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ANALIZA REZULTATA DOBIVENIH METODOM AUTONOMNOG STARTA BAZNOG UREĐAJA I TILT OPCIJOM

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Sažetak:

Visoko precizni pozicijski servis (VPPS) hrvatske mreže referentnih GNSS stanica pod imenom CROPOS danas je vrlo brz, pouzdan i precizan sustav korišten za određivanje koordinata točaka u Republici Hrvatskoj. Prednosti GNSS mreža za potrebe RTK pozicioniranje dobro su poznate, međutim, u nekim je situacijama klasičan sustav RTK baza-rover prikladno rješenje, čak i kada korisnik nema mogućnost postaviti bazni uređaj na točku čije su koordinate poznate u državnom koordinatnom sustavu (HTRS96). Korištenjem metode autonomnog starta baznog uređaja, isti je moguće postaviti na najpogodnije mjesto za primanja signala GNSS satelita. Osim što bazni uređaj šalje diferencijalne korekcije roveru, simultano obavlja i prikupljanje statičkih opažanja za kasniju obradu i korekciju koordinata baznog uređaja i rovera. U ovome su radu testirane mogućnosti navedene metode. Uz to, testirana je i funkcionalnost opcije za mjerenje pri nagibu štapa (TILT opcije) koju je tvrtka Topcon integrirala u prijamnik Hiper HR.

Ključne riječi: CROPOS VPPS servis, autonomoni start baznog uređaja, TILT opcija

ANALYSIS OF POSITIONING RESULTS OBTAINED BY A SINGLE BASE RTK WITH AUTONOMOUS BASE START AND TILT OPTION

Abstract:

HPPS service of the CROPOS system is today a fast, reliable, precise and commonly used tool for coordinates determination in Croatia. The advantages of a networked RTK method are well known, but in some situations, a single-base RTK method could be a reliable method for coordinates determination, even without a base station having known coordinates. Single-base RTK method with Autonomous base start can be set up on any (unknown) station with a clear sky and GNSS satellites visibility enabled. Differential corrections are usually broadcast to the rover GNSS receiver via a communication link, enabling the coordinates determination with cm-level precision in real time. Simultaneously, the base GNSS receiver collects static observations for base station determination in post-processing and subsequent rover coordinates shift. In this paper, the above mentioned method was tested on the ground, together with TILT option integrated into newest Topcon GNSS receiver.

Keywords: CROPOS HPPS service, Autonomous base start method, TILT option

1. INTRODUCTION

Nowadays, due to technological improvements, surveyors can get their job done much faster and accurate than ever before. Such improvements include precise satellite positioning techniques which were developed after GPS (Global Positioning System) satellites were launched. Today, it is common to use both American GPS and Russian GLONASS for satellite positioning purposes, while European Galileo and Chinese BeiDou are still under development and are expected to reach Full Operational Capability (FOC) by 2020.

GNSS RTK (Real Time Kinematic) is the most widely used and the fastest method for coordinate determination on the surface of the Earth. Like other satellite relative positioning method, RTK method requires at least two GNSS (Global Navigation Satellite System) receivers: base and rover. At the early stages of RTK method, a base receiver was set up at station with known coordinates observing the same GPS (Global Positioning Satellites), calculating the differential corrections of phase observations which were via the radio link transferred to the rover GPS receiver enabling it to solve the phase ambiguities and subsequently the coordinates in real-time. This positioning method was referred to as conventional RTK providing cm-level accuracy up to 20 km distance from the base receiver [1]. In the meantime, the concept of Networked RTK (NRTK) was developed, modelling the distance dependent errors of the GNSS observations (ionospheric and tropospheric refraction, orbital errors) and thus extending the distance between permanent GNSS stations up to 70-100 km [2]. Such networks have become essential surveying tool and are used in most geodetic tasks. Although GNSS networks have many advantages over conventional RTK method, there are some situations in which they cannot be properly utilized. One of these situations is certainly when a mobile Internet signal is not available. Despite a generally good spatial coverage of mobile Internet availability, there are still poorly populated areas (mainly mountainous area) with no signal. Without it, NRTK positioning is not possible since the rover cannot receive correction messages from the server. In such situations, a conventional single-base RTK is more appropriate solution. Having that in mind, a technique which allows the operator to set up a base receiver at arbitrary location (not over a known point) and perform RTK measurements was developed. Such method is based on performing both static and RTK observations at the same time and is called 'Autonomous base start method with coordinate shift'. It is a method that requires post-processing, but it also enables the user to simplify their field work and finish it much faster compared to conventional RTK method. The most important part is that end results are satisfying in terms of both accuracy and precision.

Another great step in modern RTK positioning was made by virtue of integration capabilities of GNSS and IMU (Inertial Measurement Unit) measurements. By utilizing inertial based measurements, it is possible to perform RTK observations without maintaining vertical position of a GNSS range pole. Today, there are several GNSS receivers available on the market which incorporate so-called tilt option. Such option has shown big potential and is getting more attention every day.

The aim of this paper was to test both Autonomous base start method and TILT option on the ground. Complete field and post-processing procedures, followed by accuracy and precision analysis and conclusion are systematically carried out.

2. CROATIAN POSITIONING SYSTEM – CROPOS

CROPOS is the state network of permanent GNSS reference stations of the Republic of Croatia. The network consists of 33 stations at the average distance of 70 km distributed over the national territory for the purpose of collecting satellite observation data and determination of correction parameters [3]. The inclusion of additional permanent GNSS stations data from the neighboring countries into CROPOS enabled a better coverage and reliability of the system as well as the better modelling of corrections in the border areas of the Republic of Croatia [3], [4]. The system provides three services which differ in accuracy, availability, and way of data transfer, data format and positioning methods. High Precise Positioning Service - HPPS (VPPS in Croatian) is the most frequently used tool by surveyors for every kind of land and cadastral survey in Croatia. The VPPS offers a networked solution of phase measurements in real-time, and the coordinates are determined with declared accuracy 2 cm (2D) and 4 cm (3D). Geodetic Precise Positioning Service (GPPS) provides the GNSS observation data collected at CORSes or at arbitrarily selected Virtual Reference Stations (VRS) with a sub-centimeter level of accuracy. Observation data are available for post-processing in versions of RINEX format (2.10, 2.11, 3.02). CROPOS as system of networked permanent GNSS stations is based on VRS (Virtual Reference Station) concept. Currently, the GNSS receivers Trimble NetR5 involved in CROPOS support the observation of only GPS and GLONASS satellites thus, the differential corrections and CORS observation data are available only for those satellite systems [3].

3. AUTONOMOUS BASE START METHOD

One of significant disadvantages of single base RTK is the necessity of having at least one point with known coordinates in national coordinate system. It is necessary because the base receiver needs to be started from a known point to ensure rover’s absolute positioning accuracy. It is not unusual that there is no such a point in the field or it is not situated in a suitable location for satellite positioning. If a user has to utilize single base RTK method in such location, it is often necessary to traverse or to use any other traditional surveying method for coordinates determination. Nevertheless, such methods are considered to be impractical and time consuming. Another option is to perform fast static observations. While relative static method is highly accurate and simple, it takes some time to be carried out. Moreover, it disables quick start of the base receiver and prolongs field work.

Mentioned problems indicate that a proper solution should utilize both static and RTK observations simultaneously. Such solution involves setting up the base receiver on any (unknown) station with a clear sky and GNSS satellites visibility provided. Base receiver is then started with Autonomous position, providing the base station coordinates with low precision, usually around 2 m [5]. In spite of that, relative positions between base and rover are determined with high precision. Simultaneously with the GNSS satellites observation and differential correction broadcasting, the base GNSS receiver collects static observations for subsequent station coordinates determination in post-processing. Once the base station coordinates have been determined, rover RTK receiver coordinates can be corrected accordingly. Such coordinate “shift” is possible since the vector between the first (inaccurate) base point and the one determined with static observations is known. After coordinate shift, all of the rover’s coordinates are considered to match the desired RTK accuracy [5].

For the purposes of field investigations presented in this paper, Topcon's Magnet Office Tools software was used to perform all of the necessary computations, including coordinate shift.

4. TILT TECHNOLOGY

GNSS RTK method made a great impact on surveying techniques and has developed rapidly over the last 20 years. The increase of number of satellites, development of permanent GNSS networks, better algorithms enabling detection and elimination of multipath, high-quality GNSS antennas, faster initialization and general simplification of RTK workflows has led to a global democratization of such technology.

Significant step towards such democratization of GNSS technology occurred in 2013, when Trimble presented GNSS receiver R10 utilizing "Trimble SurePoint" option. It allowed the user to perform tilted measurement and still get reliable results since such technology compensated for mis-leveled field measurements out of plumb by as much as 15° [6]. Although the so-called tilt option was very innovative and enabled users to perform field measurements faster, first receivers incorporating this option have shown some disadvantages. Some of those receivers couldn't perform tilted stake-out, user had to ensure that receiver is aligned with field computer [6] and had to define when tilted measurement was about to be carried out in field software. Additionally, the performance of tilt compensation was often slow providing data with variable quality.

A big step forward was made in 2016, when Topcon company announced its new GNSS receiver Hiper HR (Figure 1). This receiver incorporates patented TILT (Topcon Integrated Levelling Technology) technology able to compensate measurements out of plumb by as much as 15° (Figure 2). As a company that has a long and successful history with GNSS+INS (Inertial Navigation System) integrations (mostly for precise agriculture and machine control purposes), Topcon integrated 3-axis digital compass and its own 6-axis Hybrid IMU to create advanced 9-axis MEMS (Microelectromechanical system) [7]. Unlike its predecessors, TILT technology enables tilted stake-out, user doesn't have to align the receiver and field computer to perform accurate tilted measurement, tilt compensation is turned on all the time (it is not necessary to tell the software if one would measure with tilted pole or not) and it is operating really fast.

Figure 1. Topcon Hiper HR (https://www.topconpositioning.com)

Figure 2. TILT technology (https://www.topconpositioning.com)

Like any receiver with TILT option, it is necessary to perform digital compass calibration prior to any field measurements. In case of Hiper HR, the calibration consists of three steps [8]:

1) calibrate level,
2) calibrate compass,
3) calibrate compass in the horizontal plane.

Compass calibration is recommended in the following situations [8]:

- survey location changes frequently,
- receiver's firmware has been updated,
- receiver takes a shock such as being dropped,
- temperature has changed by 10 degrees or more,
- receiver is transported by a car or airplane,
- receiver is near a strong magnetic object or material, such as a permanent magnet, electromagnet, electric transformer, AC power supply, etc.

5. GEODETIC NETWORK ESTABLISHMENT

In order to perform the field investigations, an appropriate geodetic network had to be established. The chosen location was dr. Franjo Tuđman's park in Zagreb, Croatia. The network consisting of 10 stations is shown on Figure 3. The coordinates of stations S1 and S2 were determined by static method, while coordinates of the remaining stations were determined by terrestrial observations (total station), since those stations had partially obstructed horizons. Such stations were chosen to simulate a real-life situations since today's surveyors expect their receivers to get fixed solution in almost any location.
Both static and terrestrial measurement were conducted on December 5th 2017.

Figure 3. Geodetic network configuration (https://www.google.hr/maps)

For the purposes of static observation, Topcon Hiper HR and Topcon Hiper SR GNSS receivers were used. Receivers were set up over stations S1 (Hiper HR) and S2 (Hiper SR), which were marked with wooden stakes (a nail served as a center). Elevation mask was set on 10° and observation interval was 10 seconds. Observed constellations were GPS and GLONASS. Antenna heights were measured before and after the station occupation. According to the 'Regulations on the fundamental geodetic works performance ' [9], minimum static observation time window should be 20 min + 2 min per km of the longest baseline. Thus, a minimal observation time for this purpose should have been 22 min. In spite of that, the observation time window was deliberately extended. In the end, static occupation of both stations lasted for 47 min.

After static observations were done, receivers were removed from tripods and were replaced with total station (S1) and prism (S2). For this purpose, Sokkia SET500 total station was used. Station S2 served as the azimuth reference mark. Points P1, P2, …, P8 were surveyed by measuring distances and angles in both theodolite faces. During the measurement, the total station was set up on station S1 all the time, the tripod with prism was moved from one point to another.

6. RTK MEASUREMENT

6.1. Field GNSS observation planning

Before conducting any field GNSS observation, it is always recommended to carry out the mission planning. For the purposes of precision analysis, the aim was to define two-time windows, one with better and the other with worse satellites visibility. Observation conditions are influenced by a number of visible satellites, DOP (Dilution of Precision) values etc. Since RTK observations were planned for December 6th 2017, mission planning was carried out for that day by using online tool Navmatix [10].

The satellite visibility and DOP values plot pointed out that the best time interval for satellite observations was the one between 7:00 and 13:00 (UTC), due to high number of satellites (17 in average) and low DOPs (GDOP being 1.5). On the other hand, the worst time period was the one between 13:00 and 19:00 (UTC), with 14 satellites and maximal GDOP value of 2.2. Therefore, the first session of RTK measurements were carried out between 8:00 and 12:00 (UTC), while the second session was carried out between 14:00 and 18:00 (UTC).

6.2. RTK field survey - Autonomous base start method and CROPOS HPPS

After the geodetic network was established and mission planning was done, it was possible to conduct the RTK survey in order to test Autonomous base start method and TILT option on the ground. After the coordinates of all stations were determined by a single base RTK utilizing Autonomous base start method, CROPOS HPPS was used as well. Five observations were done on each station: one with vertical range pole and 4 with tilted range pole. The ranging pole was tilted in 4 directions: north, east, south and west in order to determine whether the tilt orientation affects the positioning accuracy. Those 4 observations were done by using TILT option. According to the Technical specifications for coordinates determination [11], minimal observation duration for points that define landmarks and other borders must be 5 epochs. Since the goal of this paper was to simulate real-life RTK measurements, all of the observations were carried out according to those specifications. Observations were performed with Topcon Hiper HR and Hiper SR GNSS receivers and field computer Topcon FC-5000 running Magnet Field software.

The survey procedure is explained as follows. The first step was to calibrate a digital compass integrated in Hiper HR receiver. It was done by following 3 steps described in chapter 4. At the beginning, Bluetooth connection between receiver and field computer was established. For the purposes of calibration and all of the field measurements, Topcon Magnet Field software was used. First step of calibration includes setting a tripod with a universal tribrach and tribrach adapter. Tribrach must be levelled. Receiver is set on an adapter and level calibration step is triggered inside the software. After waiting for 30 seconds, the software displays a message that the first calibration step is completed. The second step consists of rotating the receiver in vertical plane along the Y axis. After one turn, receiver should be rotated about 30° to the left in a vertical plane along the X axis and then rotated again for 360° in a vertical plane along the Y axis. Those two steps must be repeated until receiver completes a full circle around the X axis. Finally, the third step is done by setting the receiver back on a tripod and by rotating it clockwise in the horizontal plane. After competing 15 turns, the software displays the massage that calibration is done.

Occupation and observation of all stations was firstly done by the single-base RTK method. The base GNSS receiver Topcon Hiper SR was setup on a tripod over the arbitrary station named B, which was chosen for its good position and clear horizon. In order to ensure that the base receiver was placed over the same station in second session, station B was marked with a nail. The slant antenna height was measured twice from the nail up to the Antenna Reference Point (ARP) and static observations were triggered by pressing the ON/OFF button 3 times within 2 seconds. It should be noted that all observation settings were set prior to measurement by using Topcon Receiver Utility (TRU) software which was installed on FC-5000 field computer. Elevation mask was once again set to 10° while the logging interval was set to 10 seconds. After static observations was started, base receiver was connected to FC-5000 inside Magnet Field software via Bluetooth in order to perform the base start step. For the base reference position, coordinates of station B were used. Since those coordinates were unknown, they were determined with Hiper SR receiver by Autonomous positioning method. Communication link between base and rover receivers was established by using Topcon's patented long-range Bluetooth called LongLink. It enables the communication range of 300 m and is ideal solution for small-scale projects. Rover GNSS receiver Hiper HR was setup on the range pole with bipod support. The bipod was used to get the rover in vertical position and as a support for tilted measurements. After the pole was set in vertical position, "Reset RTK" option inside the field software was triggered. It is the option that resets the RTK engine after which the receiver restarts the initialization process [12]. It was done so the initialization time could be measured by stopwatch installed on a cell phone. Initialization time was measured only once on each station. After all stations have been occupied, static observations were stopped and base receiver was removed from station B. Hiper HR receiver was then connected to CROPOS HPPS and the measuring procedure was repeated. There were no visible problems or difficulties during the first session.

The second session was carried out between 14:00 and 18:00 (UTC) according to the plan. It was performed identically as the first session, starting up with single-base RTK with Autonomous base start method and ending up with networked RTK. However, one problem was encountered during the second session. Tilted measurements could not have been done on station P4 since the software displayed the warning about strong magnetic field. Most likely such a warning was caused by the proximity of the transformer station. Since such stations are much more active during the evening hours (residential area), the mentioned problem hasn't occurred during the first session. According to that, tilted measurements weren't conducted on station P4 in the second session.

7. DATA POST-PROCCESING

7.1. Geodetic network coordinates computation

After all field activities were done, the next step was to perform data post-processing. Firstly, coordinates of geodetic network stations were computed. It was done by post-processing of raw static data (stations S1 and S2) and by computing coordinates of stations P1 – P8 upon measured angles and distances. All the data were processed in Topcon Magnet Office Tools software. Before conducting any processing, 2 VRS and 1 CORS raw data files in RINEX format were downloaded from CROPOS GPPS service. They were imported into software together with Topcon's raw observation files in *.tps format created by Hiper HR and Hiper SR receivers. After processing baselines, fully constrained adjustment was carried out with fixed 2 VRS and 1 CORS stations (control points). Due to short baselines (around 600 m), adjustment provided good position accuracies resulting in 1 mm standard deviation in both horizontal and vertical direction for both stations. Finally, raw observation file from total station was imported and coordinates of remaining stations were computed. The plane coordinates (E, N) were determined in the official coordinate system HTRS96/TM, the heights were determined in HVRS71 system.

7.2. Rover coordinates shift in single-base RTK with Autonomous base start

Since GNSS base RTK receiver was started in Autonomous mode, it was necessary to shift the reference base coordinates to their "truth" coordinates. Such coordinates were determined by static observations during the RTK survey. Since two sessions were performed, there are two sets of coordinates for the same station B. In theory, those two coordinate sets should be identical. However, two static sessions have led to coordinate difference in horizontal (0.5 cm) and vertical direction (1 cm). In case both coordinate sets had been used for the purposes of coordinate shift, it would have led to inconsistent accuracy and precision analysis. Thus, it was decided to use only coordinates of station B provided by static observations in the first session.

After post-processing of static data collected by Hiper SR receiver during the RTK survey in the first session (in the same way as coordinates of stations S1 and S2 were obtained), job file containing all field measurements conducted by a single-base RTK method was imported into Magnet Office Tools. Under a tab named “GPS Occupations”, which contains all stations occupied during the survey, there is a column called “Method” (Figure 4). It describes the way station coordinates are used or determined (Static, Kinematic, Base, Topo). During the survey, “Base1” was the arbitrary name of base reference point, consequently the “Method” for that station was automatically set to “Base” inside the software. In order to perform coordinate shift, it is necessary to change the base reference point from “Base1” to “B”, which is, in this case, the station with accurate coordinates determined in post-processing. Finally, coordinates shift is done by pressing the “Adjustment” key. After that, all stations are placed to their “truth” coordinates. The same procedure was followed for the station coordinates determined by single-base RTK method in the second session.

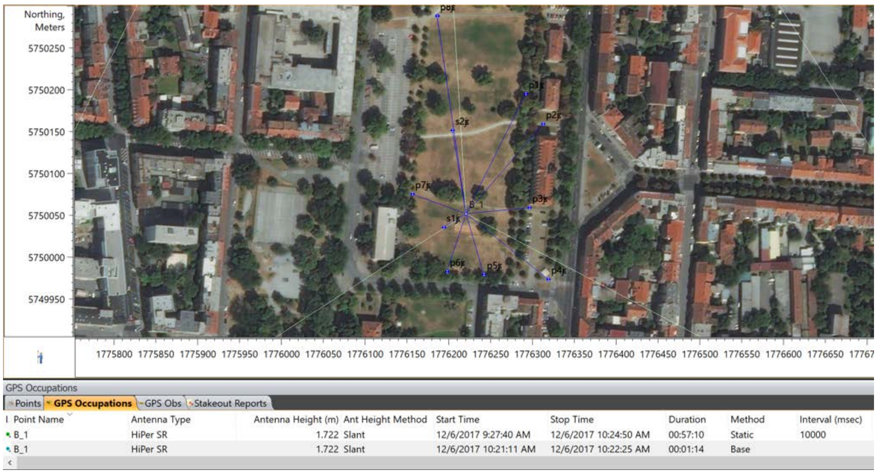

Figure 4. GNSS vectors after coordinate shift carried out in Magnet Office Tools

8. ANALYSIS OF THE OBTAINED RESULTS

After post-processing step, all station coordinates were exported to *.CSV file and imported into Microsoft Excel for further analysis. The analysis of obtained results was divided into three separate segments: coordinate accuracy analysis, coordinate precision analysis and TILT option accuracy analysis. Although the initialization time were also measured in the field, those data are not presented since there is no significant difference between used methods. Both CROPOS HPPS service and single-base RTK method provide the same initialization time of 5-6 seconds on each station and in both sessions.

8.1. Coordinates accuracy analysis

In order to provide valid accuracy analysis, it is necessary to have reference coordinates of occupied stations. Reference coordinates values were determined by GNSS post-processing method (S1, S2) and by total station measurements (P1-P8). Coordinates accuracy was estimated by subtracting the reference coordinates from RTK determined coordinates. Since the complete analysis is too detailed, average, minimum and maximum coordinate deviation values are taken into consideration and are listed below (Table 1 – 4)

Table 1. Coordinates accuracy provided by single-base RTK method during first session

	dN (m)	dE (m)	dH (m)
AVG	0,00	0,00	0,02
MAX	0,03	0,01	0,04
MIN	-0,02	-0,05	0,00
AVG	0,00	0,00	0,02
MAX	0,02	0,01	0,04
MIN	-0,02	-0,02	0,00

Table 2. Coordinates accuracy provided by CROPOS HPPS during first session

	dE (m)	dN (m)	dH (m)
AVG	0,00	-0,01	-0,04
MAX	0,01	0,01	-0,02
MIN	-0,03	-0,03	-0,08
AVG	0,00	-0,01	-0,03
MAX	0,01	0,01	0,00
MIN	-0,02	-0,03	-0,06

Table 3. Coordinates accuracy provided by single-base RTK method during second session

	dE (m)	dN (m)	dH (m)
AVG	-0,01	0,00	0,02
MAX	0,01	0,06	0,10
MIN	-0,05	-0,03	-0,02
AVG	-0,01	0,01	0,02
MAX	0,01	0,06	0,04
MIN	-0,04	-0,01	0,00

Table 4. Coordinates accuracy provided by CROPOS HPPS during second session

	dE (m)	dN (m)	dH (m)
AVG	-0,01	0,01	-0,04
MAX	0,04	0,05	-0,02
MIN	-0,04	-0,01	-0,06
AVG	0,00	0,01	-0,04
MAX	0,02	0,03	0,00
MIN	-0,02	-0,01	-0,06

White table part represents the values where all coordinate deviations were taken into account (from all 5 observations on each station), while blue table part represents the values where only observations with vertical pole positions were considered and TILT option wasn't used. The purpose of such distinction was to estimate whether TILT option affects the overall accuracy. Presented tables show that there is no significant difference in terms of accuracy between two tested methods. Furthermore, coordinate differences obtained in two sessions can be considered insignificant. Single base RTK method performs slightly better in terms of accuracy, with average deviation values of 1 cm horizontally and 2 cm vertically. Only one deviation value could be distinguished as significant. It is the maximum height difference (0.10 m) value in Table 3. The reason for such deviation could be slightly higher VDOP value (3.09) visible in job file for the measurement made on station P1. It is also important to point out that TILT option does not affect coordinate accuracy since the deviations values are almost the same in both blue and white table parts.

8.2. Coordinate precision analysis

Precision analysis can be done when at least two observation sessions were made on the same station. Coordinate precision is estimated by subtracting the second session coordinate values from the first session coordinate values. Similar to accuracy analysis, only average, minimum and maximum coordinate difference values are presented below (Table 5 – 6).

Table 5. Coordinate precision – single base RTK methos

	dE (m)	dN (m)	dH (m)
AVG	0,002	-0,002	0,002
MAX	0,051	0,028	0,044
MIN	-0,025	-0,057	-0,074
AVG	0,007	-0,007	0,004
MAX	0,045	0,008	0,040
MIN	-0,016	-0,057	-0,013

Table 6. Coordinate precision – CROPOS HPPS

	dE (m)	dN (m)	dH (m)
AVG	0,007	-0,024	0,000
MAX	0,043	0,015	0,039
MIN	-0,032	-0,061	-0,034
AVG	0,000	-0,017	0,005
MAX	0,023	0,015	0,039
MIN	-0,022	-0,061	-0,017

The white and blue table part contents are analogous to those in accuracy analysis. It can be argued that coordinate repeatability is quite satisfying, despite observation conditions during the second session. Lower satellite number and less favorable conditions (in terms of clear horizon and obstacles) on some stations haven't affected the results. Minimum height difference value (-0.074 m) in Table 5 should be pointed out since it is the result of measurement error on station P1 described in accuracy analysis. Another significant value is the minimum Northing difference (-0.061 m) in Table 6. It is about the observation on station P3. It is not possible to determine the cause of this error since the observation conditions were optimal when this station was occupied. It is also meaningful to notice that the observation was done with vertical pole position, which means that TILT option is not responsible for such coordinate difference.

Despite the above mentioned, data provided by both methods are equally satisfactory for the practical purposes. Just like with accuracy analysis, TILT option does not affect station coordinate precision in a negative way.

8.3. TILT option accuracy analysis

Accuracy analysis of TILT option was done by estimating what would have been the position error of point in case the TILT option hadn't been used in order to compensate tilted measurement, and by comparing that value to the true position error. True error was calculated by subtracting the coordinate obtained by tilted measurement from coordinate obtained by vertical pole position observation. In order to calculate the "expected error" value, antenna height needs to be known. During the entire survey, antenna height was set to 2,000 m. Complete analysis is shown in Table 7 and Table 8. It is important to mention that all tilt values were completely coincidental and they vary from 2 to 9 degrees. There were no rules regarding the tilting of the range pole. It is obvious that TILT option was able to compensate tilted range pole measurements very successfully. Maximum error values during first and second sessions were 5 cm and 7 cm, respectively. Average position error is 1 cm for the first session and 2 cm for the second session. According to that, it can be argued that there is no significant difference between TILT option performance independently of positioning method (single-base RTK, CROPOS HPPS) or measurement session.

Table 7. TILT option accuracy analysis – 1st session

	Single base - session 1			CROPOS HPPS - session 1		
#	TILT [°]	Expected error	True error	TILT [°]	Expected error	True error
P1_i	6	0,21	0,01	3	0,10	0,01
P1_j	9	0,31	0,02	7	0,24	0,02
P1_s	5	0,17	0,02	3	0,10	0,01
P1_z	7	0,24	0,01	5	0,17	0,01
P2_i	5	0,17	0,02	5	0,17	0,03
P2_j	7	0,24	0,04	6	0,21	0,02
P2_s	5	0,17	0,01	4	0,14	0,03
P2_z	6	0,21	0,02	4	0,14	0,02
P3_i	6	0,21	0,02	4	0,14	0,02
P3_j	5	0,17	0,03	5	0,17	0,04
P3_s	4	0,14	0,01	2	0,07	0,02
P3_z	3	0,10	0,04	4	0,14	0,05

P4_i	4	0,14	0,02	4	0,14	0,01
P4_j	6	0,21	0,04	5	0,17	0,01
P4_s	2	0,07	0,02	1	0,03	0,01
P4_z	4	0,14	0,02	5	0,17	0,01
P5_i	4	0,14	0,01	3	0,10	0,01
P5_j	6	0,21	0,00	7	0,24	0,01
P5_s	2	0,07	0,01	2	0,07	0,01
P5_z	4	0,14	0,01	5	0,17	0,02
P6_i	5	0,17	0,01	4	0,14	0,00
P6_j	6	0,21	0,02	7	0,24	0,00
P6_s	5	0,17	0,01	3	0,10	0,01
P6_z	5	0,17	0,01	4	0,14	0,01
P7_i	3	0,10	0,01	3	0,10	0,01
P7_j	6	0,21	0,01	7	0,24	0,02
P7_s	3	0,10	0,01	4	0,14	0,01
P7_z	4	0,14	0,01	4	0,14	0,01
P8_i	4	0,14	0,02	3	0,10	0,01
P8_j	6	0,21	0,01	7	0,24	0,02
P8_s	2	0,07	0,01	3	0,10	0,01
P8_z	5	0,17	0,01	4	0,14	0,01
S1_i	8	0,28	0,02	4	0,14	0,01
S1_j	6	0,21	0,01	7	0,24	0,01
S1_s	6	0,21	0,02	3	0,10	0,02
S1_z	5	0,17	0,01	5	0,17	0,01
S2_i	8	0,28	0,01	2	0,07	0,02
S2_j	8	0,28	0,01	9	0,31	0,01
S2_s	3	0,10	0,00	3	0,10	0,02
S2_z	5	0,17	0,01	6	0,21	0,01

Table 8. TILT option accuracy analysis – 2. session

	Single base - session 2			CROPOS HPPS - session 2		
#	TILT [°]	Expected error	True error	TILT [°]	Expected error	True error
P1_i	7	0,24	0,00	5	0,17	0,01
P1_j	8	0,28	0,01	7	0,24	0,02
P1_s	5	0,17	0,02	6	0,21	0,03
P1_z	6	0,21	0,01	4	0,14	0,03
P2_i	5	0,17	0,01	5	0,17	0,02
P2_j	8	0,28	0,03	5	0,17	0,05

P2_s	7	0,24	0,02	6	0,21	0,02
P2_z	4	0,14	0,00	5	0,17	0,05
P3_i	6	0,21	0,03	4	0,14	0,04
P3_j	7	0,24	0,01	7	0,24	0,04
P3_s	4	0,14	0,01	3	0,10	0,03
P3_z	5	0,17	0,01	5	0,17	0,03
P4_i	-	-	-	-	-	-
P4_j	-	-	-	-	-	-
P4_s	-	-	-	-	-	-
P4_z	-	-	-	-	-	-
P5_i	5	0,17	0,01	6	0,21	0,02
P5_j	7	0,24	0,01	7	0,24	0,04
P5_s	3	0,10	0,00	4	0,14	0,02
P5_z	5	0,17	0,01	4	0,14	0,01
P6_i	5	0,17	0,02	6	0,21	0,01
P6_j	7	0,24	0,04	7	0,24	0,02
P6_s	3	0,10	0,01	4	0,14	0,02
P6_z	5	0,17	0,04	4	0,14	0,01
P7_i	4	0,14	0,00	4	0,14	0,01
P7_j	6	0,21	0,01	7	0,24	0,00
P7_s	4	0,14	0,01	5	0,17	0,01
P7_z	5	0,17	0,01	5	0,17	0,02
P8_i	5	0,17	0,07	5	0,17	0,02
P8_j	7	0,24	0,06	5	0,17	0,03
P8_s	5	0,17	0,07	5	0,17	0,02
P8_z	5	0,17	0,06	4	0,14	0,04
S1_i	4	0,14	0,01	5	0,17	0,02
S1_j	6	0,21	0,01	6	0,21	0,03
S1_s	4	0,14	0,01	5	0,17	0,01
S1_z	4	0,14	0,00	6	0,21	0,03
S2_i	4	0,14	0,01	4	0,14	0,02
S2_j	8	0,28	0,02	7	0,24	0,02
S2_s	3	0,10	0,00	2	0,07	0,01
S2_z	7	0,24	0,01	4	0,14	0,01

9. CONCLUSION

The aim of this paper was to examine two different RTK method and TILT option. Tested methods were 'Autonomous base start' method with coordinate shift and CROPOS HPPS (Networked RTK). For the purposes of field investigations and subsequent accuracy analysis, a geodetic network was established and coordinates determined. Moreover, in order to conduct precision analysis, all station coordinates were determined during two independent sessions. Those analyses enabled deriving valid arguments about used methods.

Today, Autonomous base start method is not regularly used by surveyors due to the existence of GNSS networks. Nevertheless, certain situations require a single-base RTK method to be utilized. Autonomous base start method simplifies the field work and allows the surveyor to get their job done faster due to the fact that it eliminates the need for known base station reference coordinates. Furthermore, such approach enables the surveyor to set up the base receiver on any suitable location. Although this method requires post-processing, it can be done quite simple and fast. Results obtained by Autonomous base start method meet the desired accuracy level of 1 cm in horizontal and 2 cm in vertical direction. Level of coordinate precision is also very high, resulting in average values of 1 cm or less. Those results indicate that this method could be utilized for not only the cadastral needs, but also for the purposes of more precise geodetic tasks.

CROPOS HPPS is most widely used RTK positioning method in Croatia. CROPOS network covers the whole state territory, but its significant limitation is a mobile Internet signal coverage. Obtained coordinate accuracy assessment indicate that CROPOS HPPS meets its specification, resulting in 1-2 cm accuracy in horizontal and 3-4 cm in vertical direction. Average coordinate precision value is 2 cm, which is also very satisfying. However, it should be noted that such results are probably highly influenced by proximity of one of CROPOS reference stations. The distance between nearest CORS and location of the surveyed area was only 600 m. In order to get a true evaluation about CROPOS HPPS service accuracy and precision, the survey should be carried out in a location which is equally remote from all three used reference stations. In spite of that, obtained results definitely wouldn't be considerably worse than those presented in the paper.

Finally, the goal was to test the TILT option which was integrated into Topcon's newest GNSS receiver Hiper HR. This technology was tested thoroughly and has shown very high level of accuracy, resulting in average values of position errors of 1-2 cm. Such results suggest that this option is accurate enough to be used in practice. During the field work it was observed that TILT option makes RTK survey much faster and easier since operator doesn't have to concentrate on maintaining the range pole in vertical position. Tilt compensation proved to work really fast. The only significant disadvantage of used TILT option was the necessity to perform digital compass calibration. Although such procedure takes only about 2 minutes, it definitely forms an obstacle for some surveyors. Future progress and development of GNSS+INS integration will certainly lead to standardization of such technology. It can be argued that most of future GNSS receivers will rely on such integration.

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