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Accuracy assessment of GPS and surveying technique in forest road mapping

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Abstract. Forest road networks provide access to the forest as a source of timber production and tourism services. Moreover, it is considered the main tool to protect forests from fire and smuggling. The prerequisite of road management and maintenance planning is to have spatial distribution and map of the roads. But newly constructed or some other forest road segments are not available in national maps. Therefore, mapping these networks is raised as a priority for a forest manager. The aim of this study was to assess accuracy of routine methods in road mapping. For this purpose, Patom district forest road was selected and road network map was extracted from the National Cartographic Center maps as the ground truth or base map. The map of the network was acquired using two methods, a GPS receiver and survey technique. Selecting 70 sample points on the network and considering the National Cartographic Center map as base map, accuracy was determined for two methods. The results showed that while the survey method was more accurate at the beginning of the path (first 500 meters), accumulation of errors resulted in higher rates of error in this method (up to 263 meters) compared to GPS. Mann-Whitney test revealed significant differences in accuracy of two methods and mean accuracies were 38.86 and 147.90 for GPS and surveying respectively. The results showed that for samples 1-15 there was no significant difference between the survey and GPS data but for samples 28-42 and 56-70 statistically significant difference were existed between the survey and GPS data. Regression analysis showed that the relation between GPS and surveying accuracies and distance were best defined by cubic (R^2_{adj} = 0.65) and linear (R^2_{adj} = 0.83) regression models respectively. Applying 10 and 5 meters buffers around base map, 68 and 41% of GPS and 44 and 21% of surveying derived road were overlapped with buffer zones. The time required to complete the survey was found to increase the overall cost of mapping road network. The lower time requirements associated with the GPS methods were found to reduce the costs associated with mapping forest roads.
Keywords GPS, survey technique, accuracy, Mann-Whitney, forest road.

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Introduction

Forest road construction is a prerequisite of forest management plans. Management of hardwood forest is important in order to maintain or enhance ecosystem functions and provide access for other uses (Rummer et al. 1997). A well planned, designed, constructed and maintained system of roads is essential to facilitate forest management and the protection of natural resources. Road design is the process of determining the "what, when, and how" for a new road construction, road improvement, or extra-ordinary road maintenance product. Road inventory is a prerequisite of road management and maintenance that provides primary and important information about road features. Sustainable road management requires proper spatial data for the road network.

There are different ways of acquiring and gathering spatial data. Global positioning system (GPS) receivers are frequently useful for engineering activities in the forest environment and for forest inventory and road inventory (Evans et al. 1992), topography and cadastral forest surveys (Soler et al. 1996, Yoshimura et al. 2002), locating or mapping boundaries to monitor harvesting machinery (MacDonald et al. 2002), geographic information system (GIS) forest applications (Wing and Bettinger 2003), resource and spatial area management (Wing & Kollegg 2004), and forest area and perimeter estimation (Tachiki et al. 2005). A variety of GPS receiver hardware configurations and satellite systems are now available to consumers to assist in field data collection, reconnaissance, and other activities (Wing et al. 2007). There are three recognized GPS receiver grades: consumer grade, mapping grade and survey grade. Within these grades, the consumer GPS receivers are quicker and easier to use for gathering position digitally, compared to other available devices (Rodríguez-Pérez et al. 2007). Mapping grade receivers are considered the best suited for forestry purposes but they are usually unavailable in forest management plans due to higher cost (20 times) compared to consumer receivers (Wing et al. 2007). Another alternative to gain the data is surveying technique. Before the advent of GPS, surveying techniques were utilized for mapping. Surveying (also known as land surveying) is the technique and science of accurately determining the terrestrial or three-dimensional position of points and the distance and angles between them (Tamadoni 1987).

Surveying has many restrictions when used to collect measurements in forests environments. Trees commonly create barriers along measuring areas, while forest topography can also be problematic. Also, errors in surveying technique are accumulative and cause increased errors at the end of a path. There are also several likely sources of error associated with GPS which include: signal interference due to atmospheric conditions, the synchronization of satellite and receiver clocks, and tracking of satellite position and patterns (Leick 2004). However, the GPS errors are less user-dependent. Forested landscapes place significant impediments to collecting resource measurements through the canopy, understory vegetation, land forms, and other factors that block satellite signals from reaching a GPS receiver (Wing et al. 2007). The main concerns of using a GPS receiver in forest environments are the availability and characteristics of satellites under the forest canopy (Rodríguez-Pérez et al. 2007). Branches, trunks and leaves attenuate, distort or brake GPS signals within a forest stand; hence accuracy and location are markedly lower than in area with un-obstructed sky conditions (Hasegawa & Yoshimura 2003). A number of studies were done to reduce the location errors of GPS receivers. Differential Global Positioning system (DGPS) improves accuracy and precision in forest environment (Hasegawa & Yoshimura 2003, Sawaguchi et al. 2003, Satirapod et al. 2003). However, DGPSs are not available for consumer GPS receivers, which are cheaper, easier to use, and require less user training than DGPS receivers.

Sigrist et al. (1999) tested mapping-grade GPS receivers in the Midwestern US mixed hardwood forest and determined horizontal position errors between 12.3 m and 25.6 m during leaf-on periods and between 3.8 m and 8.8 m during leaf-off conditions. Wing et al. (2007) tested five Trimble mapping-grade GPS receiver using several different configurations in western Oregon US, in three different conditions (open sky, young forest, and closed canopy), and found that the non-DGPS average horizontal errors of mapping-grade GPS receiver of 0.8 m, 1.3 m, and 2.2 m in open sky, in young forest and closed canopy conditions, respectively, while the average errors in the post-processed data were 0.5 m, 0.6 m, and 1.7 m for the same conditions.

In Iran, the higher cost of mapping grade GPS receivers restricted their usage in forest management plans and forest managers instead rely on consumer grade receivers, which are cheaper and easier to use. In spite of their wide usage, there is no information about their accuracy in forest environment of Iran. Therefore we decided to compare the horizontal accuracy of a typical consumer GPS and comparing it with traditional surveying technique that is still an alternative for GPS in forest management plans. We hypothesize that there is no difference in accuracy of survey technique and errors in GPS.

Material and methods

Study site description

The study was carried out in the University of Tehran Research Forest Station, located approximately 7 km East of Nowshahr, Mazandaran Province, northern Iran. Kheyrud Forest consists of eight districts, including the Patom district. The Patom district is located approximately at a latitude of 36^o 38’ N and a longitude of 50^o 34’ E. The average stand volume is about 55.76 m^3/ha, dominant stand height 25-30 meters, 70% canopy cover and 263 stems/ha. Dominant tree species are *Carpinus betulus* (Hornbeam), *Fagus orientalis* (Oriental Beech) and *Parrotia persica* (Persian Ironwood).

Methods

A total of 7,000 meters of the road network was mapped with a GPS receiver and surveying technique. In the surveying technique, azimuth and distance of 10-15 meter segments were recorded. The distance and azimuth were measured from segment start point to endpoint using a tape meter and a compass, respectively. This process was continued to the end of the road path. Segments were combined to produce a continuous road network with ArcGIS Desktop 9.2 (Environmental Systems Research Institute, 2004). GPS data were collected for the road network in clear sky conditions with a consumer grade Garmin-Colorado 300 GPS receiver. It should be noted that this GPS receiver cannot mask for PDOP (Position dilution of precision). It takes into account each satellite’s location relative to the other satellites in the constellation. A low DOP indicates a higher probability of accuracy. A high DOP indicates a lower probability of accuracy) and does not collect files suitable for differential correction. The GPS data were imported into ArcGIS Desktop 9.2 for analysis. The base map of the road network that was provided by Iranian National Cartographic Center (NCC) was in DGN (Design (file)(The name used for CAD file formats supported by Bentley Systems’ MicroStation and Intergraph’s Interactive Graphics Design System (IGDS) CAD programs). Finally three different maps were available for the selected road network: DGN (Design (file)(As the base layer), GPS and surveying derived layers (figure 1).

Fixed points were selected along the routes to calculate the accuracy of each method. Routes were divided in to 100 m segments. Accuracy assessment points were located at the middle

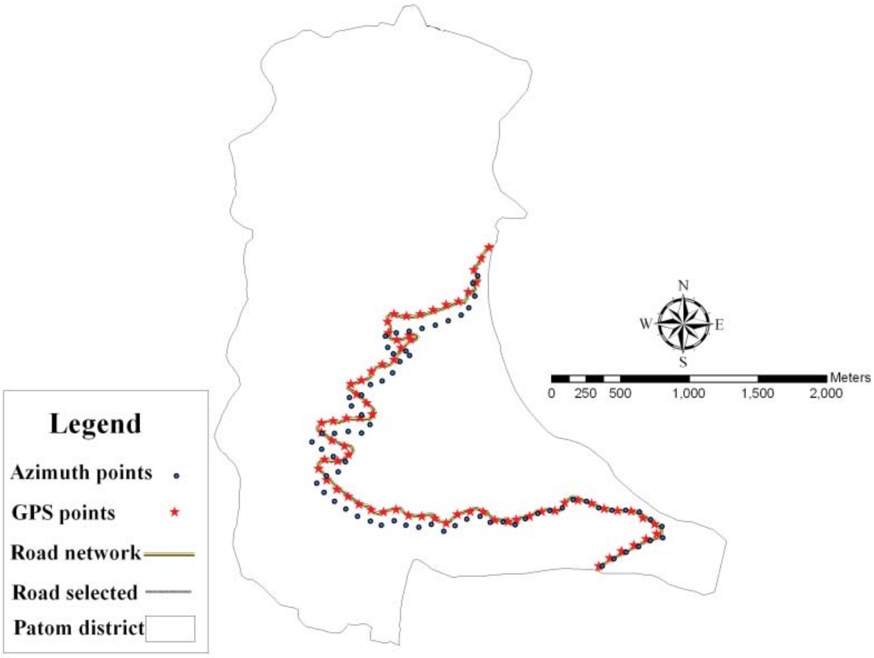

Figure 1 Road pathways in the three methods to assessment accuracy

of each segment. This resulted in accuracy assessment points spaced roughly 100 m apart.

Horizontal accuracies were calculated for each point using following equation (Rodríguez-Pérez et al. 2007).

$$H_{-acc} = \sqrt{(x - x_{true})^2 + (y - y_{true})^2} \quad (1)$$

where $H_{\_acc}$ is the horizontal accuracy, x and y are positions along the easting and northing of point for GPS and surveying maps; x_{true}, and y_{true} are Corresponding true positions (Position from the NCC map) along the easting and northing. The x and y coordinates of the points were exported in to Microsoft Office Excel 2003 for accuracy calculations.

Accuracies of two groups were plotted against the distance to each point to show the effect of increasing distance on accuracy. Kolmogorov-Smirnov and Shapiro-Wilk normality tests were performed, at 95% confidence level to determine if the two variables (accuracies) were normally distributed, and to select appropriate analysis (Parametric or non-parametric) to compare different groups (Rodríguez-Pérez et al. 2007, Lopez et al. 2008). Using Mann-Whitney test, we also compared means of samples 1-15, 28-42 and 56-70 (at the beginning, middle and end of the path respectively) of the two methods to illustrate the possible effect of increasing distance on accuracy. Regression analysis was used to investigate and model the relationship (trend) between accuracy and distance. All statistical analyses were conducted with SPSS16.0 statistical software (SPSS Inc, 2007). Finally the NCC road network map was buffered by 5 and 10 meters to assess the amount of overlap between the NCC road network map and the survey and GPS-acquired road network maps.

Results

The results showed that there was relatively a wide variation in accuracy levels. Some descriptive statistics are shown in Table 1.

The results showed that while the survey method was more accurate at the beginning of the path (first 500 meters), accumulation of errors resulted in higher levels of error in this method (up to 263 meters) compared to GPS (Figure 2).

Normality tests showed that the accuracy data (GPS and Survey) were not normally distributed (p value < 0.01, df = 70).Therefore, the Mann-Whitney nonparametric test was used to compare groups (McCune 2004). There was a significant difference between the accuracy of the survey and GPS ($U = 434$, $p < 0.001$). Hence, we reject the null hypothesis saying that the surveying method (Mean 147.90) was shown to be less accurate than the GPS method. (mean 38.86).

For samples 1-15, there was no significant difference between the survey and GPS data ($p > 0.05$). However, the Mann-Whitney Tests for samples 28-42 and samples 56-70 showed statistically significant difference between the survey and GPS data ($p < 0.01$) (Table 2).

Thus, our results show that in the survey technique, errors are cumulative and for long distances along the paths, higher errors are possible.

To evaluate the trend between data, analysis of regression was conducted. The results

Table 1 Descriptive statistics of accuracies for two groups

Statistics	GPS	Survying
Mean	38.86	147.90
Median	33.75	162.68
Std. deviation	19.64	70.55
Minimum	6.49	6.82
Maximum	88.03	263.41

Table 2 Mean ± standard deviation for beginning, middle and end of the path samples

	Mean ± Standard deviation	
Samples	GPS	Survey
1-15	23.36 ± 6.62	51.45 ± 33.69
28-42	32.54 ± 8.84	169.40 ± 26.29
56-70	63.44 ± 18.89	216.41 ± 36.80

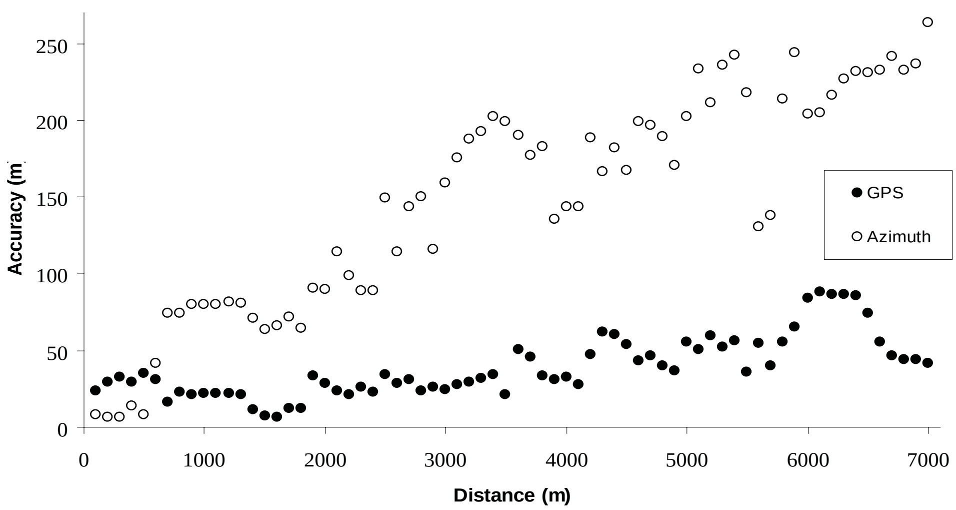

Figure 2 Relationship between accuracy and distance in two groups

showed that there is a significant cubic relation (Figure 3) between GPS accuracy and distance (R^2_{adj} = 0.67, p < 0.01, F = 48.69). The regression equation is:

$$Accuracy = 36.47 - 0.02543\ Distance + 0.000010\ Distance^2 - 0.000001\ Distance^3$$

As figure 3 shows accuracy regression line tends to decrease in the beginning of path, then increases and at the end of path again tends to decrease. Therefore it can be concluded that the errors in GPS method are not systematic and cumulative.

The results also showed that there is a significant linear relation (Figure 4) between survey accuracy and distance (R^2_{adj} = 0.84, p < 0.01, F = 372.16). The regression equation is:

$$Accuracy = 34.73 + 0.03188\ Distance$$

Figure 4 shows that errors of the survey method, tend to increase with increasing distance due to accumulation of errors.

The results of buffer overlay showed that the 10 m and 5 m NCC buffers covered 68% and 41% of the GPS and 44% and 21% of survey-derived road respectively. This also show that GPS derived road is more consistent with the base map.

Discussion

Horizontal accuracy of survey and GPS derived road maps were compared with regard to the map created by the NCC as base map. In the forest environment tree canopies and stems distort or break satellites signal and can result limited access to signals (Rodríguez-Pérez et al. 2007). On the other hand, there are two types of errors that may take place in survey technique: 1- User errors in measuring phase, 2- User errors in delineation phase (Tammadoni 1987). So if the user is poorly trained or prone to error, obvious errors may occur. One should keep in mind that if the user is well trained, the results will have high accuracy.

Saghravani et al. (2009) stated that traditional surveying provides good accuracies only in small study areas. Our results showed that in the beginning of path, survey errors are lower than that of GPS and with increasing distance accumulation of errors resulted in higher lev-

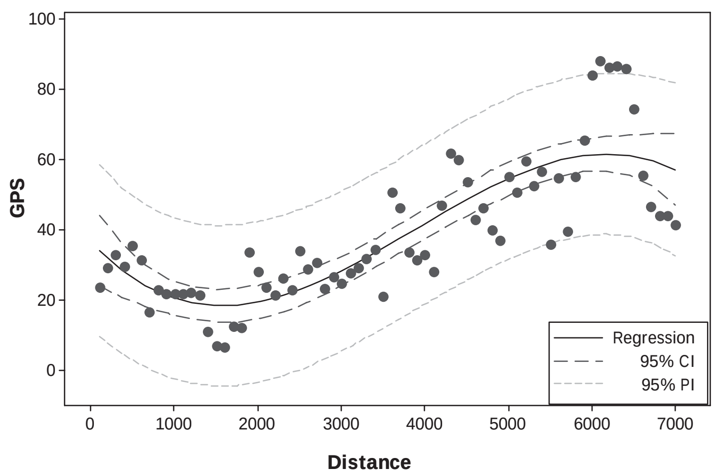

Figure 3 The model for relationship between GPS accuracy and distance (CI is the 95% confidence limits for the Accuracy PI is the 95% prediction limits for new observations)

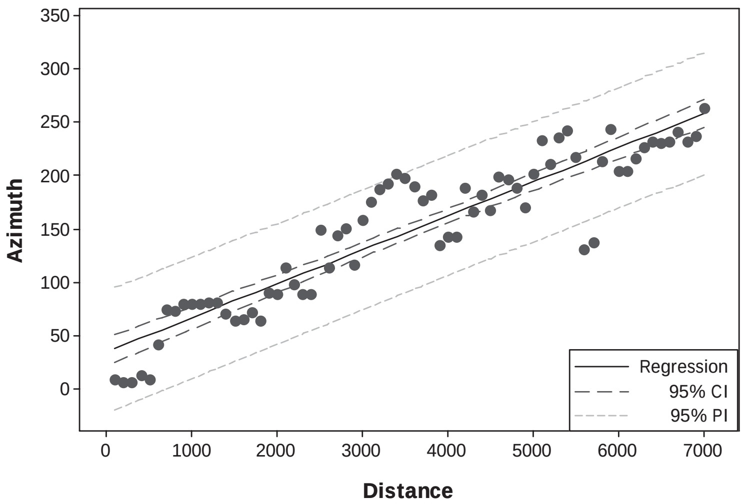

Figure 4 The model for relationship between survey accuracy and distance. (CI is the 95% confidence limits for the Accuracy. PI is the 95% prediction limits for new observations)

els of errors. On the other hand, GPS errors are less user dependent, and in forest environment GPS accuracy depends more on the amount of canopy cover and access to the satellites' signals (Hasegawa and Yoshimura 2003, Rodríguez-Pérez et al. 2007, Pirti 2008). Our results also showed that the errors are not systematic. In this study low-cost, real-time, hand-held GPS receiver was used, so that neither post-processing nor long time observations were available (Rodríguez-Pérez et al. 2007). Horizontal accuracy of GPS in this study was variable and values ranged from 6.49 to 88.03 m, depending on GPS signal or barriers. This is a general problem using GPS under forest canopies and may be solved by increasing the observation time period and applying DGPS (Næsset & Jonmeister 2002, Sawaguchi et al. 2005). Different studies have shown variable average accuracies (from below 1 to 40 meters) due to the different methodologies and GPS receivers used (August et al. 1994, Bilodeau et al. 1993, Deckert & Bolstad 1994, 1996, Gehue et al. 1993, Leclerc et al. 1997, Wolniewicz 2001, Rodríguez-Pérez et al. 2007). Wide ranges of methodologies, equipment, and study sites (forest type), as well as variations in the number of measurements taken, explains the diversity of results observed in previous studies. Furthermore, the reference points used to estimate positioning variations are often measured or calculated differently in different tests, which limits possible comparisons (Piedallu & Gégout, 2005). The errors in this study are comparable to findings from previous studies (Sigrist et al. 1999, Johnson & Barton 2004). Sigrist et al. (1999) in hardwood forest determined horizontal accuracy between 12.3 to 25.6 meter, during leaf-on period. Deckert & Bolstadt (1996) found that the positional accuracy was higher for open sites compared to sub-canopy and for deciduous sites versus coniferous. Wing et al. (2007) reported the highest accuracy of GPS receivers under open sky conditions. Pirti (2008) reported 50-70 percent of accuracy improvement after adjacent forest was cut off. He also noted signal blockage as the main problem affecting the use of GPS in forested areas. The GPS receiver that was used in this study had showed average accuracy of 10 meter in urban environment (unpublished results). This accuracy is significantly lower than that of the results from this study and is consistent with other studies about the effect of canopy. Wing et al. (2007) suggested point averaging and D,Eno (1996) suggested increasing antenna height to improve accuracy of GPS measurements. Our results also showed that the accuracy of GPS readings was user independent and relatively constant with increasing distance contrary to survey technique. Saghravani et al. (2009) suggested traditional surveying be utilized for only small study areas, which is consistent our finding. When considering cost, a GPS receiver may be a good choice for creating new maps and updating existing maps in forestry districts. The obtained accuracy in this study may be relatively higher and in addition to forest canopy, the inability of the GPS receiver to mask for PDOP and post-process the data contributed to this accuracy. Serr et al. (2006) concluded that accuracy and cost of GPS receivers are directly linked and higher accuracy results in higher receiver costs.

Conclusions

This study assessed the accuracy of GPS receivers and surveying techniques for mapping seven km forest road network. The results showed that accuracy was statistically different between two methods. The increased accuracy of the GPS collected data was obtained in spite of leaf-on conditions that have been previously shown to have adverse effects on GPS accuracy. While selection of the optimal GPS receiver is a project-dependent consideration, the only GPS receivers that are available in forest management plans in Iran are consumer grade. If accuracy requirements are moderate to low, the tested receiver may provide valuable positional data under the forest canopy. As forest roads are open sites in the forests and tree canopy is removed on the top of roads, it seems that using GPS for road mapping may be a good choice for forest managers. Also as they are long linear features, accumulation of errors in survey technique is a major problem. Using GPS may be a good alternative for mapping purposes when consider accuracy and costs.

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