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GPS / Map Position Coordinate Issues: GPS Position Accuracy

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Latitude and *longitude* are key numbers in an amazingly precise location address system that works anywhere in the world. Low cost Global Positioning System (GPS) receivers have made these two numbers more accessible, and potentially more useful, in ordinary work and recreational activities. This fact sheet:

- Gives examples of *position error* for GPS computed coordinates.
- Calls attention to some common sources of GPS position error.
- Relates GPS position error, expressed as a distance, to errors in *latitude* and *longitude.*
- Illustrates in very general terms the effect of *differential correction*.
- Helps identify *situations that call for* differentially corrected position coordinates.

For additional help and references related to position latitudes and longitudes in Arkansas, see the related fact sheet *GPS / Map Position Coordinate Issues: Latitude / Longitude in Arkansas*. For help with using coordinates that are computed and displayed by GPS receivers, together with USGS 7.5' Topographic Maps for Arkansas, see the related fact sheet *GPS / Map Position Coordinate Issues: Datum and Coordinate Settings.*

GPS Position Error

Every location has its own coordinate address. With GPS, instead of street names and house numbers, the location's address consists of its position coordinates: latitude (lat), longitude (long), and height above ellipsoid (HAE).

- If a GPS receiver displays position coordinates that are different from the "true coordinates" of the antenna position, this is position error. Due to environmental influences on the satellite signals that these receivers use, small position errors are always present in GPS computed coordinates. Currently, a Department of Defense security measure, known as Selective Availability (S/A), also causes GPS position error.
- Most GPS equipment is designed for a particular type (or types) of positioning task. As long as a receiver is used on jobs that do not exceed its design limitations, position error will not be a problem, and it may not even be noticed.

Although the HAE coordinate can be very important for land surveys, construction and land leveling jobs, there are a lot of mapping and other GPS uses where HAE is not critical. In fact, some GPS receivers do not display HAE. This fact sheet is limited to *horizontal* position errors, where the latitude and longitude are slightly different from the "true" latitude and longitude of the position.

Example: The lat/long for the gate that opens from a feed lot to a neighboring 30 acre pasture is:

Latitude:	36° 14' 39.3" N
Longitude:	93° 25' 14.7" W

At the gate the GPS receiver screen displays the following latitude and longitude:

Latitude:	36° 14' 37.2" N
Longitude:	93° 25' 14.7" W

The receiver screen is showing the correct longitude, but it displays a latitude that is 2.1" lower than the true latitude. Since in Arkansas a one-second latitude difference is equivalent to 101.1 feet of horizontal distance, the true gate position is a little more than 200 feet north of the position indicated on the receiver's coordinate display. The coordinate error is 2.1" latitude. The position error, expressed as a distance, is approximately 212 feet.

Common Sources of GPS Position Error

A GPS receiver antenna detects signals from several of the DOD's NAVSTAR satellites at the same time. The receiver uses precise time and satellite-position data, along with other information in the transmitted signals, to calculate position coordinates. The time that it takes the signal to travel from the satellite to the receiver is one of the critical values that the receiver must calculate. Uncontrollable atmospheric conditions that affect how fast the signals travel can cause small errors in the calculated coordinates. Under some conditions the receiver can confuse the signals from one or more satellites with reflections of the same signals from water surfaces or buildings that are nearby (multipath). Table 1 contains a list of these most common sources of positioning error. The last item in the list, satellite positions relative to the receiver, refers to the satellites that a receiver is using to compute its position coordinates. Once or twice each day there is a short period of an hour or two when the only satellites whose signals the receiver can detect are in positions that do not favor accurate coordinate determinations. The effect of this unfavorable satellite positioning is to multiply the effects of the actual sources of error (first five items in the list). At present, Selective Availability (S/A) is usually the greatest contributor to GPS position error.

Table 1. Factors that affect GPS position accuracy.

Satellite clock and position errors
Atmospheric delay of the transmitted satellite signals
Receiver noise and receiver clock errors
Multipath
Selective Availability (S/A)
Satellite position in sky relative to receiver

- S/A is the name given to a Department of Defense security measure. Signals received by military GPS equipment carry more precise positioning information than the signals that can be picked up by civilian receivers. The reason is that S/A is applied only to the signals available for civilian use and not the signals transmitted for military use.
- S/A causes error in a civilian GPS receiver's computed coordinates. The error in a single computed position can vary anywhere from 0 up to 100 meters or more in any direction. In other words, the position that has the coordinates that a receiver is displaying at a given time can be 100 meters or more from where the receiver antenna is actually located. The position error caused by S/A is not always the same at any given location. It changes rapidly.
- The "100 meters" is not an absolute upper limit on GPS position error. The error due to S/A can exceed 100 meters, especially for short periods of time. More often than not the position error due to S/A will be no more than about 50 meters. If necessary, the DOD has the capability to degrade the positioning accuracy to an even greater extent.
- Currently the U.S. Government is planning to eliminate S/A. Probably S/A will continue to degrade position accuracy until 2004 to 2006. Even if S/A is discontinued, position errors (without correction) may be in the 15 to 25 meter range, depending on the receiver capability and operating conditions.

Reducing Position Error and Improving Position Accuracy

Averaging the latitudes and longitudes of computed GPS positions can reduce error and improve position accuracy. To reduce error by any great extent, positions must be computed at frequent intervals over a period of several hours and then averaged. It is difficult to predict in advance exactly how much reduction in error should be expected from averaging a certain number of positions over a given time period.

Although there are several approaches to improving position accuracy, *differential correction* is common to most of them. Differential correction can remove most of the effects of S/A and other common sources of error in GPS computed positions. It is the most consistent and effective means of improving position accuracy.

What Is Differential Correction?

With differential correction, one receiver (base station receiver) collects position coordinates at a definite location where the coordinates are known beforehand. The position data and other information that are obtained at this base location are used to correct the coordinates obtained by other receivers.

There are many approaches to differential correction, which vary widely in cost and also in the resulting accuracy of corrected position information. Some receivers are designed so that they can provide only uncorrected coordinates. Other receivers provide an option for differential correction, with the stipulation that additional equipment and computer software be purchased to aid the process.

Example: In Figure 1 is a diagram of a small lake located in the Ouachita Mountains. The lat/long coordinates of the "X marks the spot" positions on the north end of the pond and on a small bridge at the southwest corner of the pond were obtained by collecting and storing about 100 latitudes and longitudes for each position. The receiver's instruction manual was followed to obtain these 100 positions. They were later transferred to a computer and differentially corrected with publicly available GPS position data from an internet web site (http://cast.uark.edu). This web site is maintained by the Center for Advanced Spatial Technology (CAST) on the U of A Fayetteville campus. The individually corrected position coordinates were averaged to obtain the latitudes and longitudes of Figure 1. According to the receiver manufacturer, at least half of the individually corrected positions should be in error by no more than 2 to 5 meters. Our experience has shown that if the receiver is used under more or less "ideal" operating conditions, we can expect position coordinates (after differential correction and averaging) that are correct within 2 meters. The conditions at this lake site were not "ideal." The trees in the area may have forced the receiver to use satellites that were not well positioned in the sky. Both the trees and the water surface could have reflected the signals of some of the satellites, causing "multipath" error.

Figure 1
GPS Computed Coordinates Averaged But Not Differentially Corrected

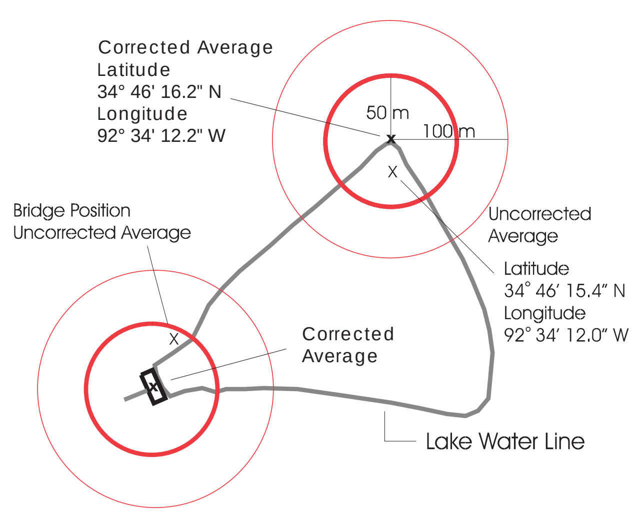
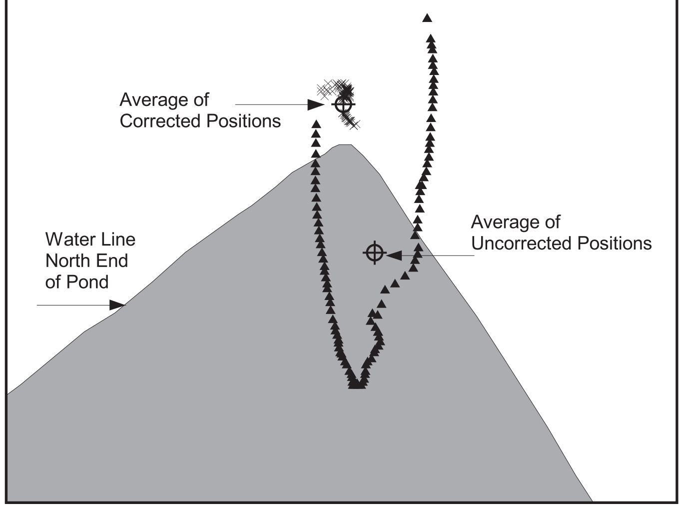


Figure 2. Location of Individual GPS Positions With Corrected and Uncorrected Average Positions for North End of Lake



Uncorrected: The "triangle" symbols in Figure 2 show the locations of the 100 positions with uncorrected coordinates. In this case, the worst uncorrected positions were in error by only 46 meters, or about 150 feet. Notice that some of them (lower part of the crooked "V" shape) are out over the water, and others are further up the bank from the shoreline. The circle-+ symbol below the tip of the lake is the average of the uncorrected positions. Although it is better than the worst of the uncorrected positions, it is still 25 meters, or about 80 feet, away from where the GPS receiver was located (circle-+ above the shoreline).

Corrected: The 100 differentially corrected positions are gathered into the small patch of gray behind the upper circle-X symbol in Figure 2. The center of that circle-X symbol is the "average" location of those 100 differentially corrected positions.

The large circles in Figure 1 indicate distances of 50 meters (164 feet) and 100 meters (328 feet) out from the "North End" and "Bridge" positions. *Notice the lighter X just below the water line at the north end of the pond.* This position was the result of averaging the same 100 latitudes and longitudes that were used to get the "true" coordinate addresses shown in Figure 1. But the ones used to get the lighter X out over the water had not been differentially corrected. S/A and a mixture of the other common GPS error sources gave us an "average" latitude/longitude address for the north end of the lake that is in error by 25 meters or about 80 feet.

Matching the Tool to the Task

In the example of the "gate" position, an ordinary recreational GPS receiver, and with no differential correction, would get someone within view of the gate, unless the gate was hidden among trees.

However, to be confident of actually going to the gate, on-the-fly differential correction, accurate within one meter, would be necessary. There could still be a problem if the gate is hidden among trees with a canopy thick enough to block either the positioning signals from the NAVSTAR satellites or the radio signal carrying the data required for the on-the-fly differential correction. State-of-the-art receivers can achieve cm accuracy, and some are better equipped to function under tree canopies, but keep in mind that this more advanced technology is accompanied by higher receiver prices.

Likewise, if all someone wanted to do was get to the lake, we could give them any one of the original 100 latitude/longitude "addresses," or we could give them the latitude and longitude of the lower "X" that we obtained by averaging. All they would have to do is enter any one of those coordinate addresses into their receiver as a waypoint, and it could "take them to the lake." More than likely it would get them within 150 feet of the north end of the lake. If for some reason it was very important for them to get within 25 feet or so of the points where "X marks the spot," they would need to use differentially corrected coordinates. Also, they would need to use a GPS receiver that is capable of on-the-job or "on-the-fly" differential correction. In order to approach one of these positions without getting feet wet, it would be necessary to use equipment capable of on-the-fly differential correction, accurate within one meter. Also, it would help to have a detailed map of the area, in addition to the GPS equipment.

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Horizontal distances associated with latitude and longitude differences were calculated with software that is available to the public from the National Geodetic Survey. Supporting measurements were made from several USGS 7.5' Topographic Maps for Arkansas, supplied by the Arkansas Geological Commission.

Related References

Langley, Richard B. 1995. "A GPS Glossary." Innovation Column in *GPS World* magazine, October issue, pp. 61-63.

Langley, Richard B. 1997. "The GPS Error Budget." Innovation Column in *GPS World* magazine, March issue, pp. 51-56.

National Security Council. 1996. *U.S. Global Positioning System Policy*. Fact sheet posted on U. S. Coast Guard internet site (http://www.uscg.navcen.mil/gps).

Trimble Navigation, LTD. 1989. *GPS, A Guide to the Next Utility*. Trimble Navigation, P.O. Box 3642, Sunnyvale, CA, 94088-3642.

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