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Evaluation of the RTK receiver's capability of determination the accurate position

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Abstract. The main aim of this experiment was to compare low-cost RTK receiver, that possible can be used for precise agricultural application, another that is currently used for these applications and the third one that suits for static measurement the most and gives the reference point for results comparison. The main idea of this research was to compare the measured positions during static measurement of RTK receivers. Were discovered that the receiver Trimble 750 was not able to work in fix mode (mode when the RTK receivers are capable to measure the most accurately) for the whole time. This fact affects the results from whole measurement and showed that errors were a little higher than producers specifies. The low-cost receiver u-Blox C94-M8P showed satisfying results when in most cases it was capable to solve the problem of ambiguity integer phases. The main parameters in this work that were counted and summarized were: accuracy, precision, RMS error, system status ratio and number of satellites.

Key words: localization, positioning, survey-ing, accuracy, precision, agriculture, RTK, VRS.

INTRODUCTION

Nowadays, one of the most accurate localization methods which is available on market is RTK (Real Time Kinematic). This system uses signal correction by reference stations for more accurate positioning (Feng & Wang, 2007). This method, which has according to its producers the precision around 20 millimetres, already found new uses in many fields of industry. The RTK method which is increasingly common is used for precision farming purposes as an automatic guidance of agricultural machines. RTK system as all satellite navigation systems is affected by different influences that cause errors. These influences are: ephemeris data error, satellite clock error, ionosphere influence, troposphere influence, antennas construction and placement (including multipath error) (Tamura et al., 2002). For minimizing these errors RTK system typically involves two GNSS receivers: the base station and one or more rovers (including technology for transmission of correction data). During operation, the base station and the rover are observing a common set of satellites and simultaneously the base station sends its position and satellite observation to the rover. The rover combines these data with its own satellite observations and determines its position in real time (Berber & Arslan, 2013).

In a certain way the classic principle, which is mentioned above, is simple but still have some disadvantages. The main disadvantage is the requirement of the base station to be located within ten kilometres or in some cases five kilometres close to rover (Mageed, 2013; Carballido et al., 2014). The precision decreases when required maximal distance from the base station increases.

However, the method called Virtual Reference Station (VRS) can solve the problem of the required proximity of base with higher efficiencies and lower costs. The main idea is to generate virtual reference station that simulates reference/base station nearby the user receiver. The wide network covered by multiple reference stations is used to create the virtual station that allows doing precise positioning everywhere in a wide area only by receiving the correction data (Retscher, 2002). The communication network is performed by using common phone data lines.

More affordable low-cost systems emerged on the market in the course of development of RTK receivers. However, it appeared that these low-cost systems exhibit characteristics that negatively affect the accuracy of position determination (Beran et al., 2005). The worse ability of reaching the fix mode is more common for cheaper variants. Probably it is given by the receiver's inability to solve the problem of ambiguity phases.

The main aim of this research was to verify and to compare the properties of modern RTK systems from different price relations. The method for this research was to compare the measured positions during static measurement of RTK receivers. In this research was verified that individual receivers perform different deviations and in most cases do not reach parameters of errors mentioned by producers.

MATERIALS AND METHODS

The main idea of this experiment was to compare low-cost RTK receiver, that possible can be used for precise agricultural application, with another receiver that is currently used for these applications and with the third one which suits the most for static measurement and gives the reference point for results comparison. The reference point was generated from long-term measurement (lasted for 21 hours) from Trimble 5800 receiver.

Three different RTK receivers were chosen for this experiment. All of them used correction data from VRS (Virtual Reference Station) through NTRIP clients (Network Transport of RTCM data over IP) in RTCM 3.1 format and sample rate 1 Hz. Placement of VRS was provided by service 'Trimble VRS Now' in closer area of measurement.

The first device was low-cost receiver u-Blox C94-M8P-C with Novatel GPS-702-GG antenna. The second receiver was Trimble CFX-750 with Trimble AG25 GNSS antenna that is commonly used for precise agricultural applications. And the third receiver was Trimble 5800 set with own built-in antenna and data controller Trimble TSC2 that is more often used for static positioning for example for geodetic targeting positioning.

The notebook model Lenovo E540 was used during measurement for more functions. During all measurements, this notebook was connected on the internet for receiving correction signal for the u-Blox M8P receiver. This correction signal was obtained through the NTRIP client in native application u-center v8.24 and in the same application the logging of NMEA GNGGA messages was conducted. In case of Trimble 750 receiver was used RTKM2 v.01 modem with own NTRIP client for transmission of data corrections. The NMEA messages in the GPGGA protocol format were logged from the serial line to notebooks console in 9,600 baud rate. Trimble 5800 setting communication and logging were provided by Trimble TSC2 with its own modem and NTRIP client through the Bluetooth transmission. Then data exported from controller were obtained by internal software to the computer. All three receivers were receiving and recorded in the period of one second.

The measurements were realized in areal of The Czech University of Life Sciences on the roof of the building of The Faculty of Engineering. The whole experiment took two days with three measurements. Two measurements were realized on the first day and the third measurement was realized the next day. All three measurements were running for one hour period with sampling rate of obtained positions one sample per second (1 Hz). The received signal of all receivers was obtained from sufficient number of satellites, apparent from the Table 1 in values μ_s. Measurements of Horizontal Dilution of Precision (HDOP) were different for each receiver, in average: u-Blox M8P achieved 0.72, Trimble 750 achieved 1.15 and Trimble 5800 achieved 2.24. The antennas were placed in the line on the distance of five meters from each other (further in text: 'PLACE A' and 'PLACE B'). Three antennas were attached to wood construction on the same line on the distance of 0.7 meters. The construction was arranged in a way to be stable and ensure manipulation with antennas without changing the distance from each other. First and third (from day two) measurements were realized on 'PLACE A' and the second on 'PLACE B' (Fig. 1).

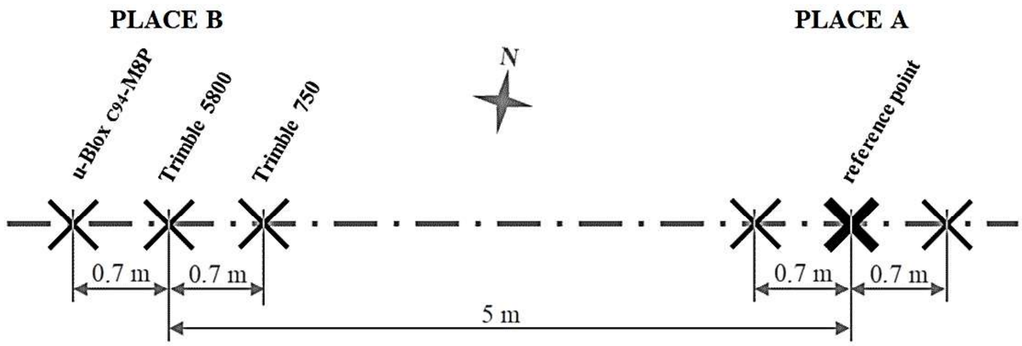

Figure 1. Placement of receiver antennas.

From data processing perspective all measured coordinates were needed to convert to the Cartesian coordinate system END (East-North-Down) for future calculations of horizontally positioning errors. The orientation of this coordinate system allows calculating of the positioning deviations in meters with knowledge of the azimuth and ignored altitude. The logged coordinates by all three receivers was in WGS84 (World Geodetic System 1984) format, i.e. in the spherical coordinate system. The first coordinates were converted to the ECEF (Earth-centred, Earth-Fixed) Cartesian coordinate system and then this obtained cloud of points was rotated to END coordinate system. Then the determination of horizontal distance was calculated for each coordinate from the data set of one measurement (in ENU) toward to the created reference point. The reference point was determined for each antenna placement by deducting of the antennas place offsets on the line (Fig. 1) and deducting of previous calculated azimuth. Were obtained the azimuth from two averaged coordinates in END. Both coordinates were surveyed by receiver Trimble 5800 from 3,600 samples of measurement.

Theory and modelling

For evaluation of the results were chosen these parameters:

1. Accuracy (μ_{err}) – sample mean of deviations from reference point (error offset):

$$\mu_{err} = \frac{1}{n}\sum_{i=1}^{n} d_i \tag{1}$$

where n – data-set of measured samples; d_i – deviation from reference point at the i index of a data-set, m.

2. Precision (σerr) – standard deviation of error (stability of positioning):

$$\sigma_{err} = \sqrt{\frac{\sum_{i=1}^{n}(d_i - \mu_{err})^2}{n-1}} \tag{2}$$

where n – data-set of measured samples; d_i – deviation from reference point at the i index of a data-set; μ_{err} – sample mean of deviations from reference point, m.

3. RMS error (RMSerr) – value specified by the manufacturer (metric emphasizing large errors):

$$\mathrm{RMS}_{err} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} {d_i}^2} \tag{3}$$

where n – data-set of measured samples; d_i – deviation from reference point at the i index of a data-set, m.

4. System status ratio (SSR) – ability of the system to solve the problem of ambiguity integer phases:

$$\mathrm{SSR} = \frac{m}{n} * 100 \tag{4}$$

where n – data-set of measured samples; m – data-set of samples with solved ambiguity integer phases, %.

5. Number of satellites (µs) – the average value of the number of received GPS satellites:

$$\mu_{\mathbf{s}} = \frac{1}{n}\sum_{i=1}^{n} s_i \tag{5}$$

where n – data-set of measured samples; s – number of received satellites at the i index of a data-set, -.

RESULTS AND DISCUSSION

All the monitored parameters are summarized in the table (Table 1). For better presentation, ratings were divided into these three categories:

All measurement – represents all values from the range of measurement.

Without fix – represents the values when the receiver was not capable to solve the problem of ambiguity integer phases. It includes states 'RTK float' and 'Only GPS'.

Fixed – represents the values when the receiver was capable to solve the problem of ambiguity integer phases, i.e. in a mode when the RTK receivers are capable to measure the most accurately. This category includes only state 'RTK float'.

Due to the impossibility of logging except the fixed positions by Trimble 5800 receiver (due to logging principle of the receiver), only these positions were evaluated. The results of all three measurements and their average values were always written to the table below.

Table 1. Measured values overview

		Whole measurement		Without fix		Fixed		
	*)	u-Blox M8P	Trimble 750	u-Blox M8P	Trimble 750	u-Blox M8P	Trimble 750	Trimble 5800
μ_{err} [m]	1st	0.013	0.188	0.026	1.096	0.013	0.008	0.009
	2nd	0.012	0.223	0.175	1.293	0.010	0.010	0.013
	3rd	0.016	0.080	0.092	1.318	0.009	0.009	0.012
	mean	**0.014**	**0.164**	**0.098**	**1.236**	**0.011**	**0.009**	**0.011**
σ_{err} [m]	1st	0.004	0.406	0.005	0.080	0.004	0.005	0.005
	2nd	0.027	0.480	0.132	0.103	0.006	0.006	0.006
	3rd	0.019	0.299	0.066	0.199	0.004	0.006	0.007
	mean	**0.014**	**0.156**	**0.122**	**1.282**	**0.010**	**0.009**	**0.012**
	$1\sigma_{err}$	0.014	0.156	0.122	1.282	0.010	0.009	0.012
	$2\sigma_{err}$	0.028	0.311	0.243	2.565	0.020	0.019	0.024
	$3\sigma_{err}$	0.042	0.467	0.365	3.847	0.030	0.028	0.036
RMS_{err} [m]	1st	0.014	0.188	0.027	1.099	0.014	0.009	0.010
	2nd	0.030	0.223	0.219	1.297	0.011	0.011	0.014
	3rd	0.025	0.080	0.113	1.333	0.014	0.011	0.014
	mean	**0.023**	**0.164**	**0.120**	**1.243**	**0.012**	**0.010**	**0.013**
SSR [%]	1st	-	-	-	-	99.31	83.44	81.00
	2nd	-	-	-	-	98.39	83.36	96.58
	3rd	-	-	-	-	96.72	94.61	97.61
	mean	**-**	**-**	**-**	**-**	**98.14**	**87.14**	**91.73**
μ_s [-]	1st	8.015	7.918	7.800	8.000	8.017	7.901	7.568
	2nd	7.743	7.948	8.241	9.302	7.735	7.677	6.916
	3rd	7.976	7.891	8.119	8.000	7.971	7.885	7.224
	mean	**7.911**	**7.919**	**8.053**	**8.434**	**7.907**	**7.821**	**7.236**

*) measurement number.

The means of the errors (μ_{err}, σ_{err} and RMS_{err}) showed that receivers are capable to measure better in a state of 'Fixed' than in a state of 'Without fix'. In case of u-Blox M8P receiver the all of three monitored error parameters were more than eight times higher. In case of Trimble 750 receiver it was even more than one hundred times higher in all three parameters representing the errors. Following two figures of graphs better show the described phenomenon (Figs 2 and 3):

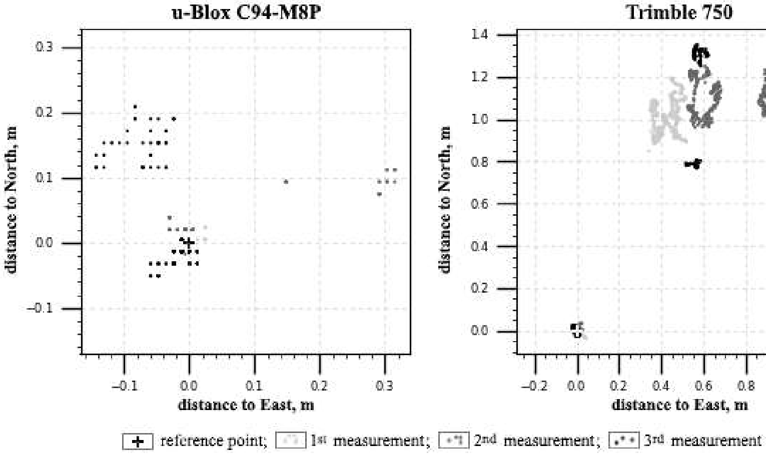

Figure 2. Positioning of the wholle measurement.

If we filtered out the samples when the receivers, were not capable to solve the complete ambiguity of the phase of carrier wave, from all measurement (Fig. 2) we obtained the cloud of points concentrated closer around the reference point (Fig. 3). Then the results of measured errors of all of three receivers had the similar character. The best in this evaluation was Trimble 750 which had the best result of all three error parameters. In all of three errors parameters were in the second place u-Blox M8P and the worst was Trimble 5800. The deviations in this evaluation were small in opposite to errors from whole period of measurement.

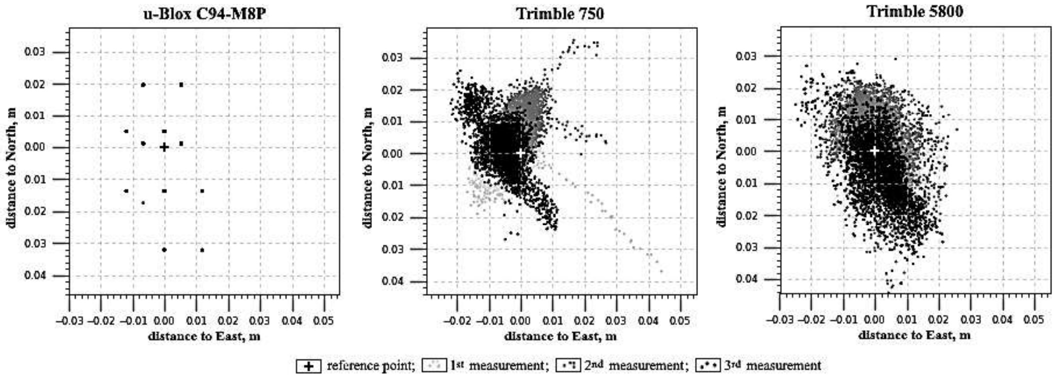

Figure 3. Positioning during fixed ambiguidy.

As we can see u-Blox M8P receiver was not capable to obtain finer resolution. That happened due to less number of decimal places in minutes values of geographic coordinates in NMEA message. Nevertheless, the measured coordinates oscillated mostly in four coordinates around the reference point.

In the range of the whole measurement, the parameters that influenced measured errors can be described by the state of what receivers were listed when they lost the capability to solve the ambiguity of phase. In this work the consequences of loss of ability to solve ambiguity was as follows: u-Blox M8P receiver always entered into state 'Float' (the state when is RTK receiver capable to solve only the decimal part of ambiguity of the carrier phase) and Trimble 750 receiver always entered into state of 'Only GPS' (the state when the RTK receiver is not capable to solve the ambiguity at all). It can be assumed that the complete loss of ambiguity of the Trimble 750 receiver had occurred due to the RTKM2 v.01 modem quality.

Other parameters that also influenced the results were the SSR, i.e. the percentage ratio of samples when the RTK receivers were capable the ambiguity of carrier phase, opposite to other possible states. Both these facts are obvious in graphs below (Figs 4 and 5). However, it is worth pointing out that these graphs have the different scale factor of the vertical axis (the distance deviation).

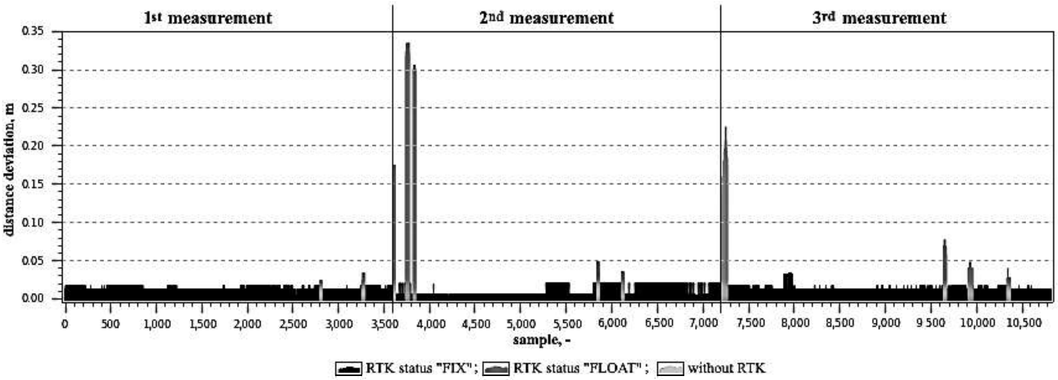

Figure 4. Accuracy deviation and system status of u-Blox M8P.

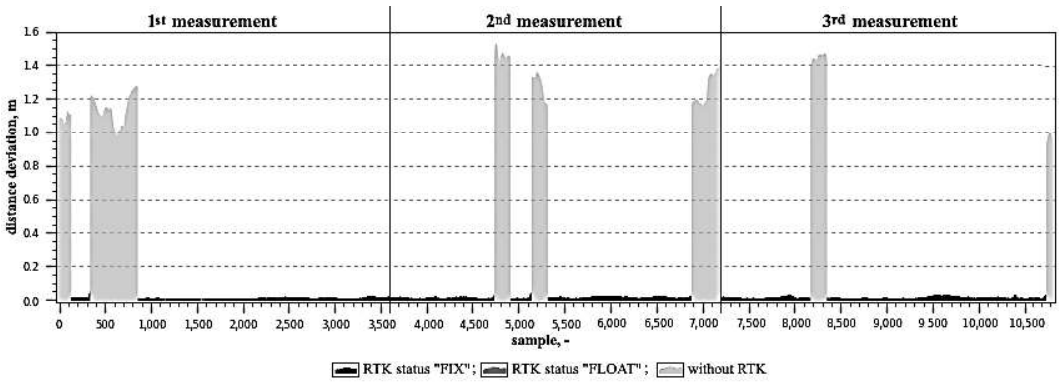

Figure 5. Accuracy deviation and system status of Trimble 750.

Due to results of SSR (87%) the ability of the system Trimble 750 to solve the problem of ambiguity integer phases was the worst during whole measurements. The better result was obtained from Trimble 5800 (92%) and surprisingly the best ability to solve ambiguity phases (98%) was shown by low-cost receiver u-Blox M8P. In this case, we cannot argue that this system provide the best ability to keep the fix mode because this ability can be influenced by different factors. One of them is the base station placement distance. In research of author Feng (2008) it's obvious that the baseline distance to a receiver can affect the system status ratio. In this research was confirmed the dependence of distance when in distance of 21 km the SSR was 99%, at 56 km 87% and at 74 km 77%. It is obvious that with base station placement distance the SSR was decreased.

The accuracy for three receivers was around 0.01 m during fix mode that corresponds with manufactures data's and results from other researches during static measurements (Garrido et al., 2011; Berber et al., 2012). In cases when receivers were measured in float or only GPS mode the errors were in terms of 0.10 m and in some cases more than one meter, that affected and increased errors for whole measurement data. Our next measurement will be based on these knowledge's and focused on finding how the receivers will be able to measure with fix mode and how without fix mode will affect accuracy, precision and RMS error during dynamic measurement.

CONCLUSIONS

The methodology of this research was based on static measurement (antennas had unchanged position during measurement). After evaluation of measurement, we discovered that the receiver Trimble 750 was not able to work in fix mode (the mode when the RTK receivers are capable to measure the most accurately) for the whole time. This fact affects the results from the whole measurement and showed that errors were a little higher than producers specifies. The low-cost receiver u-Blox M8P showed satisfying results when in most cases it was capable to solve the problem of ambiguity integer phases.

This static method can be applied for application where motion monitoring is not required, for example geodetic targeting. Therefore, we can ignore the samples of data with the unsolved ambiguity phase and use only the accurate ones (fix mode). The question is, if accuracy and precision of positioning will be influenced by the long-term monitoring or by the dynamic movement of the antennas. These properties of RTK receivers will be assessed in our next research.

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