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SEASONAL VARIATION OF GPS ACCURACY AND PRECISION IN FOREST ROAD MAPPING

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Abstract: *GPS receivers are frequently used for engineering activities in forests; however, a number of factors, including natural barriers (mountain and tree canopy) in the forested areas, affect their accuracy. The aim of this study was to evaluate the accuracy and precision of a consumer grade GPS (Colorado 300) receiver in road mapping. For this purpose, a length of 12.2 km of main forest road was selected in the Hyrcanian forest, northern Iran, and a ground truth map was extracted from the National Cartographic Center maps. The forest road was mapped in four seasons for three days to evaluate the seasons' effects on the location accuracy and five- and ten-meter buffers were used for the same purpose. The results of two-way ANOVA showed that there were significant differences in the precision and accuracy of the GPS receiver due to the season. The best and worst mean accuracy and precision were in spring (24.45 m and 24.97 m) and autumn (56.10 m and 53.65 m), respectively. The findings showed a positive effect of averaging (5-61% improvement in relation to season) on the position accuracy. Also, ANOVA did not show any significant differences between the overlay lengths due to season in both the five-and ten-meter buffers. It can be concluded that consumer grade GPS receivers could meet forestry needs. The averaged accuracies in spring are acceptable for many forestry applications and satisfy the mapping requirements.*

Key words: *accuracy, forest road, consumer-grade GPS, point averaging, precision, season*

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1. Introduction

Global positioning system (GPS) is a space-based global navigation satellite system that provides reliable location information irrespective of weather, at all times and anywhere on Earth when and where there is an unobstructed line of sight to four or more GPS satellites [15], [26]. GPS was created by the US Department of Defense (DOD) and was originally run with 24 satellites. It was established in 1973 to overcome the limitations of previous navigation systems [4], [39]. Since each satellite emits a unique signal, a receiver can match the signal to the satellite and its orbital position by triangulation. The distance from the receiver is then calculated (for each satellite) and from that data, the receiver calculates its geographic position. A number of factors, including satellite positions, noise in the radio signal, atmospheric conditions, and natural barriers (mountain or tree canopies) to the signal [11], [20-22], [24], [28], affect GPS accuracy. Objects between the satellite and the receiver such as mountains or tree canopy in forested areas can produce errors. GPS receivers are frequently used for engineering activities in forest environments such as locating or mapping boundaries, monitoring harvesting machinery [6], [17], [23], running topography and cadastral forest surveys [37], supporting forest inventories [11], running forest engineering and resource management activities [43], delimitating forest areas and estimating perimeters [38], as well as in integrating GPS data in geographic information system (GIS) applications [41].

Among other forestry infrastructure, forest roads are necessary for providing economical access to forest resources and services, representing an important component in forest management [7], [9], [30]. In order to facilitate the operations in areas managed for timber production, a well-developed network of roads is essential [2]. A road inventory is required for road management and maintenance, and provides important data about road features. Systems used for road management and planning integrate the spatial attributes of the road network. Among the available land surveying equipment, GPS receivers were found to be good tools in providing spatial data about road networks [12], [44].

There are three recognized GPS receiver categories: consumer, mapping, and survey grade. Within these categories, the consumer-grade GPS receivers are quicker and easier to use for gathering [33], but they have lower accuracy and precision [42]. Availability at low costs has significantly increased the use of consumer-grade GPS receivers over the past decade. However, they are not able to differentially correct the data following field data collection, and any obstruction such as tree canopy has a significant effect on their accuracy. In general, the high cost of mapping grade GPS receivers limits their use in developing forest management plans; instead, forest management relies on consumer grade receivers which are cheaper and easier to use [2]. The most accurate determination of position occurs when the satellite and the receiver have a clear view (open sky) of each other and no other objects interfere. However, in practice many users have to operate GPS receivers in less favorable conditions such as forest cover (obstructed sky). The presence of an overhead canopy may degrade the positional accuracy [35], [40].

A number of studies were conducted to compare the accuracy and precision of GPS receivers in forest environments. Hasegawa and Yoshimura [14] showed that Differential Global Positioning system (DGPS) improves accuracy and precision in forest environments. Rodríguez-Pérez et al. [33] showed that accuracies were different depending on canopy cover and forest characteristics. In some studies, higher horizontal [28], [29] and vertical [42] accuracies were reported in winter (leaf-off) compared to summer (leaf-on). Most of the previous studies concerning the effect of the seasons evaluated the effect of forest canopy in summer and winter as leaf-on and leaf-off periods [3], [10], [18], [27], [28], [35], [38]. This study evaluated the accuracy and precision of a consumer-grade GPS unit in road mapping, not only in summer and winter, but also in spring and autumn, as there is a lack of information about variations in accuracy and precision brought by the four seasons. In addition, the study explores the effect of averaging on accuracy enhancement.

2. Material and Methods

2.1. Study Area

The study area is located in the University of Tehran’s research forest station, a part of the Hyrcanian forest, which is located at approximately 36 ^{o} 38´ N (latitude) and 50^{o} 34´ E (longitude; Figure 1). Patom is the first district which has a 900-ha area and elevation ranges from 0 and 934 ma.s.l [1]. The average annual rainfall ranges between 1300 and 1500 mm and the mean air temperature is 16.1˚C [13]. In the area of study, the average stand volume is 290 m^3/ha, the dominant stand height is 25-30 meters, and forests are characterized, on average, by a 70% canopy cover and 263 stems/ha. The dominant tree species are *Carpinus betulus* L. (Hornbeam), *Fagus orientalis* Lipsky (Oriental Beech), and *Parrotia persica* (DC.) C.A. Mey (Persian Ironwood) [8]. The district has 12.2 km of unpaved permanent main forest road (Figure 1). The road network is mainly used for timber harvesting and ecotourism purposes.

2.2. Methods

A 12.2 km main road was selected from Patom district to evaluate the accuracy and precision of the GPS receiver (Figure 2). During the four seasons (spring, summer, autumn, and winter) and in three days (replications) for each season, the forest road was mapped using a Garmin-Colorado 300 consumer grade GPS in clear sky conditions. The GPS receiver was fastened to a stick and attached to a Pick-up truck. The truck had a steady speed of about 20 km and followed the center line of the road network. The height of the receiver was about 3.0 m from the ground. As a low cost, real-time, hand-held GPS receiver was used, neither post-processing nor observations conducted over a long time were required [33].

Fig. 1. *Location of the study area and the road taken into study*

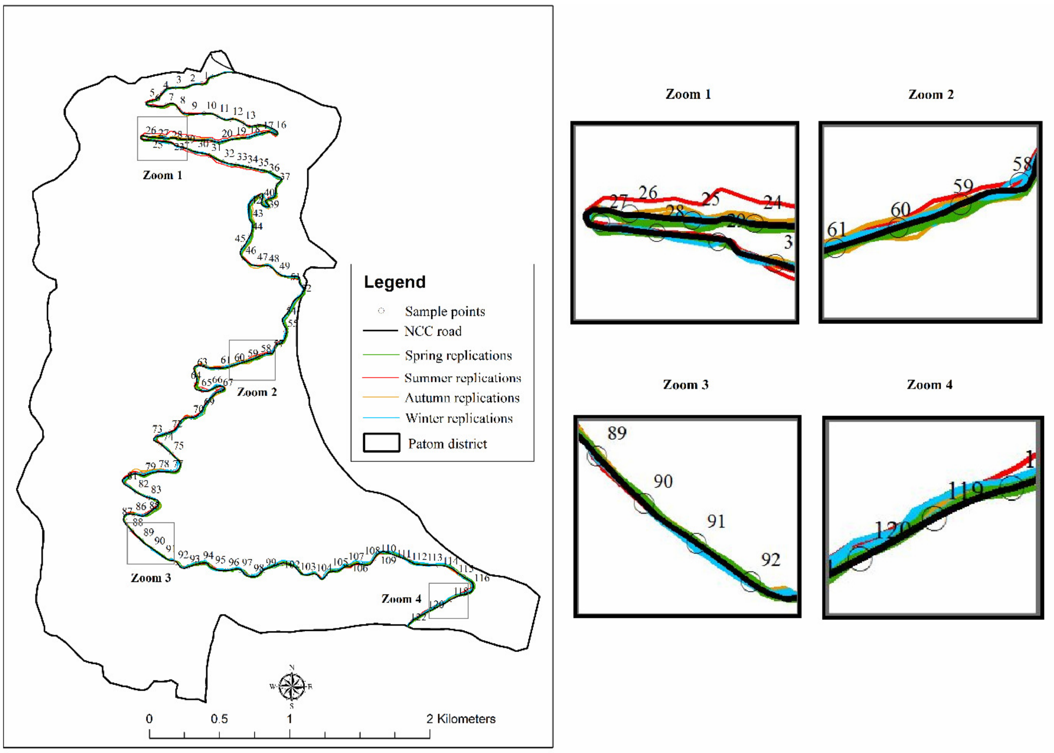

Fig. 2. *Location of the road taken into study and of the sampling plots within the study area*

To calculate accuracy, ground control points (GCPs) were needed, but there were none of this kind of spatial references in the study area. Therefore, a base map of the road network that was provided by the Iranian National Cartographic Center (NCC) in DGN format (CAD file formats supported by Bentley Systems' Micro Station) was used to get reference data for comparison. To select GCPs for accuracy and precision assessment, the NCC road network was divided into 100 m segments and control points were located in the middle of each segment [2]. This resulted in 122 control points spaced 100 m apart (Figure 2). A similar process was implemented to specify the corresponding points in the GPS-mapped road layers. All the mapping process was run in ArcGIS version 9.3. The *x* and *y* coordinates of the points were exported to Microsoft Office Excel 2007 for accuracy and precision assessment. Therefore 1464 (4 seasons × 3 replications × 122 sample points) positions were used in the process. The accuracy and precision were estimated using the following Equation [33]:

Horizontal accuracy:

$$\sigma_{H\_acc} = \sqrt{\left(\bar{E} - E_{true}\right)^2 + \left(\bar{N} - N_{true}\right)^2} \quad (1)$$

Where: (σ_{H_acc}) is the horizontal accuracy; $\bar{E}$ and $\bar{N}$ are the positions along the easting and northing of the GPS positions; E_{true} and N_{true} are the corresponding ground truth positions (positions extracted from the NCC map as GCPs) along the easting and northing.

The horizontal precision (σ_{H_pre}) represents the standard deviation of easting and northing measurements, and it is computed as the quadratic component of standard deviation for easting (σ_E) and for northing (σ_N) directions, according to Equations (2) to (4) [33].

$$\sigma_{H\_pre} = \sqrt{\sigma_E^2 + \sigma_N^2} \quad (2)$$

$$\sigma_E = \sqrt{\frac{\sum_{n-1}^{n}\left(E_i - \bar{E}\right)^2}{n-1}} \quad (3)$$

$$\sigma_N = \sqrt{\frac{\sum_{i-1}^{n}\left(N_i - \bar{N}\right)^2}{n-1}} \quad (4)$$

Where: *n* is the total number of sample points; E_i and N_i is the location of i^{th} point along easting and northing directions, respectively; $\bar{E}$ and $\bar{N}$ are the means of the measurements along easting and northing directions, respectively. The error and bias terms in the equations are expressed in meters.

Regarding the equations, it was better to use bias and error rather than accuracy and precision since the higher the equation values, the greater the bias and error and the lower (worse) the accuracy and precision [3]. Therefore, we used bias and error instead of accuracy and precision in the following sections. Because consumer grade GPS does not have the capability for post processing, point averaging is known as a useful way to decrease residual positional bias [35], therefore point averaging was used to evaluate the effect on GPS accuracy. In a quantitative analysis, two buffers of 5- and 10-meter width were placed around the NCC road network. Then the clip function of ArcGIS was used to assess the percentage of the road network length that was inside each buffer as specific to each treatment.

2.3. Data Analysis

A Kolmogorov-Smirnov test was used to check the normality of the data before proceeding with the analysis of variance. Where the normality assumption was violated, the data were log transformed prior to analysis to ensure a homogeneous residual variance. To determine whether there were any differences in accuracy (bias) and precision (error) due to the seasons, the data were subjected to a two-way analysis of variance. As each treatment had three replications, the effect of averaging on the resulted accuracy was also evaluated. By using ANOVA, we compared the lengths of each variant that surrounded the buffers.

3. Results

3.1. Precision

The variation of errors as specific to the seasons of data collection along the sample points is shown in Figure 3.

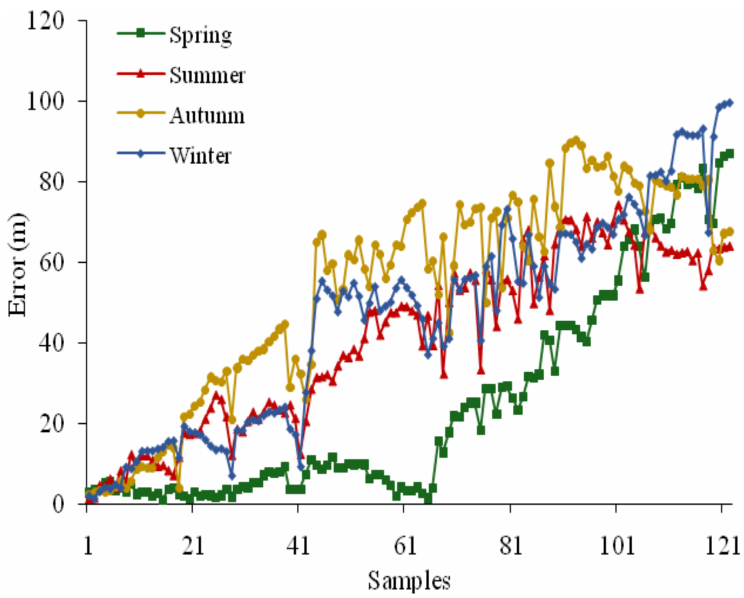

Fig. 3. *Variations of errors due to seasons (mean) and samples*

The range of variation was relatively high, from 1.05 to 99.73 meters. The results of ANOVA showed that there were statistically significant differences in precision due to season (F = 27.919, p < 0.001). The results of Duncan's test for multiple comparisons between seasons are shown in Table 1. As Table 1 shows, the best and worst precisions belonged to spring and autumn, respectively.

Table 1

Comparison of precision between seasons

Season	Mean ± Standard error
Spring	24.97±2.40[a]
Summer	41.02±1.96[b]
Autumn	53.65±2.37[c]
Winter	46.34±2.43[b]

Means with different letters are statistically different (p < 0.01)

3.2. Accuracy

The results of ANOVA revealed significant differences in accuracy among the seasons (F = 60.862, p < 0.001). Table 2 shows the results of Duncan's grouping test for accuracy as specific to each season. The results indicate that the best and worst accuracies belonged to spring and autumn, respectively.

Table 2

Comparison of accuracy between seasons

Season	Mean ± Standard error
Spring	24.45±1.26[a]
Summer	44.45±1.26[b]
Autumn	56.10±2.85[c]
Winter	40.45±1.02[b]

3.3. Effect of Averaging

The effect of averaging was evaluated by applying average accuracy values as specific to each season, instead of the three replications. Figure 4 shows the effect of averaging in variation of bias for each season. As shown, in all seasons, the bias tends to increase with increasing distance from the beginning point but when using the averaged positions this was not the case.

ANOVA conducted on averaged positions showed significant differences between seasons (F = 89.723, p < 0.001). The results of Duncan's test are summarized in Table 3. Regarding the mean bias values, the averaged positions improved accuracy by about 40, 16, 5 and 61% for spring, summer, autumn, and winter, respectively.

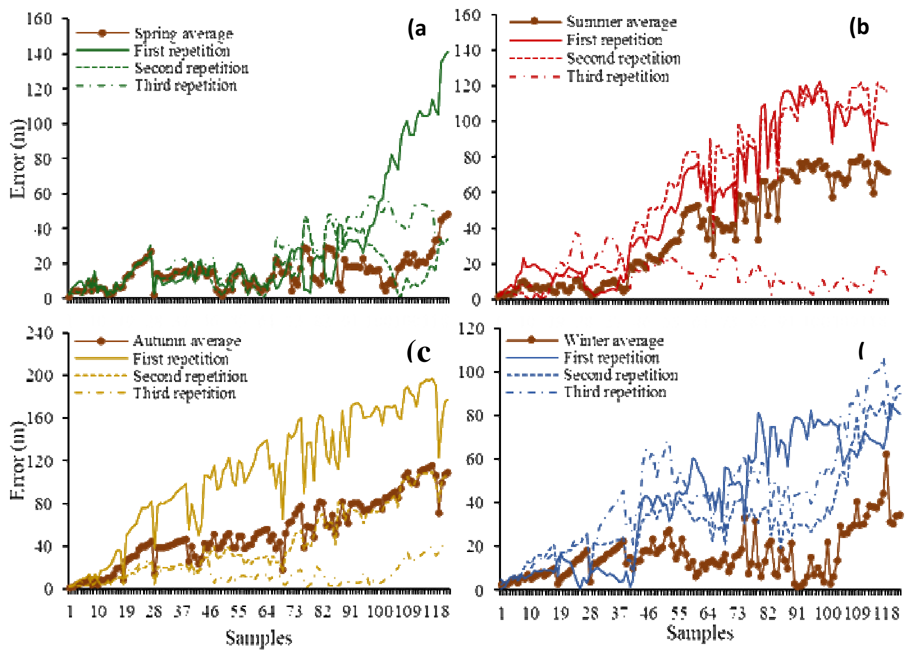

Fig. 4. *Effect of averaging on accuracy in (a) spring, (b) summer, (c) autumn, and (d) winter*

Table 3

Comparison of averaged accuracy between seasons

Season	Mean ± Standard error
Spring	14.65±1.26[a]
Summer	37.46±1.26[b]
Autumn	53.33±2.85[c]
Winter	15.85±1.02[a]

3.4. Buffer and Road Overlays

The results of ANOVA showed that there were no significant differences between the overlay lengths due to the seasons in both 5 (F = 1.262, p > 0.05) and 10 (F = 0.201, p > 0.05) meters buffer widths. The descriptive statistics of the overlay percentages are summarized in Table 4.

Descriptive statistics for overlay percentages in two applied buffers Table 4

	Spring (Mean±SD)	Summer (Mean±SD)	Autumn (Mean±SD)	Winter (Mean±SD)
Five m buffer	52±11%	59±6%	55±10%	65±3%
Ten m buffer	84±7%	85±9%	85±6%	88±3%

4. Discussion

There are many environments in which it is far from ideal to operate GPS units as a result of limited field of view and temporally unstable overstorey characteristics. Forests are a good example, with blocking overhead canopies (interference with and attenuation of the GPS signal). Under windy conditions, moving canopy components may cause multi-path effects [16], [35]. The effects of the seasons on the accuracy of positions in previous research [2] have been considered in summer and winter as leaf-on and leaf-off periods. Surprisingly, in this study, the best precision and accuracy was related to spring (Tables 1 and 2). Owari et al. [27] reported that the GPS error rate was less in winter than in summer, and this was related to the absence of crown canopy in winter. It seems that in addition to this canopy effect, other conditions affected GPS accuracy and precision in this study, such as the atmospheric condition [32], crown humidity, relative humidity, and ionosphere errors [36]. These factors limit the possibility of obtaining a good satellite geometry and the necessary GPS accuracy [19], [31]. Skone and Jong [36] related the effect of season on the accuracy of GPS receivers to the effect of ionosphere and its Total Electron Content (TEC). Also, Rizos [32] reported variations of TEC along the signal path, as a function of the season.

In this study, the accuracy of the GPS receiver in winter was better than in summer (Table 2), which is consistent with the findings of Owari et al. [27] and Sigrist et al. [35]. An improved accuracy in spring has not been reported in previous studies. The reason for this outcome may be the solar radiation, the electron content in the ionosphere layer [25] or the effect of tree trunks and air humidity (relative humidity). Olynik [25] reported the ionosphere errors as the error source with the largest changes over time. Attarod et al. [5], who conducted research in the same study area, reported maximum and minimum air humidity in autumn and spring, respectively.

Some previous studies proved the positive effect of position averaging on the accuracy improvement of mapping-grade GPS receivers [34], [35], [40]. The results of this study were consistent with the results of previous work, and showed that averaging positions stand for a useful and easy way to decrease residual positional errors even for hand-held GPS receivers. For example, a simple averaging of three replicates collected in spring improved the results by about 40% (Figure 4). Also, the highest positive effect was related to winter with an improvement of 60%.

The qualitative buffer analysis showed that the effect of the seasons on the overlay percentages was insignificant. In this analysis, we considered the linear nature of roads, instead of the control points, and more than 84% of road lengths were located in 10-meter buffers. Therefore, the GPS positions could be cost effective and suitable to map new road segments and skidding paths in forests.

5. Conclusion

This study evaluated the effect of the seasons on the consumer-grade GPS accuracy and precision in mapping forest roads. The results showed that, in the study area, the best and the worst accuracies and precisions of GPS receivers were related to spring and autumn, two seasons that have been neglected in previous studies. Therefore, there may be factors other than canopy cover that affect accuracy, such as ionosphere errors and air humidity. Simple averaging improved the accuracy and the highest effect was related to winter, with an improvement of 60%. If the accuracy requirements are moderate to low, then a consumer-grade GPS receiver may provide valuable positional data even under canopy conditions, and it is possible to use such units to collect the data needed for road planning and management systems.

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