Site-Specific Management Guidelines

D. Pfost, W. Casady and K. Shannon

SSMG-6

Global Positioning System Receivers

Summary

The global positioning system (GPS) and GPS receivers provide the means to determine position at locations anywhere on earth. Developed by the U.S. Department of Defense (DoD) and used for many civilian purposes, from fishing to flying, GPS has also made precision farming a reality. A typical configuration for on-farm agricultural applications includes a GPS receiver and antenna, a differential correction receiver and antenna, and cables to interface differentially-corrected (DGPS) data from the receiver to other electronic equipment such as a yield monitor or a variable rate controller. Accurate, automated position tracking with GPS receivers allows farmers and agricultural service providers to record geo-referenced data and to apply variable rates of inputs to smaller areas within larger fields.

GPS can provide accurate position data when installed and operated properly, but can produce false readings under poor conditions. Few, if any, receivers provide accurate position estimates 100 percent of the time.

GPS Technology

A GPS receiver can be compared with a simple AM or FM radio. A GPS receiver "listens" for the signals that are broadcast from the 24 GPS satellites operated by the DoD. Orbiting around the Earth at an altitude of 12,550 miles, these satellites are in predictable locations; hence, we refer to the system of satellites as the GPS constellation.

Each satellite broadcasts "almanac" data that contain information about the actual position of the satellites within the constellation. Minor variations in their orbits occur due to gravitational forces from the sun and the moon. The DoD continuously monitors the satellites and adjusts the almanac data to represent the actual orbits of the satellites.

The broadcast signals also contain a precisely timed, predictable code. There is a very small delay between the time the signals leave the satellites and the time they arrive at a GPS receiver. Yet, as a GPS receiver moves farther away from a satellite, this tiny delay becomes a little larger. A GPS receiver uses these delays to determine its distance from the satellites. The receiver then uses triangulation to determine its position on the earth.

Triangulation is a mathematical method for locating points in three-dimensional space. If the distances to each of three satellites and the approximate location of the receiver are known, the GPS receiver can calculate its position on earth. If information from four satellites is available, elevation can also be determined.

Accuracy

The overall accuracy of a GPS receiver at any given time depends on five factors: 1) proper installation, 2) the degree of technology used in the receiver, 3) the number and location of satellites, 4) errors introduced by selective availability (SA), atmospheric conditions, the troposphere, the ionosphere, and multipathing-radio signals bouncing off objects in the area, and 5) differential corrections.

Installation

GPS antennas should be mounted on the centerline of a combine, tractor or truck and above any part of the machinery that might obstruct a line of sight to a satellite. The top of the cab is often the best location. GPS and DGPS receivers may have separate antennas, but usually there will be a combination antenna so that both are centered at the same location.

A delay of several seconds often occurs in agricultural applications because the antenna is generally mounted on the roof of the cab, but processes such as planting, spraying, fertilizer applications, and even threshing and separating occur behind the cab. Threshing and separating also require more than 10 seconds to complete.

Example: If the antenna on a sprayer traveling 10 mph is mounted 30 feet ahead of the boom and a rate change at the controller requires 2 seconds to show up at the boom, the rate change will occur at the exact moment the boom reaches the location of the antenna where the change was

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made. If the sprayer was operated slower than 10 mph, the new rate would show up at the boom before the boom passed the point. If the sprayer was operated faster than 10 mph, the boom would pass the point before the new rate was effected. In the usual case, a time adjustment is factored into the system to compensate for time delays in sensing or applications.

Electrical interference can result from electrical storms, power lines, 2-way radios, nearby radio transmitters, electric motors, microwave towers, cellular phones, vehicular electrical equipment such as alternators and ignition systems on spark-ignition engines, and other sources. Interference from alternators and ignition systems can often be cured by repositioning the antenna or adding noise suppression kits. Follow the instructions for installation of the GPS equipment, making sure that all connections are tight.

Technology

Low-cost receivers, and especially older receivers, acquire signals from one satellite at a time. Receivers that use multiple channels to receive as many as 8 to 12 satellite signals simultaneously are quicker and more accurate than single channel multiplexing receivers. Receiver accuracy (or error) may be reported using various types of statistical measures such as root mean square (RMS) or circular error probable (CEP). You will need to find some accuracy statistic in common to be able to compare the performance of two or more units.

Reacquisition time is the time it takes to get an accurate position fix after a short-time loss of satellite signals; this may occur for a variety of reasons, including traveling near trees or buildings where some satellites are no longer in 'line of sight'. Reacquisition time is important for most agricultural applications and, especially, for guidance with applicators and aircraft. New technology in GPS receivers has shortened reacquisition time. Receivers that can track 8 to 12 satellites are less susceptible to acquisition loss.

Satellite Constellations

Using triangulation to calculate position, small errors in distance can cause large positional errors. The error in determining position through triangulation increases when satellites are close together. Best accuracy is produced when the receiver can pick up signals from many widely dispersed satellites (**Figure 1**).

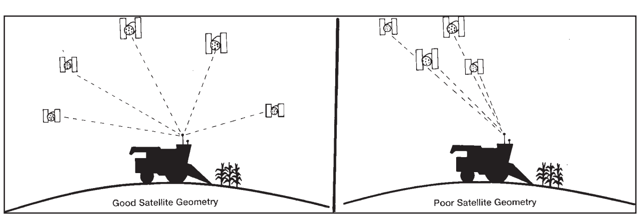

Figure 1. Good satellite geometry (widely and evenly-spaced satellites) yields more accurate GPS position estimates than poor satellite geometry. (Deere & Company ©)

Selective Availability and Other Errors

The DoD intentionally introduces an error into the signal. Although the error is predictable, only a select group of users is allowed to know the error in advance. Atmospheric, tropospheric, and ionospheric conditions, however, also cause distortions or errors in calculating distance; natural errors due to these conditions are not easily or reliably predicted. Hence, even in the absence of SA, differential corrections will still be required to accurately calculate position.

Multipathing, the same phenomenon that creates distorted television signals, is caused by signals that bounce off of other objects before reaching the antenna (**Figure 2**). Multipathing cannot be corrected by differential corrections.

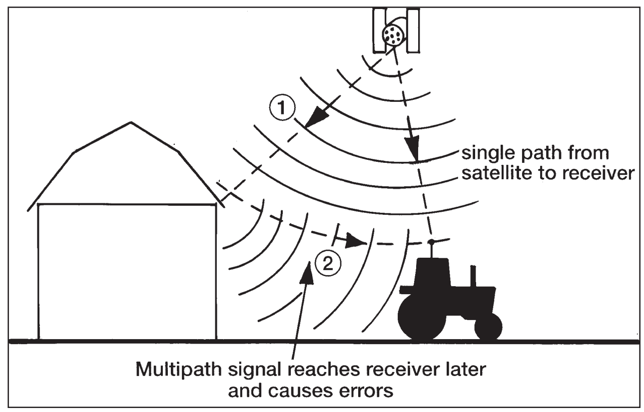

Figure 2. GPS signals can sometimes "bounce" off of objects in their path and cause the signal to reach the receiver on a different path. This is called multipath error. (Deere & Company ©)

Differential Corrections

Stationary GPS receivers are used to calculate the total error due to SA, variable atmospheric conditions, and other factors. The concept is simple. A stationary receiver always has a known location. Because the actual positions of the satellite and the receiver are known, the true range (distance) is known. The distance calculated by the receiver using the broadcast signals is known as the pseudorange, which is generally in error due to the combined sources of all errors. The difference between the true range and the pseudorange is the error and is known as the differential correction (**Figure 3**).

Differential correction data can be purchased and used at a later time in a process known as post-processing to reduce errors. However, the most common approach is to connect a differential corrections receiver to a GPS receiver to provide real-time corrections (**Figure 4**).

Many units incorporate GPS receivers and differential corrections receivers into the same unit. Differential corrections signals are available from the Coast Guard or Army Corps of Engineers and through commercial sources, which, for a fee, will provide signals from a satellite or a land-based tower. Where these sources aren't available, or for special applications, a private differential corrections source can be installed.

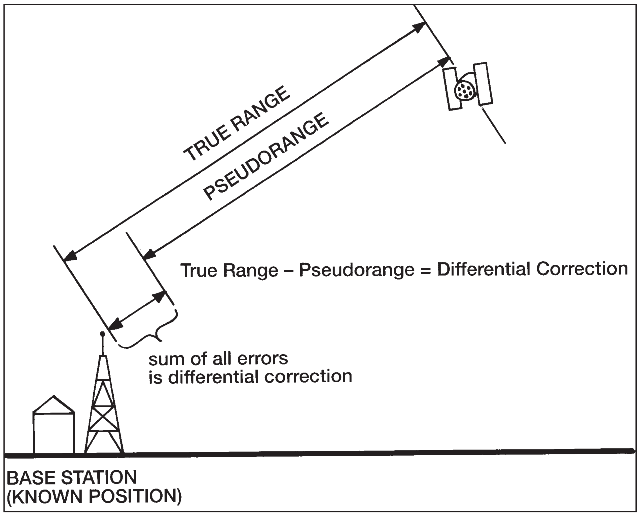

Figure 3. A stationary receiver (base station) measures its distance from each satellite (pseudorange) and then calculates the error pseudorange minus true distance). This error is called the differential correction. (Deere & Company ©)

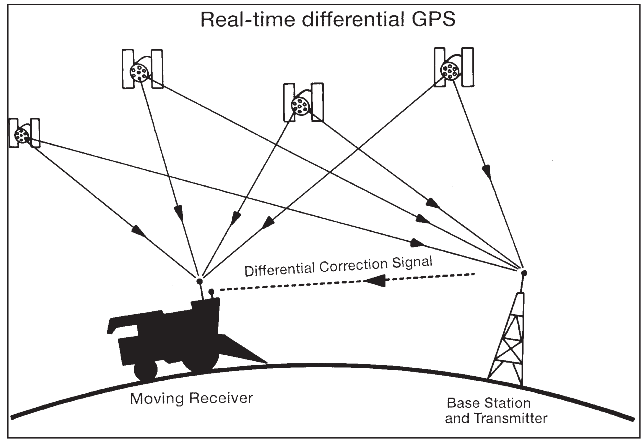

Figure 4. In real-time DGPS, the stationary receiver transmits the differential correction to the moving receiver via another radio signal. (Deere & Company ©)

Some of the newer DGPS receivers combine the capability of receiving differential signals from both the Coast Guard beacons and from a satellite service. Refer to **Table 1** for a comparison of features of Coast Guard and satellite-based differential corrections sources.

Coast Guard correction signals

Coast Guard signals are broadcast in the frequency range of 285 to 325 kHz (just below the usual AM-radio band) where radio waves travel as ground waves and are not limited to line-of-sight reception like FM-radio stations.

The signals are series of pulses similar to those of the GPS satellites and are referred to as Minimum Shift Keying modulation. Minimum Shift Keying is less sensitive to electrical interference and noise than AM-radios.

The range of the Coast Guard beacons is approximately 150 miles in good weather (electrical storms cause interference). Accuracy decreases with distance from the transmitter. This service is expected to become the choice of many agricultural users, especially near navigable waters where the signals are available.

A disadvantage of the Coast Guard differential corrections signal is the rate at which the beacon transmits or repeats messages. Most Coast Guard sites broadcast at 200 bits per second. At this broadcast rate, the age of a satellite's differential correction can be as old as four seconds. For some applications, such as guidance, this update rate may be unacceptable. For guidance applications, update rates of 2 to 10 times per second may be required.

Typical Coast Guard beacon receivers have two channels. One channel receives the differential correction, and the other is searching for the best incoming signal. This helps to ensure against loss of a DGPS signal if at least two beacons are within range.

Satellite-based correction signals

Satellite-based broadcasts are the most convenient and reliable source of differential corrections and are provided for a fee by commercial sources such as Omnistar and Racal. Typical annual user's fees range from $500 to $800. These correction signals are available throughout most of North America and are characterized by minimal interferance. Satellite-based signals are nearly overhead at all times and are less likely than land-based systems to be obstructed by trees and buildings.

Table 1. Comparison of Coast Guard and satellite differential corrections sources by feature.

Feature	Coast Guard Beacon	Satellite Differential
Accuracy (RMS)	<1m-(depends on distance from beacon station)	<0.75 uniform over service area—depends on service provider
Initial equipment cost	Lower initial cost	Higher initial cost
Subscription cost	None in US but beacon not available in many regions	$500 to $1000 per year, depending on level of service
Interference susceptibility	Subject to local man-made noise sources	Minimal interference from man-made sources
Range	100 to 250 miles	Large area coverage area—most of US

Land-based correction signals

Several commercial land-based correction signal services are also available for a fee. Some companies put up their own transmitters to broadcast correction signals; these include Accqpoint and others. Some commercial service providers piggyback correction signals onto commercial FM radio station transmitters. These sub-carriers include DCI and others.

Private GPS receiver and radio transmitter

GPS users not covered by Coast Guard or commercial sources of differential corrections can install a stationary receiver and transmitter to provide their own differential corrections source. For very accurate positioning (real-time kinematic), such as for surveying and machine control, a local differential receiver may be required.

For more information on differential satellite correction sources, refer to:

http://www.fse.missouri.edu/mpac/links/dgps.html

Cost Versus Accuracy

The accuracy attainable with GPS depends partly on how much you are willing to spend, ranging from approximately $100 to $100,000. A low-cost (from $100 to $500) GPS receiver without DGPS capability may be sufficiently accurate for some crop scouting applications, for navigating highways, or for locating your favorite fishing spot on a lake. The RMS horizontal accuracy may be about 50 yards.

The cost for a basic DGPS receiver suitable for most agricultural applications is about $3,000 to $5,000 and provides RMS accuracy of at least 10 ft. with a typical accuracy of 3 feet, which is sufficient for yield monitoring and grid soil sampling.

If you need a GPS receiver for guidance (for spraying, fertilizer application, etc.), the cost may be up to $25,000. Such systems provide accuracy down to a few inches. Since sprayers and fertilizer spreaders can travel fairly quickly, lower quality GPS equipment may not update position quickly enough to be used for guidance or control, although GPS systems with high update rates and accuracies in the range of one foot or less are becoming available at lower prices.

The annual subscription cost for some differential correction services varies with the level of service (accuracy). Some providers offer three levels of service, e.g., one provider has a premium service for better than 3 feet accuracy, intermediate service for accuracies in the range of 15 feet and a basic service for accuracies in the range of 30 feet. Typical approximate costs may be $600, $250 and $75 per year, depending on the level of service.

Coordinate Systems

Most GPS receivers can report position information in more than one format. The use of latitude and longitude (lat/lon) is common. Lat/lon coordinates are recorded in angular units of degrees, minutes and seconds. GPS receivers may display lat/lon in degrees plus minutes to four decimal places (instead of minutes and seconds). Example: latitude: 38° 58' 58"; longitude: -92° 11' 21" (degrees, minutes, and seconds) is equivalent to latitude: 38° 58.9667'; longitude: -92° 11.3500' (degrees and minutes to four decimal points). One second of latitude is equal to about 102 feet on the Earth's surface. The distance equivalent for one second of longitude decreases with distance from the equator. One second of longitude at Moline, Illinois equals about 67 feet on the ground. Most geographic information system (GIS) software is capable of using more than one format and may automatically convert lat/lon coordinates to a coordinate system such as Universal Transverse Mercator (UTM) or State Plane Coordinates (SPC) to calculate distances in meters or feet.

UTM and SPC systems project portions of the Earth's curved surface onto a flat map and report locations as actual distances from a reference point in meters and feet, respectively. Hence, no conversions are necessary to calculate distance or area. ■

References/Suggested Reading Material

G.P.S.: A Guide to the Next Utility. 1993. Trimble Navigation Ltd., P.O. Box 3642, Sunnyvale, CA 94088-3642.

Differential G.P.S. Explained. 1996. Trimble Navigation Ltd., P.O. Box 3642, Sunnyvale, CA 94088-3642.

The Precision-Farming Guide for Agriculturalists. 1997. John Deere Publishing, Dept. 374, John Deere Road, Moline, IL 61265-8098. Phone 1-800-522-7448.

For a list of Internet sites refer to: http://www.fse.missouri.edu/mpac/links

Note: ***Mention of companies does not imply recommendation or endorsement over other companies not mentioned.***

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This Site-Specific Management Guideline was prepared by:

Dr. Donald Pfost
Extension Agricultural Engineer
Agricultural Engineering Department
University of Missouri
207 Agr Engineering Building
Columbia, MO 65211
(573) 882-2731
E-mail: PfostD@missouri.edu

Dr. William Casady
Extension Agricultural Engineer
Agricultural Engineering Department
University of Missouri
211 Agr Engineering Building
Columbia, MO 65211
(573) 882-2731
E-mail: bill@missouri.edu

Mr. Kent Shannon
Associate Director
Missouri Precision Agriculture Center
University of Missouri
238 Agr Engineering Building
Columbia, MO 65211
(573) 884-2267
E-mail: shannond@missouri.edu

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