GPS Performance Under-the-Forest Canopy

A series of field tests conducted by Ken Lucas in 2007

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I'm a professional timber cruiser, based in the Redwood region of northern California. I wanted to determine the accuracy of GPS data capture at points under varying amounts of forest canopy, using a variety of available GPS receivers, software, accessories, and varying satellite conditions.

This series of tests were conducted in an approximately 60-year old stand of mixed Redwood and hardwood trees in the central part of Humboldt County, California.

Test parameters.

- The test area is located just east of Carlotta, California.
- Two types of points were used as controls for the tests. The primary control point was A National Geodetic Survey monument, NGS PID number DH6341, California, Humboldt. The primary control point is located approximately 50' from the edge of the forest on a road shoulder in a heavily forested valley, approximately 1 mile wide.

The secondary control points were six temporary test points that were selected & marked with wooden stakes in the 60-year old mixed Redwood and Hardwood timber stand immediately adjacent to the primary control point. I selected positions for these six secondary control points under varying amounts of overhead forest canopy, ranging from moderate sized openings(up to 33' in diameter) to locations with dense overhead canopy.

The primary control point functioned as a point of origin for a hand compass bearing and laser distance traverse that tied all of the secondary control points to the primary control point. The traverse closed with minimal error back on the primary control point and the traverse data entered into a GIS database. UTM coordinates were obtained for the control point from the NGS website: http://www.ngs.noaa.gov/cgi-bin/datasheet.prl

The projection system selected for all of the GPS units and the GIS database was WGS 1984, UTM, Zone 10, meters. UTM coordinates were obtained from the GIS database for each of the secondary control points.

The utm coordinates for each of the control points was entered into the GIS database to create point features. Captured gps data was post process corrected, if possible, and then the data was imported into the GIS to create point features. Measurements could then be made to deter the distance error for each capture effort.

Test Objectives.

I. Determining Optimum data collection conditions.

1. Determine the optimum number of data points to collect. Comparisons were made following data point collections of 2,000, 1,000, 500, 250, 200, and 100.
2. Determine how much accuracy advantage is gained by collecting data during periods of optimum satellite availability.
3. Determine how much accuracy advantage is gained by collecting data with an external antenna, if available.

4. Determine how much accuracy advantage is gained by differentially correcting data files with coordinates obtained from establishment of temporary base stations immediately adjacent to the test area.
5. Determine how well the various units can do without post process correction.

II. Determining performance of specific GPS units.
GPS equipment and software used for these tests:

- ESRI **ArcInfo** software, with the GPS Analyst application. Retail cost: $11,000.
- All of the Trimble Geo series GPS receivers were used in the tests, including the XM, XT, and the XH. The GeoXH is the best mapping-grade GPS unit offered by Trimble. These Geo series units had either the ArcPad or Terra Snyc software packages installed, although most of the XH data capture efforts were done using the Terra Snyc software. The ArcPad software had the Trimble GPS Correct application added, which is required to collect the raw satellite data need to post process data captured in ArcPad. In addition, the Trimble Pathfinder Office software package was required to post-process the field data. Retail Costs: Geo series GPS recievers= $3,000 - $5,300
ArcPad software= $500   GPS Correct= $500
Terra Snyc software= $800. Pathfinder Office= $1,200

- The Trimble Geo receivers were equipped with either a Hurricane external antenna or the GeoBeacon DGPS receiver for some of the field tests.

- Trimble ProXH GPS receiver and Ranger data collector.

The ProXH receiver made a bluetooth wireless connection with a Ranger 02 data collector, which was used to store the raw satellite data.
Retail costs: Reciever = $3,000   Trimble Ranger data collector= $3,150.

- Trimble ProXRS GPS reciever mated to a Hurricane antenna and a TDC-1 Data logger. Retail Cost= $4,000.

- Garmin 60CS sportsman-grade reciever, equipped with an optional external antenna.

As the Garmin unit stores NEMA GPS data only, post process correction of satellite data is not possible with these units, although it will receive the WAAS real time correction signal. Also, these units are not equipped with the windows mobile operating system and, therefore, do not allow installation of applications, such as ArcPad. However, these units appear to be well sealed against wet weather and can download data directly to GIS via the MX GPS GIS application. Retail Cost= $400

- Garmin 10 reciever.This is a small gps antenna with a wireless signal transmitter.

This unit will only store NMEA satellite data, so post processing is not possible; although it will receive the WAAS real time correction signal. This unit was employed to make the Bluetooth wireless connection to a Dell Axim PDA equipped with Bluetooth and the ESRI ArcPad software. Retail costs: Garmin 10 = $200 Dell Axim= $300.

- HP model 6945 PDA, equipped with an integral gps antenna and the windows mobile 5 operating system. I was able to install the ArcPad software onto this unit. This unit will only store NMEA satellite data, so post processing is not possible. Retail Cost= $500.

- To determine the figures for the various tests described later in this paper, I made over **400** separate gps data capture efforts at the various points in the test area. The multiple captures completed at each point were done in order to obtain enough separate readings to permit some averaging for each specific test.

GPS Unit	**Number of GPS collection efforts**
GeoXH	179
ProXT	50
GeoXM	29
ProXRS	42
ProXH	15
Garmin 60CS	63
HP 6945	42
Garmin 10	16

For the majority of gps data capture, the antennas for various gps units were positioned from 4 to 6' above the ground at the control points. For the majority of data capture by the mapping-grade units during the tests, the gps satellite parameters were set to maintain an average data capture quality, with PDOPs not to exceed 6.

Test results.

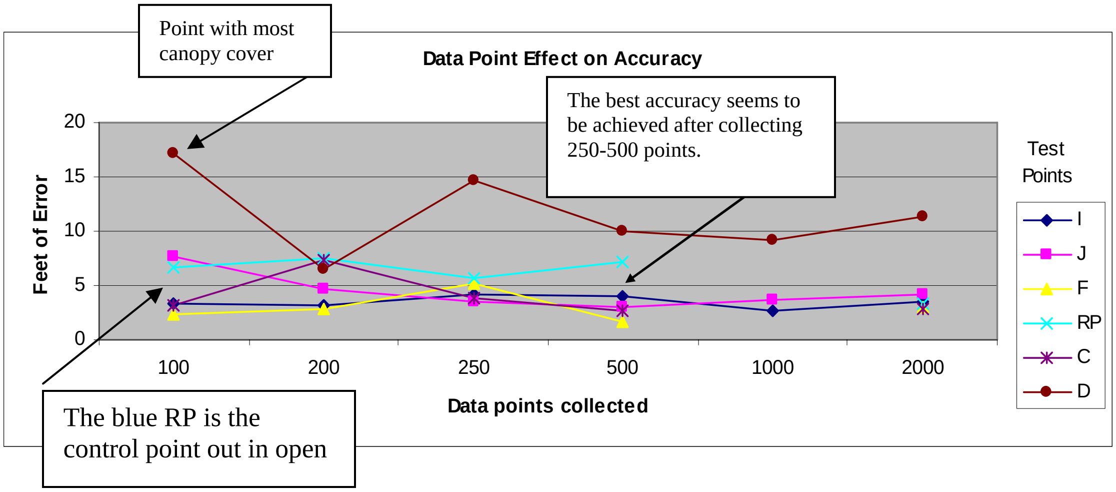
- The **best accuracy** achieved at the test area points under test conditions including: 250-500 data points captured, optimum satellite conditions, and GPS units equipped with external antennas, except for the HP 6945, Garmins 60CS, & 10.

GPS Unit	Ave Error Under-the-Canopy Points	Ave Error CP in-the-open
Trimble Geo Series	**4.2'**	**3.8'**
Garmin 60 CS	**9.5'**	**5.5'**
ProXRS	**4.8'**	**3.8'**
ProXH	**4.4'**	**--**
Garmin 10	**11.3'**	**--**

- Accuracy achieved at the test area points under average conditions, including 250-500 data points captured, all satellite conditions, and GPS units employed without external antennas.

GPS Unit	Ave Error Under-the-Canopy Points	Ave Error Primary CP in the open
GeoXH	4.9'	4.5'
GeoXT	5.8'	4.2'
GeoXM	6.6'	9.8'
Garmin 60CS	14.6'	5.6'
Garmin 10	14.9'	11.7'
HP 6945	20.4'	14.8'

- A test was made to determine what the optimum amount of captured data points are to obtain the best accuracy.



The best accuracy at the 3 test points with the most canopy cover were achieved after capturing 250 data points, with external antennas, and during optimum satellite conditions. Post processing done on all of the units, except for the Garmin 60 & 10.

GPS Unit	Ave Error
GeoXH	6.8'
ProXRS	4.2'
ProXH	3.2'
Garmin 60	10'
Garmin 10	18.1'

- A test was made to determine the accuracy of capturing GPS data during different satellite conditions. Optimum satellite conditions for these tests were those periods where mission planning showed the most satellites above the horizon; the window of time with lowest possible PDOPs. The average error figures were calculated from all of the gps tests done with the varying amounts of captured data points at the 6 under-the-canopy control points.

GPS unit classes	**Not optimum sat conditions**	**Optimum sat conditions**
Garmin(no post processing)	11.6' ave error	8.4' ave error
Geo/ProXRS (data post processed)	6.5' ave error	4.7' ave error

This comparison shows an approximate **28%** increase in accuracy for both types of gps instruments by capturing data during the optimum satellite conditions.

- A test was made to determine the accuracy gained by using the Trimble Geo Beacon reciever to make a real time correction of the gps signal. This test was done by capturing 500 data points during different satellite conditions, using the Trimble GeoXH with a wireless connection to the GeoBeacon. No post processing of the data was done.

Ave Error Under-the-Canopy Points. **Without** the GeoBeacon	Ave Error Under-the-Canopy Points. With the GeoBeacon	Ave Error Control Pt. In-the_Open **Without** the GeoBeacon	Ave Error Control Pt In-the-Open With the GeoBeacon
7.3’	5.5’	4.7’	0.9’

The test results show the Geobeacon improved the accuracy by **25%** for the under-the-canopy points and by **81%** for the control point in the open.

- A test was made to determine the accuracy gained by employing the GPS units with external antennas.

GPS unit classes	No external antenna	External Antenna Attached
Garmin(no diff Correction done)	8.4’ ave error	7.1’ ave error
Geo series (diff correction done)	6.3’ ave error	4.0’ ave error

Employing an external antenna increased the accuracy by **36.5%** for the Geo series of units and by 15% for the Garmin GPS unit.

- A test was made to compare the accuracies of post process correction with a distant base and a gps unit set up on the survey monument near the test area. This test was done to evaluate the commonly used technique of simply letting a gps unit, set in base mode, capture data, in order to correct the data captured by a rover gps. Employing a gps in base mode requires an initial input of coordinates for the base unit’s location. In a real world situation, operators would likely have to follow a 2-step process: leave a gps on to capture data at a control point and then use the coordinates determined from a post process correction of this data to later set up a gps in base mode.

In this test I employed a gps unit in base mode to collect data at the primary control point, which is in the open and just adjacent to the forested test area. The base GPS unit was set to capture data for an overlapping time period, during which a second GPS unit was used in rover mode to capture data at each of the test points. The base unit was given the **actual utm coordinates** of the survey monument. This test showed that making a post process correction of data from a rover gps, with the temporary base station’s data, was **5 % more** accurate than correcting with data from a distant permanent base station. A couple of points to bear in mind for this test:

1. The permanent base station, from which the comparison was made, is within 20 miles of the control point.
2. The 5% increase is the average of the results I got from only 2 tests.

- Since it would be unlikely for a surveyed monument to be located right adjacent to a GPS work area in a “real world” work situation, I conducted a follow up test to determine the effect of bringing base control into a work area from a distant permanent base station. In this test, of a 2-step technique, I left a GPS unit on, in base mode, to capture data at a survey monument, approximately 5 miles distant from the test area. While at the same time, I captured data with a second GPS unit, in rover mode, set up on the primary control point for my test area. Both points are at locations fairly open to the sky. I post processed the rover unit's data with the base unit's data to determine a coordinate location for the rover control point.

The second step of this technique was to leave a gps unit on to capture data in base mode over the test area primary control point, using the coordinates determined from step 1. This temporary base station's data was then used to post process the data captured by a rover gps at the nearby under-the-canopy test points. The good news is that this test indicated that accuracy was increased approximately **5%**, the same increase as test 1, where we knew, and used, the coordinates of a survey monument located immediately adjacent to the test area. Bear in mind that, for this test, we did not use the coordinates of the survey monument, we proceeded as if they were not available to us. The results of this test indicate that this 2-step technique, of bringing base control to a point open to the sky and near a gps work area, would increase rover accuracy at nearby under-the-canopy points. It's possible that if the nearest permanent base station was considerably farther away than 20 miles this technique might yield a significantly better accuracy.

- Some tests were done to compare the accuracies of capturing data with the 2 software packages available, ArcPad & the Trimble GPS correct add-on application and the Trimble Terra Snyc software. The GeoXH, which had both software packages installed, was used for these tests. In the first test to compare the 2 software packages for accuracy in **real time** data capture, the results showed that ArcPad was **12%** more accurate than Terra Snyc. However, the second tests results showed that after **post processing** the captured data, The Terra Snyc test point locations were **11%** more accurate.

- Test to determine the accuracy of the Geo-series and Garmin units used in a **real-time** mode at the test area points. These tests were done to evaluate the feasibility of using GPS to determine the coordinates of a start point, from which a bearing and distance to distant target points could be calculated during the course of a field session. This capability could result in a significant time and effort-savings for the real time control work required to set sample plots on a systematic grid for various types of natural resources surveys, particularly timber cruises. These results were achieved by letting the GPS units capture from **100-200** data points, in any satellite conditions, and with no external antennas attached. No post processing was applied to the raw gps data. The average error figures in the table below indicate the potential error of target points, or plot centers, not including any error that might be incurred during movement to the target point from compassing and/or chaining error.

GPS Unit	Ave Error Test Points in small canopy openings	Ave Error All Under-the-Canopy Points	Ave Error Primary CP In-the-open
Geo series	5.9'	7.6'	3.4'
Geo series w/ Geo beacon	--	4.1'	1.5'
Garmin 60CS	11.8'	13.1'	17.1'
Garmin 10	15.7'	23.0'	13.3'

Once the UTM coordinates (the easting & northing) of both the target point and the GPS point are known, the following procedure can be used to calculate a bearing and distance from the GPS point to the target point:
Adjusted Easting UTM coordinate = Target Easting coordinate – GPS Easting Coordinate
Adjusted Northing UTM coordinate = Target Northing coord – GPS Northing Coord

Quadrant Bearing = Tan-1 of the Adjusted Easting / Adjusted Northing
A + Easting & a + Northing pair will be a Northeast quadrant bearing
A + Easting & a – Northing pair will be a Southeast quadrant bearing
A – Easting & a – Northing pair will be a Southwest quadrant bearing
A – Easting & a + Northing pair will be a Northwest quadrant bearing

Distance (in Feet) =
SquareRoot of [((Ajdusted Easting^2) + (Adjusted Northing^2))/ 0.3048]

- Tests were made to determine the accuracy of using mapping grade GPS units in dynamic line mode to plot the centerline of a canopy-covered road. I selected a segment of road, approximately 350‘ in length and covered by a 60-year old forest canopy. I completed a compass and chaining traverse along the centerline of the 12’ wide gravel-surfaced road in order to create a control line to allow a comparison with the gps line tests. In order to capture the most amount of data points while continuously moving along the road segment, I set all of the gps settings to maximum productivity, meaning that the signal parameters were reduced to accept PDOPs of up to 20. I postprocess corrected all of the captured data.

I tried 3 slow runs each with the ProXRS and GeoXH; I employed external antennas with both units. The slow runs were done at a moderate walking pace, stopping only to collect 1 data point at the start and end points of the control line. I then tried 3 fast runs each with both units. The fast runs were done at about 5mph in my car, with the gps antennas sitting on the car roof.

The error indicated for each gps unit constitutes the amount that a depiction of a road centerline could vary, if a line was drawn along the approximate plot of the gps line, not including obvious deviations in the gps line.

Run Speed	ProXRS Error	GeoXH Error	Garmin 10 Error
Slow	6.5’	6.5’	
Fast	13’	8’	7’

I tried line capture, using the Garmin 10 with the ArcPad software. ArcPad permits 2 ways to capture line data, dynamic and vertex mode. In dynamic mode the unit captures data automatically. In vertex mode the operator can capture any number of points he specifies while moving in the field. As shown by the results: the amount of accuracy difference between capturing real time line data while walking and while in a slow-moving vehicle probably justifies the ease of doing the data capture in a vehicle for most road mapping applications.

Summary.

- These tests seem to verify gps data capture aspects that we'd expect, specifically, that the most accuracy for data capture at under-the-canopy points might be improved by managing some or all of the following conditions:
  - Collect during optimum satellite conditions, as determined from mission planning software, such as Pathfinder Office.
  - Use a gps unit that permits post processing of the data and process with data from the closest permanent base station.
  - Use an external antenna, if available, for the gps unit.
  - Capturing data in small to moderate-sized openings, that are clear of direct over-head cover, improves accuracy. Taking advantage of nearby moderate-sized openings and adjacent clear areas, by off-setting, is usually preferable to attempting to capture data directly under the forest canopy. Exercise judgment in determining if the time and effort required to traverse from an off-set point to the target point would be worth the potential additional accuracy. The tests showed a 20% increase in accuracy for capturing data at points in adjacent open areas.
- Surprisingly, the best balance of capture time and accuracy seems to happen by capturing between 250-500 data points. Spending an extra 30 minutes at each point to capture 2,000 data points, would probably not be worth the minor increase in accuracy for many GPS applications.
- Although my tests were done with the parameter settings on the gps units mostly set to "mid-range", I recommend raising the parameters (reducing the amount of poor quality signals the gps will accept as a captured data point) of the gps unit as much as time and conditions allow. Always set the logging interval to1 second, rather than the usual default setting of 5 seconds. The 5 second interval saves memory, but the unit will take 5 times as long to capture a given amount of data points. I recommend setting the 5 second interval only on units in base mode and then only if the rover data capture effort is likely to exceed 2 hours. Some of the older trimble units, such as the Pro XRS use older, external batteries. Beware of batteries that may drain out before the base station set up is completed. Have spare batteries available and be prepared to change batteries out during the overlapping base capture session.
- There are rarely delays in capturing data with NMEA-only data units, such as The Garmin 60 and the Garmin 10. However, for the mapping-grade gps units, such as the Geo series which allow setting minimum reception parameters, I noticed that, occasionally, there would be long delays in the units to start capturing data, even at points in the open. These delays are caused by the current satellite situation not meeting the set minimum defaults on the receiver. If a mapping-grade unit is having problems getting started, some measures you can try (in order):
  1. Turn the unit on and let it "see the sky" and attempt to capture satellite data prior to beginning the capture work at designated points under the canopy. If possible, turn the unit on while driving or walking to the work area. Hook an external antenna up to the unit, if available. You can always remove the antenna once the unit starts capturing data, in the event that you don't want to pack the antenna into some of the target points.
  2. Set the gps satellite parameter settings to minimum. If and when the unit starts capturing points re adjust the settings for more accuracy.

3. Skip collecting data at the problem capture point for the time being and return later to try capturing data after the satellite conditions have changed. Even a minor change in satellite positions will usually improve the reception. If possible, make a work plan that attempts data capture at problem points during periods of optimum satellite availability. I definitely noticed it was easier to capture data during the optimum satellite periods.

4. Evaluate the surrounding area for a clearing with a larger, less obstructed view of the sky and consider collecting data at an off-set point in the opening. If good gps data can be captured at a nearby off-set point, tie that point to the desired capture point with a bearing & distance traverse. A series of bearing & distance records can later be entered into a GIS or a survey application, such as COGO, in order to calculate the coordinates of the desired capture point. I found that a hand compass and handheld laser distance device provided acceptable accuracy for capture points tied to an off-set point with a traverse.

- If a permanent base station is a considerable distance away from the work area, consideration should be given to selecting one of the two base station techniques I tested. Of course, both of these techniques require the availability of 2 GPS units, both of which must allow post processing of data.
- I recommend the Terra Snyc software over ArcPad, even though ArcPad appears to be a little more accurate for real time data capture. Some considerations:
  - ArcPad will not permit changing the projection in the field, it uses Lat/Long or whatever projection is assigned to the arcmap (APM) file open at the time. I recommend GPS data be captured in the UTM, meters projection, as the math to determine the difference between coordinates of 2 points is easier.
  - Downloading and uploading files is more involved, as it necessitates using the more expensive ESRI ArcGIS software, while Terra Snyc only requires PathFinder Office.
  - ArcPad seems to "lock-up" more, requiring rebooting; probably because it requires much RAM to run and most GPS units don't have enough RAM, at the usual 60 megs.
  - One of the advantages to using ArcPad, however, it that it allows the user to specify the number of data points to capture; this means that, unlike Terra Snyc, the user can attend to other matters after starting the data capture and ArcPad will stop the routine when the specified number of data points are captured.
- If the need is for the most accurate capture data for a real time application (no opportunity to post process), I'd highly recommend using the Trimble Geobeacon receiver to offer a real time correction. These Geobeacons can be used with any GPS unit equipped with Terra Snyc and a bluetooth capability, including the hard & software. My real time test showed that the Geobeacon tremendously improved the accuracy of the Geo series of GPS units by **46%** at the under-the-canopy points and **55%** at the primary control point in-the-open. Unfortunately, my experience with attempting to employ the Geobeacon is that the DGPS signal can only be received at approximately half of the remote forest locations in this area.
- I completed some more real time tests during various cruise projects I worked on during the test period. My cruise partner compassed and paced to cruise plot locations from starting points identified on ortho photos. While, at the same time, I used the

Garmin 60CS to determine start points and then compassed & paced into the same plot locations. On all occasions, we would end up acceptably close together at the end of the control efforts. Also, both methods took about the same approximate time to implement, when both of our start points were fairly close together. However, since it's sometimes difficult to identify specific trees on an ortho photo, there were a number of occasions where I was able to use a start point much closer than my partner's start point. Consequentially, I was able to beat my partner to the plot center and not have to contend with as much underbrush on the way as he did.

Considering the approximate $4,000 price difference between the Trimble Geo-series of mapping-grade gps units and the Garmin 60CS, I think the Garmin provides all of the accuracy needed for most forestry applications. However, ideally, the Garmin 60CS unit should only be used to determine a real time starting location for setting cruise plots if the data capture can occur in a large clearing. The Garmin is quite portable and appears fairly weather-proof. Garmin 60CS units can be purchased on EBAY for approximately $200.

- I'd like to sum up the uses for GPS in natural resource applications:
  1. To obtain the spatial control necessary to establish and set sample points. Use of GPS will probably result in a cost and time savings over conventional sample point establishment.
  2. To allow verification of sample points set by other parties in quality control efforts.
  3. To allow determination of polygon acreages. GPS traversing will probably result in a significant cost and time savings over conventional traversing methods. I completed another research project in 2006 to prove the feasibility of using GPS to determine acreages of forested polygons. The link to this PDF is: http://www.tsiwood.com/GPSTRAV.pdf
  4. To permit more precise mapping of the location of specific points under the canopy. The ability to more precisely plot a specific objects location may allow more uses for LIDAR data.
- I'm interested in anyone else's work on this subject. Please feel free to write to me at: cavtrooper@sbcglobal.net or ken@tsiwood.com .