Static Horizontal Positions Determined with a Consumer-Grade GNSS Receiver: One Assessment of the Number of Fixes Necessary

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Abstract – Nacrtak

Over the course of a year, a consumer-grade GNSS receiver was used to collect data in three forest types in northeastern Georgia (USA). During each visit, fifty position fixes were collected to estimate a horizontal position. Since there has been a significant amount of debate regarding the appropriate number of position fixes to collect to determine a position, this analysis was conducted to understand whether the static horizontal position error (a) changed over the collection period of fifty position fixes, (b) was significantly different than a single position fix collected to estimate the positions, and (c) was a function of forest type. We failed to reject the hypothesis that static horizontal position accuracy does not significantly change with increasing numbers of position fixes collected to determine a position, yet we favor rejecting the hypothesis that trends do not differ by forest type or by density of trees per unit area. The results are not entirely conclusive, and the time (season) of year may influence the results observed within certain forest types (e.g., young coniferous forests). We observed a trend that the static horizontal position accuracy in a young coniferous forest, on average, improved from a position determined by a single position fix to a position determined from the average of fifty position fixes. A much less relevant trend in accuracy was observed in a deciduous forest, and no trend at all was observed in an older coniferous forest.

Keywords: Global navigation satellite systems, static horizontal position accuracy, root mean squared error, linear regression

1. Introduction – *Uvod*

Satellite navigation and positioning systems (or more commonly, *Global navigation satellite systems* (GNSS)) utilize electromagnetic energy emitted by earth-orbiting devices (space vehicles, or satellites) to establish positions on earth. The United States (NAVSTAR GPS), the Russian Federation (GLONASS), the European Union (GALILEO), India (IRNSS), and China (COMPASS or BěiDou-2) all either have developed, or are developing, GNSS that will provide signals useful in determining positions on earth. Each of these programs broadcasts, or plans to broadcast, signals in various ranges near the L1 (about 1575 MHz) and L2 (about 1228 MHz) band frequencies of the electromagnetic spectrum. GNSS receiver manufacturers are developing (or have developed) technology to collect and use the information emitted by the satellites to determine positions on earth, and to facilitate mapping or navigational processes. In practice and in the published literature, GNSS receivers are generally divided into three classes: survey-grade, mapping-grade, and consumer-grade (or recreation-grade). Survey-grade receivers can provide sub-centimeter static horizontal position accuracy in open conditions, and sub-meter accuracy in or near forests (Pirti 2008), yet lengthy signal acquisition times may be required. Mapping-grade receivers may be able to provide sub-meter static horizontal position accuracy in open conditions, but usually 2 – 5 m accuracy in forests. Consumer-grade receivers are the lowest cost of the three classes, and generally provide static horizontal position accuracy in the 5 to 15 m range in forested conditions.

Augmentation processes are available to increase the quality of data collected by GNSS receivers. These include space-based augmentation systems (e.g., the United States WAAS program, the European Space Agency EGNOS program, the Canadian MSAT program, and others), ground-based augmentation systems (differential GPS or DGPS, and real-time kinematic or RTK processes), and post-process differential correction. Depending on the receiver used and the data the receiver provides, some or all of these augmentation processes may be available. In some cases, particularly with low-cost consumer-grade GNSS receivers, very few augmentation processes may be available. Using GNSS technology in a forested environment presents perhaps one of the most challenging data collection situations, because of the effects of trees on signals (Pirti 2005). The influence of tree canopies on satellite signals is important, as horizontal and vertical accuracy and precision (even with survey-grade receivers) can be affected (Pirti 2008). Even though contemporary GNSS receivers may have advanced satellite tracking technologies, signals are noisier, weaker, and subject to multipath and diffraction when forced to pass through tree canopies (Pirti 2008). Therefore, in forestry, the accuracy of positions determined with GNSS technology is of concern, since manufacturer's statements of typical data quality do not include a description of the testing environment.

GNSS technology is now widely used in forestry and other natural resource fields, and professionals frequently use data collected with these devices for positional and navigational purposes. Some examples of uses include the delineation and identification of forest cutting area boundaries, forest roads, forest trails, inventory plot locations, streams, and wildlife nest locations. The need and desire for highly accurate locational information is understandable since many management decisions are based on data such as these. A number of recent research efforts have evaluated and illustrated the usefulness of GNSS technology in natural resource management (e.g., Andersen et al. 2009, Danskin et al. 2009a, 2009b, Keskín et al. 2009, Wing 2009, Bettinger and Fei 2010, Klimánek 2010, Pirti et al. 2010, Ransom et al. 2010). These and other studies conducted within the last decade provide forest managers with periodic assessments of the positional accuracy of GNSS technology under forested conditions. However, the number of determined horizontal position fixes necessary to obtain the highest level of static horizontal position accuracy possible under tree canopies is still open to debate. About a decade ago, Sigrist et al. (1999) suggested that numerous (300) static horizontal position fixes were necessary at each point visited, yet others (e.g., Bolstad et al. 2005, Wing and Karsky 2006) have since suggested that the static horizontal position determined from an average of a large set of position fixes may be no better than the position determined from a single position fix. Other research (Wing et al. 2008, Danskin et al. 2009a) has suggested a small set (30 or fewer) of static horizontal position fixes are preferred. Most of these discussions concern consumer-grade or mapping-grade GNSS receivers, since it is well known that survey-grade GNSS receivers need a significant amount position fixes to arrive at very precise and highly accurate positions (Hasegawa and Yoshimura 2003, Yoshimura and Hasegawa 2003, Naesset and Gjevestad 2008, Andersen et al. 2009).

The objectives of this work were therefore to understand how static horizontal position accuracy might change with the number of position fixes collected during a visit to a known control point.

The hypotheses are:

H_1: Static horizontal positional accuracy does not significantly change with an increasing number of position fixes used to determine a position's location.

H_2: Trends in static horizontal positional accuracy, with an increasing number of position fixes, do not differ based on forest type or tree density.

Using data collected over the course of one year (and previously described in Bettinger and Fei 2010), we address these two hypotheses.

2. Materials and Methods – *Materijal i metode*

Between September 2008 and September 2009, data were collected with a Garmin Oregon 300 consumer-grade GPS receiver nearly every day, under a variety of environmental conditions. Static horizontal positions were determined in a young coniferous forest (loblolly pine, *Pinus taeda*), an older coniferous forest, and a deciduous forest, each located within the Whitehall Forest GPS Test Site[1] in Athens, GA. The purpose of this study was to determine whether long-term data collected with a consumer-grade GPS receiver were sensitive to stand type, time of year, and a number of environmental variables. In a previously published study (Bettinger and Fei 2010), we found no significant relationship between observed

[1]http://warnell.forestry.uga.edu/Warnell/Bettinger/GPS/UGA_GPS.htm

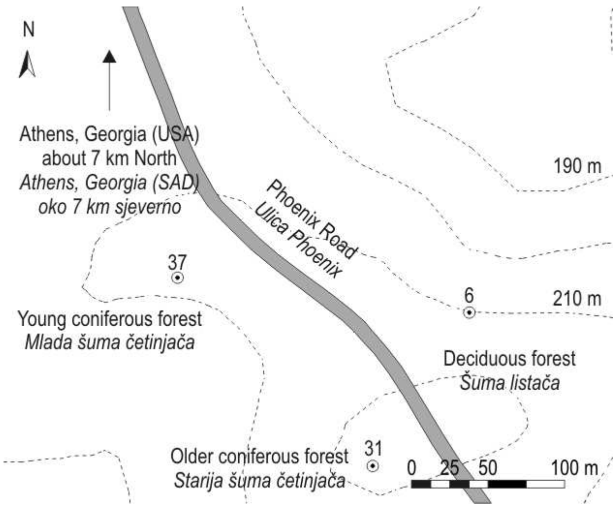

Fig. 1 A map of the three Whitehall Forest GPS Test Site points used in this research

Slika 1. *Karta pozicijâ pokusa GPS-om u šumi Whitehall koje su se koristile u ovom istraživanju*

static horizontal positional accuracy and several environmental variables (air temperature, relative humidity, atmospheric pressure, and solar wind speed). No significant differences were noted within a forest type as seasons of the year changed. The average static horizontal position accuracy was 11.9 m, 6.6 m, and 7.9 m for the young coniferous, older coniferous, and deciduous forests, respectively (Bettinger and Fei 2010).

Three control points (numbers 6, 31, and 37) from those available at the Whitehall Forest GPS Test Site were selected for this research (Fig. 1). Control point 37 is located in the young loblolly pine forest (Fig. 2), and the forest conditions at the time of the study are illustrated in Table 1.

Control point 31 is located in the older coniferous forest, and control point 6 is located in the deciduous (older hardwood) forest. The deciduous forest is dominated by oak (*Quercus* spp.) and hickory (*Carya* spp.). All three control points are located in what we considered upper slope positions for the surrounding area, and therefore represented the best choices for comparison among the three forest types. The three control points were visited once per test day over the course of a year, the order of visit to each point was randomized, and fifty position fixes were collected at each point during each visit. The travel time between each of the three required about three minutes. Our assumption (collecting fifty position fixes at each point during each visit) is consistent with recent studies (Danskin et al. 2009a, 2009b, Wing 2008, Wing et al. 2008), yet is a compromise based on previous research in this area. Although until now

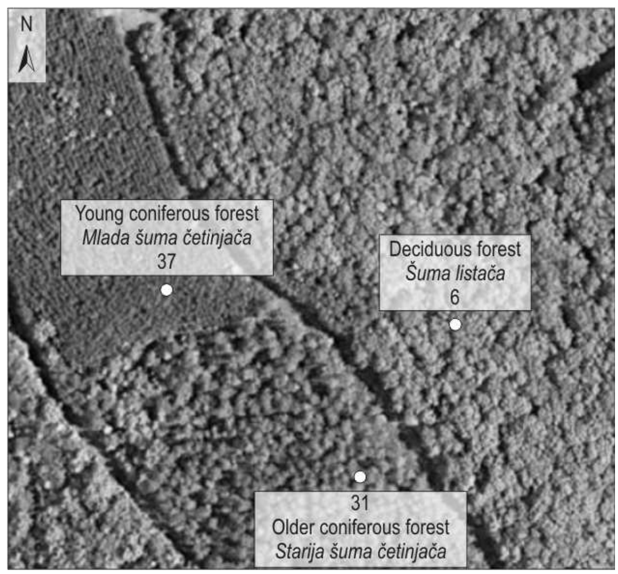

Fig. 2 An aerial view of the Whitehall Forest GPS Test Site and the three test points used in this research

Slika 2. *Zračni snimak GPS-om pokusnih pozicija u šumi Whitehall i triju testnih pozicija korištenih u ovom istraživanju*

Table 1 Characteristics of the forests on the Whitehall Forest GPS Test Site (Georgia, USA) where the study was conducted

Tablica 1. *Značajke šuma na području Whitehall (Georgia, SAD) ispitivanom GPS-om gdje je provedena studija*

Forest type – *Tip šume*			
Characteristic – *Značajka*	Young coniferous – *Mlada šuma četinjača*	Older coniferous – *Starija šuma četinjača*	Deciduous – *Šuma listača*
Forest age – *Dob šume*	15 years	60 – 70 years	60 – 70 years
Basal area – *Temeljnica*	30 m^2ha^{-1}	20 m^2ha^{-1}	20 m^2ha^{-1}
Tree density – *Broj stabala*	182 ha^{-1}	146 ha^{-1}	356 ha^{-1}
Aspect – *Položaj, inklinacija*	Southwest – *Jugozapadna*	South – *Južna*	Northeast – *Sjeveroistočna*
Slope – *Nagib*	8%	2%	18%
Elevation – *Nadmorska visina*	212 m	222 m	210 m
Canopy closure – *Obrast*	95%	50%	90%

the results have not been statistically tested, at the time of data collection we observed a number of patterns in the fifty position fixes collected. These included: (1) static horizontal position accuracy increased as the number of position fixes increased, (2) static horizontal position accuracy decreased as the number of position fixes increased, and (3) static horizontal position accuracy increased, then decreased, or vice versa as the number of position fixes increased. There seemed to be no clear reason for these patterns, and the patterns were not consistent within a forest type on a data collection day.

This research was unfunded, therefore the lead author decided that approximately 20 minutes per day could be spared to collect data at the test site. In addition, it was assumed that only one GNSS receiver would be assessed, and that the operating parameters of the receiver would be fixed for the entire duration of the study so that similar data collection conditions would be used. This implied that during each visit to each control point, the consumer-grade receiver was plumbed directly over the control point. The lead author would then stand on the north side of each control point as data was collected. Space-based augmentation of signals would be disabled since the receiver was unable to report the percentage of time the service was available. Finally, position fixes were captured manually, using a 2 – 3 second interval.

Static horizontal position data were collected between 10:30 AM and 16:30 PM, and varied according to the daily schedule of the lead researcher. We found it impossible to collect data during a consistent period of time throughout a year, given other responsibilities. That being said, the average Coordinated Universal Time (UTC) for data collection activities in the older coniferous forest was 19:45 in the fall season, 19:40 in the winter season, 18:11 in the spring season, and 17:04 in the summer season (as reported in Bettinger and Fei 2010). The effect of variations on data collection activities on the results is unknown, however trends in data collection times (e.g., consistently collecting data in the morning in the winter season) were not evident.

The raw (non-transformed) data representing the root mean squared error (RMSE) of each position fix determined was used in a linear regression analysis to determine the slope and coefficient of determination (R^2) of a line that best fits the fifty position fixes of a visit to a control site. This analysis was performed for all 298 days of the study, and each of the three forest types visited during these days. The slope of the regression line should be negative if additional position fixes increase the static horizontal position accuracy, should be positive if additional position fixes decrease the static horizontal position accuracy, and will be nearly zero if additional position fixes have no effect on static horizontal position accuracy. In these cases of simple linear regression, the independent variable is the RMSE of each position fix, and the dependent variable is the position fix number (1 to 50). For presentation purposes, we average the slope values and the coefficient of determination values to help determine whether to accept or reject the first hypothesis, that static horizontal positional accuracy would not be significantly different with an increasing number of position fixes used to determine a position's location. An analysis of these results by season is also performed. For the purpose of this study, the fall season covered the period from September 15, 2008 to December 14, 2008, the winter season covered the period from December 15, 2008 to March 14, 2009, the spring season covered the period from March 15, 2009 to June 14, 2009, and the summer season covered the period from June 15, 2009 to September 15, 2009.

Given a full set of fifty position fixes collected during a single visit to a single control point, this data was reduced to six estimates of RMSE: (1) the first position fix, (2) the average of the first ten position fixes, (3) the average of the first twenty position fixes, (4) the average of the first thirty position fixes, (5) the average of the first forty position fixes, (6) the average of all fifty position fixes collected. To be clear, RMSE was determined for each position fix, and the RMSE values were then averaged to arrive at the group average static horizontal error. Since there was a significant amount of variation in RMSE values from one day to the next, the difference between the RMSE of the first position fix and the average RMSE values of the other five groups were used in the analysis. This analysis was designed to address the second hypothesis, which suggested that the results may differ based on forest type or tree density. This analysis was also performed by season to determine whether seasonal variation may explain some of the differences in the data collected.

3. Results – *Rezultati*

The average change in static horizontal position accuracy for positions determined in each of the three forest types, from the first position fix determined to the last (the fiftieth), was negligible, as evidenced by the mean and median slope of regression lines fitted to the sequence of position fixes captured during each visit to a control point (Table 2).

This implies that the first hypothesis cannot be rejected, however other results should also be considered. For example, in Table 2 one can see that the

Table 2 Average regression-related information from 50 position fixes collected per visit to three forest types on the Whitehall Forest GPS Test Site (Georgia, USA)

Tablica 2. *Prosječni regresijski podaci za 50 položajnih čvrstih točaka prikupljenih po snimanju u različitim tipovima šuma na istraživanom području – Whitehall (Georgia, SAD)*

	Mean *Srednja vrijednost*	Median *Medijana*	Minimum *Minimalna vrijednost*	Maximum *Maksimalna vrijednost*	Percent of days within one standard deviation of the mean *Postotak dana unutar standardne devijacije srednje vrijednosti*
Young coniferous – *Mlada šuma četinjača*					
Slope, b_1 – *Nagib*, b_1	–0.020	–0.011	–0.588	0.297	92
Coefficient of Determination R^2 *Vrijednost koeficijenta određivanja*, R^2	0.595	0.700	0.000	0.893	79
Older coniferous – *Starija šuma četinjača*					
Slope, b_1 – *Nagib*, b_1	–0.003	–0.006	–0.300	0.332	92
Coefficient of Determination, R^2 *Vrijednost koeficijenta određivanja*, R^2	0.546	0.640	0.000	0.938	72
Deciduous – Šuma listača					
Slope, b_1 – *Nagib*, b_1	0.003	–0.008	–0.250	0.562	91
Coefficient of Determination, R^2 *Vrijednost koeficijenta određivanja*, R^2	0.548	0.674	0.000	0.917	69

minimum and maximum slope values for regression lines developed on individual visits can be either positive (indicating a reduction in accuracy as the number of position fixes captured increases) or negative (indicating an increase in accuracy as the number of position fixes captured increases). Fig. 3 illustrates two cases with high coefficient of determination (R^2) values that suggest either of these trends may be observed. Further, while the R^2 values of the regression lines fit to the fifty position fixes from

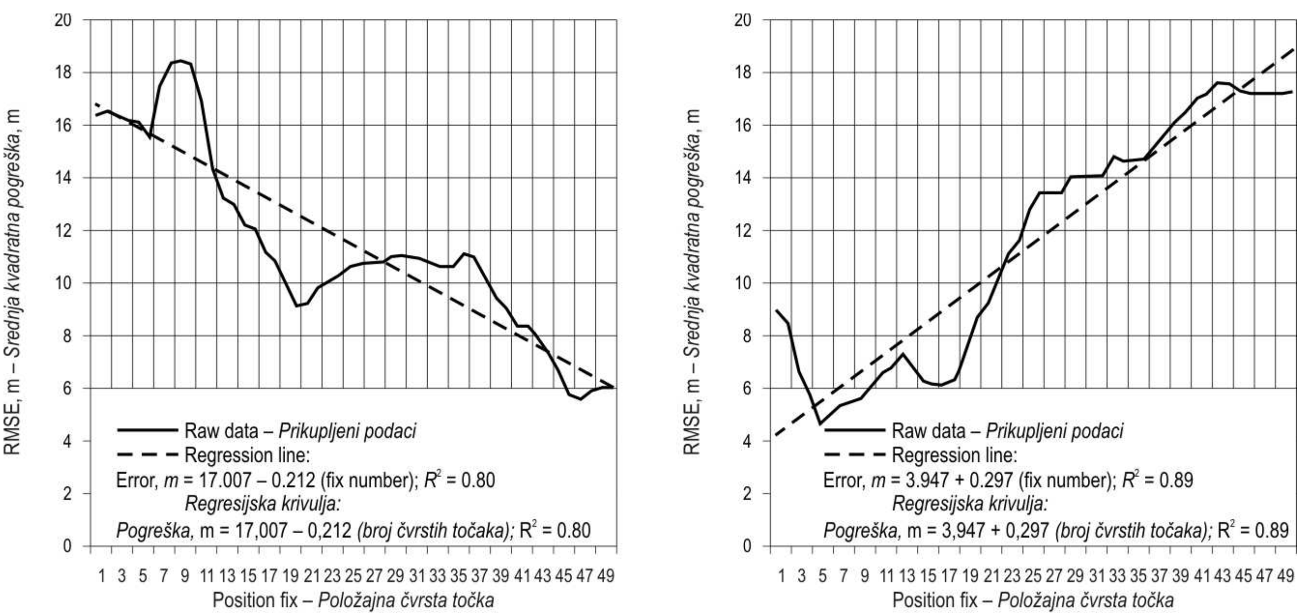

Fig. 3 RMSE values for fifty consecutive position fixes collected at a control point in the young coniferous forest, and regression lines drawn to describe changes ((a) improvement and (b) decline) in static horizontal position accuracy

Slika 3. *Vrijednosti srednje kvadratne pogreške za pedeset uzastopnih čvrstih točaka prikupljenih na kontrolnoj točki u mladoj šumi četinjača i regresijske krivulje povučene kako bi prikazale promjene ((a) poboljšanja i (b) pogoršanja) točnosti statičkoga horizontalnoga položaja*

Table 3 Difference in RMSE (m) from one position fix collected to an average of *X* position fixes (up to 50, in steps of 10) collected per visit to three forest types on the Whitehall Forest GPS Test Site (Georgia, USA)

Tablica 3. *Razlika u srednjoj kvadratnoj pogrešci (m) od jedne položajne čvrste točke do prosječne vrijednosti za X položajnih čvrstih točaka (do 50, u koracima po 10) prikupljenim po jednom snimanju unutar različitih tipova šuma istraživanoga područja Whitehall (Georgia, SAD)*

Difference between one position fix collected and *X* position fixes, m – *Razlika između jedne položajne čvrste točke i X položajnih čvrstih točaka*, m					
Forest type – *Vrsta šume*	*X* = 10	*X* = 20	*X* = 30	*X* = 40	*X* = 50
Young coniferous – *Mlada šuma četinjača*	–0.126	–0.252	–0.381	–0.477	–0.568
Older coniferous – *Starija šuma četinjača*	0.008	0.002	–0.024	–0.034	–0.053
Deciduous – *Šuma listača*	0.031	0.110	0.160	0.193	0.184

each visit ranged from 0.55 to 0.70 on average, some visits produced highly linear trends ($R^2 > 0.90$), while some visits did not show any trend ($R^2 = 0.00$). However, the percentage of days with regression slope values that were within one standard deviation of the mean was very high for all three forest types (Table 2). In the young coniferous forest, only 5.4% of the regression slope values were below one standard deviation from the mean, and only 2.3% were one standard deviation above the mean. In the older coniferous forest, only 3.4% of the regression slope values were below one standard deviation from the mean, and only 5.0% were one standard deviation above the mean. And in the deciduous forest, only 2.0% of the regression slope values were one standard deviation below the mean, while only 7.4% were one standard deviation above the mean. Further, in the young coniferous forest, the trend during the spring season (a slight increase in static horizontal position accuracy with increases in numbers of position fixes) was significantly different ($p < 0.05$) than the trends observed in the other seasons of the year. No other significant differences among the seasons were observed with regard to the young coniferous forest. No significant differences ($p < 0.05$) among the seasons were observed with regard to the older coniferous forest and the deciduous forest. So while it seems that static horizontal positional accuracy does not significantly change with an increasing number of position fixes used to determine a position's location (leading to a decision not to reject H_1), the results are not entirely conclusive, and the season of year may influence results for some forest types (e.g., young coniferous forests), where there is a relatively high density of trees per unit area that are also relatively short.

Due to the high level of variation among RMSE values observed each day, statistical tests designed to examine the difference between the first position fix RMSE and an average RMSE of a larger set of position fixes all show no significant differences among the mean values. However, if one were to simply examine the difference in static horizontal position accuracy (as represented by RMSE values) between the first and an average of a larger set, trends do emerge (Table 3).

Through this analysis, we find that the difference in RMSE between the first position fix and an average of fifty position fixes is over 0.5 m in the young coniferous forest, which suggests that a larger set (at least 40 or 50) of position fixes would be necessary in the young coniferous forest to better describe a static horizontal position. In examining the results related to the older coniferous forest, we find very little difference, on average, between the first position fix collected and the average of larger sets of position fixes. In this case, where trees are taller and the forest is less dense, a static horizontal position could be estimated just as accurately with one position fix as with a larger set of position fixes (using the receiver tested in this research, of course). In the older deciduous forest we found that static horizontal position accuracy tended to decrease slightly, to about 0.2 m worse after averaging fifty position fixes. Therefore, as with the older coniferous forest, a static horizontal position could be estimated just as accurately with one position fix as with a larger set. Given these observations, we suggest rejecting the second hypothesis, which proposed that the trends do not differ by forest type or by density of trees per unit area.

4. Discussion –*Rasprava*

In previously published research involving the data used here (Bettinger and Fei 2010), we found that static horizontal position accuracy was significantly different in deciduous, older coniferous, and younger coniferous forests, regardless of the season. The consumer-grade receiver that was tested determined static horizontal positions that were consistent with other similar devices tested in the same area, and however it was observed that trends in individual position fix values were evident during visits to the control points. Therefore, this analysis was conducted in order to delve into the trends that were observed during individual visits to control points in three types of forests in the southern United States.

When using low-cost consumer-grade GNSS receivers, fifty position fixes seems to be the most one would need to determine a horizontal position. In fact, in some cases (older, less dense forests), one position fix may return an estimated position that would be just as accurate as the average of a larger set. However, we have shown that younger and more dense coniferous forests (with shorter trees) may require an average of 40 – 50 position fixes to better describe the horizontal position, if an improvement of 0.5 m of accuracy were important. These suggestions are for management applications, of course. When studying the effects of terrain, vegetation, and weather on the accuracy of positions determined by a GNSS receiver, one would want to collect at least fifty position fixes given the variability that can be observed within a 2 – 3 minute span of time.

One obvious limitation of this work is that a single GNSS receiver was studied, and it was a relatively low-cost device (around $ 400 USD). Unfortunately, time and funding constraints influenced the protocols developed for the study. We acknowledge that an assessment of a larger set of GNSS receivers in the manner described here would provide further evidence of trends in position fix accuracy. The more troubling aspect of this enhancement is the time required to perform a long-term study. For the work presented here, 20 minutes per day were required for field data collection purposes. With each additional receiver or each change in parameter setting, 20 more minutes would be required per day. We are not implying that this type of research is impossible to conduct, however, receiver manufacturers and government agencies seem reluctant to invest in these types of forestry studies. In our case, the research was unfunded, therefore while improvements to the study design were considered, given time constraints, many were not pursued.

5. Conclusions – *Zaključci*

In an assessment of the changes in static horizontal position accuracy of a single low-cost, consumer-grade GNSS receiver, we failed to reject a hypothesis that static horizontal position accuracy does not significantly change with increasing numbers of position fixes collected. However, we favor rejecting the hypothesis that trends do not differ by forest type or by density of trees per unit area. Therefore, we suggest that when using a GNSS receiver similar to the one we studied, static horizontal positional accuracy does not significantly change with an increasing number of position fixes used to determine a position's location (leading to a decision not to reject H_1). However, the results are not entirely conclusive, and the season of the year may influence results for certain forest types (e.g., young coniferous forests). Daily visit trends in the improvement (or decline) of static horizontal position accuracy for three forest types were observed over the long-term study. We found that the static horizontal position accuracy in the young coniferous forest, on average, improved from that determined by a single position fix to that determined by a set of fifty position fixes. A much more minor decline in accuracy was noted in the deciduous forest, and no trend was observed in the older coniferous forest.

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Sažetak

Statičke horizontalne pozicije određene prijemnikom GNSS (korisničke vrste): procjena broja potrebnih čvrstih točaka

Ciljevi su ovoga rada sadržani u utvrđivanju mijenjanja točnosti statičkoga horizontalnoga položaja s obzirom na broj čvrstih točaka prikupljenih tijekom snimanja na poznatoj kontrolnoj točki. Hipoteze su sljedeće:

***H_1**: Točnost statičkoga horizontalnoga položaja ne mijenja se značajno s povećanjem broja čvrstih točaka korištenih za određivanje položaja.*

***H_2**: Kretanja se točnosti statičkoga horizontalnoga položaja, s porastom broja čvrstih točaka, ne razlikuju s obzirom na tip šume ili gustoću stabala.*

Između rujna 2008. i rujna 2009. godine pomoću GPS prijamnika Garmin Oregon 300 gotovo svakoga dana prikupljani su podaci u raznolikim stanišnim uvjetima. Statički horizontalni položaji snimani su GPS-om u mladoj šumi četinjača (Pinus taeda), u starijoj šumi četinjača te u šumi listača na lokaciji ispitnoga područja Whitehall Forest, Athens, GA (Atena, Georgia, SAD).

Prosječni statički horizontalni položaji iznosili su 11,9 m, 6,6 m, i 7,9 m za mladu šumu četinjača, stariju šumu četinjača, odnosno bjelogoričnu šumu.

Tri su kontrolne točke (brojevi 6, 31, 37) odabrane za ovo istraživanje između raspoloživih na istraživanom području Whitehall (slika 1). Kontrolna točka 37 smještena je u mladoj borovoj šumi (slika 2), a sastojinski čimbenici u vrijeme istraživanja prikazani su u tablici 1. Kontrolna točka 31 smještena je u starijoj šumi četinjača, a kontrolna točka 6 u šumi listača. Sve tri kontrolne točke smještene su na povišenim mjestima (upper slope positions) u odnosu na okolno područje te predstavljaju najbolji izbor za usporedbu između tih triju tipova šume. Točke su obilažene jednom dnevno tijekom godine, raspored posjeta bio je u potpunosti nasumičan i svaki je put prikupljeno pedeset čvrstih položajnih točaka.

Nadalje, pošlo se pretpostavkom korištenja samo jednoga prijamnika GNSS koji bi imao nepromjenjive radne parametre tijekom cijele studije kako bi se koristili slični uvjeti prikupljanja podataka.

Snimljeni (neobrađeni) podaci, koji predstavljaju srednju kvadratnu pogrešku svake određene čvrste položajne točke, izjednačeni su linearnom regresijom čime se odredio nagib i koeficijent određivanja (R^2) linije, a ona najbolje *odgovara uklapanju unutar pedeset čvrstih točaka svakoga pojedinoga dana snimanja na kontrolnom položaju. Analiza je vođena tijekom svih 298 dana istraživanja i za svaki od triju tipova šume.*

U tim slučajevima jednostavne linearne regresije nezavisna je varijabla srednja kvadratna pogreška svake čvrste točke, a zavisna je varijabla broj čvrstih točaka (1 do 50). Za potrebe prikazivanja uprosječene su vrijednosti nagiba i koeficijenta određivanja kako bi se moglo zaključiti prihvaća li se prva hipoteza, pri čemu se točnost statičkoga horizontalnoga položaja ne mijenja značajno s povećanjem broja položajnih čvrstih točaka korištenih za određivanje stvarnoga položaja.

S obzirom na mnoštvo od pedeset čvrstih točaka prikupljenih prilikom svakoga mjerenja na pojedinoj kontrolnoj točki, ti su podaci smanjeni na šest procjena srednje kvadratne pogreške: (1) prva čvrsta točka, (2) srednja vrijednost prvih deset čvrstih točaka, (3) srednja vrijednost prvih dvadeset čvrstih točaka, (4) srednja vrijednost prvih trideset čvrstih točaka, (5) srednja vrijednost prvih četrdeset čvrstih točaka, (6) srednja vrijednost svih pedeset prikupljenih čvrstih točaka. Kako bi bilo jasnije, srednja je kvadratna pogreška određena za svaku položajnu čvrstu točku, a potom su vrijednosti pogrešaka uprosječene u grupnu prosječnu statičku horizontalnu pogrešku. Budući da je postojala velika količina varijacija u vrijednostima srednje kvadratne pogreške od dana do dana, u analizi je korištena razlika vrijednosti između srednje kvadratne pogreške prve čvrste točke i prosječne kvadratne pogreške ostalih pet skupina. Ova je analiza osmišljena za rješavanje druge hipoteze, koja je sugerirala kako se rezultati mogu razlikovati s obzirom na vrstu šume i obrast.

Na temelju svega navedenoga izvedeni su ovi zaključci: pri korištenju prijamnika GNSS tipa nižega cjenovnoga razreda točnost statičkoga horizontalnoga položaja ne mijenja se značajno s povećanjem broja čvrstih točaka korištenih za određivanje lokacije položaja (što vodi do zaključka da se hipoteza H1 ne odbacuje). Međutim, rezultati nisu u potpunosti pouzdani jer i godišnje doba može utjecati na rezultate u pojedinim tipovima šuma (mlada šuma četinjača). Kretanja dnevnih snimanja u poboljšanju (ili pogoršanju) točnosti statičkoga horizontalnoga položaja za tri tipa šuma promatrana su kroz dugotrajnu studiju. Utvrđeno je da se točnost statičkoga horizontalnoga položaja u mladoj šumi četinjača u prosjeku poboljšala od one određene jednom čvrstom točkom do one određene pomoću pedeset čvrstih točaka. Mnogo manji pad točnosti utvrđen je u listopadnoj šumi, dok nikakva kretanja točnosti nisu otkrivena u starijoj šumi četinjača.

Ključne riječi: globalni navigacijski satelitski sustavi, točnost statičkoga horizontalnoga položaja, srednja kvadratna pogreška, linearna regresija

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