STATUS OF GPS RESEARCH AT THE WHITEHALL GPS TEST COURSE

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Abstract

In 2004, a GPS test course was installed on the University of Georgia Whitehall Forest. Twenty-four monuments (points), located in a predominantly hardwood stand, were surveyed to about 1.3 cm accuracy. The test course is open to the public, and has been used for at least four research studies aimed at determining the quality of GPS data collected with different receiver and antenna configurations, collected at different times of the year, and collected in different physical environments. One of these studies was designed to delineate the effect of multipath by using a choke-ring antenna designed to filter out spurious signals. This presentation summarizes the studies that have been conducted thus far on the test site, and presents a plan for the future that involves teaching, research, and outreach activities.

Keywords. Global positioning systems, multi-path, differential correction, accuracy assessment.

Introduction

Global positioning systems (GPS) are common tools used in natural resource management for navigation and mapping purposes. Advances in GPS technology provide increasingly accurate positional data, faster signal capture, longer signal maintenance, and lower ownership costs. Questions regarding the relative accuracy of one system over another linger, therefore investigations into the relative performance of GIS technology have been pursued (e.g., Wing and Eklund 2007, Wing and Karsky 2006).

Vegetation plays a significant role in obstructing GPS signals in forests, and in introducing error into the system through the multipath effect of signals that are redirected from obstructive surfaces. In general, more multipath is experienced, and lower signal-to-noise realized under a forest canopy. Data collected for point locations, for example, can vary from one moment to the next (Figure 1). The quality of a GPS signal may be improved by better antenna design, and may be enhanced by post-processing techniques. However, the improvement in data quality from an individual GPS receiver in high multipath environments is often unknown. A manufacturer's statement of GPS receiver accuracy is often ambitious, and perhaps only applicable to open sky conditions. We have therefore embarked on a series of studies to determine the accuracy of various receivers and antenna configurations, and to understand the behavior of data positioning in a southern hardwood forest environment.

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GPS technology changes rapidly, thus advances in all aspects of GPS technology require continual review. Three general classes of GPS receivers are (1) survey grade, (2) mapping grade, and (3) recreation or consumer grade. Survey grade GPS receivers are reported to be capable of providing sub-centimeter positional accuracy under most conditions, yet at a cost of $10,000 dollars or more per unit. As a result, survey grade receivers are not typically used by natural resource managers performing general day-to-day management activities. Mapping grade receivers, which in some cases can provide 1-5 m accuracy, range in price from about $1,500 to $10,000. These types of receivers are frequently used in forestry applications. Recreation-grade receivers generally provide the least accurate positional information, usually between 5 m and 20 m accuracy under optimal conditions, and range in price from $100 to about $1,000. Recreation-grade receivers have become popular among many outdoors enthusiasts, and this popularity has likely influenced the wide variety of inexpensive GPS receivers available on the market today. The potential cost savings made available from an evaluation of a range of receivers might

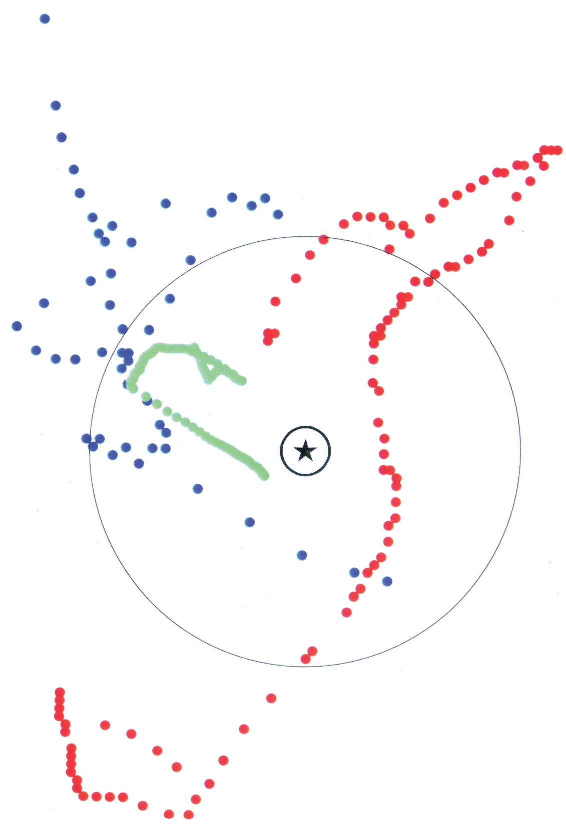

Figure 1. Example of the range of position locations over a 100-second time period using three different GPS receivers (the star represents a surveyed point, the buffer is 5 m around the point).

encourage forest managers to more readily apply mapping or recreation grade technology to their day-to-day operations.

The GPS research presented here was conducted at the GPS test course facility in Whitehall Forest, located four miles south of the University of Georgia campus in Athens, Georgia. Three On-line Positioning User Service (OPUS) benchmarks were established within two kilometers of the field course. Position determination of twenty-seven permanent monuments was then made using standard surveying techniques. Each survey point consists of a brass survey cap mounted on a 0.6 m rebar post, which is encased in concrete. Survey points were established under a range of topographical and forested conditions, and positional accuracy is known to about 1.3 cm. Twenty-four of the points were classified as being under full canopy (not influenced by forest edge). Aspect ranges from north to southeast, while slopes vary from 2 - 40%. Forest conditions change nominally over these positions, a general pattern of species gradation occurs, changing from bottomland hardwood forest with a larger component of beech (*Fagus grandifolia*) and related species to an upland dominated by oak (*Quercus* spp.) and hickory (*Carya* spp.) with some remnant shortleaf pine (*Pinus echinata*) still present.

This paper describes four studies conducted at the GPS test site. Since this paper provides an overview of each study, the usual *Methods* and *Results* sections that are typical for a single study are absent and replaced with a single *GPS Studies* section.

GPS Studies

<u>Study #1: A comparison of GPS performance in a southern hardwood forest: Exploring low-cost solutions for forestry applications</u>

This study was conducted by University of Georgia graduate student Scott Danskin as part of his PhD dissertation work. The formal study methodology and results will likely soon be available in the *Southern Journal of Applied Forestry*. Four GPS receivers were tested on numerous points within the GPS test course. The receivers included one mapping grade receiver (Trimble ProXR), and three recreation grade receivers (Garmin Etrex, Garmin Map 60C, and Thales Mobile Mapper). The study was performed in both the summer and the winter, thus the forests at the time of the study consisted of "leaf-on" and "leaf-off" conditions, respectively. Measurements were collected on three slope conditions: upper slopes, lower slopes, and mid-slopes. Measurements were also randomized by receiver and repeated several times. Wide Area Augmentation System (WAAS) was enabled in receivers that could accommodate this service. WAAS was begun in 1994 as a joint project between the United States Department of Transportation and the Federal Aviation Administration (FAA), and was initially meant to provide service for all classes of aircraft in all phases of flight in the United States. However, it is now available for use in a variety of hand-held GPS receivers. The Trimble ProXR data was differentially corrected as well, because processes for doing so were readily available.

Results of the study provide verification of several concepts related to GPS performance in the field. First, positional accuracy tended to increase as slope position changed. Higher levels of accuracy were typically found on higher slope positions, and lower levels of accuracy were found in bottoms and along a river (Table 1). Second, WAAS provided some improvement in accuracy, although it did not reduce error to the 6-7 m range that is usually suggested. When error was above 10 m, WAAS provided several meters of improvement in position location. Third, the mapping grade receiver out-performed the recreation grade receivers, which was expected. Fourth, differential correction did lead to improvements in the mapping grade receiver performance. Accuracy of data after differential correction was 2-3 m. Fifth, accuracy improved in the winter, under leaf-off conditions (Table 2). Finally, through an evaluation of the sequence of fixes captured with each receiver on each point, we noticed that accuracy did not improve with higher numbers of fixes collected.

Table 1. Leaf-on (summer) accuracy of various GPS receivers, as represented by the raw root mean squared error (RMSE) of data collected on points within the Whitehall Forest GPS test site.

	Slope position		
GPS receiver	Lower slope	Mid-slope	Upper slope
Garmin Etrex	14.2	10.6	9.4
Garmin Etrex with WAAS	10.7	10.5	7.4
Garmin Map60C	21.0	15.9	13.7
Garmin Map60C with WAAS	13.9	12.1	12.5
Thales Mobile Mapper	31.5	31.0	22.4
Trimble ProXR	8.1	8.4	5.6
Trimble ProXR differentially corrected	3.1	3.0	3.1

Table 2. Leaf-off (winter) accuracy of various GPS receivers, as represented by the raw root mean squared error (RMSE) of data collected on points within the Whitehall Forest GPS test site.

	Slope position		
GPS receiver	Lower slope	Mid-slope	Upper slope
Garmin Etrex	6.3	5.5	7.7
Garmin Etrex with WAAS	6.0	4.7	6.6
Garmin Map60C	32.4	31.9	26.1
Garmin Map60C with WAAS	18.3	14.6	8.8
Thales Mobile Mapper	32.6	19.2	21.3
Trimble ProXR	8.9	7.5	5.7
Trimble ProXR differentially corrected	2.0	2.0	2.1

Study #2: Multipath mitigation under a forested canopy: Using a choke-ring antenna

This study was also conducted by University of Georgia graduate student Scott Danskin as part of his PhD dissertation work. The formal study methodology and results will likely soon be available in *Forest Science*. Two GPS antenna configurations were tested on numerous points within the GPS test course. The antennas included one embedded within the Trimble ProXR mapping grade receiver, and a Topcon choke-rink antenna. The choke-ring antenna was crafted from a single billet of aluminum, with concentric rings radiating outward from the receiver. The design is meant to divert multipath signals from the receiver. As with the previous study, this study was performed in both the summer and the winter, thus the forests at the time of the study consisted of "leaf-on" and "leaf-off" conditions. Measurements were collected on three slope conditions: upper slopes, lower slopes, and mid-slopes. Measurements were also randomized by receiver and repeated several times.

In this study we found some very interesting results (Table 3). First, the data collected was independent of the earlier study, thus the Trimble ProXR results are not exactly the same as the previous results, yet they are very similar. Second, the choke ring antenna obviously filters out a great deal of multipath signals, since data that is not differentially corrected is about as good as data collected by the Trimble receiver (after being differentially corrected). After the Topcon data was differentially corrected, the position error was sub-meter. The effect of multipath in the summer conditions is about 2.5 m (when differential correction is used) to 5.8 m (when differential correction is not used). In winter conditions (Table 4), the effect of multipath is about 1.5 m (when differential correction is used) to 5.5 m (when differential correction is not used).

Table 3. Leaf-on (summer) accuracy of two GPS antenna configurations, as represented by the raw root mean squared error (RMSE) of data collected on points within the Whitehall Forest GPS test site.

	Slope position		
GPS receiver	Lower slope	Mid-slope	Upper slope
Trimble ProXR	6.5	8.1	5.6
Trimble ProXR differentially corrected	3.1	2.8	3.0
Topcon choke ring	2.8	2.0	2.0
Topcon choke ring differentially corrected	0.3	0.2	0.2

Table 4. Leaf-on (summer) accuracy of two GPS antenna configurations, as represented by the raw root mean squared error (RMSE) of data collected on points within the Whitehall Forest GPS test site.

	Slope position		
GPS receiver	Lower slope	Mid-slope	Upper slope
Trimble ProXR	8.7	7.3	5.7
Trimble ProXR differentially corrected	1.9	1.9	1.9
Topcon choke ring	2.8	2.1	2.4
Topcon choke ring differentially corrected	0.3	0.2	0.2

As with the previous study, positional accuracy increased with increasing slope position, and the change in root mean squared error was not as predictable as we might have expected (more fixes collected did not necessarily lead to increases in positional accuracy).

Study #3: A comparison of GPS performance in a southern hardwood forest: Exploring real-time data accuracy of forestry receivers

The University of Georgia assisted with this study of several GPS receivers over a four-hour period of time under realistic working conditions, in an effort to understand the positional error that might be observed in an ordinary working day. This study was performed during a single day in early August, 2007. Six GPS receivers or antenna configurations were tested on several randomly selected points across the GPS test site. The order of use of each GPS receiver at each point was randomly drawn. The six receivers included four mapping grade receivers (Trimble ProXH, Trimble GeoXH, Garmin 17HVS, and TDS Nomad) and two recreation grade receivers (Garmin Etrex and Trimble Juno). The study was performed during leaf-on forest conditions on the mid- and lower-slopes of the test site.

In analyzing the data associated with this study we found some interesting results (Table 5). First, the overall accuracy of the GPS receivers was fairly good. Among the mapping grade receivers, reasonable accuracy (2-6 m) was found in most cases. In some conditions we found higher levels of error, which may be attributed to chance. However, the stability of the Trimble GeoXH seems promising. Each of these results are from data that were not differentially corrected, thus 2-6 m of error is impressive. However, if previous studies are indicative of the potential to improve positional data, differential correction may allow these to be in the 1 m range. The recreation grade receivers performed well, and improved as one moved up the slope. As with previous studies, positional accuracy tended to increase as slope position increased. However, these were one-time measurements that are typical of operational work. For a more

Table 5. Leaf-on (summer) accuracy of six GPS receivers or antenna configurations, as represented by the raw root mean squared error (RMSE) of data collected on points within the Whitehall Forest GPS test site.

	Slope position	
GPS receiver	Lower slope	Mid-slope
Trimble ProXH	2.3	9.1
Trimble GeoXH	3.5	2.5
Garmin 17 HVS	11.6	6.1
TDS Nomad	6.5	17.9
Trimble Juno	12.9	6.2
Garmin Etrex	12.4	9.8

robust assessment of the average error of these GPS receivers or antennas, repeated measurements would seem necessary.

Study #4: A test of the static and dynamic accuracy of ScoutPak

A fourth study that was recently conducted at the GPS test site involved the Juniper Systems ScoutPak GPS system. The ScoutPak system is a mapping grade GPS receiver, and in this case the University of Georgia assisted with the study. Here, instead of a static point position accuracy assessment, we performed a dynamic assessment of areas. A collection of points on course that encompassed about five acres was chosen, and the study participants walked the course three times, collecting data every one second. The post-process accuracy of the data collection effort was assessed by performing a buffer analysis. In this case, three buffers (1.5, 3.0, and 5.0 m) were developed around the boundary of the course, and the number of position fixes contained within each were reported. The number of position fixes within the 1.5 m buffer ranged from 68-84% for the three trials. The number of position fixes within the 3 m buffer was 100% for two trials, and 95% for the third trial. All of the position fixes from the three trials were within 5 m of the course buffer. At no time was it observed that the ScoutPak lost a signal.

Discussion

The University of Georgia GPS test site is a public facility that can be used to test GPS equipment in either static or dynamic modes. Time of day and day of week of studies may be limited to normal working hours, however a number of researchers and consultants have taken advantage of the resource. The plan for the GPS test site includes research and educational opportunities as well. One of our students (Scott Danskin) has used the GPS test site to develop information necessary for a Ph.D. dissertation. A small portion of this research was presented here, and the rest will soon be available in peer reviewed journals. From an educational perspective, we incorporate the test site into the teaching of GPS principles to our undergraduate students. During the delivery of their Forest Measurements course, students collect positional data over several of the test points and determine the root mean squared error of the data. In addition, we have incorporated a similar exercise into a GPS for Beginners continuing education short course that is designed for landowners and other professionals seeking more insight into GPS technology. Finally, we have installed several more GPS test points nearby in a pine stand. We hope to have these points surveyed to the same accuracy as the original 27 points, thereby expanding the capability of the test site to another type of forest typical of the southeastern United States.

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