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Accuracy Assessment of Recreational and Mapping Grade GPS Receivers

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Abstract

Since its development in the early 1970s, Global Positioning System (GPS) technology has become more accessible and affordable for consumers. GPS applications have become ubiquitous in society. With the increased use of GPS, the question of accuracy is of concern. This study assessed the accuracy of four Garmin recreational GPS receivers, eTrex®, eTrex Legend®, eTrex Vista®, GPSMAP® 76CS, and three Trimble® mapping GPS receivers Juno™, GeoExplorer3™ and GeoXH™. Thirty-three ground control points (GCPs) were established in three different landscapes using survey grade GPS (Trimble's 4700) that were corrected using National Geodetic Survey's Online Positioning User Service (OPUS). Eleven GCPs were established in a forest landscape, eleven near buildings to simulate an urban landscape, and eleven with a clear unobstructed sky. The GPS receivers were tested with the Wide Angle Augmentation System (WAAS) on and off. In addition, results from averaging 30 GPS positions were evaluated. This study showed the GeoXH was the most accurate receiver and that the accuracy of the recreational (Garmin) receivers was from 2.52 to 18.42 meters depending on the landscape. The accuracies of the Garmin GPS receivers were similar.

Introduction

The Global Positioning System (GPS), developed by the United States Department of Defense was started in 1972. The first satellite was placed into orbit in 1978. President Ronald Reagan declared in 1983 that the GPS system would be made available to the public once it was operational (US Commerce Department 2006). By 1985, there were eleven Block-1 satellites in orbit so that the system could be validated. By 1994, there was a full constellation of 24 satellites in orbit and the system reached full operational status in April 1995. Since the inception of the system, the uses for GPS have exploded in the marketplace, with applications in nearly every sector. It is no longer just for military and aviation but also used by the average consumers and business professionals.

Many errors should be examined when working with GPS data. There are three categories of GPS error: the space segment, ground control segment, and the GPS user segment (Sickle 2008). Space segment location errors are caused by satellite clock instability, satellite perturbations, and thermal radiation. Control segment errors are ephemeris data predictions and controlling satellite thruster performance. User segment errors are Ionosphere delay, Troposphere delays, receiver noise, and multipath. All of these errors affect GPS location accuracies and precision. One of the errors that can be reduced by the user is multipathing when collecting GPS data. Multipathing is the scattering of GPS signal from the satellite to the receiver. According to Jan Van Sickle (2008), multipathing occurs when part of the signal reaches the receiver after reflecting from the ground, a building, or another object. There are several ways to correct these errors.

In August 1995, the Federal Aviation Administration (FAA) set out to have a real-time correction system built for GPS for aviation navigation. It was not until July 10, 2003 that the FAA commissioned the Wide Area Augmentation System (WAAS) for use. WAAS works from a network of twenty-five ground reference stations in North America and Hawaii which uploads real-time corrections to geostationary satellites. The satellites broadcast the correction to GPS receivers and correct the data as it is recorded. The purpose of WAAS was so that aircraft could rely on GPS navigation. This system not only works with aircraft but with any WAAS enabled GPS receiver. WAAS provides a method to improve accuracy using real time differential correction. However it is still not as accurate as post-process differential correction because of the time delay in receiving the correction data from the WAAS satellites.

Post-process differential GPS correction (DGPS) is another option for correcting GPS data. For most mapping applications this process is done after data collection, commonly known as post-processing. Post-processing software uses the data collected from the field GPS then computes a baseline with a fixed base station that is near to the field collection site. Essentially this method analyzes the data received at the base station and the correction needed to correct the known base station coordinates and applies the same correction to the field GPS data. Not all GPS receivers have this capability.

Materials and Methods

Thirty-three ground control points (GCPs) were established on the University of Arkansas at Monticello (UAM) campus to test the seven different GPS receivers (Figure 1). All the GPS receivers can track 12 satellites and only the GPS internal antennas were used in the study. Of the thirty-three GCPs, eleven were in a clear unobstructed sky, eleven next to buildings, and eleven under tree canopy. Figure 2 shows the project area on the UAM campus. The GCPs next to buildings and under tree cover were established to force multipathing and satellite signal loss to understand the performance of the receivers for these landscapes.

Figure 1. The seven GPS receivers tested in this study were Trimble GeoXH, Trimble GeoExplorer3, Trimble Juno, Garmin GPSMAP 76CS, Garmin eTrex Vista, Garmin eTrex Legend, Garmin eTrex (left to right with their cost shown below).

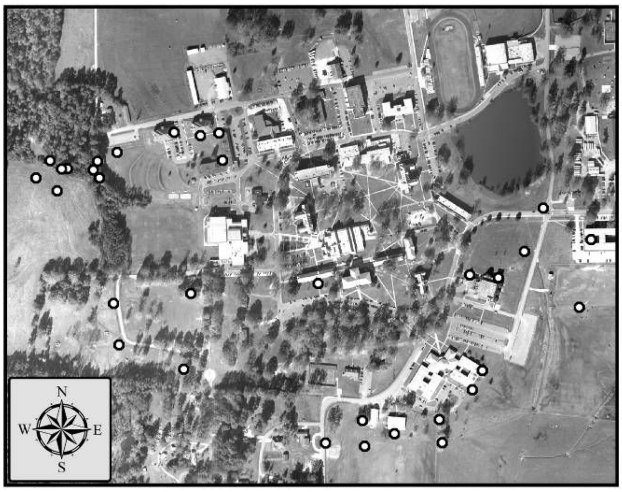

Figure 2. Project area on the University of Arkansas at Monticello campus with the 33 Ground Control Points displayed.

The GCPs were established using Trimble's 4700 survey grade GPS receiver and corrected using the National Geodetic Survey's (NGS) Online User Positioning Service (OPUS). Each GCP was occupied for more than 2 hours. According to the National Geodetic Survey's website, "*OPUS allows users to submit their GPS data files to NGS, where the data will be processed to determine a position using NGS computers and software. Each data file that is submitted will be processed with respect to three CORS sites. The sites selected may not be the nearest to your site but are selected by distance, number of observations, site stability, etc. The position for your data will be reported back to you via email in both ITRF and NAD83 coordinates as well as UTM, USNG and State Plane Coordinates (SPC) northing and easting*" (http://www.ngs.noaa.gov/). The results from NGS also included information on the Root Mean Square Error (RMSE) for each GCP and its corrected geographic location. The overall OPUS corrected GCPs' RMSE ranged from 0.011 to 0.033 meters with a mean of 0.017 meters in the horizontal direction.

For some of the buildings and the entire set of tree GCPs, the multipathing and satellite signal interference was too large for the survey grade GPS to establish a reliable location. This was determined by the survey-grade GPS receiver software. To establish those GCPs the position was calculated using a Topcon total survey station from a known location using standard surveying practices. Figure 3 shows an example of a building GCP (#B001) that was calculated using this method.

After establishing the GCPs, point data at each of the GCPs was collected with each of the receivers. At each location with each unit, single point was collected with WAAS on, WAAS off, and an average of thirty points with WAAS on was collected. The receivers collected data at the same time so Positional Dilution of Precision (PDOP) values would be similar, to

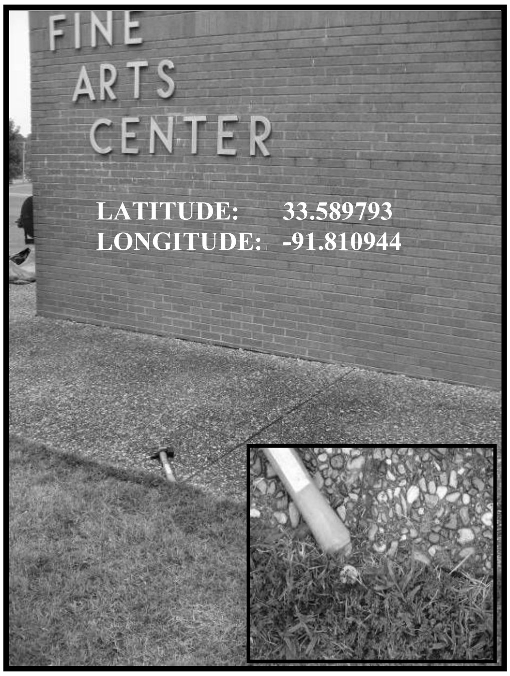

Figure 3. Ground Control Point B001 (Urban landscape).

control errors caused by different PDOPs during a session. PDOP is a measure of the geometrical strength of the GPS satellite configuration, which could increase error as the number increases. The only exception to that was the Trimble GeoExplorer3, which does not have WAAS capability. This was repeated for five samples at each of the 33 ground control points with all seven receivers totaling more than 35,000 individual points. Each session was at least twenty-four hours apart to have completely different satellite geometry for each series of the five samples to simulate user data collection. For each data recording session all possible sources of error were controlled (similar) for all the GPS receivers.

Following the fieldwork, Trimble Pathfinder Office was used to post process the mapping grade receivers, the Juno, GeoXH and GeoExplorer3. For the Garmin receivers the GPS data was exported to an ESRI shapefile using a free program called DNR Garmin. DNR Garmin was developed by the Minnesota Department of Natural Resources (DNR) (http://www.dnr.state.mn.us). The Garmin receivers could not be differentially corrected. The difference between each point's x and y position from the GCP location, which was assumed to be the true location for that point, was calculated. Basic descriptive statistics were calculated for the five sessions. From those calculations, a comparative analysis for the receivers by landscape and data collection method was done.

Results and Discussion

The study showed there is an advantage of being able to differentially correct GPS data. It can increase accuracy substantially when using a mapping grade receiver (Trimble GeoXH, Trimble GeoExplorer3, and Trimble Juno). With that being said, of the receivers in this study, the GeoExplorer3 had the most difficulty obtaining the minimum four satellites required for a position.

Using a recreational grade GPS unit with clear, unobstructed skies, users can expect 2.52 to 5.52 meters accuracy. Wing et al. (2005) also found position accuracies to be within 5 meters with recreational GPS receivers. For the same receivers under an obstructed sky, near buildings or under tree canopy, accuracy decreased to 10.50 to 18.42 meters in this study (See Table 1).

Table 1. The average RMSE in meters for the recreation GPS receivers used in this study.

GPS Receiver	Open	Building	Tree Canopy
Average 30	3.83	12.05	14.22
WAAS Off	2.52	16.03	13.23
WAAS On	5.52	10.50	18.42
Average	3.95	12.86	15.29

Several problems were encountered during this study. One problem encountered was with the GeoExplorer3. This GPS unit would not receive satellite signals for any of the GCP locations under tree canopy. In addition, it was difficult to receive signals for some of the GCPs near buildings.

Also, once the differences were calculated between the GPS receiver and GCP for given points, the authors discovered that one of our GCPs was not accurate. GCP C003's OPUS solution was not correct. The reason for the incorrect position is not known. For this reason we eliminated all C003 data.

Another problem was with the eTrex Legend. It is not reflected in our analyses, but there was one day during data collection under the tree canopy that the Legend collected several bad positions. The locations it collected were hundreds of kilometers away.

Through this research, the authors became very familiar with the functionality and use of the seven GPS receivers tested. The use of the eTrex was more difficult than the other Garmin receivers when it came to naming points and switching between windows. As far as functionality, the Garmin eTrex Legend, eTrex

Vista, and 76cs were much more user friendly. Garmin (http://www.garmin.com/garmin/cms/site/us) lists a complete set of functions.

If a user is interested in collecting extra attribute data, then a mapping grade GPS receiver such as the Trimble Juno, GeoXH or GeoExplorer3 should be used. The touch screen control of the Juno and GeoXH made attribute entry and data collection fast and efficient.

After examining the data, a good correlation could not be determined between using WAAS and not using WAAS correction with the recreational grade receivers. The recreational receivers do not allow you to view when WAAS is being received. The receivers allow you to turn WAAS on or off under the systems setting; however, turning the capability on does not mean that the receiver can receive the signal from one of the WAAS satellites. Considering that there are only two geostationary WAAS satellites (FAA.gov), one on the East coast and one on the West coast of the United States, it is possible to have an obstruction such as building or tree canopy between the receiver and the satellite, causing the receiver not to receive a signal from the geostationary WAAS satellite. This made the comparisons of the recreational GPS (Garmin GPSMAP 76CS, Garmin eTrex Vista, Garmin eTrex Legend, Garmin eTrex) WAAS ON data questionable.

Being able to see the status of the WAAS signal is an advantage of the Juno and GeoXH, as it allows the user to know whether or not they are presently receiving real-time corrections.

In today's GPS market, more and more receivers come equipped to receive WAAS corrections; however, few receivers have the capability to average locations within the unit. For this study the averaging in the eTrex class receivers (eTrex, eTrex Legend, eTrex Vista) was done by collecting thirty individual WAAS positions for each GCP and averaging their coordinates in the processing phase. The Garmin 76CS is the only recreational grade unit tested that had an averaging feature within the unit.

On average, differential correction of the GeoXH improved the data collected by approximately 0.5 meter for all points in the study. With WAAS OFF, DGPS improved the data by approximately 0.9 meter, while averaged and WAAS on point locations improved by 0.3 meter. The GeoXH's average RMSE for all points collected was less than 3 meters. For the points that were in a clear landscape setting, the average RMSE was observed to be less than 2 meters.

But by differentially correcting these same clear points the RMSE improved to less than a meter. According to our study, the GeoXH produced sub-meter accuracy when data is collected in an open landscape and differentially corrected. The GeoExplorer3 did poorly in most landscapes and could not record data under a tree canopy (Table 2). The data collected with the Juno was more accurate than the Garmin GPS receivers in most situations, especially when the data was differentially corrected.

Based on the median, 1st Quartile, 3rd Quartile, minimum and maximum values for the GPS receivers, the variability for the recreational GPS receivers were greater than the mapping GPS receivers. Figure 4 and 5 show the box and whisker plots for WAAS ON in the open and under tree canopy, respectively. The GeoXH consistently had less variability than the other GPS receivers, especially in the open where the error was less than 2 meters. As obstruction increased in the sky the recreation GPS receivers' errors became more variable. This is shown in Figure 5 with WAAS ON.

The eTrex and eTrex Legend, which were the least expensive recreational GPS receivers, collected data within approximately 2 meters in the open and less than 16.5 meters in canopy cover. The Garmin Map 76cs, which was the most expensive recreational GPS receiver tested, did not perform as well as some of the less expensive receivers in this study.

Conclusions

After examining the data it can be fairly stated that tree canopy and building interferences are a major hindrance to the accuracy of the Global Positioning System. The Trimble GeoXH out-performed all other receivers compared in this study. However, for casual recreational use, the GeoXH may not be the best option due to its high cost (Figure 1). Also, the GeoXH requires the user to have more training and general knowledge of cartographic systems. A less expensive option, with many of the same functions as the GeoXH, would be the Trimble Juno. As far as comparing Garmin recreational GPS receivers, there is little correlation between accuracy and cost of unit.

The overall mean for all points studied with the Garmin GPS receivers was less than 5 meters for a clear unobstructed sky. There was no pattern observed in our analysis that portrayed any of the Garmin GPS receivers to be dominant. For the Gamin GPS receivers, cost seems to be correlated to the functions rather than the accuracies of the receivers.

As sky obstructions increased, GPS error variability increased for all receivers (Figure 5), but less with mapping GPS receivers. Bolstad et al. (2005)

Table 2. Average RMSE in meters for individual receivers grouped by data collection method.

Average Position (30 points) Receiver	Open	Building	Tree Canopy
Map76cs	3.18	8.67	9.41
eTrex	1.94	12.99	8.73
GeoExplorer3 DGPS	51.98	33.39	n/a
GeoExplorer3	44.53	32.69	n/a
eTrex Legend	1.71	8.50	16.11
eTrex Vista	8.47	18.04	22.62
GeoXH DGPS	0.74	1.95	3.92
GeoXH	1.07	2.50	4.13
Juno DGPS	1.13	3.70	4.03
Juno	1.74	3.64	3.61
WAAS OFF Receiver	**Open**	**Building**	**Tree Canopy**
Map76cs	3.87	37.91	11.62
eTrex	1.88	15.24	14.58
GeoExplorer3 DGPS	4.98	20.92	n/a
GeoExplorer3	5.49	20.72	n/a
eTrex Legend	2.30	4.43	14.18
eTrex Vista	2.02	6.52	12.53
GeoXH DGPS	0.88	5.64	3.53
GeoXH	3.10	4.69	4.94
Juno DGPS	1.66	3.94	4.33
Juno	1.97	3.67	3.41
WAAS ON Receiver	**Open**	**Building**	**Tree Canopy**
Map76cs	4.55	12.14	24.56
eTrex	2.02	14.39	15.28
GeoExplorer3 DGPS	n/a	n/a	n/a
GeoExplorer3	n/a	n/a	n/a
eTrex Legend	2.00	7.63	16.39
eTrex Vista	13.50	7.84	17.47
GeoXH DGPS	1.05	1.64	3.92
GeoXH	1.34	2.16	4.06
Juno DGPS	1.56	4.11	3.55
Juno	2.03	3.31	2.81

also found that recreational GPS receivers' accuracies varied with larger errors under forest canopy.

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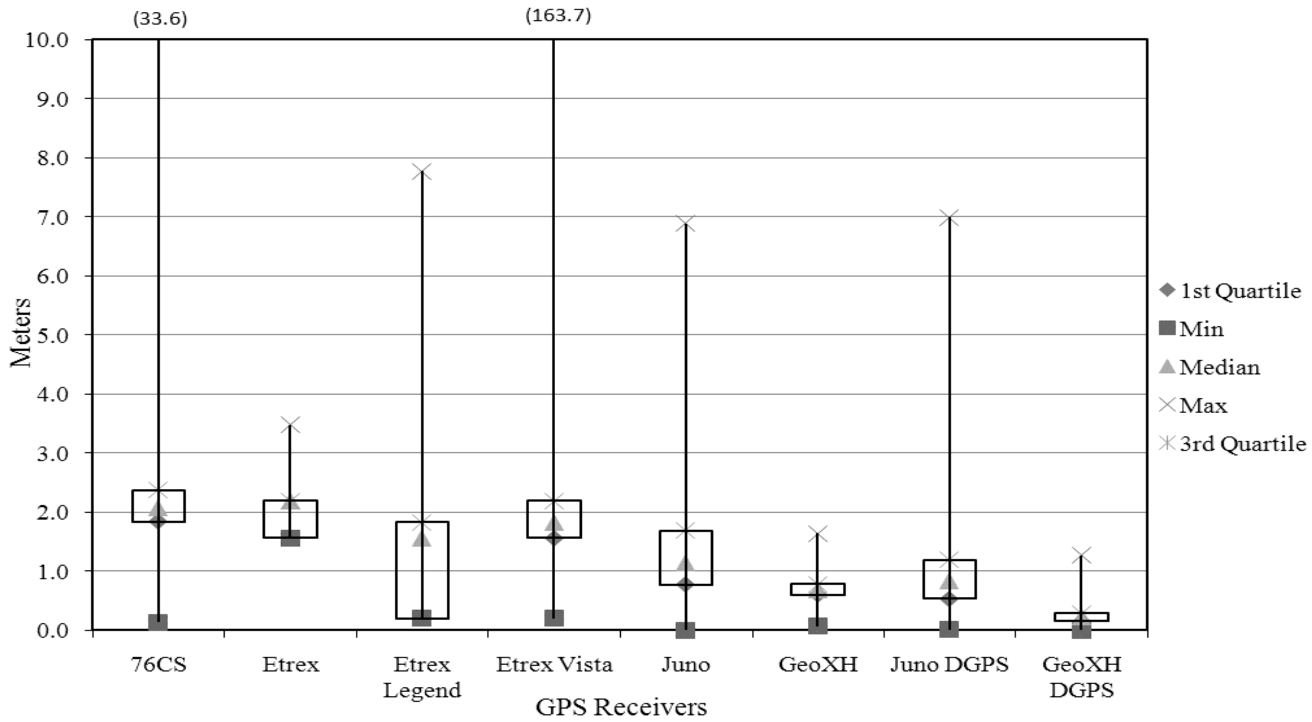

Figure 4. GPS descriptive statistics in for clear unobstructed sky with WAAS ON.

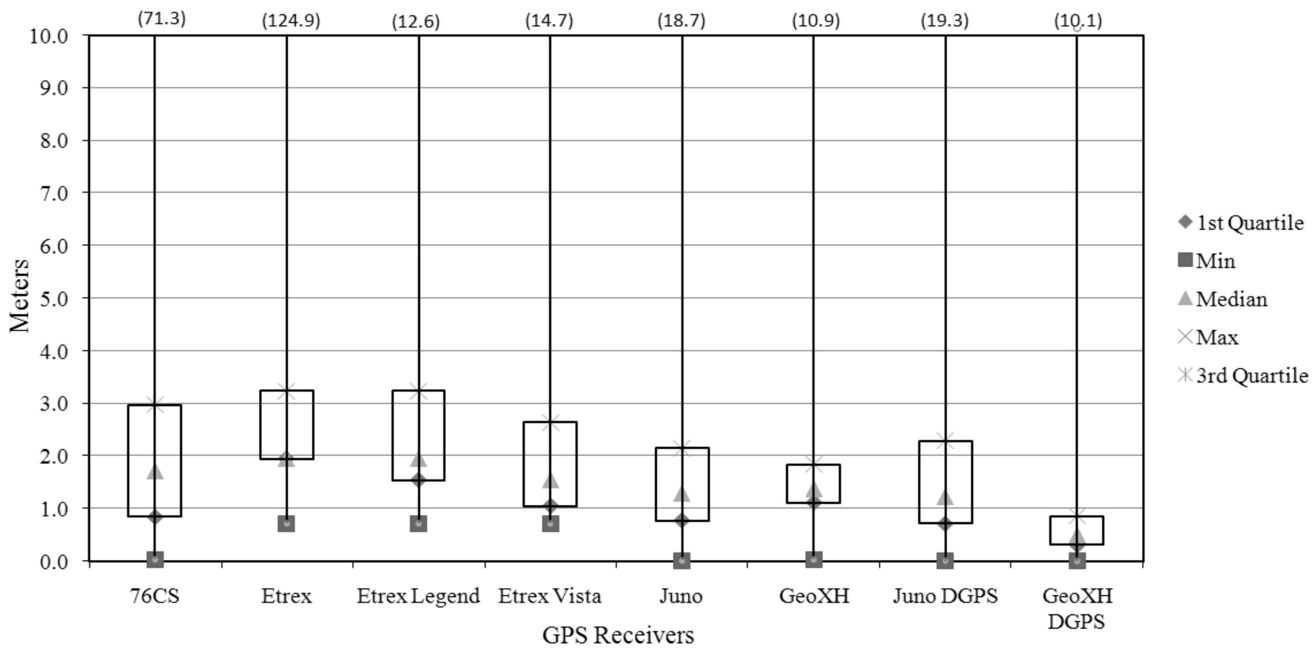

Figure 5. GPS descriptive statistics under tree canopy with WAAS ON.