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EXPERIMENTAL RESEARCH OF THE ACCURACY OF POSITIONING USERS IN THE NETWORK RTK MODE

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Introduction

Among all services which provide the Ukrainian networks of GNSS base stations, the special place is taken by issue of correcting information for RTK mode realization. Popularity of RTK – corrections can be explained to that users can directly in field getting coordinates of points, and their measurement time will be significantly less than in the post processing mode. Users can obtain the correction information as from a single base station of network and formed by appropriate network methods. Network corrections allow to receive precise coordinates on wide area, avoiding thus increase of position error at moving away from the base station. [1].

There are different ways of formation of network RTK – corrections: Flachen-Korrektur Parameter (FKP), Virtual Reference Station Method (VRS), MAX and i-MAX.

The aim of the work

The aim of this work is estimation the accuracy of network RTK measurements depending on the distances between base stations forming a network segment and relative positioning of base stations in network.

Experimental researches

For experimental researches precision of positioning in the network RTK mode used software package GNSS Spider developed by Leica Geosystems. Experimental researches of accuracy were performed using information from NGC.NET – GNSS network of base stations in Kharkiv region [2]. Communication between all base stations of a network and the server on which the software package GNSS Spider is installed, was performed by leased line connection. Thus the information from base stations in real time transferred to the server in a Leica Geosystems firm format.

By administrators of a network the base stations were merged in the corresponding cells necessary for perform experimental research. Cell is a segment of the network, including several adjacent base stations. The cell can consist of three and more adjacent base stations. Further on networks NTRIP caster were created mount points through which users can access to the network corrections which formed the base stations of a particular cell. For access of users to NTRIP to caster the corresponding accounts were created.

Experiments were performed in the following network cells:

1. The segment of a network consisting of base stations, located in the settlements: Zolochev, Volchansk, Chuguev, Valky. In this case the maximum distance between the base stations ("Valky " - "Volchansk") is 107 km. Experimental researches of the accuracy of determining the coordinates of users using network RTK - corrections were performed in the city of Kharkov. Location of base stations forming cell and the mobile receiver are shown in Fig. 1

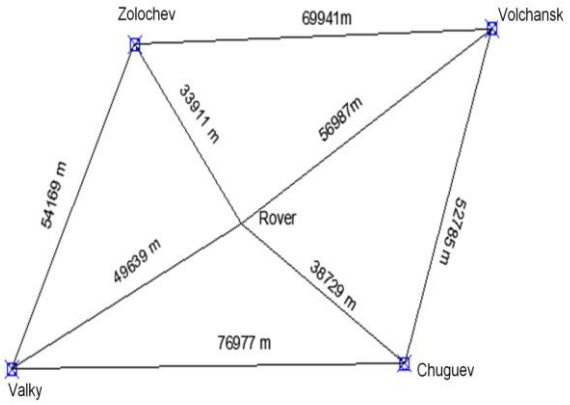

Fig.1 Location of base stations forming cell number 1 and the mobile receiver

2. The segment of a network consisting of base stations, located in the settlements: Valky, Zolochev, Volchansk, Kupiansk, Izium, Pervomaiskyi. In this case the maximum distance between the base stations is more than 150 km. The aim of this experiment is estimation the accuracy of network RTK measurements depending on relative positioning of base stations in segment. Experimental researches of the accuracy of determining the coordinates of users using network RTK - corrections were performed in the city of Kharkov in place of the experiment 1. (Fig. 2)

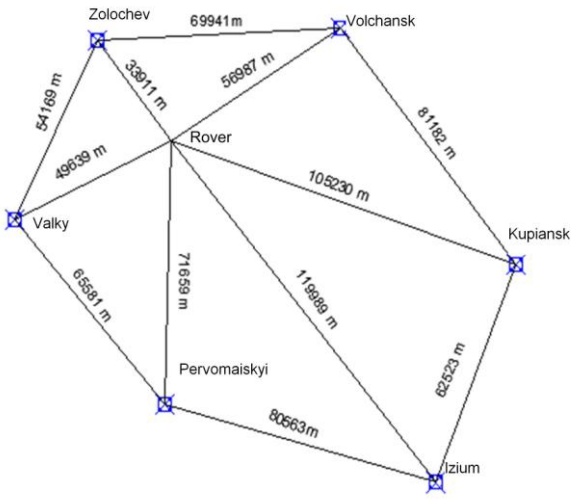

Fig.2 Location of base stations forming cell number 2 and the mobile receiver

3. The segment of a network consisting of base stations, located in the settlements: Pervomaiskyi, Chuguev, Kupiansk, Izium. In this case the maximum distance between the base stations is more than 110 km. Experimental researches of the accuracy of determining the coordinates of users using network RTK corrections were performed in the geometric center of the shape formed by the base stations (Fig. 3).

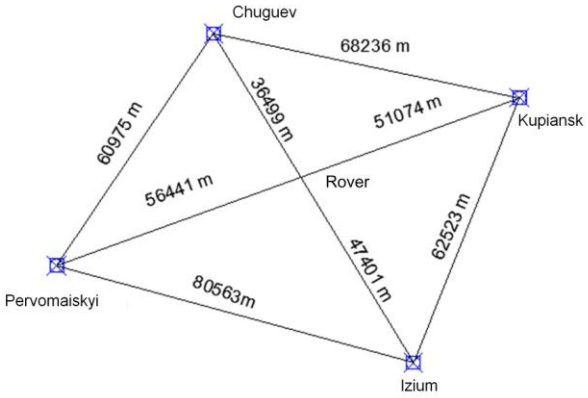

Fig.3 Location of base stations forming cell number 3 and the mobile receiver

In all cases, the choice of areas for experimental researches took into account such factors as the existence of an open sky and a steady job GPRS link.

For estimation the accuracy of the coordinates of points reference points were created. For this purpose, in the place of research, on the reference point mounted dual-frequency GNSS receiver. Receiver collected data in static mode for at least 4 hours. Thus was performed surveying reference point.

GNSS receiver has been configured as follows: recording interval - 5 sec., elevation mask - 10 degrees. Then on the reference points were mounted RTK rovers, which perform a series of measurements:

1. Connecting to the mount point which provides network corrections with the use of MAX technology. A series of at least 10 measurements was performed. For each measurement was limitation on time (15 epochs).

2. Connecting to the mount point which provides network corrections with the use of i-MAX technology. A series of at least 10 measurements was performed. For each measurement was limitation on time (15 epochs).

3. Connecting to the mount point which provides network corrections with the use of FKP technology. A series of at least 10 measurements was performed. For each measurement was limitation on time (15 epochs).

4. Connecting to the mount point which provides network corrections with the use of Virtual RS technology. A series of at least 10 measurements was performed. For each measurement was limitation on time (15 epochs).

Information from the mount points, which transfer network corrections using technologies Virtual RS, MAX, i-MAX, has been available in the format RTCM 3.1. Information from the mount points, which transfer network corrections using technologies FKP, has been available in the format RTCM 2.3.

Communication with NTRIP caster was performed using a mobile internet company "Kyivstar".

Final processing of measurements was carried out at office. Coordinates of reference points were defined by processing the data of measurements with respect to the nearest base station network. Then coordinates of reference points and coordinates of points obtained by RTK survey were compared.

For experimental researches used GNSS receiver NetRover developed by Leica Geosystems. The Leica Viva NetRover is optimized for RTK network use and integrates the latest technology from Leica Geosystems. All components work together, creating a lightweight and cable-free network rover. The Leica Viva NetRover consists of a GS08 GNSS receiver (GNSS module) and a CS10 3.5G field controller to create an easy to use all-in-one GNSS Network Solution. Communication between the field controller and GNSS module is performed by Bluetooth technology. On the field controller used software Leica SmartWorx Viva LT, with which users can control the GNSS module. The field controller has a fully integrated high-speed 3.5G modem to connect to RTK reference networks and allow mobile broadband internet connectivity for field-to-office data transfer. In addition to 3.5G, the field controller can also include Bluetooth, WiFi and TPS radio for further connectivity. With the unique intenna technology, antennas are out of sight and cannot be forgotten, broken or lost. Leica Viva NetRover helps users to complete their measurements tasks by automatically connecting to any

reference station network. With full support of the RTCM 3.1 transformation message, it is no longer necessary to measure control points for the determination of a local transformation, saving time and reducing errors. The main technical characteristics of NetRover are presented in Table 1.

Table 1

NetRover – Technical Specifications

No. of channels	120 channels
Satellite signals tracking	GPS: L1, L2, L2C (C/A, P, C Code) GLONASS: L1, L2 (C/A, P narrow Code) SBAS: WAAS, EGNOS, GAGAN, MSAS
Accuracy (Post Processing static mode)	Horizontal: 3 mm + 0.5 ppm Vertical: 6 mm + 0.5 ppm
Accuracy (RTK Static mode)	Horizontal: 5 mm + 0.5 ppm Vertical: 10 mm + 0.5 ppm Compliant to ISO 17123-8 standard
RTK data formats	Leica proprietary formats (Leica, Leica 4G), CMR+, RTCM2.x, RTCM3.x, full support of RTCM 3.1 transformation message
Network positioning	VRS, FKP, iMAX, MAX, Nearest Station
Temperature operating	-30°C to +60°C
Sealed against water, sand and dust	IP67 (CS) / IP68 (GS08) according IEC60529 and MIL STD 810F – 506.4-I, MIL STD 810F – 510.4-I and MIL STD 810F – 512.4-I Protected against blowing rain and dust Protected against temporary submersion into water: Max. depth 1,0 m (CS) / 1,4 m (GS08)
Internal power supply Operation time	Removable & rechargable Li-Ion battery, 2.6 Ah / 7.4 V (1x in CS10 and 1x in GS08) 10 hours GNSS only, 7 hours GNSS RTK

Processing of results of experimental researches

Processing of results was performed as follows [3]. For processing coordinates of reference points used software package LGO which developed by Leica Geosystems. Coordinates of points measured in RTK mode was imported on PC directly from the GNSS receiver.

Coordinates which obtained in post processing mode was adopted as reference values [4]. The coordinates which was measured in RTK mode, compared with reference values.

There are a number of applications, for which it is necessary to determine the components of the planned coordinates and altitude coordinates component (for example, topographic and geodetic surveys) [5]. So, it is necessary to estimate accuracy of the determination, planned components of coordinates and altitude coordinates components. For this purpose measured and reference values of coordinates were transformed from geodetic system of coordinates (BLH) to the local system of coordinates (XYH) received on the basis of a cylindrical projection of Merkator.

Further, the following calculations were made. Differences were determined for each coordinate component (Equation. 1):

$$\begin{aligned} \Delta X &= X_{ref} - X_{meas}, \\ \Delta Y &= Y_{ref} - Y_{meas}, \\ \Delta H &= H_{ref} - H_{meas}, \end{aligned} \quad (1)$$

where X_{ref}, Y_{ref}, H_{ref} – reference value of coordinates;

X_{meas}, Y_{meas}, H_{meas} – the measured value of coordinates.

The difference between measured and reference coordinates calculated by the equation:

$$\Delta XY = \sqrt{(\Delta X)^2 + (\Delta Y)^2} \quad (2)$$

In addition, average values of coordinates on all measurements were calculated and there were average divergences:

$$\begin{aligned} \Delta X_{av} &= X_{ref} - X_{av}, \\ \Delta Y_{av} &= Y_{ref} - Y_{av}, \\ \Delta H_{av} &= H_{ref} - H_{av}, \\ \Delta XY_{av} &= \sqrt{(\Delta X_{av})^2 + (\Delta Y_{av})^2}, \end{aligned} \quad (3)$$

Also were defined values the root mean square deviation (RMS) σ_{XY}, σ_H estimated coordinates relative to their average value.

In the table 2 presents the results of measurements which was performed in a network cell consisting of base stations located in the settlements: Zolochev, Volchansk, Chuguev, Valky. In the table 3 presents the results of measurements which was performed in a network cell consisting of base stations located in the set-

tlements: Valky, Zolochev, Volchansk, Kupiansk, Izum, Pervomaiskyi. In the table 4 presents the results of measurements which was performed in a network cell consisting of base stations located in the settlements: Pervomaiskyi, Chuguev, Kupiansk, Izum.

Table 2

Results of measurements which was performed in a network cell consisting of base stations located in the settlements: Zolochev, Volchansk, Chuguev, Valky

RTK network corrections	ΔXYav, м	ΔHav, м	δ_{xy}, м	$\delta_{н}$, м
i-MAX	0.005	0.013	0.005	0.009
MAX	0.007	0.013	0.005	0.015
Virtual RS	0.027	0.029	0.013	0.017
FKP	0.051	0.075	0.098	0.202

Table 3

Results of measurements which was performed in a network cell consisting of base stations located in the settlements: Valky, Zolochev, Volchansk, Kupiansk, Izum, Pervomaiskyi

RTK network corrections	ΔXYav, м	ΔHav, м	δ_{xy}, м	$\delta_{н}$, м
i-MAX	0.005	-0.022	0.006	0.010
MAX	0.016	-0.004	0.008	0.009
Virtual RS	0.005	0.007	0.004	0.011
FKP	0.004	0.021	0.007	0.011

Table 4

Results of measurements which was performed in a network cell consisting of base stations located in the settlements: Pervomaiskyi, Chuguev, Kupiansk, Izum

RTK network corrections	ΔXYav, м	ΔHav, м	δ_{xy}, м	$\delta_{н}$, м
i-MAX	0.01	-0.044	0.016	0.017
MAX	0.009	-0.051	0.02	0.03
Virtual RS	0.009	-0.01	0.004	0.006
FKP	0.036	0.065	0.08	0.09

Conclusions

1. The type of RTK network corrections doesn't influence to the accuracy of measurements. An exception is the FKP technology, the use of which was noticed insignificant degradation positioning accuracy;

2. If distances between adjacent base stations in the network cell does not exceed 110 km. possible to obtain centimeter level of accuracy. It is enough for performance of the applied tasks connected with geodetic survey;

3. If distances between adjacent base stations in the network cell does not exceed 110 km. the relative positioning of the mobile receiver and base stations forming a cell doesn't influence the accuracy of determination of coordinates in a network RTK mode.

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Experimental research of the accuracy of positioning users in the network RTK mode

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Performed a series of experimental research the accuracy of the location of users using different types of network RTK corrections generated by the existing network of GNSS base stations. The results of the measurements and the estimation accuracy are presented.