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PLGR ACCURACY EVALUATION

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BIOGRAPHICAL SKETCH

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ABSTRACT

Personnel in the Corps of Engineers are authorized users of Precise Positioning Service (PPS) GPS. The Precise Lightweight GPS Receiver (PLGR) is the Army's authorized GPS receiver (Corps of Engineers personnel can obtain this). The U.S. Army Engineer School requested TEC evaluate the positional accuracies attainable with the PLGR. The evaluation covered four areas: real-time absolute, real-time differential, "post-processed" absolute, and "post-processed" differential. This paper discusses the techniques used and the accuracies observed. Capabilities, as well as limitations, of the current PLGR will also be discussed.

INTRODUCTION

The U.S. Army Engineer School requested TEC evaluate the positional accuracies attainable with the Precision Lightweight Global Positioning System (GPS) Receiver (PLGR). Based on current military survey tasks, these accuracies indicate to what extent the PLGR can be utilized by a military surveyor.

The evaluation primarily focused on the PLGR, as is. Four types of accuracies were examined: (1) real-time absolute, (2) real-time differential (relative), (3) "post-processed" absolute, and (4) "post-processed" differential. PLGR observed accuracies are shown in Table 1.

Further testing, in different environments (such as locations with higher ionospheric activity), is desired to determine if similar results can be obtained.

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	<u>Real-time</u>	<u>Post-processed</u>	
Absolute	10	2-10*	*Depends on amount of averaging time.
	14	3-14*	
Differential	NOT	2	
	TESTED	4	

Table 1. Summary of PLGR Accuracies (Horizontal on top, vertical below) at 95% confidence in meters.

WHAT IS PLGR?¹

PLGR is the Army authorized GPS receiver for tactical operations. It is a 5-channel L1 C/A, P, and P(Y) code hand-held GPS receiver. Five satellites can be continuously tracked, but the four "optimal" satellites are used for the position computation. PLGR outputs position, velocity, and time information. When "keyed", PLGR will operate in any "GPS environment"; the keys enable PLGR to negate the effects of selective availability (SA) and provide anti-spoofing (AS) capability. This is referred to as the Precise Positioning Service (PPS). Several non-DOD government agencies are exploring the possibility of establishing a Memorandum of Agreement with DOD to obtain authorization to procure PLGR or other PPS receivers.

The specifications for PLGR are given below:

Horizontal	10 meter (CEP, 50%)
Vertical	10 meter (VEP, 50%)
3-D	16 meter (SEP, 50%)

Capabilities

PLGR was designed to act as a stand-alone positioning and navigating device. PLGR horizontal positions can be referenced to a user-selectable datum (including NAD27 and NAD83). PLGR can output positions in Latitude and Longitude or Universal Transverse Mercator (UTM). It has a RS-232 communications port for interfacing to other devices, and it can store up to 99 waypoints internally. PLGR has the capability of user-selecting/deselecting individual satellites. For horizontal positioning requirements on the order of 10-20 meters, a PPS receiver such as PLGR, that requires no communication link or post-processing is an option.

¹PLGR refers to the actual DOD PPS hand-held GPS receiver; other manufacturer's PPS GPS receivers will have other capabilities/limitations.

Limitations

Below are some limitations of the current version of the PLGR. A user can NOT input a desired elevation mask into the PLGR; PLGR may select satellites at any elevation angle. PLGR outputs positions but does NOT output raw observables (such as pseudo-range and carrier phase information); therefore, many of the data processing functions performed on data from commercial GPS receivers are NOT possible with the current PLGR. Because it does not record raw observables, data from PLGR can not be written into a RINEX file format for post-processing with data from a reference station. If unkeyed, PLGR can receive C/A code differential corrections. Currently, however, it requires a computer with the appropriate hardware and software to receive RTCM SC 104 Type 1 and 2 messages, reformat them, and then send them to the PLGR. There is no easy way to switch between keyed (PPS) and unkeyed (SPS) modes. The interface protocol for communicating with the PLGR is a proprietary format; it does NOT provide output data messages such as those for NMEA0183.

PLGR ACCURACY TESTING

Testing primarily took place in the vicinity of Fort Belvoir, Virginia. For long-range differential testing, sites at Fort Belvoir, VA and Fort Monmouth, NJ were used. Initial data collection began in August, 1993 with pre-production PLGRs. An eight day absolute GPS data collection session was conducted from August 31, 1993 to September 8, 1993. Relative GPS data were collected between October, 1993 and January, 1994. All testing was conducted with "keyed" PLGRs.

Statistical Terms

No measuring system can measure perfectly; a system normally has an accuracy and probability statistic stated for it. The probability statistic indicates the level of confidence (probability) that any random measurement will be accurate to within the stated accuracy. PLGR specifications use statistics which are based on a normal distribution of measurements with no systematic biases. PLGR specifications use the .50% probability statistic: CEP for horizontal, VEP for vertical, and SEP for 3-D positions. This means that 50 percent of the time PLGR should provide positions to better than 10 meters, horizontally. Often times, 90 percent or 95 percent probability statistics are used. As a rule of thumb, to convert a 50 percent probability statistic for normally distributed data to a 95 percent probability statistic use the formulas:

- (1-D) $VEP \times 2.9 = 95\%$
- (2-D) $CEP \times 2 = 95\%$
- (3-D) $SEP \times 1.8 = 95\%$

Therefore, a PLGR with good satellite geometry should compute horizontal positions to better than $CEP \times 2$ (10×2) = 20 meters 95 percent of the time.

Real-time Absolute

This is the mode that most Army users of PLGR will employ. It is primarily intended for navigation purposes. One receiver, stand-alone, determines a position directly on the WGS84 datum. The specifications listed before are for this mode of operation; the specifications also assume a good satellite geometry (see Figure 1).

In the 2-D example, good geometry (low Dilution of Precision, DOP) occurs when the area of the triangle formed between the GPS receiver and the two satellites is a maximum. Geometric DOP (GDOP) relates to the geometry of the four satellites being used in the position computation. Theoretically, the lower the GDOP value, the better the accuracy of the position. The elevation angle of the satellites can also impact the accuracy attainable. Range measurements from satellites very low on the horizon (0-3 degree elevation angle) may have larger errors which result in not-so-accurate positions.

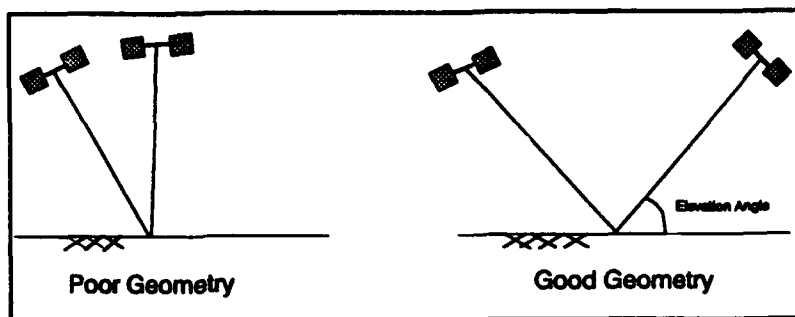


Figure 1. Simplified 2-D example of satellite geometry.

Appendices 1 and 2

show the real-time accuracies attained with PLGR. The first 30 trials in Appendices 1 and 2 were with good geometry (PLGR displayed an accuracy indicator of +/- 10 meters). Trials 31-60, 61-90, and 91-120 were when PLGR reported +/- 20 meters, +/- 30 meters, and +/- 40 meters. Note that in the first 30 trials, on two occasions even though PLGR indicated +/- 10 meters, the error was more than 15 meters. In these cases, several satellites were at elevation angles below three degrees.

Under good satellite geometry conditions, PLGR easily exceeds specifications. For a sample of more than 10,000 positions computed from good geometry conditions in "CONTINUOUS" mode, accuracies were on the order of 5 meters (CEP and VEP). PLGR operating in a "QUICK FIX" mode was not directly tested. Soldiers will sometimes be in terrain where optimal satellite geometry is not possible. Be aware of the accuracy indicated by PLGR--it will NOT always be optimal (within 10 meters)!

Real-time Differential

Real-time differential GPS involves at least two GPS sets: one over a "known" reference control station and at least one "roving" to other points of interest. For real-time operation, a data communication link from the control station to the roving stations is required. Basically, the known station computes corrections to its position computation (between what is measured and what its known values are) and then transmits those corrections for the roving stations to use for a better position

computation. There are two common ways to generate these corrections: pseudo-range corrections (PRCs) and delta positions.

Corrections by PRCs is the preferred method. A pseudo-range is the raw range (distance) from a satellite to the GPS receiver. At the control station, PRCs are computed by differencing the measured raw pseudo-range and the known true

range (for each satellite). The PRCs are then transmitted to the remotes where the PRCs are applied to the remote's pseudo-ranges to obtain better range measurements. Corrected range measurements are then used for a better position computation. PRCs are more flexible from an operational perspective; RTCM formats for real-time differential GPS are based on PRCs.

Transmission of classified encrypted Y-code PRCs is not an option with the current PLGR; therefore, PLGR can only operate in a real-time differential mode (following RTCM standards) by using C/A code. In addition, PLGR can act as a rover (it can receive C/A code PRCs) but NOT as a reference over a known control station (it can NOT generate PRCs). Because the C/A code is not encrypted, it is not authorized for tactical operations; therefore, real-time differential GPS with C/A code is not authorized for tactical operations. Because we "Train as we fight...", real-time C/A code differential GPS was not tested.

Commercially available real-time C/A code differential GPS vendors often quote 3-5 meter relative horizontal accuracies over ranges of several hundred kilometers. Commercial systems using a combination of C/A code and carrier phase information have obtained sub-meter relative accuracies in real-time. New "on-the-fly" GPS systems will use code and carrier information to obtain centimeter level relative accuracies in real-time. Commercially available GPS receivers can use the code and carrier information to obtain these accuracies; PLGR can NOT.

Post-processed Absolute

Post-processed absolute is an averaging of real-time absolute positions over some time interval (one receiver, stand-alone).

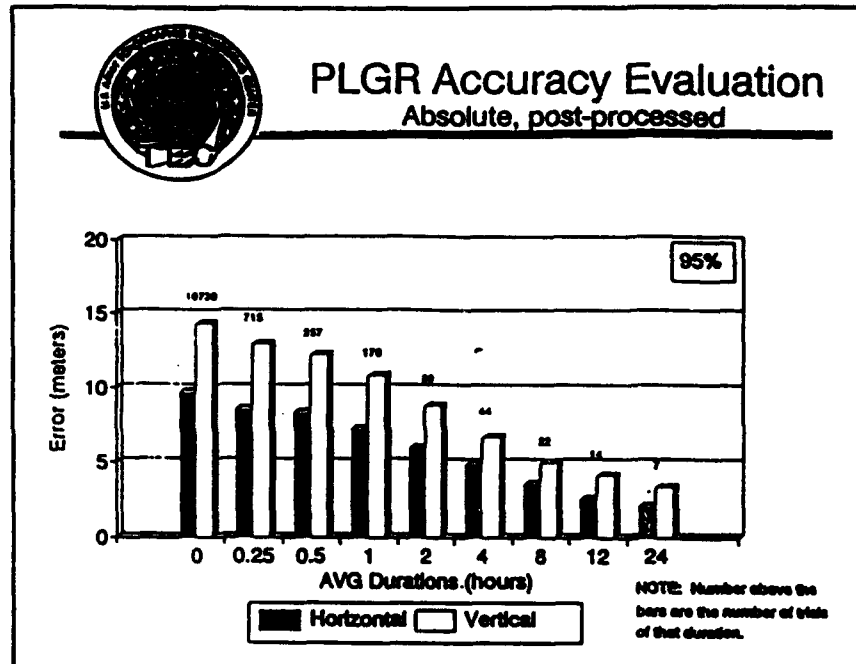


Figure 2. Post-processed Absolute (Averaging).

In the case of the PLGR, this is simply an arithmetic mean of position computations over time. Two of the main considerations in averaging are time interval and satellite geometries.

At TEC, continuous PLGR data were collected over an eight day period. This data set could be segmented and examined as separate data sets; this enabled us to look at five minute averaging durations, one hour durations, four hour durations, and so on. As shown in Figure 2, positional accuracies improved over time. For 24 hour sessions, absolute positional accuracies were on the order of 3 meters (95 percent confidence). For a one hour averaging duration, absolute positional accuracies were on the order of 7 meters, horizontally (95 percent confidence). It is interesting to note how satellite geometry affects these results. Averaging with the same constellation over time did not improve accuracy. Same constellation averaging accuracy for one hour did not show any significant improvement over five minutes. Averaging with the same constellation gives the appearance of a systematic bias. To try to randomize this bias and improve accuracy, multiple complementing satellite geometries are required. This happens automatically when averaging for durations longer than an hour. Further testing is being conducted to determine if software can reduce the observation time required to obtain multiple complementing satellite geometries from hours to minutes.

For vertical, PLGR outputs either an ellipsoid height (h) or a mean sea level, MSL, height (H). The MSL is derived from h by the following formula:

$$H = h - N$$

The geoid undulation (N) is selected from a geoid model. PLGR uses a 10° x 10° geoid model. For best results with the vertical, a user should average with ellipsoid heights and then use a better geoid model (such as GEOID93) to convert it to a MSL (H) height.

Post-processed Differential

Whereas real-time differential requires a communication link, post-processed differential does not. Data from the reference

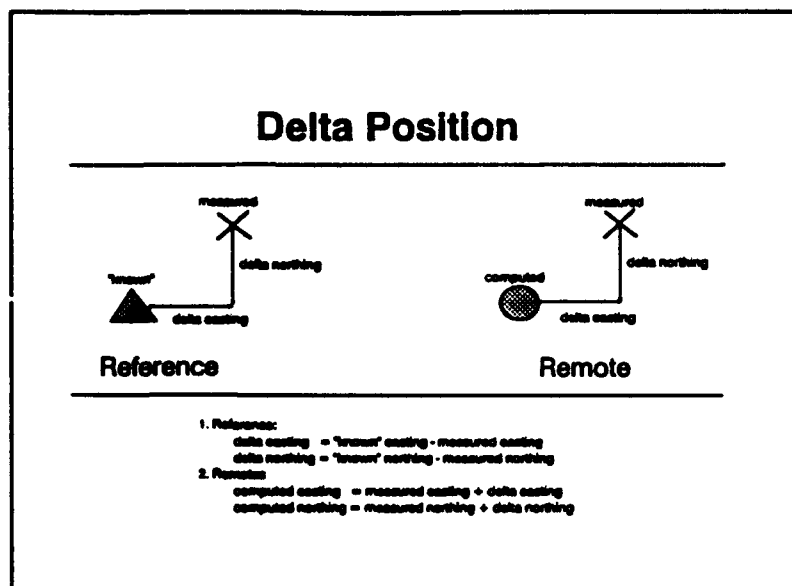


Figure 3. View from above of delta position differential GPS.

and remote GPS receivers are combined and processed. Again, differential requires one reference GPS set to be over a "known" control station to compute corrections.

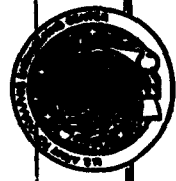
As discussed in the "Real-time Differential" section, differential GPS using PRCs in a tactical area is not an option with PLGR; therefore, it was not tested. Corrections by delta positions are possible with PLGR. This method computes corrections to the actual position computation at the "known" control and applies the "delta positions" to the position computations for the rovers (see Figure 3). Several conditions **MUST** be met for this technique to be valid. These consist of the following:

1. Reference GPS receiver and remote GPS receivers **MUST** use the same position computation algorithm.
2. For PLGR, reference and remotes **MUST** use the same four satellites in the position computation.
3. Positions **MUST** be computed for the same times.

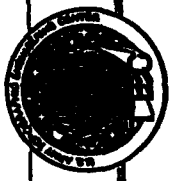
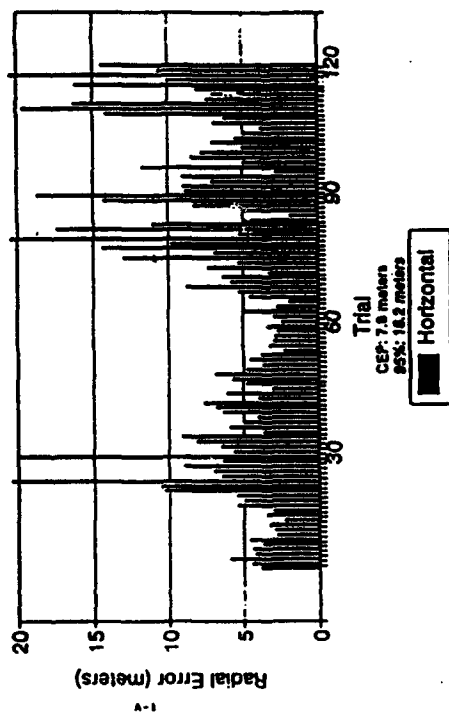
This technique has been applied over baselines ranging from 10 meters to 300+ kilometers. Relative accuracies on the order of 2 meters, horizontally, and 4 meters, vertically, have been obtained. Appendices 4 and 5 show the results of these tests.

RECOMMENDATIONS AND CONCLUSIONS

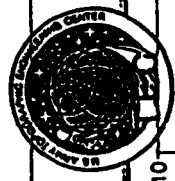
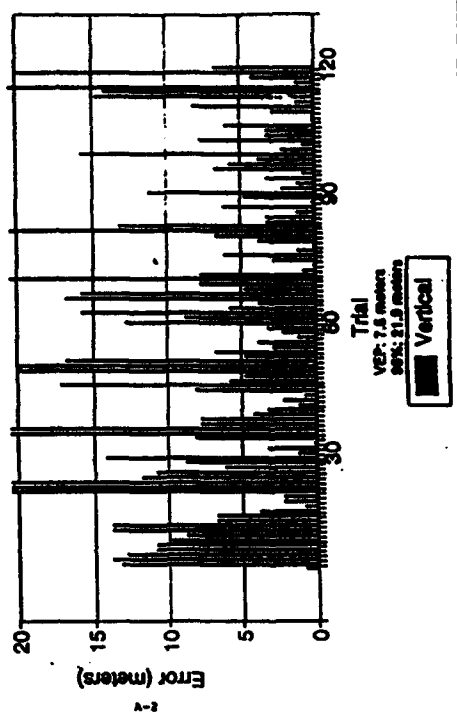
1. Further testing, in different environments (such as locations with higher ionospheric activity), is desired to determine if similar results can be obtained.
2. Cost of PLGR under the DOD contract will be around \$1500; delivery time may exceed one year. With DOD approval, other PPS receivers can be procured. Cost of comparable PPS receivers are approximately \$4500; delivery time may be several months. For some applications, PPS GPS may be the right tool.



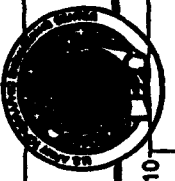
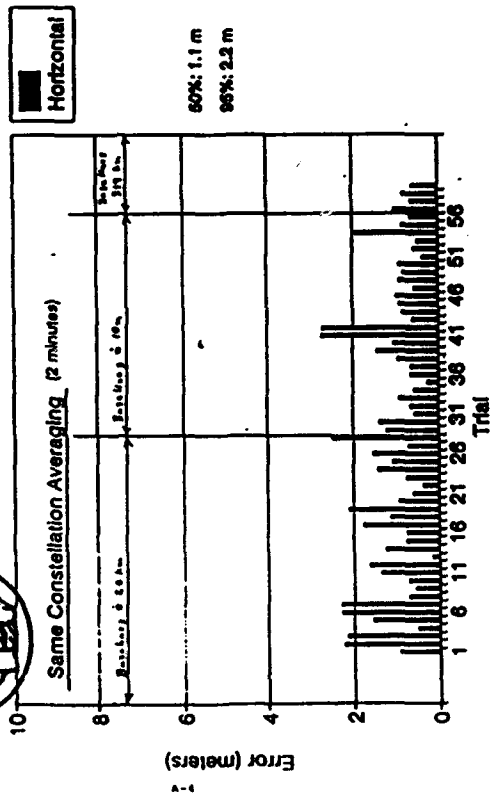
PLGR Accuracy Evaluation Real-Time Absolute (+/- 10 to 40m)



PLGR Accuracy Evaluation Real-Time Absolute (+/- 10 to 40m)



PLGR Accuracy Evaluation Relative (Delta Pos)



PLGR Accuracy Evaluation Relative (Delta Pos)

