More On GPS Distance

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I read with interest Alan Dragoo's article in the July-August issue of the *Maryland Surveyor*. I agree completely that there will be some difference between GPS and EDM measurements; however, this disagreement should seldom approach the one centimetre (0.03 foot) fixed error allowed for first order GPS surveys (short lines). Alan's article was triggered by the disagreement between a GPS survey that I had supervised and conventional survey measurements. Although I have not had the opportunity to review the number and magnitudes of the discrepancies, they were characterized

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as being in the magnitude of 0.07 foot, which I know from experience is an unusually large discrepancy. The project in question was a control survey paralleling an elevated highway (in Baltimore), and many of the points were close to the steel structure in what I would designate as a "bad multipath" environment (more about this later).

Example of Good Results

Before explaining the error sources for GPS measurements, I would like to present the results of a recent airport control survey. This project provides an excellent comparison, because the points occupied by GPS were virtually obstruction free, and were sufficiently distant from metal reflecting objects to provide a "good multipath" environment. Also there is a measure of quality of both the conventional and GPS measurements, since both surveys consisted of a network of loops which formed a highly redundant geometric framework. The STAR*NET least squares adjustments program was used to adjust both the conventional and GPS surveys, with the adjustments in both cases indicating first-order accuracy was achieved.

A comparison was made between the distances inversed from the adjusted conventional coordinates and the unadjusted GPS distances. The comparison was made in this manner since no direct comparison between the conventional distance and GPS was possible as the GPS points were too far apart for direct comparison. Table 1 shows the inversed (grid) distance, the GPS (grid) distance, and the difference between the two distances. The mean of the differences is 0.002 foot and the standard deviation is 0.015 foot. The low mean shown that there is not systematic error or bias between the two types of measurement and the 0.015 foot standard error appears to me (based upon experience) to be well within the error to be expected from both conventional and GPS measurements. It should also be noted that the largest difference (0.029) approaches the 0.032 foot constant error allowed by the NGS (or FGCS) specifications. Actually the allowable error for line 4007-4009 would be 0.032 + 0.029 foot (1 cm + 10 ppm x dist.) so the 0.029 error is well within the allowable error.

COMPARISON OF GPS & EDM
FEET

LINE	SURVEY	GPS	DIFF.
1010-1014	3551.993	3551.974	0.019
1014- C2	3016.364	3016.368	-0.004
4020- C2	2090.299	2090.302	-0.002
4020-4005	3191.902	3191.898	0.004
C2-4005	3866.574	3866.559	0.014
4007-4005	2901.967	2901.976	-0.009
4007-4009	2898.234	2898.205	0.029
4007-4009	2910.019	2910.013	0.006
3010-4009	2789.461	2789.447	0.014
3003-4007	3468.696	3468.678	0.018
3003-3010	3468.696	3468.678	0.018
3003-3010	3626.459	3626.477	-0.019
3003-3006	2333.362	233.360	0.002
2015-2017	2291.627	2291.647	-0.020
1014-2017	2874.190	2874.165	0.026
2008-2017	5547.029	5547.027	0.002
2010- D2	1378.203	1378.223	-0.020
D2-1010	3810.980	3810.994	-0.014
			MEAN=0.002
			STD DEV=0.015

Table 1

Survey Error Model

The errors associated with GPS (survey) measurements are the same type of errors experienced by conventional survey equipment. There is a fixed error (e.g. 1 cm for 1st-order) and a proportional error that is distance dependent (10 ppm for 1st-order). In the older NGS specifications for triangulation and traverse, the fixed portion of the error was omitted for simplicity, since stations were seldom less than three miles apart and the proportional portion or the error dwarfed the fixed portion. This omission was corrected in the GPS specifications, since GPS points are often quite close together. Many surveyors incorrectly reject valid survey measurement because they fail to include the allowable fixed portion of the error in their analysis.

Typical GPS Errors

The fixed portion of the error model for GPS measurements is due to four major sources, mainly:

1. antenna centering error (i.e. tribrach error)
2. antenna alignment (normal few millimetres)
3. near body effect (thought to be less than a centimetre)
4. multipath error (up to a few centimetres)

The first two errors can be easily minimized by using care in centering the antenna over the mark and aligning all antennas in the same direction (e.g. magnetic north). The third error is due to the presence of large metal objects near the antenna. These objects (e.g. a truck) distort the antenna pattern and can result in a small error at that point. This error can be minimized by parking your vehicle as far from the antenna as possible (e.g. 30 feet).

The final error is the largest and most difficult to control. Multipath is an error that was common in the older microwave EDMs such as the Tellurometer. It results from the radio signals being reflected from metal objects near the antenna and creating a false reading or shifted phase. Typically, objects such as steel bridges, chain-link fences, and metal buildings near GPS antennas cause multipath errors at a particular point. These errors can be as large as 2 centimetres and thus are particularly onerous for short lines. Unfortunately, multipath error cannot be easily detected either during data collection or from (a single day's measurements).

For example, in the survey cited in Alan Dragoo's article, individual line errors as large as 0.07 foot were found, which is amazing in that the "raw" closure of the 8.6 mile GPS traverse between NGS control was 0.001 foot in latitude, and 0.0006 foot in longitude. This seeming incongruity can be explained by the fact that four receivers were used and I made sure that the "pivot" or common point between sessions was a "multipath friendly" point. In placing the multipath unfriendly points in between the pivot or swing points the risk of a large misclosure was reduced. Those unfamiliar with GPS would now assume that the problem lines could be located by computing a loop closure for the four lines joining the four points occupied during a single session. Unfortunately this cannot be done since the "loop" composed of lines measured during a given session will always close virtually flat. The multipath error at a given point manifests itself by a slight shift in the computed point from the "true" centre of the antenna. This shift will be detected by EDM subsequent measurements but will remain undetected by loop closure or least square adjustment analysis. For example, in the Baltimore survey the largest correction to any line was one millimetre.

For simplicity let me provide another example of the magnitude of the problem. Among other activities, I teach a two-day GPS seminar in Florida, Texas, and Alabama to provide surveyors with CEUs (Continuing Education Units) required for license renewal. As part of the seminar, I measure a short (less than 100 feet) line in the hotel parking lot, and have the seminar participants tape the distance for comparison. Over scores of measurements the largest error I have experienced is 0.02 foot, while much of the time there is no discrepancy. I realize this is an unscientific characterization of data; however, it does tend to agree well with the results of the cited survey that I would characterize as a typical (good) GPS survey.

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Is there an ultimate error achievable by GPS? Again I have to draw on my ten year old experience with the Macrometer (first working GPS). In the early days of GPS we conducted fairly extensive comparisons between conventional and GPS measurements. Many of these comparisons were performed on NGS calibration baselines where the distance between points is well known. Multipath errors for the Macrometre antennas was quite small in that the antenna was about 30 inches square and designed to reject multipath signals. Using this antenna, we often achieved millimetre agreement with the known distance. I can not remember a disagreement of more than 0.01 foot in all the comparisons we made.

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Solution to the GPS Error Problem

In effect, GPS is capable of millimetre accuracy if either an antenna with a large ground plan is used or a good multipath environment is selected for both ends of the line. A good multipath site is one where there are no nearby chain link fences or large metal structures. One way to be absolutely sure the GPS line has been measured correctly is to measure the line on two different occasions at different times of the day. Multipath is a function of the satellite locations so that measurement at different times will result in significantly different results if multipath is present in one or both lines. A simpler solution for short lines is to check the distance by EDM.

The other more practical solution is the one mentioned by Alan Dragoo, namely, to keep the separation between GPS points sufficiently large so that the cumulative error in the conventional survey between the points approaches the few hundredths error in the GPS line. For the ultimate results (also mentioned by Alan) it is best to combine the GPS and conventional surveys in a single least squares adjustment and weight the measurement appropriately so that the conventional angles and distances will "correct" any significant errors in short GPS lines. I have recently tested the new version of STAR*NET which can combine both angles and distances with GPS vectors. This easy to use and moderately priced program handles the two types of measurements quite well and produces optimum results. Other programs such as the higher priced GEOLAB also can combine all type of measurements.

In any case GPS can not be used indiscriminately and be expected to provide "perfect" results. GPS is just another survey instrument and must be used with the same care as any microwave instrument.