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AN ALTERNATIVE METHOD FOR POINT POSITIONING IN THE FORESTED AREAS

ALTERNATIVNA METODA ZA APSOLUTNO ODREĐIVANJE POLOŽAJA TOČKE U ŠUMSKOM PODRUČJU

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Summary

Global Navigation Satellite Systems (GNSS) consist of satellite technologies such as GPS, GLONASS, BeiDou and Galileo. These technologies have effectively been used in many application areas. GNSS Continuously Operating Reference Stations (CORS) have also been applied successfully in many areas of forested industry. Typical applications include fire prevention and control, harvesting operations, insect infestation, boundary determination, and aerial spraying. Forest and natural resource applications can be achieved efficiently employing GNSS/CORS data collection technologies. However, there are limiting factors in the environment, such as the forest canopy, which has adverse effects on the reception of GNSS signals. In terms of saving time, Point Positioning with GNSS/CORS in forested areas is a significant challenge in the acquisition of highly accurate coordinates of points. The time for integer carrier-phase ambiguity solution takes approximately one-hour or more for point positioning under forested areas with GNSS/CORS. In this study, an alternative method for providing point coordinates under a forested area is proposed. This method gives the positioning results with centimeter level accuracy and nearly 15 minutes are required to provide the new point location in the forested area. The method proposed may also be of practical use in indoor applications with desired accuracy at cm level, which is reached in a short observation time. In this study, we conducted fieldwork to achieve coordinates of the point in a forested area with GNSS/CORS system and supplementary measurements by establishing two control points observed by GNSS/CORS located at the border of the forested area. The result shows that a satisfactory solution for forested area is reached at cm level (≈ ± 6 cm) in a short observation time.

KEY WORDS: GNSS, CORS, VRS, Accuracy, Forested Areas

1. INTRODUCTION AND RESEARCH PROBLEMS
UVOD I PROBLEMI ISTRAŽIVANJA

The forestry industry with its wide range of application areas and services has widely applied satellite-based technology and has benefited from GNSS. The key elements in the forest industry include various services and typical applications, such as the protection and efficient utilization of forests, forest road planning, supervision of the development of forest lands, detection of shanty settlements, depredation and destruction of forests, protection against or putting out of fires, making inventories, planning forests, harvesting operations, insect infestation, boundary determination, and aerial spraying. Among them, forest fires have a destructive effect on ecological life of the nations and cause irreparable damage. Accordingly, they should be monitored with an efficient system and protection planning

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strategies should be prepared beforehand. At this point, GNSS brings a key technology tool that helps the system operator to identify and monitor the exact location of the resource. Moreover, an integrated system, combined with a geographic information system (GIS) and GNSS, enables decision makers of the authorities to make appropriate decisions. Developments in the surveying technology provide the determination of information before harvesting operations are completed, unlike past years in which aerial photography was the only source of extracting the shape and location of wide blocks. The past technology was not so accurate. Today, GNSS makes it possible to acquire accurate information in real time. The required accuracy can be easily met with the use of the GNSS technology, which also makes it possible to determine the accurate locations where needed (Hoffmann-Wellenhof et al., 2008; El-Rabbany, 2006; Wolf, 2002; Pirti, 2005; Pirti, 2008; Pirti, 2010; Pirti, 2013; Bakula, 2013; Brach, 2014).

To provide sustainable management for forest life protection, an accurate forest boundary determination is of outstanding importance. In this concept, real time GNSS presents a good alternative which reduces the survey cost and duration by up to 75 percent of a project schedule and budget. However, there are some restrictions when surveying with GNSS, which are caused by the forest canopy. The heterogeneous pattern of the forest canopy, which differs from place to place, limits, disturbs or totally blocks the survey quality. For example, under heavy forested areas, GNSS receivers lose connection with GNSS satellites. Thus, the quality of GNSS survey under the forested area is determined by the type of forest canopy, which is directly related to a complete or partial signal blockage received from the satellites, where a significant role is placed by the leaves. The species and density of canopy leaves are in strong correlation between the signal quality and accuracy. As the canopy density increases, the received signal decreases. The same effect on signals occurs in terms of water percentage of canopy type or moisture. Species with higher water content have bigger obstruction reception. The pattern of the canopy behaves as a physical reflection surface for the signals. This reduces the number of visible satellite, which affects the accuracy of GNSS positions. The structure of the GNSS signal is line-of-sight, affected by solid objects around (Parkinson, 1996; El-Rabbany, 2006; Pirti, 2005; Pirti, 2008; Pirti, 2010; Pirti, 2013; Bakula, 2013; Brach, 2014). However, improvements on these obstructions can also provide users with a wide range of application facilities in forested areas, which helps making an agreement with authorities who avoid using GNSS under heavy forest canopy due to lack of accuracy. Moreover, Dilution of Precision (DOP) value is a significant indicator on the GNSS position accuracy. The Dilution of Precision indicates the accuracy that has a reverse effect between these two descriptions. Lower satellite visibility results in an increase in the DOP value and causes inaccurate position computation. Thus, the duration of observation should be prolonged in order to get more satellite signals and avoid worse satellite geometry. In certain conditions during a survey, the DOP does not allow a constant solution in the same day. Moreover, signal attenuation and multipath effect may also induce degradation of accuracy (Wolf, 2002; Parkinson, 1996; El-Rabbany, 2006; Pirti, 2005; Pirti, 2008; Pirti, 2010; Pirti, 2013; Bakula, 2013; Brach, 2014).

2. METHODS USED IN SURVEYING
METODE KORIŠTENE U SNIMANJU

2.1 Traditional Technique: Point Positioning with Total Station – *Pozicioniranje točaka pomoću totalne stanice*

Total stations (TS) are electro-optic surveying systems, which have been used for many years in geodetic precise positioning applications. Generally, TSs have been developed to survey short ranges (approx. 2-3 km). In geodetic metrology, there have been several total stations with different features for determination of precise coordinates in terms of applications based on surveying distances and angles. Some of this equipment, whose distance and angle surveying accuracies are different to each other, have the ability of operating without reflectors.

Although they allow surveying either in open-air areas or in urban, forested and indoor areas, these systems have some disadvantages. For instance, the requirement of direct line of sight, survey at daylight, bad weather conditions may be listed. In any case, total stations, which are currently still effectively used to determine precise point positioning for several engineering applications, are also often used for precise terrestrial surveying applications under forested areas (Pirti, 2005), (Wolf, 2002).

2.2 GPS/GNSS Technique – *GPS/GNSS tehnologija*

Global Positioning System (GPS), originally developed by the USA, is a system of positioning, navigation and timing, which has been commonly used by several disciplines for different applications over the last three decades. Today, GNSS consists of satellite technologies: GPS (USA), GLONASS (Russia), BeiDou (Chinia) and Galileo (EU) are used as a common abbreviation of space and satellite based positioning. In fact, these systems which enable a new manner to positioning and which are related to survey and navigation applications, have become effectively used for many services such as land management, environmental and urban planning, land use and agricultural policy, monitoring the global climate change, engineering and infrastructure services, evaluation and protection of forests and natural resources, multipurpose cadastre, e-government and personal mobile applications (Ocalan and Tunalioglu, 2010; Ocalan et al. 2013).

GNSS works 24 hours a day, in any weather conditions, anywhere in the world, and provides precise positioning information where satellite visibility is available. Although there have been some surveying constrains originated from limited satellite visibility and signal interruptions, position information with different accuracy levels may be achieved in terms of GNSS survey methods used. In GNSS technology, traditionally relative and differential positioning methods are used to achieve precise positions (Rizos, 2012; Alkan, 2013; Ocalan, 2015).

In all GNSS techniques based on relative and differential positioning principle, simultaneous observations made from one or more reference stations with known coordinates are required. In other words, simultaneous observations should be made with at least two GNSS receivers: one should occupy a reference station whose coordinates are known, and the other should be established at a point whose coordinates will be estimated. Several criteria, such as the preferred survey mode (static or kinematic), observation time, the equipment used, signals and codes, data processing algorithms, infrastructure of the reference receiver/s, satellite-receiver geometry, post-processing evaluation or real time applications, provide different level accuracies for positioning (Hoffmann-Wellenhof et al., 2008; Rizos, 2012).

For instance, while in differential GNSS (DGNSS) technique, where single-frequency code (pseudorange) observations are used, decimetre level positioning accuracy can be achieved, in real time kinematic (RTK) techniques, where dual/multi-frequency carrier phase observations are used, centimetre level positioning accuracy can be derived. From this aspect, single-base RTK and Network-RTK techniques have become indispensable for users in real time geodetic studies (Rizos, 2012).

This situation has enabled the establishment of so-called CORS networks by several governments, organizations and companies to support RTK users, and the development of different mathematical correction models of Network-RTK technique. In developed and developing countries, widespread use of these networks provides significant contributions and advantages to all RTK users in terms of criteria such as time, cost and accuracy. Bringing a new concept to GNSS applications, CORS networks, which broadcast the correction data to all users in real time by data transmission and communication equipment, have been generally operated at national or local scale. Today, this technique which handles mathematical correction models such as VRS (Virtual Reference Station), MAC (Master Auxiliary Concept) and FKP (Flächen-Korrektur-Parameter) and then estimates high-accurate positioning information (centimetre-level), can provide solutions under the forested area as well (Ocalan and Tunalioglu, 2010; Rizos, 2012).

However, in some geodetic and geodynamic studies, deformation analysis where millimetre level accuracy is needed the post-processing static GNSS relative survey method is still applied.

2.2.1 Virtual Reference Station (VRS) Model – *Virtualna referentna stanica (VRS)*

Using CORS for real time kinematic applications, one of the correction models, namely VRS technique, uses a complex filter state model to determine virtual reference station dataset which is located near the rover (Hoffmann-Wellenhof et al., 2008; Wübbena, 2001; Wanninger, 2003). It has become a common procedure in which more than 95 % of the Network-RTK installations use this technique to transmit the correction stream in standardized formats RTCM 2.3, RTCM 3.0, RTCM3.1 or CMR/CMR+ from the server to the field user that is supported by all geodetic receiver manufacturers (Landau, 2003). Moreover, the VRS technique uses the latest model for all error sources that can continuously adjust the correction transition for each rover position (Cannon, 2001; Landau, 2002). In every second the correction values are updated, then connection to the system by a rover provides immediate product transmission after connection. After connection, bidirectional communication should be enhanced by the VRS method, which can be supported by GSM, GPRS and cell phone-based data transmission methods (Wanninger, 2002; Retscher, 2002). Nowadays, bidirectional communication is used worldwide by users with a ratio of more than 99 % in Network-RTK installations for accessing and user accounting.

3. MATERIALS AND METHODS
MATERIJALI I METODE

3.1 Study Environment – *Područje istraživanja*

We established four temporary test stations to compute the coordinates of the point under the forested area, located at the Yildiz Technical University, Campus of Davutpaşa, Istanbul, Turkey. The characteristic property of the area of interest is that it is located at the border of the forested area and open sky. GNSS receiver observations made in forestry are affected by data distortion and signal losses and this negatively affects precision and accuracy measurements. To avoid this, RTK GNSS surveys have been conducted at the open area side of the border aimed at providing observations accurately to enhance the communications of the GNSS receiver with satellites from two points. In addition, terrestrial surveys have been conducted simultaneously by using the other two points. The point whose coordinates are being calculated was established at the forested area side, and terrestrial surveys and static GNSS surveys were also con-

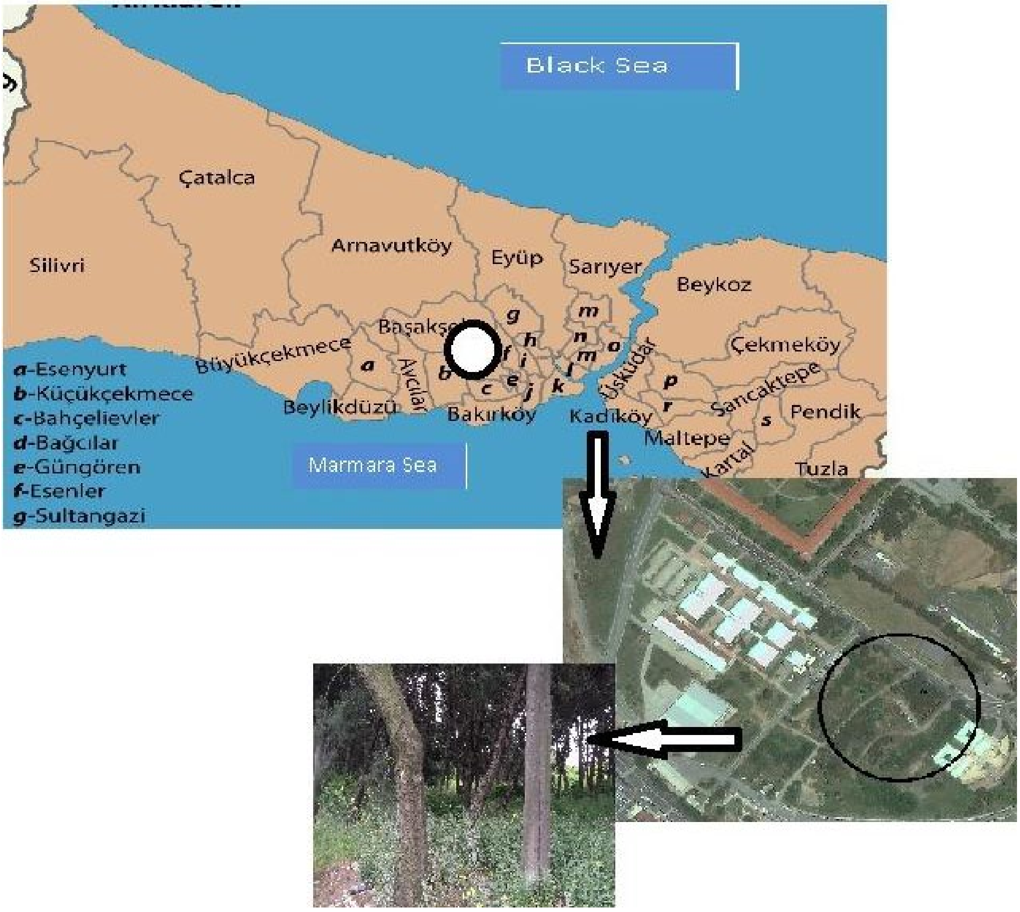

Figure 1 Project Area and Study Environment

Slika 1. Projektno područje i područje istraživanja

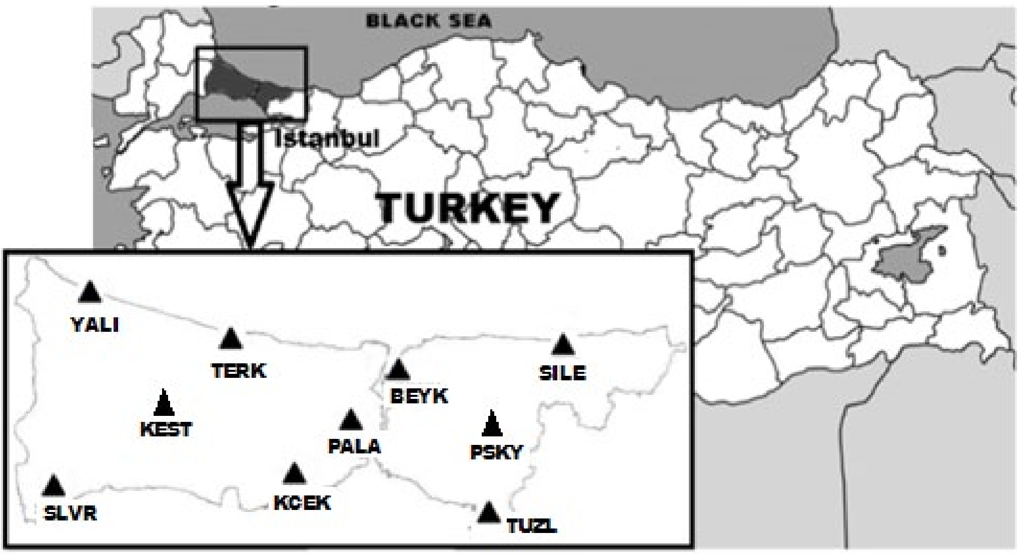

Figure 2 ISKI-CORS Network Stations (Ocalan et al., 2013)

Slika 2. ISKI-CORS mrežne stanice

ducted. The study environment selected in the forested area is presented in Figure 1.

In this study, static GNSS observations were evaluated with post-processing computation based on ISKI-CORS network, which covers the study area. Real-time VRS correction data were also obtained from this network, where RTK surveys were implemented on the indicated points. As mentioned above, the local GNSS network, called ISKI-CORS Network, whose coverage area is İstanbul, was established by Istanbul Water and Sewerage Administration (ISKI) and involves 10 permanent stations. The ISKI-CORS network is an active GNSS network and transmits the correction data to all users completely real-time via the data links and communication systems. The system consists of

Figure 3 Survey Scheme
Slika 3. Shema snimanja

a number of automated GNSS tracking stations, which continuously record carrier phase and pseudorange measurements for all GNSS satellites in view. Figure 2 shows the coverage area of ISKI-CORS network, which contains the boundary of the province of İstanbul.

3.2 Model Construction – *Izgradnja modela*

The objective of this study is to examine the applicability of GNSS and total station integration for determining the position of a point located under the forested area, according to short observation length and the required horizontal accuracies. Two observation stages were conducted simultaneously: (1) GNSS observations (2) terrestrial total station measurements. As has been stated above, the current study also aims to provide an economical and practical survey method to obtain accurate point positioning under the forested areas for forestry applications.

Four points in all were established around the forested area, namely N_1, N_2, N_3 and N_4 (Fig.3). Simultaneous observations were achieved from the field site to shorten the observation time, and then, within 15 minutes the GNSS and total station surveys were completed. To compute the coordinates of K, located under the forested area, coordinates of N_1 and N_2 were determined by CORS RTK GNSS surveys. Coordinates of N_3 and N_4 were determined using terrestrial measurements from two triangles (Triangle I & III, see Fig. 4). To control the coordinates of K, static GNSS survey was performed during 3-hour observation time.

As is well known and currently used, resection is a method for determining an unknown position measuring angles with respect to known positions. The method involves taking azimuth or bearing angles to two or more objects, then drawing lines of position along those recorded bearings or azimuths. Since the intersection method uses angular in-

Table 1 Formulas for solving Triangle I & III
Tablica 1. Formula za trokut I & III

	Coordinates of N_3: Koordinate N_3	Coordinates of K from Angle I: Koordinate K
Azimuth Azimut	$t_{N_1N_3} = t_{N_1N_2} + \psi + \xi$	$t_{N_3K} = t_{N_3N_1} + \alpha$
Coordinates Koordinate	$Y_{N3} = Y_{N1} + S_1 * \sin t_{N_1N_3}$ $X_{N3} = X_{N1} + S_1 * \cos t_{N_1N_3}$	$Y_K = Y_{N3} + S_2 * \sin t_{N_3K}$ $X_K = X_{N3} + S_2 * \cos t_{N_3K}$
	Coordinates of N_4: Koordinate N_4	Coordinates of K from Angle III: Koordinate K
Azimuth Azimut	$t_{N_2N_4} = t_{N_2N1} - \lambda - \varphi$	$t_{N_4K} = t_{N_4N_2} - \beta$
Coordinates Koordinate	$Y_{N4} = Y_{N2} + S_5 * \sin t_{N_2N_4}$ $X_{N4} = X_{N2} + S_5 * \cos t_{N_2N_4}$	$Y_K = Y_{N4} + S_6 * \sin t_{N_4K}$ $X_K = X_{N4} + S_6 * \cos t_{N_4K}$

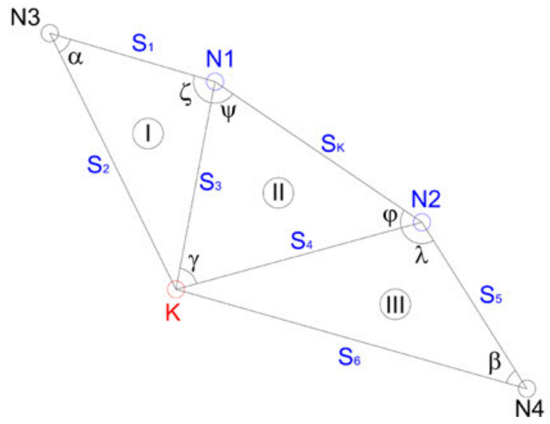

Figure 4 Computation Scheme
Slika 4. Shema izračuna

tersecting directions regarding to traditional methodology, distances are also measured in this study to enhance control on measurements. This also increases the reliability of the observations and enhancement of the accuracy for point positing to be determined.

Figure 4 also illustrates the measurement sketch. Although one triangle is enough to solve the point coordinates, namely K, located under the forested area (forest condition), the model is built for solving the problem using two triangles, not only to control the measurements surveyed at field site but also to control the coordinates of the points, namely N_3, N_4 and K, whose directions or distances are measured. The above-mentioned angular variables seen in Figure 3 were calculated for each triangle using the following expressions (Eq.1 and Eq.2). The formulas below formulas were generated according to Triangle 1:

$$\alpha = \arccos\left(\frac{S_1^2 + S_2^2 - S_3^2}{2 * S_1 * S_2}\right) \tag{1}$$

$$t = \arctan\left(\frac{\Delta Y}{\Delta X}\right) \tag{2}$$

Eq.1 is the cosine rule for finding bearing angles and Eq.2 is the formula of finding the azimuth, which is defined as a horizontal angle measured clockwise from the north base line. Here, α is one of the interior angles of Triangle-1. S_1, S_2 and S_3 indicate measured horizontal distances of the Triangle-1. t is the azimuth angle. ΔY and ΔX are departure and latitude values, which are Y and X components of a line in a rectangular grid system, respectively.

Table 1 shows the coordinates calculation procedure of point K. The formulation has been given for triangle I and III.

3.3 Model Validation – *Valjanost modela*

In this study, the precision of GNSS positioning was calculated using the following equation:

$$D_P = \sqrt{\Delta_X{}^2 + \Delta_Y{}^2} \tag{3}$$

Where D_P indicates the precision of GNSS positioning; Δ_X and Δ_Y indicate the differences of positional errors along the x and y axes, respectively.

4. RESEARCH RESULTS
REZULTATI ISTRAŽIVANJA

4.1 Surveys at Field Site – *Terensko snimanje*

To supply the available condition in this computation strategy, visibility between points N_3 – K, and N_4 – K should be provided. The terrestrial surveys conducted with total station presented in Table 2 were performed to obtain the horizontal directions, vertical directions and horizontal lengths.

GNSS surveys were conducted at N_1 and N_2 simultaneously. Stations N_1 and N_2 illustrated in Fig.4 were surveyed by RTK GNSS method by using İSKİ-CORS network (Fig.2), and corrections were made via VRS mode, then the coordinates of these points were determined. The Position dilution of precision (PDOP) values for N_1 and N_2 are 2.089 and 1.615, the horizontal RMS (root mean square) and vertical RMS values are 7 mm and 14 mm, and 9 mm and 18 mm, respectively. The visible satellite numbers for N_1 and N_2 are of total 12 with 5 GPS+7 GLONASS, of total 14 with 6 GPS + 8 GLONASS, respectively. The elevation mask is 10 degree, and record interval is 10 seconds. The provided coordinates depending on these survey situations are computed as shown in Table 3.

A 3 hour-static GNSS survey at point K (under the forested area, see Fig. 6) was computed by using ISKI-CORS reference stations PALA and KCEK (approx. 10 km far away from the

Table 2 Total Station (TS) surveys
Tablica 2. Snimanje totalnom stanicom (TS)

Station No Broj stanice	Target No Broj stanice	Horizontal Angle (grad) Horizontalni kut (stupanj)	Vertical Angle (grad) Vertikalni kut (stupanj)	Horizontal Lenght (m) Horizontalna dužina (m)
N_3	K	0.0000	96.3286	33.246
	N_1	52.7032	103.9488	20.034
N_4	K	0.0000	101.4936	42.453
	N_2	46.6188	105.4066	22.919
K	N_1	0.0000	104.5318	24.608
	N_2	71.2160	99.7884	29.672

Table 3 Coordinates of N1 and N2 by using ISKI-CORS VRS Technique
Tablica 3. Koordinate N1 i N2 korištenjem tehnike ISKI-CORS VRS

Point Točka	Y (m)	X(m)
N1	406699.920	4543692.672
N2	406724.004	4543676.303

Figure 5 Project area and ISKI-CORS Network
Slika 5. Projektno područje i mreža ISKI-CORS

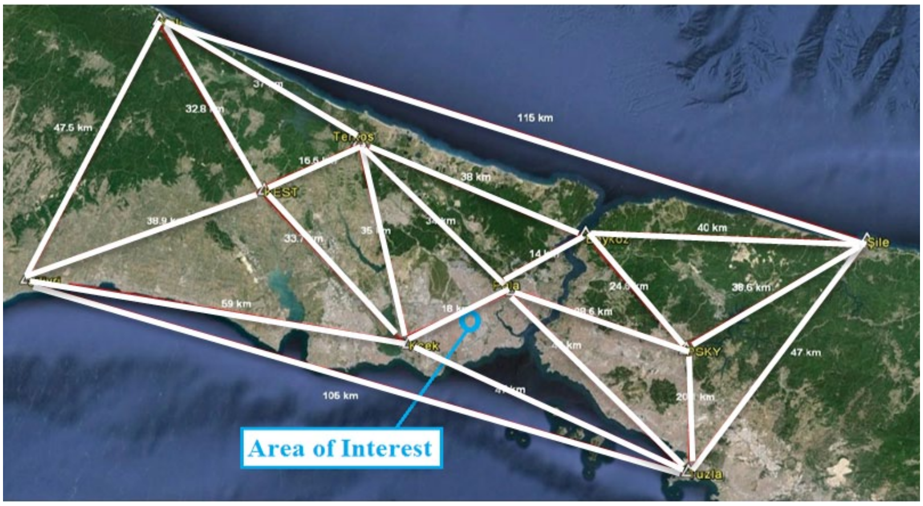

Table 4 Angle computations
Tablica 4. Izračuni kutova

Triangle Trokut		
I	II	III
$\alpha = 52^g.7032$	$\psi = 73^g.8101$	$\beta = 46^g.6188$
$\zeta = 106^g.3627$	$\phi = 54^g.9739$	$\lambda = 118^g.8347$

project area) with commercial post-processing GNSS software, Topcon Tools v8.2. The location of the area of interest into the ISKI-CORS Network can be seen in Figure 5.

4.2 Results and Discussion – *Rezultati i rasprava*

Equations (1) and (2) were used to calculate the interior angles of generated triangles and the azimuth of related line (N_1N_2). All the others were computed in the same way. The results are listed in Table 4 and Table 5.

The closure vector of differences between the static and combined total station and real time kinematic GNSS (CORS/VRS) surveys (see Table 6) results calculated by Eq.3, indicated as D_P, was obtained as ± 0.065 m. Pirti (2008) states that Naesset et al. (2000) demonstrate that accuracy can be achieved for static measurement under the forest canopy only within ±(1-9) cm.

Since the ambiguity was solved in CORS survey, due to lack of validity, errors occurred in the CORS/VRS method.

Figure 6 (a) GNSS survey at Point K (b) Sky visibility from Point K
Slika 6. (a) GNSS snimanje na točki K (b) Vidljivost neba iz točke K

Table 5 Computation results of coordinates
Tablica 5. Rezultati izračuna koordinata

	Coordinates of N_3: Koordinate N_3	Coordinates of K from Angle I: Koordinate K
Azimuth Azimut	$t_{N_1N_3} = 318^g.1756$ $t_{N_1N_2} = 138^g.0028$	$t_{N_3K} = 170^g.8788$
Coordinates Koordinate	$Y_{N3} = 406680.697\,m$ $X_{N3} = 4543698.314\,m$	$Y_K = 406695.380\,m$ $X_K = 4543668.486\,m$
	Coordinates of N_4: Koordinate N_4	Coordinates of K from Angle III: Koordinate K
Azimuth Azimut	$t_{N_2N_4} = 164^g.1942$	$t_{N_4K} = 317^g.5754$
Coordinates Koordinate	$Y_{N4} = 406736.2255\,m$ $X_{N4} = 4543656.914\,m$	$Y_K = 406695.380\,m$ $X_K = 4543668.486\,m$

Table 6 Comparison of survey results
Tablica 6. Usporedba rezultata snimanja

		K	
	Surveys Snimanja	Y (m)	X (m)
1	Post-Processing Static GNSS Statičko	406695.442	4543668.506
2	Alternative Method (TS+ISKI-CORS/VRS) Alternativna metoda	406695.380	4543668.486
3	ISKI-CORS/VRS	406695.995	4543671.017
	Coordinate Differences Razlike koordinata		
	Surveys Snimanja	ΔY (m)	ΔX (m)
	1-2	0.062	0.020
	1-3	–0.553	–2.511
	2-3	–0.615	–2.531

When the accuracies were compared with static GNSS surveys in both coordinate components, computation showed differences in Y and X coordinates up to -0.553 and -2.511 m, respectively. Signal attenuation caused by leaves or branches of trees resulted in low accuracy. The results obtained in this study are consistent with Pirti (2008). In addition to this, Pirti et al. (2010) also obtained similar results. Pirti (2010) states that in their study the variations were about 2-5 cm in the X-Y coordinates and about 3-10 cm in the H coordinate. They indicated that there were significant differences in the horizontal and vertical coordinates at difficult points. The results derived from this study show that with an integrated survey methodology within quite short duration of the survey (approx. 15 min.), measurements with ± 10 cm can be guaranteed under similar conditions.

5. CONCLUSIONS
ZAKLJUČCI

This paper shows that CORS-RTK (VRS) can be used for forest surveys (obtaining accuracy dm or m level), although a common obstacle, sky blockage, hinders its full effectiveness. However, this problem can be overcome if supplemented by conventional survey techniques. In this study, the CORS-RTK (VRS) required approximately 60 minutes to survey a point (K). The integrated methodology provides accurate coordinate solutions by resection computation method to obtain the coordinates of point (K). The new alternative method of surveying a point took approximately 10-15 minutes in the field. For a point (K under the forest) the horizontal plane coordinates differed up to ± 6 cm. Therefore, it appears that in difficult environments, measurements with ± 10 cm can be guaranteed in all situations by using this new alternative method.

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Sažetak

Apsolutno određivanje položaja točke s GNSS/CORS (Globalni navigacijski satelitski sustav) u šumskim područjima predstavlja značajan izazov u smislu uštede vremena, kako bi se dobile što točnije koordinate točaka. Vrijeme za rješenje neodređenosti faze cijelih brojeva nosača obično traje jedan sat ili više za apsolutno određivanje točaka pod šumskim područjem s GNSS/CORS. U ovom istraživanju predložena je alternativna metoda za određivanje položaja točke, koja daje rezultate položaja s preciznošću na razini centimetra i potrebno je skoro 15 minuta kako bi se dala nova lokacija točke u šumskom području. Predložena metoda može također imati praktičnu primjenu za unutarnje prostore sa željenom preciznošću na razini cm, koja se postiže u kratkom vremenu promatranja. U ovom istraživanju, proveli smo terenski rad kako bi dobili koordinate točaka u šumskim područjima s GNSS/CORS sustavom i dodatnim mjerenjima, utvrđivanjem dviju kontrolnih točaka promatranih s GNSS/CORS lociranih na granici šumskog područja. Rezultati pokazuju da se zadovoljavajuće rješenje za šumsko područje postiže na razini cm (≈ ± 6 cm) u kratkom vremenu promatranja.

KLJUČNE RIJEČI: GNSS, CORS, VRS, preciznost, šumsko područje