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Comparing the Performances of Real-Time Kinematic GPS and a Handheld GPS Receiver under Forest Cover

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Abstract: In forestry, to facilitate re-finding, especially permanent sample plots or some sample points in forest inventory for control, precise position information is needed. Various techniques are used to increase the performance of basic GPS (Global Positioning System) measurements and to achieve more accurate positioning. These techniques are based on the principles of relative positioning, for which 2 or more receivers are used generally. For a forest inventory, the corrected coordinates should be provided in the field and at the moment of measurement. Therefore, real-time measurements are required. The cost of GPS receivers used for sensitive measurements through relative positioning techniques is fairly high. Before widespread usage, to determinate the efficiency of them according to simple GPS receivers will be useful. In this study, both a handheld GPS receiver and the “Kinematic on the Fly” (KOF) technique, a special form of kinematic method, were used to perform measurements at 9 sampling points individually, and the results were compared. Since obtaining the real coordinates of the points measured through KOF and the handheld GPS receiver was not possible, these measurements were compared with each other, not with the real coordinates. For this reason, the precision of the measurements was determined. Small differences among the repeating measurements were considered the indicator of precision. The results obtained by the kinematic method are more precise.

Key Words: Forest inventory, GPS, Differential GPS, KOF

Gerçek Zamanlı Kinematik GPS ile El GPS’inin Orman Örtüsü Altındaki Performanslarının Karşılaştırılması

Özet: Ormancılıkta özellikle sabit deneme alanlarının veya orman envanterinde kontrol amacıyla bazı ölçüm noktalarının tekrar bulunmasında kolaylık sağlayabilmek için yüksek doğrulukta konum bilgisi gerekmektedir. Basit GPS (Küresel Konum Belirleyici) ölçümlerinin performansını artırmak ve daha yüksek doğrulukta konumlama yapmak amacıyla çeşitli teknikler kullanılmaktadır. Bu teknikler genelde iki veya daha fazla alıcının kullanıldığı bağıl konumlama prensiplerine dayanmaktadır. Orman envanteri için; düzeltilmiş koordinatların arazide, ölçüm anında sağlanması gerekmektedir. Bu durum ölçümlerin gerçek zamanlı yapılmasını gerektirmektedir. Bağıl konumlama teknikleri ile hassas ölçüm yapmaya yarayan GPS aletlerinin maliyetleri yüksek olup yaygın olarak kullanımlarından önce el GPS’ine göre etkinliklerinin belirlenmesi yararlı olacaktır. Bu çalışmada 9 adet örnek noktanın her birinde hem el GPS’i hem de kinematik yöntemin özel bir şekli olan “Kinematic on the Fly” tekniği ile ölçümler yapılarak karşılaştırılmıştır. Her iki teknikle elde edilen koordinatları gerçek koordinatlarla karşılaştırmak mümkün olmadığından ölçümlerin tutarlılığı incelenmiştir. Her bir noktada yapılan tekrarlı ölçümler arasındaki farkın küçük oluşu tutarlılığın göstergesi olarak kabul edilmiştir. Kinematic teknikle daha tutarlı sonuçlar elde edilmiştir.

Anahtar Sözcükler: Orman envanteri, GPS, Diferansiyel GPS, KOF

Introduction

In Turkey, auxiliary tools such as compasses, ropes and aerial photographs have been used in order to find the locations of sampling areas during studies of forest inventories for many years. However, some difficulties and various errors may occur in this process due to land conditions, the tools used or subjective evaluations. Determining the centers of sampling areas accurately is generally very difficult in densely covered and sloping areas, where the reference point is difficult to determine exactly. In the same way, the lesser vegetation and mechanical obstructions can make walking and especially moving with the rope in the direction of the angle determined by compass very difficult. Moreover, finding

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the points again to check is a big problem. Therefore, attention must be given to utilizing the existing technological opportunities and introducing new inventory techniques to achieve the aims of forestry by working more rationally and efficiently.

Aksoy et al. states that as a result of being able to obtain accurate and reliable position information in a space-time system economically at any time and in any point of the world by using space and satellite technologies, many economical systems and methods have been developed and applied (Aksoy et al, 1999). Besides being developed for military purposes, the positioning devices – GPS (Global Positioning System) – play an important role in civil use and are expected to make a considerable contribution to studies of forestry. Using GPS for positioning has become prevalent in many sectors due to the advantages of the device, such as accuracy, speed, multi-purpose use and efficiency.

For positioning via GPS, 4 unknowns consisting of 3 parameters of position – latitude, longitude and height – and time error should be solved. To compute these 4 unknowns, at least 4 satellites should be monitored and the results of distance measurements of these satellites should be obtained.

Different techniques are used for positioning via GPS. Relative positioning techniques (techniques that necessitates at least 2 GPS receivers) are used for sensitive measurements. There is insufficient research about the usage of relative positioning techniques in forest inventory and especially in finding fixed sample plots. The research is generally related to the stands of only one tree species because of several factors affecting the accuracy of GPS. It is known that more accurate positioning can be obtained via relative positioning techniques than simple handheld GPS measurements in open area conditions. In the forest, conditions are different from those in open areas and there can be several factors affecting GPS signals and positioning in this way. It is stated that the error level of positioning in a stand consisting of coniferous species is higher than that in a stand of deciduous species and the relation is not completely clear (Holden et al., 2001a).

In order to determine the performance of DGPS (differential GPS), Holden and colleagues divided stands of Sitka spruce, selected from different regions with different heights, into 3 groups as stands without coverage, stands reached the first thinning period and old stands, and then performed measurements at 31 points. The study shows that in the areas without cover above 2 m, position can be determined with an error of approximately 1.5 m and in the areas with cover above, the accuracy varies from 2.6 to 2.8 m. As a result of a study conducted to determine the equipment and process method suitable for some forestry applications, the aim of which was to achieve an accuracy level below 2 m through DGPS, it was noted that 3-dimensional positioning can be interrupted throughout the study (due to an insufficient number of satellites), and this interruption occurs more often than the interruption of differential correction signals and has greater effect on the achieved accuracy level (Holden et al., 2001a).

As a result of a study conducted to associate forest cover and the corruption of the position information obtained through DGPS, again Holden et al. (2001b) determined that, in the event of a small coverage area (20%) between the satellites and the receivers, the performance of DGPS is as effective as in an open area, and a sparse cover causes 2 or 3 times greater corruption and a dense cover causes 5-7 times greater corruption.

We conducted a study using only a handheld GPS receiver in order to determine the performance of these devices under forest cover. In the measurements performed on different types of stands, the real coordinates were determined with an error of approximately 12 m (Zengin, 2003). This error can be neglected in a standard forest inventory but more precise solutions are needed for monitoring studies.

This study aimed to determine if the sensitivity of relative positioning with regard to the handheld GPS measurements is better or not under forest cover according to the measurements obtained in different stand types. The precision or consistency of the measurements, determined according to the differences between repeated measurements, was the performance criterion. In this way, it was aimed to obtain prior information about the usage of relative techniques especially in finding permanent sample plots.

Techniques for GPS Measurement

Different techniques are used for positioning via GPS. Based on the present receivers, the degree of required sensitivity, financing and time, users select one of or a combination of these methods. Generally the measurement methods are divided into 2 basic groups (Aykut, 2001): post-processing techniques, and real-time processing techniques.

Post-Processing Techniques

Post-processing techniques are used in applications that require high sensitivity, and in studies of triangulation densification. The measurements of phase L1 (1575MHz) and L2 (1227MHz) and code-phase C/A and P are recorded in the memory of the GPS receiver in the field and transferred to the computer in the office at the end of the measurement. The data are evaluated by suitable software and the coordinates are computed. Static, rapid static or kinematic measurement methods are used, depending on the type of the point measured and the sensitivity required (Aykut, 2001).

Real-Time Processing Techniques

The sensitivity of measurements changes according to the usage of codes or carrier phases during computations. Real-time GPS measurements can be classified into 2 kinds. The first is called the "sensitive kinematic GPS method" or "real-time kinematic GPS" when carrier phases are used. The second is the "differential GPS method" when codes are used (Eren and Uzel, 1995). The real-time kinematic GPS method is used generally in geodesy studies, which require sensitivity, and differential GPS is generally used for navigation purposes. Moreover, these methods are used for both post-processing and real-time processing.

Despite being acceptable, GPS system errors should be reduced in order to provide the accuracy required by some critical positioning processes. The diversity of the error sources makes their correction harder. The method required in the application is to measure and remove the errors not individually but as a whole (Hurn, 1993). In order to achieve this and perform positioning with a higher accuracy by increasing the performance of GPS, differential GPS (DGPS) is used. Most of the natural and artificial errors in the normal positioning can be removed by DGPS. When the major part of the measurement errors arises from factors excluding the receiver and at the same time relating to the existing environment, the success rate increases (Hurn, 1993).

The idea forming the basis of this method is that certain types of errors (satellite clock, atmosphere, multipath, etc.), affect the accuracy of the system in any area and this is valid for all users similarly (Ackroyd and Lorimer, 1994). When compared with the distances of satellites, the short distances traveled by the users are very short. Therefore, the signals arriving at the receivers will have the same delay times, if the receivers are too close to each other (a few hundred kilometers) (Hurn, 1993). At least 2 receivers operate simultaneously in the differential system. One of these receivers is installed at a reference point, the position of which is known accurately, and it computes the errors and sends the corrections to other receivers within the area (Luke, 1997).

The fixed receiver at the reference point, the position of which is known, receives the same signals as the mobile receivers but does not operate in the same way and begins computing from the end. Instead of using time signals to compute the position, it uses its known position to compute timing (Hurn, 1993). After the errors are determined, the corrections should be transferred within a short time in order to increase the positioning accuracy of the other mobile receivers. To prevent losing accuracy, the correction data should be rapidly transferred in real-time. The reason for this is the continuous change in errors of signals due to the changing atmospheric conditions. Therefore, as the time of data transfer extends, the applicability of the corrections decreases. Determining the positions of mobile receivers accurately depends on many factors, as listed below (Şahin et al., 1997):

- The distance between the fixed and the mobile receivers
- Algorithm method of differential corrections
- Movement speed of mobile receivers
- Method of processing the solutions by software
- Tools used in data transfer and the speed of data transfer
- The number of fixed stations, where the corrections are computed
- Satellite geometry

The real-time kinematic (or RTK) GPS method is a special form of differential GPS and is implemented by using carrier phases instead of codes. Every carrier phase observation is a differential technique, which requires reference and mobile receivers tracking the carrier phases simultaneously. In this technique, the receivers should be located close to each other to make the ionospheric delay differences lower than a carrier wave in order to determine the accurate number of carrier waves in the reference and mobile receivers. This generally requires the distance between the reference and mobile receivers not to exceed 30 km in the measurements of carrier phases (Dana, 1999).

Materials and Methods

The study was conducted in Hacıosman Forest, Sarıyer, using 1 GARMIN 12XL handheld GPS receiver and measuring by the differential method, 2 SR 530 Leica 500 Series real-time GPS receivers. The study area, in the Thracian part of the Marmara region, is located at Eastern longitudes of 29° 01' 25" - 29° 02' 53" and Northern latitudes of 41° 07' 23" - 41° 08' 29".

In Hacıosman Forest there are different stands of tree species, which have grown up naturally or been artificially generated. The major tree species, which belong to the conifers, are Pinus nigra, Pinus brutia, Pinus maritima, Pinus pinea, Pinus sylvestris and Cupressus sempervirens. The stands of deciduous trees consist of Robinia pseudoacacia, Quercus spp., Carpinus spp., Alnus spp. Populus spp. and Acer spp. The shrub and bush species existing in the area are the major species that are included in maquis, such as Arbutus unedo, Erica spp., Quercus coccifera and Phillyrea latifolia.

The accuracy requirements of GPS depend on the objective of the related study and range from millimeters to hundreds of meters. Most users are concerned with the real-time accuracy to meter level. This level can be achieved by differential GPS. In order to obtain accuracy in meters, code lengths with corrected phase and high-performance C/A code receivers must be used. Higher accuracy may be achieved by using carrier phases. At distances within 20 km radius of the ground station, real-time accuracy can be obtained at millimeter level. In order to reach this accuracy level, the ambiguities should be resolved through the method of “on the fly” by using double-frequency receivers (Hoffmann et al., 1997). Various techniques are used in order to increase the performances of basic GPS measurements and carry out positioning with higher accuracy. These techniques are based on the principles of relative positioning. In this study, both a handheld GPS receiver and the kinematic on the fly (KOF) method were used for the measurements at 9 points representing different stands. KOF is a different form of kinematic method and is used in studies that require sensitivity.

The closure of the sample points, the locations of which were chosen consciously within the stand, is 70%-100%. Other stand parameters in these points are displayed at Table 1.

These points were selected on a certain alignment, determined through the map of stand types, so that these points represent different types of stands and facilitate the measurements to be performed by repeating 3 times. The number of these points could not be increased and only 2 measurements were performed at the ninth point due to the difficulties experienced in supplying the receivers used for the determination of the real-time

Table 1. The characteristics of stand types represented by the points, which are measured by handheld GPS receiver and KOF.

Point No.	Tree species	Mean diameter (cm)	Mean height (m)
1	Poplar	38	18.8
2	Stone pine	29	10.1
3	Ash	17	13
4	Hornbeam	19	13.7
5	Torch pine	20	10
6	Calabrian pine	15	8.6
7	Torch pine	15	8
8	Stone pine	20	8
9	Alder	38	28

coordinates with the KOF technique and due to the restricting time factor.

The DGPS or RTK method is used in the computation of real-time coordination. RTK is a special form of DGPS and carrier phases are used in this method (Spilker, 1996a). In this method, one of the receivers is installed in a location known and, on the basis of this location, it computes and transfers the errors in the GPS measurements to the mobile receivers for providing these receivers with the corrected values. Various methods are used in order to send the differential corrections from the reference receiver to the mobile one and to carry out real-time measurements. Generally, a radio connection is used for this purpose. In this study, a radio modem was used to transfer the corrected data. Under normal conditions, the distance in the real-time measurement method is approximately 10 km. However, it varies depending on the service area of the modem. In the event of long-bases, when the radio modem device is insufficient, a GSM connection may be used.

The KOF technique used in this study removes the requirement for re-initialization, in the event that the number of satellites is below 4 due to any reason both in the initial part and during the realization of measurements. During the measurement, after losing the connection with the satellites due to various obstacles like the coverage of the trees when walking under them, the system will reinitialize automatically once the satellites can be seen again (Leica, 2002). The kinematic method requires waiting for a longer time than the subsequent measurements in order to remove the integral indefiniteness in the first point, where the measurements begin. Then the measurement continues and the connection is kept with a minimum of 4 satellites throughout the measurement.

The reference receiver to provide the corrections was installed in an open area without any obstacles and various connections such as an antenna and terminal were made. The location of the reference point must be well known. As no previous measurement had been performed in the study area, the reference point was determined by single-point positioning (SPP). By this method, GPS measurements performed for a specific period are collected and evaluated and more accurate coordinates than the measurements during the survey are obtained. When point coordinates, which have been determined by GPS measurements or any other method, cannot be obtained and the distances of the receivers are within a limit of 10 km, the location of the reference point is determined by the above-mentioned method. SPP is suitable for usage in the first stage of a study (Leica, 2002).

As for environment features, the receivers under the forest cover have different conditions from the receivers in the air, sea or open areas. The signals of satellites may be weakened or completely blocked by trees and leaves. The best GDOP (Geometric Dilution of Precision) values are provided when the many GPS satellites are located at a low angle, almost horizontal. However, the extension in the coverage area of shadowing in such a position increases the blocking effect of objects. With regard to the weakening effects of trees on signals, it is stated that the stems and branches have a greater effect than the leaves, conifers have a greater effect than deciduous trees, and deciduous trees with leaves have a greater effect than trees that have shed their leaves. It is also reported that the species and height of the trees have a weakening effect on the signals but the relation between them is not specified (Spilker, 1996b; Holden et al., 2001) and there are some ambiguities (Tucek and Ligos, 2002).

Local coordinates or the coordinates in the maps of a country are based on a local ellipsoid so as to fit the GEOIDE in that region. These coordinates are generally reflected onto a flat surface to provide the grid coordinates. Each country has an identified map system or a reference network based on a local ellipsoid. Local coordinate systems only identify the region in which they are located. They do not match other regions in the world (Leica, 2002).

As the existing coordinates are generally in the local system, while the coordinates computed with GPS are based on the ellipsoid WGS 84, a transformation should be done between these coordinates. Many different methods are used for transforming coordinates. The method is selected according to the sensitivity requirement (Leica, 2002). WGS 84 coordinates obtained through the KOF method are saved on a PCMCIA card in the field, and the data are transformed to computer by installing the card into the card reader in the office. Local coordinates are obtained through 3-dimensional Helmert Transformation by the help of parameters computed previously by İstanbul Technical University Faculty of Civil Engineering, Department of Geodesy and Photogrammetry Engineering.

By adjusting the initial settlement of the GPS receiver, coordinates in the local system (ED 50 Datum) could be obtained. To be able to make a comparison with the measurements obtained by the KOF technique, handheld GPS positioning were used also in the WGS 84 system. To make an evaluation on a common coordinate system, GPS coordinates were transformed to the coordinate system of existing stand type map. In order to transform the coordinates obtained through the handheld GPS receiver, the coordinate transformation program on the web page http://www.rncelik.cjb.net (Kurt, 2002) was referred to. Firstly, WGS 84 geographical coordinates were transformed into ED 50 geographical coordinates via the Datum Transformation Program on the page. Then the local coordinate system was applied by transforming these geographical coordinates obtained in the datum of ED 50 into 3-section degree UTM coordinates.

Since obtaining the real coordinates of the points measured through KOF and the handheld GPS receiver was not possible, these measurements are compared with each other, and not with the real coordinates. For this reason instead of both precision and accuracy only the precision of the measurements was calculated and compared. Precision refers to the closeness of repeated measurements to the sample mean, while accuracy refers to the closeness of the sample mean to the true value. Precision and accuracy are briefly explained in Figure 1.

As described in Yoshimura and Hasegawa (2003), precision was calculated and compared using the root mean square (RMS), which is calculated by the following equation:

$$\sigma_{precision} = \sqrt{\sigma_r^2 + \sigma_u^2}$$

where $\sigma_{precision}$ indicates RMS; and σ_r and σ_u indicate the standard deviation of the positional error along the right and upwards coordinates, respectively.

Results

Samples are matched, a t test is applied and whether there is a significant difference between them in 95% accuracy is tested (Table 2). At the end of the analysis, the significance level (P) is found less than 0.05 for the right and upward values and the measurement values are regarded as unequal; in other words, there is a significant difference between both measurements.

Upon entering the values obtained by coordinate transformation into the computer, the relative positions of repeated measurement results according to each other are displayed on the screen and then the distances between them are measured to obtain the distance between the positions determined by the repeated measurements performed at a point. The relative positions of the results obtained at the points where the measurements are performed by KOF and handheld GPS receiver are displayed in Figure 2, and the distances between these positions are shown in Table 3.

As the measurements could not be compared with the real values, the accuracy is not known. Nevertheless, Figure 2 and Table 3 show that the differences between the repeated measurements are lower and more precise in the KOF method. A small difference between the measurements is assumed as the criterion of precision. As a result of the measurements performed in different stand types, the arithmetic mean of differences among the repeated KOF measurements is 5.24 m while it is 9.34 m among the handheld GPS measurements.

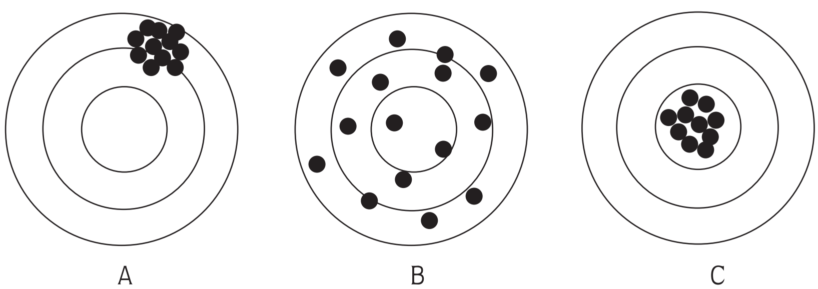

Figure 1. Precision and accuracy. A high precision and low accuracy, B low precision and high accuracy, C high precision and high accuracy (Yoshimura and Hasegawa, 2003).

Table 2. Comparison of KOF and handheld GPS measurements.

Paired values	Paired differences (m)				
	Sample size	Average	Standard deviation	Standard error mean	Significance level (P)
KOF (right) – Handheld GPS (right)	26	34.80	5.64	1.11	0.00
KOF (upwards) – Handheld GPS (upwards)		186.26	6.80	1.33	0.00

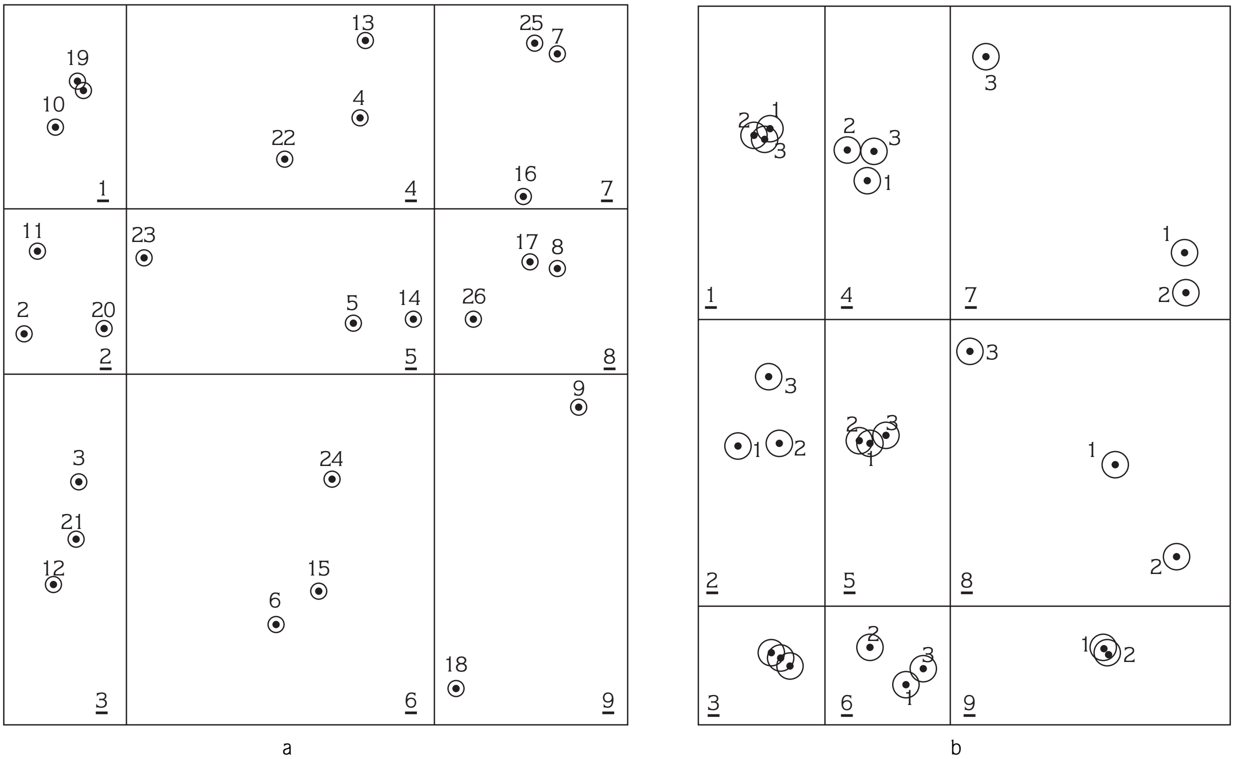

Figure 2. Relative positions of the coordinates according to each other.
a) Coordinates obtained by handheld GPS receiver.
b) Coordinates obtained by KOF.

The minimum distance obtained in the measurements performed with the handheld GPS receiver is at the first point (poplar). The maximum distance obtained by this method existed at the fifth and ninth points (torch pine and alder). At the same point the minimum distance is obtained by the KOF technique. However, differences between measurements at the seventh and eighth points (torch pine and stone pine) show the highest values for the KOF method but value of difference is below 2 m for the average of the other points.

Generally, larger precision errors occurred in coniferous stands than in deciduous ones for both the handheld GPS and KOF technique. At every point of the deciduous stands precision errors are nearly the same for handheld GPS, but there is ambiguity for coniferous stands. For handheld GPS the precision errors at some points (seventh and eighth points) are different from each other while the parameters of the stands are nearly the same. The same situation is also true for KOF measurements. While the precision errors are similar for deciduous stands there is no regularity among the precision errors of the coniferous stands. Excluding 2 points (7 and 8) in 2 coniferous stands the precision errors of the KOF technique are very small in comparison

Table 3. Distances between the coordinates measured by handheld GPS receiver and KOF.

			Distance (m)					Distance (m)	
Point No.	Stand	Measurement No.	Handheld GPS	KOF	Point No.	Stand	Measurement No	Handheld GPS	KOF
		1-2	4.123	1.068			1-2	5.830	0.790
		1-3	1.000	0.614			1-3	21.260	1.327
1	Poplar	2-3	4.472	0.828	5	Torch pine	2-3	26.870	2.042
		Mean	3,198	0,837			Mean	17,987	1,386
		Precision error (m)	3.564	0.615			Precision error (m)	13.853	1.041
		1-2	7.071	5.513			1-2	5.000	3.802
		1-3	8.062	2.960			1-3	13.038	1.796
2	Stone pine	2-3	9.220	4.946	6	Calabrian pine	2-3	9.220	4.287
		Mean	8,118	4,473			Mean	9,086	3,295
		Precision error (m)	6.021	3.268			Precision error (m)	6.316	2.447
		1-2	9.220	0.958			1-2	12.042	3.068
		1-3	5.000	1.833			1-3	2.240	20.562
3	Ash	2-3	4.472	0.921	7	Torch pine	2-3	12.806	22.883
		Mean	6,231	1,237			Mean	9,029	15,504
		Precision error (m)	5.515	0.926			Precision error (m)	2.937	12.624
		1-2	6.403	2.694			1-2	2.828	8.077
		1-3	8.062	2.059			1-3	9.055	13.849
4	Hornbeam	2-3	12.649	1.860	8	Stone pine	2-3	7.071	21.709
		Mean	9,038	2,204			Mean	6,318	14,545
							Precision error (m)	6.836	11.014
		Precision error (m)	6.595	1.580	9	Alder	1-2	26.420	0.527
							Precision error (m)	6.548	0.383

with handheld GPS measurements. The average of precision errors for KOF is 3.8 m while it is 6.5 m for handheld GPS. The mean distance difference between the measurements is about 1.2 m for KOF while it is 11.22 m for handheld GPS. Generally, in comparison to handheld GPS measurements the precision of KOF is more explicit in deciduous stands than in coniferous ones.

Discussion and Conclusion

Regarding the usage of GPS for the purpose of inventory in various fields such as finding sample plots, determining the alignments of forest roads and the borders of the areas with different characteristics, forest fire management and tracing forest vehicles, studies are conducted by various measurement techniques (Holden et al., 2001a; Yeşil, 2004). In this study, measurements were obtained by both handheld GPS receiver and KOF technique in various stand types and the results are compared in order to propose the usage of relative positioning techniques especially for finding permanent sampling points for monitoring.

For forest inventory, the corrected coordinates should be provided in the field, at the moment of measurement. Therefore, the appropriate method for this purpose is the real-time kinematic method, which gives better position information than handheld GPS receivers in open area conditions. To use this method and the receivers in monitoring applications of forest inventory, its efficiency must be determined. For this aim, KOF and handheld GPS measurements were obtained at the same points for comparison. However, as they could not be compared with real coordinates, measurements performed at the same point by KOF and by handheld GPS receiver were matched with each other and compared. At the end of the analysis, the distance between them was found significant. Through KOF measurements, more precise results (smaller differences between the repeated measurements) are obtained. In the deciduous stands the consistency of this method was very high but it was ambiguous in coniferous stands.

There are several studies about the accuracy of GPS under forest canopy but most of these have ambiguous conclusions. Janeau et al. (2004) found no negative effect of leaf presence, while Sigrist et al. (1999) reported that the presence of the foliage itself plays a major role in the signal reception and positional accuracy. Tucek and Ligos (2002) found that the error is higher under the stand canopy with Magellan and March receivers, which is consistent with logical expectations, but, unlike these, higher errors occurred with a Topcon receiver in an open area. According to Tucek and Ligos (2002), the results of their experiment do not confirm the greater influence of deciduous tree species composition and terrain configuration reported in the literature. In this study we obtained more precise measurements in deciduous stands with both handheld GPS and KOF. Moreover, the precision errors are smaller with KOF in deciduous and tall stands in comparison with handheld GPS. It is thought that terrain conditions or multipath errors were the reason for the unexpected results at the points where the precision of KOF was lower.

Yoshimura and Hasegawa (2003) obtained measurements to determine the horizontal and vertical errors of GPS positioning. They found that the DGPS, which was known to be very effective in reducing positional errors before SA (Selective Availability) was turned off, did not improve horizontal precision but did improve horizontal accuracy. Therefore, they propose to use autonomous GPS for purposes in which horizontal positional errors of maximum 10 m are allowable and to use DGPS when higher accuracy is necessary. In contrast to Yoshimura and Hasegawa (2003), the results of our study show that the KOF technique improved the horizontal precision, especially in deciduous stands.

In Turkey for current forest inventory 1:25,000 scaled topographic maps are used. Sampling points are first established on this map and then found in the field. On these maps 1 mm represents a 25 m actual distance. Therefore, a 1 mm mistake, which is only equal to the thickness of a line, can cause 25 m of distance error in the field. As emphasized before, with about 10 m (Yoshimura and Hasegawa, 2003; Zengin, 2003) average of error, position determination with handheld GPS is possible under forest cover. With this measurement handheld GPS can be seen as sufficient for current forest inventory work. However, in some forestry applications like finding permanent sample plots (monitoring), more sensitive positioning information is required. Precision of the results obtained through KOF is higher than that of the results of the handheld GPS receiver. However, this does not mean that its performance is good enough for monitoring applications.

Like satellite clocks and geometry, atmosphere, attributes of receivers and environment characteristics, there are many factors influencing positioning accuracy. It is possible to remove most of the errors by relative positioning techniques like KOF. Both the sampling technique and the sample size applied in this study are not sufficient to clearly determine the performance of the KOF technique under forest canopy. The results obtained are useful to give prior information in order to realize more complex and expanded research. From the environmental aspect, forests show a great variance. Topography and stand structures affect the GPS signals in different ways. To perform separate studies for different species, closure, density, height, age etc. parameters of a stand or developing models using relations between position accuracy and branch or leaf characteristics of trees or size of the gaps between the crowns to ensure general results will be more useful. Instead of only precision, examination of both the precision and accuracy of the techniques is needed for exact determination of the performance of the GPS.

There are other navigation systems like LORAN-C (Long-Range Navigation System), INS (Inertial Navigation System) and GLONASS (Global Navigation Satellite System). Integration of these systems with GPS, which is thought to increase the quality of positioning, is being proposed. The real-time receivers used in the KOF method, which provides real-time measurements, are expensive tools. However, with the improving technology, an increase in positioning quality along with a cost decrease is expected. Performing detailed research while waiting for improvements in technology may be better for the widespread usage of these receivers in forest inventory in terms of cost and practical usage.

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