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Performance of Mapping-Grade GPS Receivers in Southeastern Forest Conditions

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Performance of Mapping-Grade GPS Receivers in Southeastern Forest Conditions*

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Abstract

This study represents an assessment of two recently-available GPS receiver configurations used in mature southern pine and hardwood forests in the Piedmont of Georgia. Six control points were visited ten times, with WAAS (Wide Area Augmentation System) enabled, and 50 position fixes were recorded during each visit to each control point. We found that horizontal position accuracy was on the order of 2 m when WAAS was enabled in those receivers and post-collection differential correction was not employed. This was significant in that the accuracy of the receivers evaluated was greater than recent studies suggested even without the use of differential correction, revising our notion of how well GPS receivers perform in real time in forested conditions. In general, there was no significant difference in horizontal position accuracy between the two receiver configurations when the error of an average position (from a set of position fixes) was analyzed. However, when the error was assessed for each position fix, and then averaged, there was a significant difference with one of the receiver configurations when used in the pine and hardwood stands, and there were significant differences between the two receiver configurations when used in the hardwood stand. In addition, in general there was no correlation between horizontal position error and PDOP (Positional Dilution of Precision), signal-to-noise ratio, relative humidity, air temperature, and atmospheric pressure values at the time of data collection. However, one of the two receiver configurations seemed sensitive to air temperature. These results illustrate the real-time horizontal position accuracy that can be obtained with current technology in similar forest conditions throughout the Piedmont of the United States during leaf-off (winter) conditions.

KEYWORDS: global positioning systems, root mean squared error, WAAS, horizontal position accuracy

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1. Introduction

Global positioning system (GPS) receivers have received much attention in the past several decades, due to their broad appeal across a wide spectrum of both industrial and recreational users. Consumer-grade and mapping-grade receivers have, in particular, seen significant interest in the previous decade due to a decrease in the cost of technology and a decrease in the complexity of the user interface. The use of GPS in forest management activities can provide land managers the power to measure and describe resources in near-real time (Weih et al. 1993). A number of studies on the accuracy of GPS receivers have been conducted in the western United States (Wing et al. 2005, Wing and Karsky 2006, Wing and Eklund 2007, Wing 2008, Wing et al. 2008) and the northern United States and Canada (D'Eon 1996, Bolstad et al. 2005). The horizontal position accuracy of GPS receivers has received some attention in southern forests as well (Deckert and Bolstad 1996, Danskin et al. 2009a, 2009b). Although these studies generally relate to point positions or area determination, Evans et al. (1992) suggested that GPS could be used effectively for forest navigational purposes even though signals may be interrupted by canopy and terrain issues. D'Eon (1996) also suggested that an antenna raised above the head of the user might help eliminate some of the interference of GPS signals from forest vegetation.

Recent studies of GPS technology in the Piedmont of Georgia indicated that mapping-grade GPS receivers, when used in forested conditions, could have horizontal position error of 5 m or greater (Danskin et al. 2009a, 2009b). However, those studies were conducted with equipment 2-3 years old at the time of data collection, and the results were published almost 2 years after data collection. Given the recent advances in GPS technology, we conducted a study of two recently-introduced mapping-grade GPS receiver configurations during the winter season to determine how much better the new technology was with regard to horizontal position accuracy. Further, with the advent of the Wide Area Augmentation System (WAAS), it was questionable whether post-collection differential correction was still necessary. Therefore, it was our desire to report real-time accuracy levels that might be obtained with the latest equipment. As a result, our objective was to design a study that would allow us to understand the current state of real-time mapping-grade GPS receiver accuracy in leaf-off forested conditions.

2. Methods

Two mapping-grade GPS receiver configurations were evaluated for their horizontal position accuracy during a leaf-off (winter) time period in the Piedmont of Georgia. The receiver configurations were: (a) a Trimble GeoXT 2008 series, and (2) a Tripod Data Systems (TDS) Ranger equipped with a Crescent A100 antenna. The Trimble GeoXT is an integrated GPS / data collection device that relies on touchscreen technology. The TDS Ranger is a data collection device that uses both keypad and touchscreen technology. Each weigh about the same, and each are designed for use in outdoor field conditions. The Crescent A100 antenna, developed by Hemisphere GPS (Calgary, Alberta), is used externally with the TDS Ranger data collector and the antenna is more formally called the "A100 Smart Antenna." The GeoXT receivers include firmware which can reduce multipath errors, and the Crescent A100 antenna also has its own means of multipath signal rejection. Since the TDS Ranger is just a data collector, it has no signal filtering process. These two systems, Trimble GeoXT and TDS Ranger / Crescent A100, were considered to be among the most current set of technologies for forest management applications.

The antenna for each receiver configuration was plumbed over each control point as data were being collected. Thus for each visit, the antenna for each GPS receiver was positioned on the top of a 1.2 m wooden staff that was centered over the surveyed control point. A 1-second interval separated the position fixes that were collected at each visit to each control point. Our intent was to visit each control point during periods of time when the planned position dilution of precision (PDOP) was adequate (less than 8). During the data collection process, PDOP levels rarely rose above 5, and averaged about 3.5. Pre-planning to avoid high-PDOP time periods was accomplished using GPS planning software. The WAAS signal was enabled for real-time augmentation of positions, although the service was not necessarily available 100% of the time. Since the method of data collection was randomized, and since the visits to the control points were made within minutes of each other, the effect of WAAS was essentially the same for the conditions tested. Post-collection differential correction was not applied to determine whether the current accepted theory (differential correction is necessary) could be challenged.

Three similarly-positioned control points in a 60-70 year old hardwood stand (88 ft^2 per acre basal area, 144 trees per acre) were selected from the Whitehall Forest GPS test site in Athens, GA, where the estimates of "true" locations of each control point was less than 2 cm. Three similarly-positioned control points in 60-70 year old pine stand (86 ft^2 per acre basal area, 59 trees per acre) also were selected (Figure 1). Each control point was visited ten times (consistent with Deckert and Bolstad 1996) in February 2009. During the ten sets of visits, data were collected within a 20 min time period, minimizing the potential negative effects of WAAS unavailability. During each visit, 50 position fixes were recorded. The number of position fixes collected was consistent with recent studies (Danskin et al. 2009a, 2009b, Wing 2008, Wing et al. 2008). Although Sigrist et al. (1999) suggested that 300 position fixes per control point were necessary, and although Deckert and Bolstad (1996) concluded that error decreased when more position fixes were acquired, Wing (2008) sampled up to 60 position fixes per visit to a control point, and found that the number of fixes for averaging a position was significant in only one-third of the receivers tested. Wing et al. (2008) further suggested that 30 fixes per point position seemed to be appropriate for highly accurate measurements when using mapping-grade GPS receivers, supporting their earlier conclusion that collecting a greater number of points did not necessarily result in higher positional accuracy (Wing and Karsky 2006). Therefore, a sample of 50 position fixes was obtained from 30 visits to the hardwood stand and 30 visits to the pine stand. During each visit, the researcher stood on the north side of each control point and collected data. The visits in each stand were randomly arranged to avoid measurement bias. Data were collected between 11:00 a.m. and 3:00 p.m., and GPS receivers were limited to viewing satellites 15º above the horizon.

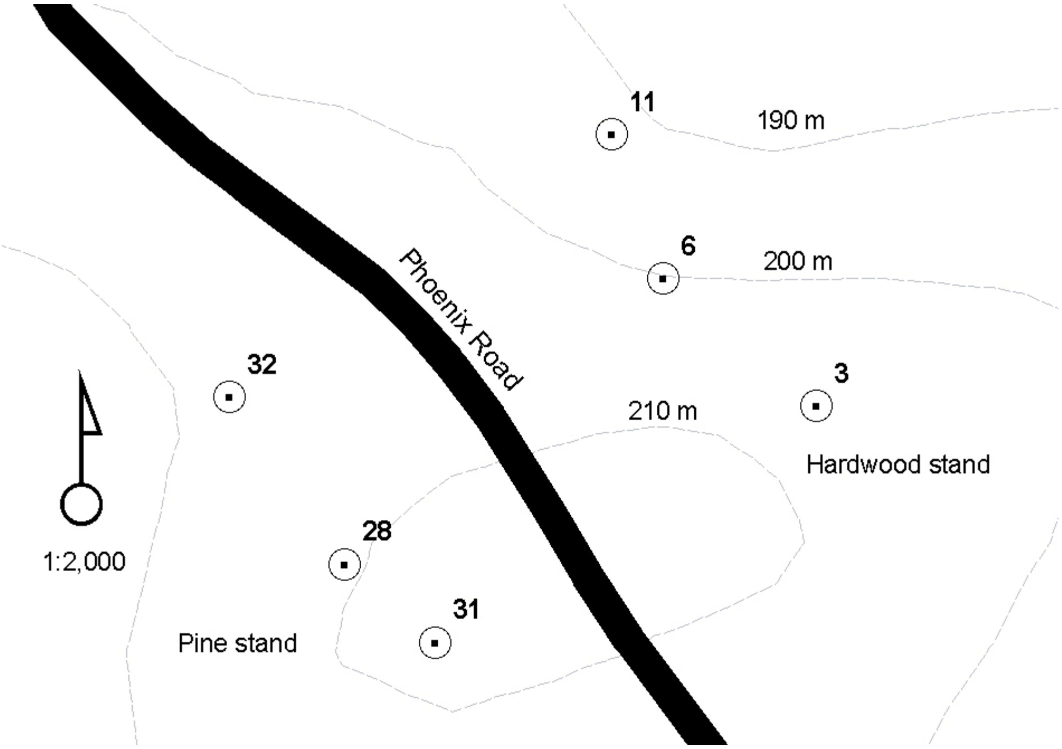

Figure 1. Positions sampled at the Whitehall Forest GPS test site in Athens, GA.

Accuracy of the horizontal positions collected with each GPS receiver configuration was evaluated by using the root mean square error (RMSE). RMSE is the raw difference between collected measurements and the control points, and places greater weight on larger errors since the error term is squared. Using raw RMSE to evaluate the differences between GPS receiver configurations may make more sense to land managers than what the federal government suggests (U.S. Forest Service 2003), which is to report accuracy in RMSE ground distances at the 95% confidence level. Here, one would take the raw RMSE, and multiply it by a factor (1.7308) to arrive at a value which would suggest that one would be 95% confident that the true accuracy is this resulting value (raw RMSE x 1.7308), or lower. For the purposes of this study, we reported the raw RMSE values.

There are two distinct ways to evaluate RMSE: (1) determine the error for each of the 50 position fixes collected on each visit to a control point, and then average the error, and (2) generate an average position using the set of 50 position fixes collected from each visit to each control point, then determine the error from this value. We have reported both of these here. For the purposes of this study, RMSE1 refers to the average root mean squared error from each of the 50 position fixes of each visit to each point in each stand by each receiver configuration. RMSE2 refers to the root mean squared error of the average horizontal position computed for each visit to each point in each stand by each receiver configuration. In the latter case, all 50 position fixes were used to arrive at an average northing and average easting, and from this average position the RMSE was computed. It should be noted that in every case, RMSE2 was lower than RMSE1.

A correlation analysis was performed between the RMSE values and the average PDOP, signal-to-noise ratio (SNR), air temperature, relative humidity, and atmospheric pressure experienced with each visit. While PDOP is a measure of the quality of satellite configuration, Sigrist et al. (1999) suggested that it is not highly correlated with horizontal position accuracy in forested conditions. However, the SNR could be degraded by atmospheric conditions or by the path the electromagnetic waves take through the canopies of trees (Yoshimura and Hasegawa 2003, Sawaguchi et al. 2005). The three environmental variables (air temperature, relative humidity, and atmospheric pressure) were easily obtained from a nearby weather station (Athens Airport), and while these may not necessarily affect the quality of GPS signals, we decided to test the correlation between them and horizontal position accuracy in order to possibly rule them out for consideration in further studies. However, dry gases and water vapor in the troposphere can lengthen the path of a satellite signal due to refraction (the change in direction of a wave of energy due to a change in its speed). Knowledge of temperature, pressure, and humidity may help determine the refractivity profile of a GPS signal through the troposphere, yet the component of this profile related to water vapor is difficult to understand, since water vapor in the troposphere varies considerably over space and time (Grewal et al. 2007). Further, most people only have access to these environmental values for the very lowest portion of the troposphere, which consists of data collected at weather stations situated on the ground. Goodness of fit tests for a normal distribution of data were accomplished using BestFit software (Palisade Corporation 1996). These tests were necessary, since a Student's *t*-test was ultimately applied (as suggested by D'Eon 1996) to determine whether significant differences existed between stand types (using the same receiver configuration) and between receiver configurations (within the same stand type).

3. Results

The horizontal position accuracies of the two GPS receiver configurations were less than 3 m, on average for the 30 visits to each control point (Table 1). RMSE1 values, which were computed by determining the RMSE for each position fix, then averaging those for each visit, ranged from 1.93 m to 2.35 m when using the Trimble GeoXT receiver configuration, and from 2.49 m to 2.67 m when using the A100 receiver configuration. The RMSE2 values, which were computed from an average of the 50 position fixes from each visit to each control point, ranged from 1.62 m to 1.84 m for the Trimble GeoXT receiver configuration,

Table 1. Results of GPS accuracy assessment.

GPS receiver configuration	Stand	RMSE1 (m)	RMSE2 (m)	Average PDOP	Average SNR
GeoXT	Pine	2.35	1.84	3.25	44.11
	Hardwood	1.93	1.62	3.93	43.61
Crescent A100	Pine	2.49	2.08	3.59	41.69
	Hardwood	2.67	2.00	4.44	40.88

RMSE1 = Average RMSE value for each of 50 fixes on each visit to each control point

RMSE2 = RMSE of average position from each visit

PDOP = Positional dilution of precision

SNR = Signal-to-noise ratio

and were about 2 m for the A100 receiver configuration. The best estimated position was about 0.2 m when using RMSE2 to describe the accuracy. The worst estimated positions ranged from 3.5 to 9.9 m when using RMSE2 to describe the accuracy. Thus on any one visit, while the average RMSE might be around 2 m, the range could be from 0.2 to 10 m, although the probability of obtaining the larger error seemed to be much less than the probability of obtaining the smaller error. When examining the RMSE of each individual position fix, then averaging those for each visit (RMSE1), the range of maximum RMSE values were from about 4.7 to 16 m. Thus, while the average of a number of fixes might be quite low, any one position fix could be off by as much as 16 m. Interestingly, the higher "maximum error" values, for both RMSE1 and RMSE2 were found using the Trimble GeoXT in the pine stand.

When testing for significant differences between the two GPS receiver configurations, the RMSE data (both RMSE1 and RMSE2) needed to be transformed through the calculation of the square-root of these values. Prior to transforming the data, seven of the eight sets of 30 RMSE values for each receiver/stand type did not represent normally distributed data. Although other transformations were attempted (log and inverse), the square root seemed to be the most appropriate, given that seven of the eight sets of 30 RMSE values for each receiver / stand type did represent normally distributed data after the transformation was applied. The results of a Student's *t*-test suggested that there were no significant differences in RMSE2 values between stand types (using the same receiver configuration) and between receiver configurations (within the same stand type). Also, results suggest that there were no significant differences in RMSE1 values between the pine and hardwood stands when using the GeoXT receiver configuration, and there were no significant differences in RMSE1 values between the GeoXT and A100 receiver configurations in the pine stand. However, there were significant differences (p = 0.07) between the pine and hardwood stands when using the A100 receiver configuration, and there were significant differences between the two receiver configurations when used in the hardwood stand (p = 0.06).

The correlation analysis produced insignificant results. There was very little correlation between PDOP and RMSE1 (-0.148 to 0.420) and RMSE2 (-0.121 to 0.384) in either type of stand. Although RMSE values should correlate positively with PDOP levels, the PDOP levels experienced during the field data collection process were only in the 2 to 5 range, where high quality signals should have been received. There was also very little correlation between SNR and RMSE1 (-0.245 to -0.080) and RMSE2 (-0.174 to -0.125) in either stand type, although the results suggested that as SNR increased (which was good), RMSE should decrease. The correlation between relative humidity and RMSE1 also was low (-0.095 to 0.163) as was the correlation between relative humidity and RMSE2 (-0.041 to 0.187) for either stand type. In addition, there was very little correlation between atmospheric pressure and RMSE1 (-0.076 to 0.291) and RMSE2 (-0.109 to 0.134) in either type of stand. The only interesting correlations were between air temperature and RMSE1 (-0.517) and RMSE2 (-0.608), when using the A100 antenna in the hardwood stand. When using the GeoXT in both forests, and when using the A100 in the pine stand, the correlation between air temperature and RMSE1 was low (-0.194 to 0.142), as was the correlation between air temperature and RMSE2 (-0.146 to 0.101). Thus, it seemed that as the air temperature increased, the RMSE of horizontal positions in the hardwood stand decreased (improved) when using the A100 antenna.

4. Discussion

Although the use of GPS in forest management is widespread, the integration of GPS into forest management has proceeded at a slower pace than other industries as a result of the difficulties in maintaining high quality satellite signals beneath forest canopies (Wing 2008). Data collected with GPS equipment are easily integrated with GIS software for visual representation of features collected, and are becoming very valuable for developing and updating corporate GIS databases. Thus under the right conditions, fairly accurate maps can be developed with GPS, and this data capture process can provide an effective method in assisting with forest management objectives (Johnson 2008). Sigrist et al. (1999) suggested that the degree of canopy cover was an important factor in the horizontal position accuracy of GPS data, and Danskin et al. (2009a) illustrated the differences one might obtain during leaf-on and leaf-off conditions in a southern hardwood forest. Recent studies have shown that under both leaf-on and leaf-off conditions, enabling WAAS can increase the horizontal position accuracy of both mapping-grade and consumer-grade GPS receivers (Danskin et al. 2009a, Wing and Eklund 2007). Although in our study the WAAS signal was not available 100% of the time, we assumed it was enabled constantly to simulate common data collection practices. However, one might argue that applying WAAS to some measurements but not others may mask the differences (correlation) we should have seen when PDOP levels changed. Further, the error involved when WAAS was not enabled for a specific position fix could have been greater than the error associated with changes in PDOP levels. While we rarely were informed through system diagnostics that WAAS was not enabled during the data collection process, unfortunately we were unable to perform the analyses necessary to understand these interactions. Future studies could be designed to understand these interactions as well as the full impact of having WAAS enabled or disabled. However, our work suggested that current technology might be able to provide forest managers with a level of quality that is acceptable for most forest management purposes, although leaf-off conditions and other forest types should subsequently be assessed.

The data collected with GPS also are being used for purposes other than map-making. Some examples include the use of GPS in airplanes and helicopters for locating aerial photo flight lines and chemical and fertilizer application routes, when applied aerially. The accuracy and precision allowed by GPS may greatly reduce the cost of chemical and fertilizer costs and increase the efficiency of these operations. Logging operations also are now taking advantage of GPS by providing operators with information valuable for visualizing treatment area boundaries and logging routes, and for assessing primary and secondary transportation scheduling issues (Veal et al. 2001, McDonald et al. 2002, Sikanen et al. 2004, Suvinen and Saarilahti 2006, Devlin et al. 2007). The increased efficiency will be recognized in the form of the reduced fuel costs and the reduced time and cost of travel (McCall et al. 2009).

While post-processing was not performed here, since real-time horizontal position accuracy was of interest to us, and even though the accuracies of the GPS receiver configurations we tested were very good, post-processing using differential correction may help further improve the accuracy of horizontal positions. Wing et al. (2008), for example, found similar results (about 2 m RMSE) for positions that were not post-processed, but also found that these could be improved by about 1 m when differential correction was used. Danksin et al. (2009a, 2009b) also illustrated 50-60% improvements in horizontal position accuracy were possible when post-processing data collected in southern hardwood forests. Therefore, one might assume that the improvement in horizontal position accuracy might be on the order of 1.0 to 1.5 m with either of the GPS receiver configurations we tested, assuming the results from the other studies are transferable to our results.

5. Conclusions

The results presented here are significant in that the accuracies of the receivers evaluated were greater than previous but recent studies suggested even without the use of differential correction, revising our notion of how well GPS receivers can perform in real time in forested conditions. Using current GPS technology, we have shown that the accuracy of GPS horizontal positions was very good under the canopy of mature pine and hardwood stands during winter time. Although our study area was located in northeast Georgia, these results should be applicable to similar stands throughout the Piedmont of the southeastern United States along the same latitude as our study (about 34° North). While our study was limited to winter-time conditions, others have noted that the difference between winter-time GPS accuracy and summer-time GPS accuracy was on the order of about 1 m for GPS receiver configurations similar to the ones we studied, if WAAS was enabled and post-collection differential correction was not employed. These results are applicable to forest managers who desire real-time data for assisting with forest management decisions.

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