RTK POSITIONING UNDER TREES

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ABSTRACT
The paper presents the results of positioning by means of the RTK *(Real Time Kinematic)* method under forest conditions. The experiments were conducted over four consecutive days on hours when the configuration of GPS satellites over the test point was optimal. During the tests a Z-Xtreme receiver by Ashtech was used. On the first and the last day the corrections from the reference station were transmitted to the mobile receiver using the NTRIP application and on the other days the radio modem by SATEL was used for transmission of the corrections. The accuracy of measurement point coordinates in the GPS/RTK is expressed in centimeters; however, achievement of that accuracy of results under forest conditions is highly difficult as a consequence of the problem with ambiguity determination by the mobile receiver. Additionally, the mobile receiver is reached by GPS signals disturbed by signal multipath and cycle slip errors. The experiments presented in this paper indicate that despite very difficult measurement conditions it is possible to determine the coordinates of points under forest conditions with the accuracy of a few centimeters.

1. INTRODUCTION

Satellite positioning method RTK/OTF (Real Time Kinematic/ On The Fly), thanks to the possibility of obtaining accurate and reliable coordinates within a short time finds increasingly wide application in land survey measurements.
In the GPS RTK measurement system a single reference station located in a point with known coordinates determines the corrections and transmits them in real time to one or a number of mobile receivers (GPS Fieldmate… 1998a, Ashtech Z-family…. 1998b). The mobile receivers receive the corrections and conduct phased observations of the same satellites as the base station and on those bases the coordinates of the mobile station are determined (Hofmann-Wellenhof, 1997). Currently, corrections from the reference station are transmitted to the mobile receivers using the radio modem or using the GPRS technology. The reach of the corrections sent using the NTRIP module is theoretically unlimited while the range of radio modem is determined by its power. Effective corrections must, however, be taken from a nearby reference station situated at a distance not exceeding 15-20 km (Ciećko et al. 2003).
The main limitation for GNSS positioning method is the necessity to assure access of the antenna to the celestial sphere. This limitation gains special importance in case of measurements taken in the urbanized (Cisak et al. 2001) and wooded area (Hasegawa et al. 2003, El-Mowafy 2000; Naesset 2001; Naesset et al. 2002; Sigrist et al. 1999;

Yoshimura et al. 2003). Conducting GPS measurements under forest conditions is particularly difficult as a consequence of very limited access to the celestial sphere and tiny branches moving under the influence of the wind causing signal multipath and cycle slip (Bakuła et al. 2006). As a consequence experience of the measurement team and limited confidence in the results obtained are necessary for determination of the position of a point under difficult conditions. To increase the level of confidence in a given measurement it is recommended to conduct such a measurement several times at the time of the best configuration of the satellites.

2. EQUIPMENT

Land survey receiver Z-Xtreme by Ashtech with Husky controller and the internal application GPS FieldMate by Ashtech was used for conducting the experiment (Fig. 1). This application allows obtaining point coordinates within the earlier defined system of coordinates and provides information on the type of solution (fixed/float), currently available number of satellites, values of DOP coefficients and the precision of measurements.

Fig. 1. Sample of the Husky controller screen during measurement with FieldMate software.

During the first and the last day of the experiment (13 April 2007 and 16 April 2007) the corrections from the reference station OLST were transmitted to the mobile receiver using the NTRIP data transfer protocol (Fig. 2). The application was installed in a Motorola mobile telephone set that was connected to the Ashtech Z-Xtreme receiver. The corrections from the reference station were received with the delay of ca. 2-5 seconds.

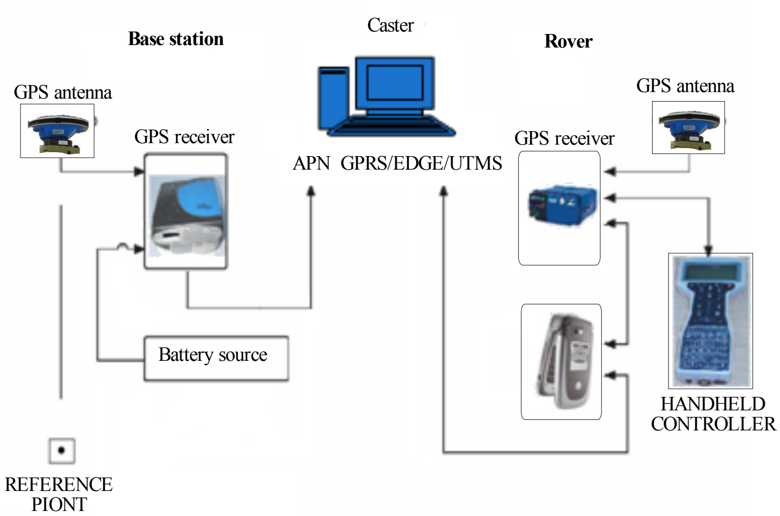

Fig. 2. Diagram presenting a measurement using the NTRIP application.

On 14 and 15 April 2007, a radio modems by Satel were used for transmission of the corrections (Fig. 3). During the measurement no delay in transmission of corrections from the base station to the mobile station was noticed.

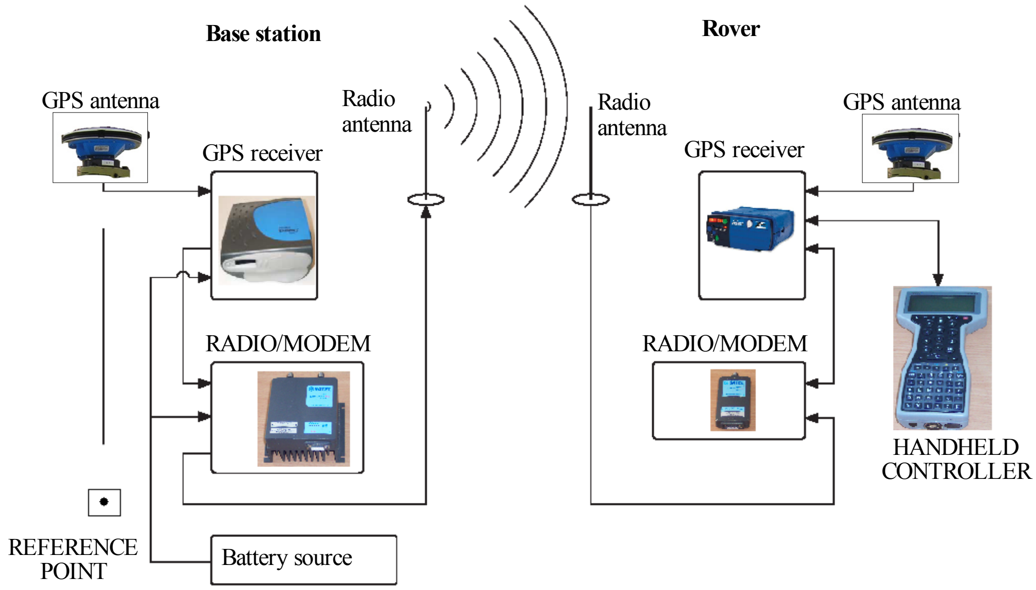

Fig. 3. Diagram presenting downloading of corrections using a radio modem.

3. FIELD MEASUREMENTS

Test measurements were carried out at a point situated in the forest on Lake Kortowskie in Olsztyn. This is a point fixed permanently by a concrete post with a metal rod in the center. The number and quality of covers over the measurement point are presented in photographs taken in the following directions: northwards (Fig. 4), southwards (Fig. 5), eastwards (Fig. 6) and westwards (Fig. 7) as well as the photograph taken upwards (Fig. 8). The time for conducting the experiment was selected to achieve the best possible situation above the measurement point (no foliage on the trees, best constellation of the satellites (Fig. 9 – 16)).

Fig. 4. Situation in northward direction.

Fig. 5. Situation in southward direction.

Fig. 6. Situation in eastward direction.

Fig. 7. Situation in westward direction.

Fig. 8. Situation over the point.

The coordinates of the measurement point were determined by means of classic land survey methods using the electronic tacheometer, on the basis of the control network points determined by means of the static GPS method. The coordinates obtained during the experiment were compared to the coordinates determined in the above-described way.

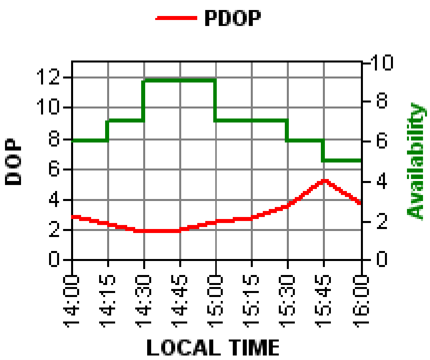

Fig. 9. PDOP and availability of satellites 13.04.2007

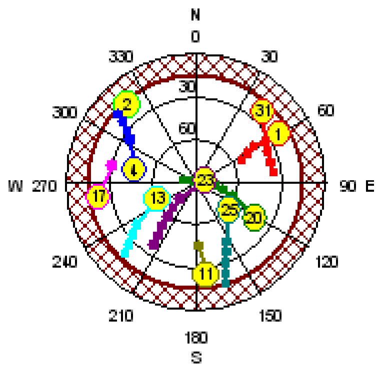

Fig. 10. Trajectory of satellites on measurement hours 13.04.2007

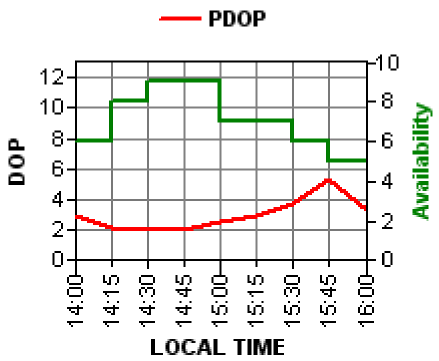

Fig. 11. PDOP and availability of satellites 14.04.2007

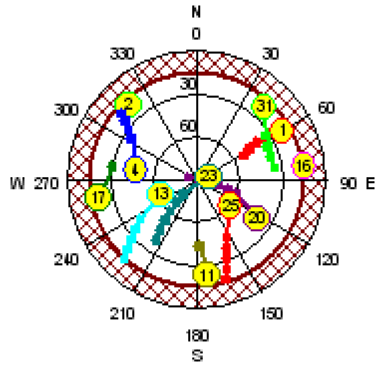

Fig. 12. Trajectory of satellites on measurement hours 14.04.2007

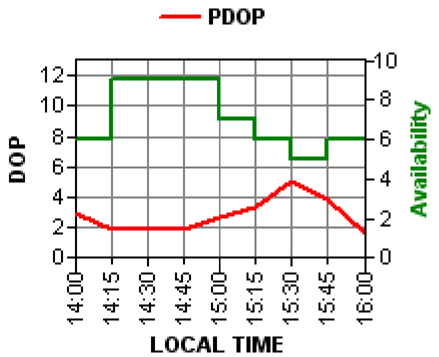

Fig. 13. PDOP and availability of satellites 15.04.2007

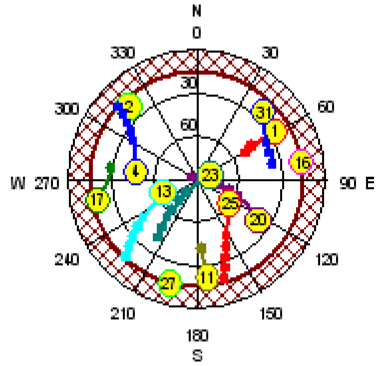

Fig. 14. Trajectory of satellites on measurement hours 15.04.2007

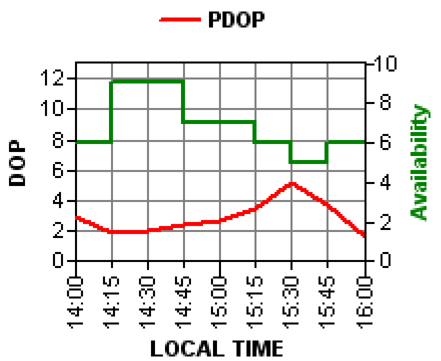

Fig. 15. PDOP and availability of satellites 16.04.2007

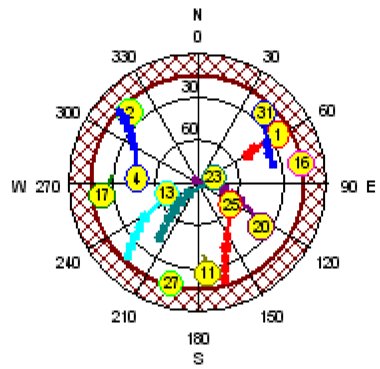

Fig. 16. Trajectory of satellites on measurement hours 16.04.2007

During the RTK tests corrections were originating from the reference station situated at the distance of 1130m from the mobile station.

4. PROCESSING OF THE RESULTS

Before analysis of the recorded coordinates the data for which the precision was worse than 20 cm was dismissed. Next the data was organized according to the height determined by the receiver. Figure 17 shows the actual spread of coordinates recorded during the experiment. During analysis of the results it was found out that very frequently despite high precision of measurement indicated the determined coordinates of the point were situated even a few meters from the true coordinates.

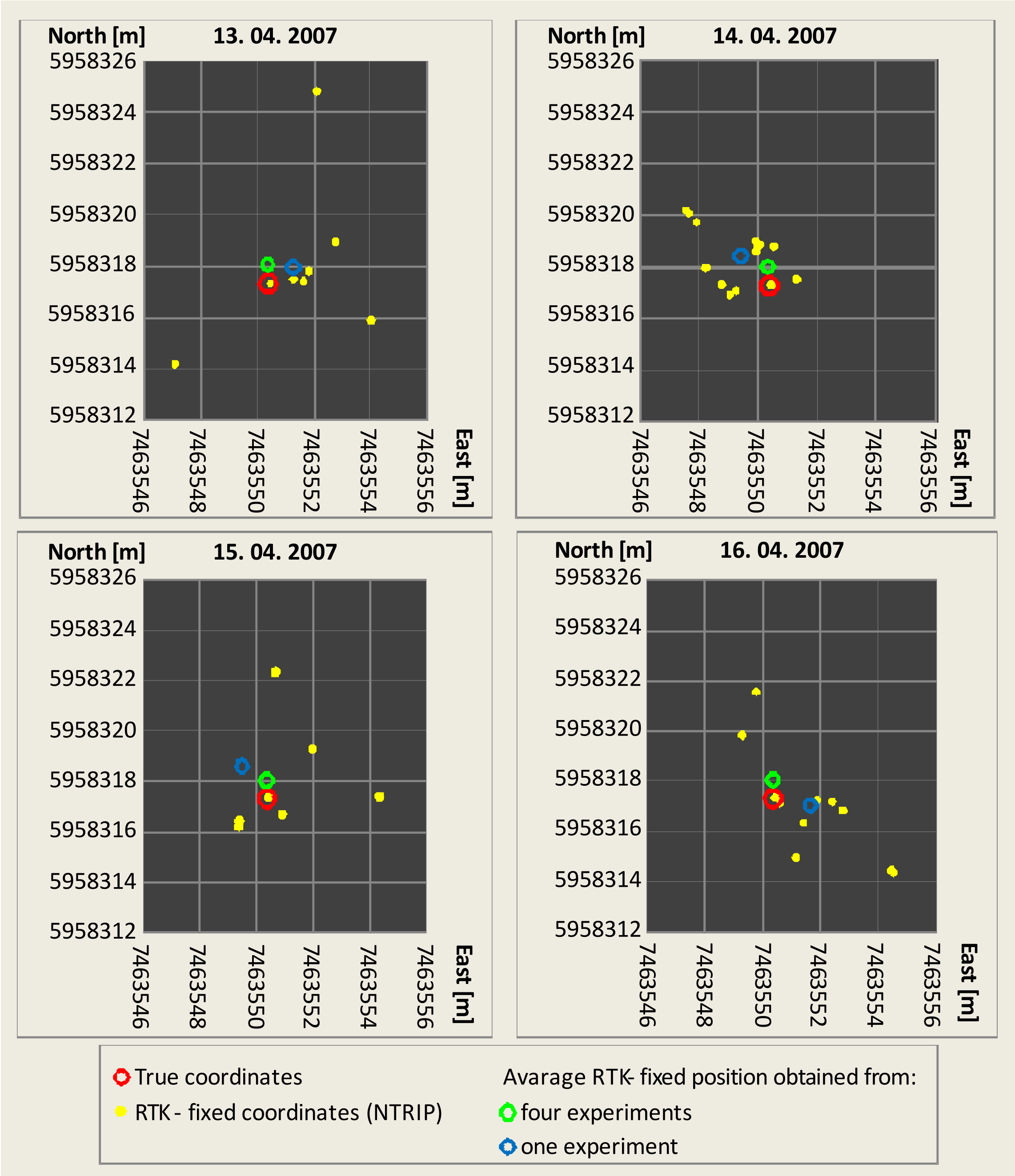

Fig. 17. Determined RTK positions.

Figure 17 also presents the true coordinates, the average coordinates from the entire measurement campaign and the average position registered on the individual days of measurements.

Every day the measurement lasted for two hours– from 14:00 until 16:00 of the local time. The measurement data from each day was divided into groups of consecutive determinations of coordinates for which the ambiguity was solved (from the moment of determining the ambiguity until its loss). Each such group was analyzed as concerns the number of recorded observations, time from determination of ambiguity until its loss and average accuracy of the coordinates determined in a given group. The analysis of the results obtained is presented in table 1.

Tab.1. Analysis of results from positioning measurements under forest conditions

day	corrections transfer technique	weather	time till solution availability[min]	number of observations recorded	□Y=Yo-Yp [m]	□X=Xo-Xp [m]	□H=Ho-Hp [m]	błąd 3D [m]
13.04.2007	NTRIP	no wind	8,4	101	0,05	0,05	-0,04	0,08
			1,0	12	3,62	-1,40	1,93	4,34
			3,4	41	1,22	0,14	1,26	1,76
			3,2	38	1,40	0,54	1,90	2,42
			0,8	9	0,04	0,04	0,02	0,06
			1,1	13	-3,34	-3,07	6,66	8,06
			2,0	24	0,85	0,21	1,19	1,47
			1,5	18	2,37	1,65	1,65	3,33
			1,3	15	1,69	7,57	11,74	14,07
14.04.2007	Radio modem	windy	1,0	12	-1,35	-0,34	7,57	7,70
			0,9	11	-1,62	0,06	7,25	7,43
			0,7	8	-2,16	0,71	2,65	3,50
			1,0	12	0,88	0,27	1,39	1,67
			0,3	4	-2,73	2,83	-4,39	5,89
			0,5	6	-2,83	2,95	-4,27	5,91
			0,3	4	-2,46	2,48	-4,31	5,55
			1,8	21	0,05	0,06	0,01	0,08
			0,7	8	-0,39	1,53	7,78	7,94
			0,7	8	-0,34	1,63	7,97	8,14
			1,7	20	-1,13	-0,17	-2,75	2,97
			2,8	34	0,06	0,04	-0,03	0,07
			1,0	12	0,15	1,54	2,79	3,19
			0,4	5	-0,46	1,74	2,32	2,94
			0,4	5	-0,41	1,67	2,19	2,78
			0,7	8	-0,43	1,35	1,89	2,36
15.04.2007	Radio modem	windy	1,1	13	-6,21	3,58	-2,23	7,51
			0,9	11	-6,11	3,53	-1,97	7,33
			1,7	20	0,52	-0,63	4,02	4,10
			0,7	8	-1,02	-1,07	7,78	7,92
			0,5	6	-0,96	-0,89	8,14	8,24
			0,7	8	3,98	0,13	2,84	4,89
			0,8	9	1,55	2,01	-1,46	2,93
			1,2	14	0,03	0,05	-0,02	0,06
			1,1	13	0,31	5,03	4,80	6,95
16.04.2007	NTRIP	no wind	1,3	15	1,04	-0,94	3,44	3,71
			0,6	7	-0,62	4,27	4,06	5,92
			2,0	24	4,12	-2,92	4,81	6,98
			1,5	18	4,06	-2,81	4,37	6,60
			5,7	68	1,48	-0,05	1,58	2,17
			1,4	17	0,18	-0,15	-0,08	0,25
			1,7	20	2,01	-0,09	4,13	4,60
			1,0	12	-1,09	2,57	6,02	6,64
			2,1	25	2,34	-0,43	4,45	5,05
			0,8	9	0,75	-2,30	-2,70	3,63
			1,0	12	0,04	0,05	0,00	0,06

Figure 18 presents the distribution of determined heights of the test point and the time for which the ambiguity was maintained. Data from the entire measurement campaign was used to generate the figure.

On the first measurement day there was no wind. NTRIP application was used for transfer of corrections. That day the total of 271 positions with the ambiguity determined were recorded, 110 of them with the accuracy better than 10 cm. The longest time between determination of ambiguity and its loss was over 8 minutes. The

average time for the group within which the solution was available was 2,5 minutes. On that date one more group of true positions was recorded the recording of which lasted for almost a minute.

On the second measurement day the weather was windy. Radio modem was used for transmission of the corrections. On that day the total of 178 positions with the ambiguity determined were recorded, 55 of them with the accuracy better than 10 cm. The longest time between determination of ambiguity and its loss was almost 3 minutes. The average time for the group within which the solution was available was 0,9 minute. The second group with the longest time of maintaining the ambiguity was almost 2 minutes

On the third measurement day the weather was also windy. Radio modem was used for transmission of the corrections. On that day the total of 102 positions with ambiguity determined were recorded, among them 14 were characterized by the accuracy better than 10 cm.

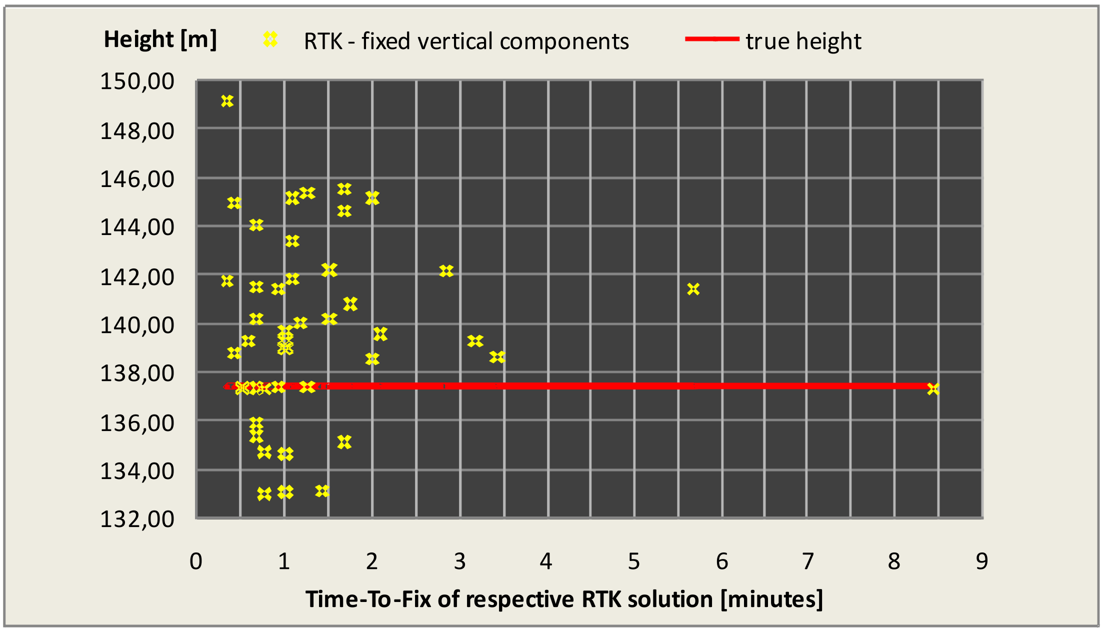

Fig. 18. Determined heights of the experimental point.

The longest time between determination of ambiquity and its loss was 1,5 minutes, and it should be noticed that the coordinates recorded were characterized by the horizontal error exceeding half a meter and height determination error exceeding 4 meters. The average time for the group within which the solution was available was 0,9 minute. The second in length group of maintaining ambiguity was characterized by both horizontal and vertical average accuracy of less than 10 cm. On that day no other coordinates close to those determined by classic land survey methods were recorded.

On the fourth measurement day there was no wind. NTRIP protocol was used for transmission of the corrections. On that day the total of 227 positions with the ambiguity determined were recorded, only 12 of them with the accuracy better than 10 cm. The longest time between initializations was 6 minutes, and the coordinates determined on that day were more than 2 meters away from the true coordinate.

The average time for the group within which the solution was available was 1,7 minute. On that day only one group of coordinates with the accuracy better than 10 cm was recorded. That solution occurred for the time of around 1 minute. On that day that was one of the shorter times for individual groups.

5. CONCLUSIONS

Measurement experiments on consecutive days were conducted at the same point during the similar constellation of satellites. Two days of the campaign were windy and there was no wind on the other two. From the theoretical point of view in case of windy weather more errors should be recorded as a consequence of the cycle slips. In the experiment described, analyzing the times from determination of indeterminacy to its loss we obtain confirmation of that theory.

During the experiment two systems were applied for distribution of corrections from the reference station to the mobile station – radio modem and GPRS technology. Despite the fact that corrections transmitted by NTRIP application reached the device with the delay of 2-3 seconds, and those transmitted by radio modem with zero delay, no significant influence of the corrections transfer method on the accuracy of the determined position was observed. As a consequence, the power of the radio modem or the range of the GSM/GPRS network are the only important technical parameters in case of works of that type.

GPS RTK measurements under forest conditions should be carried out during the period from late autumn until the early spring because of the easier access to the celestial sphere (no foliage on trees). From the theoretical point of view, the thinner the forest the more reliable the coordinates determined will be although the constellation of satellites during the measurement is also of high importance. Measurement sessions conducted under forest conditions should then be planned with particular consideration for the projected configuration of satellites.

Considering the fact that within the few nearest years the GALILEO system is to be developed with the signal more powerful than the GPS, the GPS system evolves all the time and satellites of new generations are positioned that also have new, stronger signals and that as for today in addition to the GPS system we also have the GLONASS system available, in the near future the GNSS measurements under forest conditions should become increasingly easy.

In the conclusion it can be stated that performance of accurate and reliable RTK/OTF measurements under forest conditions requires good planning of the date and time of observations, extensive experience and critical approach to the results of such measurements. It is also necessary to carry on studies for the purpose of increasing the credibility of RTK measurements results obtained under difficult measurement conditions.

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