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Ohio State University Fact Sheet

Food, Agricultural and Biological Engineering

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Unraveling the GPS Mystery

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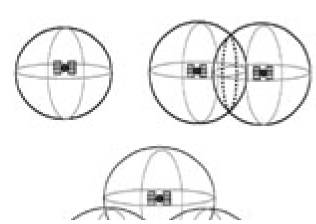
Precision agriculture is rapidly becoming an important tool for Ohio farmers. The Global Positioning System (GPS) is a key technology that has made precision agriculture possible. GPS receivers, which provide accurate, georeferenced position information, are often used with combine yield monitors, scouting equipment, or variable rate application machinery. Unfortunately, the technology behind GPS receivers is still a mystery to many users. This fact sheet answers some common questions about GPS technology and gives a clear and simple explanation of how GPS receivers work.

What is GPS?

The Global Positioning System is a $12 billion system of 24 satellites (plus a few spares) deployed and maintained by the U.S. Department of Defense (DOD). Each satellite passes around the earth twice in a 24-hour period at an altitude of about 12,500 miles. Radio signals from these satellites can be used to determine accurate georeferenced position information. Deployment of the satellites began in 1978, and the system became fully operational (uninterrupted global coverage) in 1995.

How does it work?



GPS receivers use a principle called triangulation. Triangulation is a method of determining the position of an object by measuring its distance from other objects with known locations. A GPS receiver uses the signals from a satellite to determine its distance from that satellite. As illustrated in Figure 1, if you know your distance from one satellite, you could be anywhere on a sphere

around that satellite. If you add distance information from a second satellite,
you narrow your location to the intersection of the two spheres around those satellites, which puts you somewhere on a circle. Addition of a third sphere locates you at one of two points. Though one of the points can usually be eliminated as an unreasonable location, a fourth satellite signal will give confidence in which point is valid. Though only four satellite signals are required to get a valid position, some receivers are equipped to receive as many as 12 satellite signals simultaneously. The extra satellites are used to increase accuracy.

How can a receiver measure distance to a satellite?

The GPS satellites broadcast radio signals on two different frequencies: L1 (1575.42 MHz) and L2 (1227.60 MHz). There are two different digital codes that are transmitted on these frequencies. The Precise (P) code is transmitted on both frequencies, but is scrambled so that only U.S. DOD-authorized users can interpret the information. The Civilian Access (CA) code is globally available on the L1 frequency to any civilian user, but is inherently less accurate than the P-code. Users with basic DOD-approved P-code receivers can reliably determine positions to within 70 feet; basic civilian CA-code receivers are only reliable to within about 300 feet.

The P and CA codes broadcast from each satellite contain two critical pieces of information. The first is time information. Each satellite has several atomic clocks, which generate very accurate timing signals that are transmitted to the user. The second piece of information is the satellite's ephemeris. The ephemeris is a set of orbit parameters used to calculate the position of the satellite. Ephemeris can be thought of simply as the location and orientation of the satellite.

A GPS receiver uses the timing data transmitted by the satellite to measure the amount of time it took the signal to travel from the satellite to the receiver. Since radio signals travel at the speed of light (186,000 miles per second), the distance between the satellite and receiver is the transmission time multiplied by the speed of light. This calculation must be very precise in order to get accurate position information. The locations (ephemeredes) of the transmitting satellites are then used to triangulate the receiver position.

What causes errors in GPS readings?

There are several things associated with the GPS system that can cause errors in GPS position information. Here is a list of the most common sources of GPS errors:

Clock

GPS satellites carry very accurate atomic clocks to generate timing signals. GPS receivers must also have a clock to compare the timing signals received from the satellites to internally generated timing signals. For cost reasons, most GPS receiver clocks are not as accurate as satellite clocks, nor are they tightly synchronized with satellite clocks. Though only three satellite signals are absolutely necessary for triangulation calculations, a fourth satellite signal is necessary to synchronize the receiver clock with the satellite clocks.

Ephemeris

Satellite orbits can vary slightly over time and require periodic adjustment by system maintainers. Since the orbits vary, errors can exist in the satellite ephemeris (location) data used in triangulation calculations.

Dilution of Precision (DOP)

The configuration of the satellites in view to a receiver at any given time can affect the accuracy of position determination. For instance, if all of the visible satellites happen to be bunched close together, the triangulated position will be less accurate than if those same satellites were evenly distributed around the visible sky (Figure 2). The satellite configuration is quantified by the Dilution of Precision (DOP). Many GPS receivers will display values for Horizontal DOP (quality of latitude and longitude data), Vertical DOP (quality of elevation data), Position DOP (quality of three-dimensional measurement), or Time DOP (quality of time determination). Lower values for DOPs indicate better satellite configurations. In general, DOPs less than four will give good position determinations.

Atmosphere

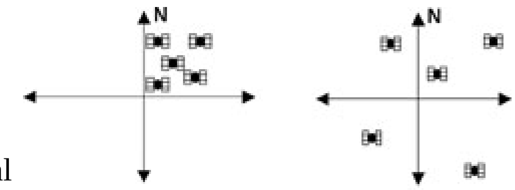


Figure 2. Satellite configurations that will give (a) poor DOP and (b) good DOP.

When radio waves from GPS satellites enter the earth's atmosphere, their paths can be bent or refracted (Figure 3). This bending will actually change the length of the path the radio signal takes to get to the receiver. This change in length will cause an error in distance determination. Atmospheric effects are usually greater on satellites low on the horizon since the radio waves enter the atmosphere at more of an angle. Some GPS receivers allow the user to ignore or mask satellites below a set angle above the horizon.

Multipath

Multipath errors are similar to atmospheric errors but are often more severe. Multipath means that the same radio signal is received several times through different paths. For instance, a radio wave could leave a satellite and travel directly to the receiver, but it also bounces off a building and arrives at the receiver at a later time (Figure 4). Multipath can confuse position calculations and cause significant errors. The most common causes of multipath errors in agricultural settings are buildings, ponds, and lakes.

Selective availability

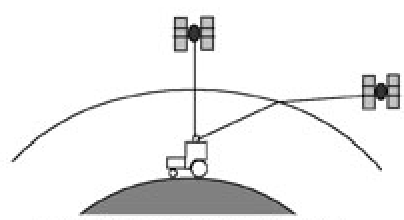


Figure 3. Signal refraction when entering the earth's atmosphere.

The most glaring source of GPS errors is selective availability. The DOD is concerned about hostile forces using this highly precise system against the United States. Therefore, the DOD purposefully induces errors, called Selective Availability (SA), into the CA codes. When SA is in effect, the best accuracy that can be reliably achieved with a stand-alone CA-code GPS receiver is about 300 feet. If SA is turned off, accuracy is improved to about 100 feet. Obviously, these accuracy levels are not adequate for precision agriculture applications.

How do we increase GPS accuracy?

In agricultural applications, the most common way to counteract GPS errors is by using Differential GPS or DGPS. In a DGPS system (Figure 5), a GPS receiver is placed at an accurately known location. This *base station* receiver will calculate the error between its actual location and the location computed from the GPS signals. The error information is communicated to the *rover* receiver being used in the field, which is then able to correct the position information it computes from the GPS signals. Accuracies of DGPS systems can range from 15 feet to 3 feet depending on system configuration.

In the early days of precision agriculture, users were forced to establish their own base station receivers in order to achieve accurate GPS positions. Fortunately, there are several external sources from which these correction signals can now be obtained.

The United States Coast Guard (USCG) has established base station receivers along major navigable bodies of water (e.g., the Ohio River and the Great Lakes). The differential correction information is broadcast from radio towers at these locations. The major advantage of the USCG corrections is that there is no subscription fee for signal usage. One disadvantage is that coverage is limited to areas near established base stations. For Ohio farmers, the nearest USCG radio beacons are at Detroit, Michigan, and Louisville, Kentucky (Figure 6). Also, signal strength will decrease, and the correction information itself becomes less accurate farther from the base station receiver.

Commercial satellite providers are the second common source for DGPS signals. These organizations will establish GPS base stations at various locations in their geographic region of interest. Error correction information obtained from these stations is sent to a communication satellite (separate from the GPS satellites) and broadcast back to the user. These satellite-based corrections tend to have a more widespread coverage than the tower-based broadcasts, and system accuracy is not greatly affected by the user's distance from the base station receivers. Most of these service providers, however, require a subscription fee for usage.

Some earlier generation DGPS receivers required separate antennas for GPS signals and differential correction signals. Most modern receivers combine all antennas into one single antenna unit.

An improvement over the standard DGPS is Kinematic DGPS or Real Time Kinematic (RTK) GPS. An RTK system will attempt to count the number of wavelengths of the carrier frequency radio signal between the satellite and receiver, thereby achieving accuracies of less than 1 foot. These systems are quite expensive, and require users to set up and maintain their own base stations; therefore, they are not commonly used in agricultural applications.

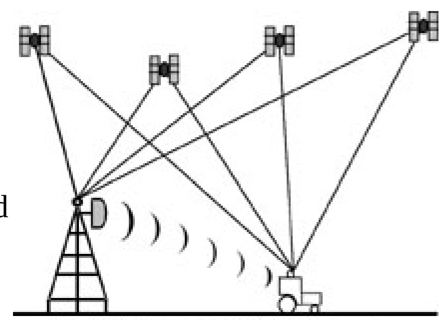


Figure 5. Differential GPS systems.

How do GPS manufacturers report accuracy?

GPS users should be aware that manufacturers use one of several methods to report the accuracy of a GPS receiver. Though it is rarely the intent of the manufacturer to be deceptive, an uneducated user can easily be misled.

Many manufacturers will base their accuracy report on the *rms* value; i.e., they will say that the receiver has "3-ft. rms accuracy." *RMS* is the same (for all practical purposes) as 1s *(1 sigma) or 1 standard deviation.* An *rms* or *1 sigma* specification is based on a 68% confidence level. This means that positions indicated by a GPS receiver that claims "3-ft. rms accuracy" will be within 3 feet of the actual position about 68% of the time. The other 32% of the time, positions may not be within 3 feet of the actual value.

Another related accuracy specification is 2*drms* or twice the distance *rms.* The confidence level for 2*drms* is 95%. Hence, if a GPS specification claims "3-ft. 2drms accuracy," you can be confident that the actual position is within 3 feet of the indicated position 95% of the time.

A third accuracy specification sometimes seen in agricultural GPS receiver literature is Circular Error Probable (CEP). CEP is based on a 50% confidence level, i.e., a 3-ft. CEP receiver will be within 3 feet of the actual position 50% of the time.

This reporting information is particularly important when comparing GPS receivers. A 2*drms* accuracy specification is twice as big as the *rms* specification for the same unit. The *rms* specification is about 1.2 times the CEP accuracy. In other words, a single GPS unit could have equivalent accuracy specifications of 1-ft. CEP, 1.2-ft. rms, or 2.4-ft. 2drms. Therefore, a unit with 5-ft. 2drms accuracy is actually more accurate than a unit with 3-ft. rms accuracy since 3-ft. rms is equivalent to 6-ft. 2drms.

Another important observation about *rms*, 2drms, and CEP accuracy specifications is that they are usually based on horizontal (latitude and longitude) position only. Vertical (elevation) data from GPS units are generally less accurate than horizontal data. In fact, a GPS receiver with a 3-ft. rms horizontal accuracy may only have 10-15 ft. rms elevation accuracy.

How does the GPS receiver transfer data to other devices?

Most GPS receivers use an RS232 serial port to transfer data to other devices. This is the same communication protocol that is used on the serial port of most personal computers; hence, GPS receivers can usually be connected directly to a personal computer via the proper cable.

There is one quirk about the RS232 communication standard that is worth mentioning here. The most common plug configurations for RS232 communications are the 9 and 25 pin connectors found on personal computers. Generally, the serial port on a personal computer is set up to transmit data from pin number 2 of its connector, and receive data on pin number 3. Most GPS receivers are set up the opposite--they transmit data on pin 3 and receive data on pin 2. Therefore, a very simple straight-through cable connection will allow the GPS receiver to send data from pin 3 of its port to pin 3 of the personal computer. Some peripheral devices such as yield monitors or hand-held personal computers use the same serial port configuration as the GPS receiver. A straight-through cable will cause both units to transmit data on the same pin, and nothing will be received. A simple solution to this problem is to use a null modem cable. The key feature of a null modem cable is that pins 2 and 3 are internally switched so that both devices can transmit on their own pin 2, and data will be received on pin 3 of the other device. Most equipment manufacturers will provide the proper cabling so that this transition is fairly transparent to the user, but atypical uses of GPS receivers may require further knowledge of RS232 communications.

The National Marine Electronics Association (NMEA) has established standards to determine how information is passed to and from GPS receivers on these RS232 serial ports. Essentially, they define specific logs, or information packets, that should be sent from the receiver. The device that reads the GPS data (yield monitor, computer, etc.) extracts the position information from the irrelevant information in the log. This standardization has helped make equipment interfacing nearly seamless and has made it possible for multiple manufacturers to produce equipment that will interface with a variety of peripheral devices.

In summary, the Global Positioning System is a pivotal technology that has made precision agriculture possible. GPS receivers with sufficient accuracy for yield mapping, grid sampling, variable rate application, and other precision activities are available at moderate cost. Differential correction signals are readily available anywhere in the United States. Industry standardization has made it possible for any GPS receiver to communicate with different pieces of equipment made by a variety of manufacturers.

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