signals.

Sources for DGPS

The U.S. Coast Guard (USCG) has established base station receivers and transmitting beacons along the coastlines and major river systems. The USCG employs transmitters on towers at these locations that deliver DGPS correction signals free of charge. However, coverage is limited to areas near established base stations and signal strength decreases (as will accuracy) with distance from these base stations. Typically, the positional error of a USCG DGPS position is 3 to 10 ft. However, only a very limited number of handheld GPS receivers are compatible with USCG DGPS.

The U.S. Federal Aviation Administration (FAA) created the Wide Area Augmentation System (WAAS) version of DGPS around 2000. It was created initially to aid the airline industry's use of GPS technology for navigation to and from U.S. airports. The WAAS system broadcasts its correction signal from geostationary satellites (not the GPS satellites) orbiting above the equator. Like the USCG beacon signal, WAAS is a free service. Typically, the positional error of a WAAS DGPS position is 9-15 ft.

There are also commercial (subscription-based) DGPS correction providers. The market leader in this type DGPS source is OmniSTAR (800-338-9178, www.omnistar.com) which provides its subscribers with continental coverage and 3 ft or better accuracy. The company maintains a network of eleven permanent base stations (10 in the U.S., plus 1 in Mexico). The base stations track all GPS satellites in view and compute corrections for each. OmniSTAR correction messages are checked, compressed, and up linked to a geostationary com-munications satellite which then broadcasts this correction info to OmniSTAR-compatible GPS receivers. Unlike beacon tower differential data (where a user's positional accuracy decreases with range), an OmniSTAR subscriber may use his GPS equipment anywhere within the coverage area and get consistent accuracy better than 3 feet. Recently, OmniSTAR introduced OmniSTAR/HP (for High Precision) that aims to provide accuracy in the 4-10 inch range. However, the OmniSTAR/HP system requires a special OmniSTAR dual-frequency receiver.

Other sources for subscription-based DGPS includes the John Deere StarFire system. This wide-area DGPS signal is available to John Deere GPS receivers throughout the continental United States. Deere offers the correction signal in two packages: StarFire and StarFire 2. The original StarFire package provides positional accuracy better than 3 feet while StarFire 2 will provide 4 inch accuracy. Like OmniSTAR/HP, the StarFire 2 system requires a special dual frequency receiver.

What Is GPS Accuracy?

What exactly do we mean by the term "accuracy" when talking about GPS receivers? In general, accuracy refers to the ability of a GPS receiver to calculate the coordinates of an exact location. If the coordinates from a GPS receiver were compared to actual/known coordinates of some point, there would likely be some discrepancy (or error) between the known and calculated. The discrepancy would be given in distance from the known point (ie., x ft or m). All of the sources of GPS error described earlier (clock, ephermeris, atmosphere, multipath, satellite geometry) contribute to the accumulative error.

The performance and accuracy of a receiver is usually directly related to cost. For example, a low-cost handheld, recreational GPS receiver without WAAS capability (about $100) can often provide GPS position data with an accuracy of about 30 ft. If a similar unit is capable of using WAAS (about $150), the accuracy often improves to 15 feet or less. Table 1 (page 5) compares GPS receivers of various classifications.

The accuracy required for the task at hand should be considered before purchasing a GPS

Table 1: GPS Receiver Classifications#

	Class I	Class II	Class III	Class IV
Price	$100 to $800	$800 to $3,000	$3,000 to $10,000	$20,000 to $50,000
Differential Correction Source	WAAS	WAAS, Coast Guard Beacon, fee-based subscriptions	Dual frequency	Real-time Kinematic (RTK) with base station
Update Rate	0.5 to 1 Hz	1 to 10 Hz	1 to 10 Hz	1 to 10 Hz
Static Accuracy*	5 ft to 12 ft	Less than 3 ft	4 in to 12 in	Less than 2 in
Static GPS Position Location	Not stable	Somewhat stable	Stable	Stable
Advantages	Compact size, mobile	Higher quality than Class I, faster update rates	Greater accuracy for precise applications	Highly accurate, survey grade, repeatability
Uses	Scouting (>15 sq ft area), mapping, limited VRT applications	Mapping, guidance (broadacre), VRT applications	Guidance (broadacre and possibly row-crop), mapping, VRT applications	Elevation (topographic) mapping, all types of guidance, surveying

* How much the reported position varies while the unit is stationary.
# Adapted from work by Sullivan and Ehsani, Ohio State University.

unit. The accuracy required to assign a soil sampling location will be quite different (larger) from the accuracy required by a GPS receiver linked to a guidance system used in planting a crop.

Output Data and Rate

Most GPS receivers provide a connector for serial data output from the unit. This allows the position data to be linked to a computer or data-logger device for recording purposes. Any GPS reciever that you will likely encounter will be able to output data in NMEA 0183 format suitable for linking to variable-rate controllers, guidance systems, mapping software, yield monitors, etc. The NMEA 0183 standard defines several information strings or "sentences" that can be output by the receiver. These include GGA, GSA, VTG and RMC, among others. The particular sentences required will depend on the device being used. The NMEA sentences may be output at a rate of one per second (1 Hz) up to 10 per second (10 Hz) depending on the GPS options.

Uses for GPS

Just as there are numerous styles and models of GPS receivers, there are many uses for GPS. Hand-held GPS units (Class I) are useful for determining locations of features and creating boundaries and

determining areas of boundaries. Features could include a well, a building, a crop scouting incidence location, an anomaly in a field — basically any item that can be identified by its location. Boundaries could include a field boundary, a pond, public park, parking lot, etc.

Class II and Class III GPS receivers, in addition to uses described for Class I receivers, are useful for connecting to guidance systems like lightbars and autosteer systems, for variable-rate applications, and for yield mapping. Class IV systems are designed for surveying, topographic mapping, and for precise GPS guidance systems.

For More Information

Before purchasing a GPS receiver, take the time to do some research. Decide the realistic accuracy level required to accomplish the task. Research the various manufacturers and models on the market. The internet provides access to a vast array of information on GPS receivers.

Some sources of GPS information on the internet include:

Manufacturers

www.trimble.com
www.garmin.com
www.magellangps.com
www.novatel.com

Dealers

www.gps4fun.com
www.bassproshops.com
www.theGPSstore.com
http://www.rei.com/shop/GPS.htm

Technical Information

http://www.colorado.edu/geography/gcraft/notes/gps/gps.html
http://tycho.usno.navy.mil/gps.html
http://vancouver-webpages.com/peter/
http://www.gpsy.com/gpsinfo/

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