EVALUATION OF GPS PERFORMANCE IN ROMANIAN MOUNTAIN FORESTS

Eugen IORDACHE, Assistant – University of "Transilvania" Braşov, i.eugen@unitbv.ro
Marius MIHĂILĂ, Assistant – University of "Transilvania" Braşov, mihaila.m@unitbv.ro

***Abstract**: Much of the information used for forest management is geographically based and requires continual updating. Such information is generally obtained from aerial photographs which are not available in a timely fashion, and existing maps of questionable geographic quality. The Global Positioning System (GPS) has the potential to improve this situation if it can be made operationally efficient. This paper covers the operational use of GPS for different tasks in Romanian mountain forests. The first is precisely locating inventory plots using GPS under the forest canopy. The second involves rapid determination of the boundaries of clear-cuts. The third task is the quick and accurate location of forest roads.*
The nature of each test, including a description of field procedures and results, will be discussed.

***Keywords:** GPS, positioning under forest canopy.*

1. Introduction

The potential of adopting GPS technology for forestry use was also explored early but with limited application (Kruczynski and Jasumback, 1993; Holden et al.,2001). These initial investigations in GPS accuracy under forested conditions were few (Gerlach and Jasumback, 1989) but have proliferated recently in response to improvements in technology and the abrogation of Selective Availability (SA) in 2000. Improvements in non-differentially corrected GPS accuracy have increased ten-fold, from errors ranging up to 100 meters reduced to within 10 meters. Additionally, advances in antenna and GPS receiver technologies and the development of real-time differential correction services, most noticeably the Wide Area Augmentation System (WAAS), have led to increased investigation of the error sources in GPS positioning data attributed to forest environments. Sources of positional error can be broadly categorized into two classes: system error and environmental error.

System error includes that associated with satellites, clocks, evil waveforms, jamming, and receiver and antenna effects (Faghri and Hamad, 2002; MacGougan et al., 2002). Some of these errors can be minimized using differential correction, including satellite error, clock error, and jamming. Others cannot be known or controlled by the end user. Fortunately, under optimal conditions these errors may collectively range from less than one to several centimeters, while only occasionally increasing to one hundred centimeters or greater depending on the health of the system (Olynik et al., 2002; Liu et al,. 2004).

Environmental error includes signal-to-noise ratio, satellite configuration (Dilution of Precision, or DOP), ionospheric delays, and multipath (in this study associated with forest vegetation effects).

Differential correction techniques may reduce some error from all these sources.

However, since the majority of receiver error realized originates from environmental sources, most notably from multipath effects, there is a decreasing return of how well accuracy can be improved by these techniques. Errors associated with signal-to-noise ratio and satellite configuration can be monitored and measured to some extent through internal controls of GPS receivers and proper mission planning of collection periods. Ionospheric delays exhibit large diurnal, monthly, and solar cycle variations and have become an area of increased interest (Van Dierendonck, 1999; Kunches and Klobuchar, 2001) . Many new ionospheric correction models have been developed to improve differential techniques by more directly correlating space/weather measurements to changes in ground reference station observations (Coster and Doherty, 2004).

Multipath is caused by the reflection of satellite signals from nearby objects, including ground and water surfaces, buildings, topography, vegetation and other sources (Ge et al., 2000). In this study, multipath was primarily caused by vegetative obstructions, from both mid-and upper canopy tree cover.

Forest vegetation effects are the specific components of multipath (the reflection of satellite signals delaying arrival of signals to a receiver) that account for the majority of error in GPS applications in forestry, and can be broadly categorized into the following: canopy closure (%), stand density (stems/ha), stand basal area (m_2/ha), stand height (m), species, stand age, and season. Other factors influencing GPS accuracy, including DOP (horizontal, positional and others), Signal-to-Noise Ratio (SNR), ionospheric interference, and receiver error, have been researched to a lesser extent in natural resource applications, and developing technologies are reducing some of these errors within the receivers themselves (Xu, 2003; FAA, 2004).

Not unexpectedly, there exists a great disparity between the rate at which GPS technologies are developed and the assessment of their application in real-world conditions. Therefore, the continual evaluation of GPS accuracy in forestry applications, and the development of new methods to mitigate the aforementioned sources of error and improve its overall value, will be necessary to fully realize the potential of this rapidly changing technology.

The objectives of this study are***:*** precisely locating inventory plots using GPS under the forest canopy, rapid determination of the boundaries of clear-cuts, quick and accurate location of forest roads.

2. Materials and methods

The territory used for this experiment is a part of Sacele Forest, the research forest of ICAS Brasov. For this territory we have a set of 1: 10000 scaled aerial photographs taken in and a forest map of the area This territory has also been digitized and is integrated into a GIS. For these tests, we chose a clear-cut that has less then 1 ha area. This is a recent cut that facilitates its exact location and boundary on both the photograph and terrain. For the test of road position, we chose a relatively straight line. A part of the road was positioned twice using the GPS. For this section we had coordinates of a road intersection which facilitates the assessment of the GPS location. Finally, for the sample plot location we measured the distance and the magnetic direction from a visible point on the photo to the intended location. The coordinates of the visible point were also known.

The first part of this project is the mapping of the clear-cut area. To analyze the area and its location, we estimated the area using three different methods. First, we used the conventional method of aerial photographs rectified with a sketch master and we estimated the size of the cut area using a planimeter and a dot grid. The second method used was to scan the aerial photographs, rectify them with a digital stereo rectifier, integrate the result into a GIS, and screen-digitize the clear-cut to estimate its area.

The final method was to use the GPS in kinematic (continuous) mode. That is, the GPS receiver was turned on and walked around the edge of the clear-cut continuously recording locations.

The second part is to analyze the locations of the clear-cut, the roads and the sample plot. For the clear-cut and the road we overlaid the GPS points on a rectified image of the scanned photographs. For the sample plot, we compared the two GPS observations, below and above the canopy, at the location measured in the field with a distance and magnetic bearing from a visible point on the photo.

There are many ways in which one can make GPS observations. One can observe based on absolute or differential positioning, kinematically or statically, and/or one can make phased or coded observations. These methods have different restrictions and requirements.

We want to present here only those factors that influence the choice of the method ultimately selected for use. In general, phased scaling observations are more accurate than coded observations, but also tend to be more restrictive. In fact, to make phased scaling observations, in order to fix the phase ambiguity, the required observation time at each station is longer than for a coded observation. With phased observations, it is important to eliminate obstacles that can cause signal interruption (cycle-slip).

For the problem of being below the forest canopy, we used a lightweight telescoping pole. This pole can be extended from 1.5 m to 10 m and its weight is only approximately 3 kg.

The GPS equipment that we used was:

- 1 Trimble Pathfinder Pro (base station)
- 1 Trimble Pathfinder Basic (rover station)
- 1 Trimble code microstrip antenna
- 1 lightweight telescoping pole (1.5 - 10 meters).

The observation method used was differential positioning.
This necessitated two stations, one fixed at a point whose exact position was known in the geodetic system, and one movable, that we used for the observations in the clear-cut, road, and sample plot locations.

For the estimation of the area of the clear-cut, we used the pole at its lowest elevation (1.5 m) and observed one position per second kinematically. For the location of the sample plot, we extended the pole to its highest length (10 m) which put the antenna (approximately) over the forest canopy. We then made 30 observations, 1 per second at this location.

3. Results and discussion

Preliminary results are presented for each part of this project in this order: clear-cut area estimation, location of the clear-cut, road, and sample plot.
Five measurements of the area were taken using a dot grid on the map of the clear-cut area and averaged . The mean area estimation is 0.82ha(Table 1). The range of this estimation is from 0.80 to 0.89ha. In the kinematic GPS measurement, the clear-cut boundary was delineated by the path of the operator who walked around the cut area. In general, we did not have a problem to identify the boundary of the clear-cut except in one place where there were some cut residues.
This problem, however, did not appear-to influence the estimation of the cut area.

The first method using the sketch master and dot grid to estimate the area of one clear cut was demonstrated to have low accuracy. First, the use of the sketch master presented difficulties because the eastern part of the territory had an ascending slope. It was difficult to match the roads on both the paper map and the photograph.

Table 1. Comparison of clear-cut area estimates using three different techniques

Method	Area Estimate(ha)
Dot grid	+ 1ha
Screen-digitizing	0.82 (0.80-0.89)
GPS (Kinematic)	0.855

Secondly, the estimation of the area of the clear-cut was made with a dot grid sheet and a planimeter for which it was difficult to read the exact position of the lines on the instrument. This same problem also appeared with the dot grid. Sometimes the position of the dot grid showed 4 points in the cut area. The second time it showed 7 points. Although the final estimate of the area is the mean of the observations, this demonstrated that for a small area, these two methods were not accurate.

In the second method, the principal advantage of using scanned aerial photography is the ability to use a numeric rectifier. After the image rectification, we were able to precisely identify the boundaries of a clear-cut area. This determination appears to be primarily influenced by the computer screen resolution and by the uncertainty of the boundary of the clear-cut area in various regions. However, this technique was more accurate then the conventional method because photo rectification performed using a digital rectifier is more precise then than that produced using a sketch master. Furthermore, the line width obtained from the digital rectifier was less than the line width on the paper map (which was approximately 10 m in this study). However, to be able to use the second method, aerial photographs still are required which means the problem of delays still exists. GPS observations can eliminate this problem. After the forest harvesting operation, it is possible to go to the field and simply walk along the cut area boundary holding a GPS receiver. The results (Table 1), demonstrate the efficiency and accuracy of using this method to determine the area of a cut block without delays. Note that these are preliminary results, but it is believed that improved image rectification and data analysis will provide a difference of less then 3,5%.

The small difference observed between the two “new” methods (GPS and rectified image), and the case with which observations were recorded in the field, shows that the GPS technique can be used operationally. In addition, the GPS observations for the cut area are shade independent with the boundaries being easier to define in the field.

The overlay of the scanned and rectified aerial photograph with the GPS observations recorded in the field allowed us to determine visually that the clear-cut location “fits” at one end of the cut fairly well, but that it is “shifted” somewhat at the other end. The difference between the GPS and the image locations varied from 0 m to 5 m. However, the differences are generally in the same direction. Thus if we move the clear-cut as mapped by the GPS observations, overlay it with the cut area on the map, it fits extremely well. The same difference was apparent for the road location; in general, the difference between a GPS location and the rectified image was from 0 to 5 meters. Where the road was close to the control points the difference was small (0,5-1m) and fairly constant. However where the road was further from the control points, the difference increased, also in a consistent fashion.

The largest difference appeared where the road was farthest from the rectified points and also where the slope of the territory increased.

For the location of the sample plot, we obtained a difference of a few meters. However, the difficulty of finding on the photo the “starting point” on the ground influenced the interpretation of the sample plot position on the photo. Nonetheless, using kinematic observations we found an accuracy of approximately 5 m. Because this information was collected with the antenna mounted on top of the telescoping pole, it is reasonable to think that we have this accuracy in the position of the sample plot despite the difficulty in exact photographic location.

The observation under the forest canopy gave a positioning difference of 95 m. because the density of the forest stand was high and the observing time short 1 minute.

The location of the clear-cut and the road was done in a kinematic mode. This method will have increased inaccuracy compared to that obtained using observations obtained in static mode. For each GPS point, the theoretic error variation is from 1 to 5 m. On the other hand, the difference between the location of the clear-cut is within 1 m at one end and within 5 m in a constant direction at the other. A slight change in the GPS observations and/or image can produce a negligible difference between the two locations. The same thing appears true for the road location. A verification made in the triangular network used for the rectification shows that the differences are bigger where the number of triangles is less and where the topographic slope increases. For the sample plot location, the use of the telescoping pole does not limit the ability to collect forest observations and eliminate the problem of being under the forest canopy.

When the GPS cut area boundaries are compared to the rectified image, the differences are principally in the boundary position rather than the shape.
In fact, if the boundaries from the GPS observations are compared to the screen-digitized boundaries from the image, it is found that greater differences arise from the human interpretation of the cut area. This is probably because when the operator digitizes the cut area, his decision is influenced by the shading of the trees on the clear-cut and the isolated trees or fuzzy boundaries between the cut area and uncut adjacency forest stand. Also, with the on-screen digitizing method, the cut area and the road locations are less accurate because the cursor is sometimes difficult to see over the scanned image. This appears to explain the most important difference in the comparison of the shapes of the two cut area boundaries. The same situation appeared in the road location. With regard to these problems, it is felt that the estimation of the clear-cut and road positions is more accurate if they are determined in the field. If the GPS observations are precise, the estimation of the clear-cut and road positions will be more accurate.

4. Conclusions

This is not an exhaustive study to determine the accuracy of the position of forest territory elements with the GPS equipment.

The use of a scanned photograph and digital rectifier improves the conventional method of determining areas and locations in terms of both time and accuracy. Rectified image accuracy depends upon the number of control points, the accuracy of their coordinates, and the slope of the territory. In the future the production of digital maps will probably decrease these problems and it will make it easy to rectify an image with a suitable network of ground-control points. To eliminate the problems of the delay in obtaining aerial photographs, GPS observations can be used. Independently of whether a site is under, over, or beside a forest canopy, the location can be observed with a lightweight telescoping pole and with compact GPS equipment. The time required to observe the contour of a clear-cut area took us 10 minutes for 0.82ha but this time can vary depending upon the amount of clear-cut residues remaining on the ground. This operation could be done in winter, to decrease the time required to make GPS observation.

The preliminary results demonstrate that the USC of GPS to locate clear-cut areas, roads and samples plots can improve the accuracy of the location and can aid the update of forest information. The simplicity of linking GPS observations with a GIS will also increase the interest in that technology.

GPS receivers are frequently useful to forest management activities related with locating or mapping boundaries as monitoring harvesting machinery (McDonald et al, 2002), topography and cadastral forest surveys (Yoshimura et al., 2002), forest inventory, resources and special management areas (Wing and Kellogg, 2004), forest area and perimeter estimations (Tachiki et al., 2005) and GIS forest applications (Wing and Bettinger, 2003).
Against a handheld digital range finders and digital total station GPS receivers are quicker and easier to digitally capture a target point; however a handheld digital range finders is cheaper and a digital total station is more accuracy and precise that a GPS receiver (Wing and Kellogg, 2004). Its principal problem is GPS receivers require satellite signal that is often unachievable under forest canopy. It is known that the positioning precision and accuracy under forest canopy are markedly lower than in areas with unobstructed sky conditions because trees attenuate or brake GPS signals.

The precision and accuracy in GPS positioning can be expressed as a percent of the data is better than the specification. The more common terms used in previous works to estimate GPS accuracy and precision are Circular Error Probable (CEP), Root Mean Square error (RMS) and Distance Root Mean Square error (DRMS). Sawaguchi et al. (2003) define CEP as the value witch a half of the data points fall within a circle of this radius centered on truth and a half lie outside this circle and use CEP to estimate GPS positioning a different forest type, antenna height, and season, and to clarify the relationship between sampling number and the convergence of positioning precision.

RMS value mean that approximately 68% of the data points occur within this distance of truth.Yoshimura and Hasegawa (2003) use RMS testing on horizontal and vertical positional errors of GPS positioning at different points in forested areas. DRMS should be expressed clearly whether the accuracy value refers only to horizontal or to both horizontal and vertical and indicates that approximately 95% of the data points occur with this distance of truth It is the method proposed to calculate accuracy in the Standard Positioning Service (SPS) (Kaplan, 1996). Dana (1997) defines 2DRMS as Estimated Positional Error (EPE) and is used to compare differences between GPS receiver under forest canopies (Karsky et al., 2000).

There are techniques as differential global positioning system (DGPS) that improve precision and accuracy under tree canopies. Hasegawa and Yoshimura (2003) achieved a mean error of a 1 to 30-min observation varied between 0.029-0.226 m (without closed tree canopies) and it was 0.415-0.894 m (with closed tree canopies), using Dual-frequency GPS receivers by carrier phase DGPS static surveying. Sawaguchi et al. (2003) using DGPS got mean CEP95= 2.80 m for deciduous broadleaved trees and 4.99 m for conifers. Additionally they demonstrated that positioning precision was not noticeably improved if the sampling number was around ten. So DGPS improve GPS positioning in precision, accuracy and efficiency because the observation time is shorter (Næsset et al, 2001; Næsset and Jonmeister, 2002).

5. References

1. *Dana, P.H., 1999, Global Positioning System (GPS) time dissemination for Real-Time Applications, Real-Time Systems, 12, 9-40.*

2. *Hasegawa, H., Yoshimura, T., 2003, Application of dual-frequency GPS receivers for static surveying under tree canopies, Journal of Forest Research, 8, 103–110.*
3. *Kaplan, E.D., 1996, Understanding GPS principles and applications, Boston, Artech House Inc.*
4. *Karsky, D., Chamberlain, K., Mancebo, S., Patterson, D., Jasumback, T., 2000, Comparison of GPS Receivers under a Forest Canopy with Selective Availability Off, USDA Forest Service Project Report 7100.*
5. *McDonald, T.P., Carter, E.A, Taylor, S.E., 2002, Using the global positioning system to map disturbance patterns of forest harvesting machinery, Canadian Journal of Forest Research, 32, 310–319.*
6. *Næsset, E., 1999. Point accuracy of combined pseudorange and carrier phase differential GPS under forest canopy, Canadian Journal of Forest Research, 29, 547-553.*
7. *Næsset, E., Bjerke, T., Øvstedal, O. Ryan, L.H., 2000, Contributions of differential GPS and GLONASS observations to point accuracy under forest canopies, Photogrammetric Engineering & Remote Sensing, 66, 403-407.*
8. *Næsset, E., 2001, Effects of differential single- and dual-frequency GPS and GLONASS observations on point accuracy under forest canopies, Photogrammetric Engineering &Remote Sensing, 67, 1021-1026.*
9. *Næsset, E., Jonmeister, T., 2002, Assessing point accuracy of DGPS under forest canopy before data aquisition, in the field and after postprocessing, Scandinavian Journal of Forest Research, 17, 351-358.*
10. *Sawaguchi, I., Nishida, K., Shishiuchi, M., Tatsukawa, S., 2003, Positioning precision and sampling number of DGPS under forest canopies, Journal of Forest Research, 8, 133–137.*
11. *Tachiki, Y., Yoshimura, T., Hasegawa, H., Mita, T., Sakai, T., Nakamura, F., 2005, Effects of polyline simplification of dynamic GPS data under forest canopy*
12. *Yoshimura, T., Gandaseca, S., Gumus S., Acar, H., 2002, Evaluating the accuracy of GPS positioning in the forest of the Macka region, In The Second National Black Sea Forestry Congress Proceedings, 1, 62-69.*
13. *Yoshimura, T., Hasegawa, H., 2003, Comparing the precision and accuracy of GPS positioning in forested areas, Journal of Forest Research, 8, 147–152.*
14. *Wing, M.G., Bettinger P., 2003, GIS: An updated primer on a powerful management tool, Journal of Forestry, 101, 4-8.*
15. *Wing, M.G., Kellogg L.D., 2004, Digital data collection and analysis techniques for forestry applications, In Proceedings of the12th International Conference on Geoinformatics, University of Gävle, Sweden, June 7 2004, p. 77-83.*