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ANALYSIS OF THE INFLUENCE OF SATELLITES CONSTELLATION IN GNSS POSITIONING ACCURACY

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Abstract: In this paper, basic concepts of GNSS systems and details of NAVSTAR GPS satellite system are explained. The special emphasis to the positioning methods, and the influence of orbital positions of satellites in GNSS positioning accuracy is given, as well as term planning GNSS measurement and software tools display that are being used for. The practical part of the work consist field work and data processing and analysis. It is chosen a certain number of points (6) with known coordinates and satisfactory accuracy. In software for planning GNSS measurements the periods of maximum and minimum number of satellites determined, and in those periods surveying of selected points is done. The data obtained by measuring process and the results are analyzed. Based on the analysis, recommendations from the standpoint of applicability software planning tool for measurements are made.
Keywords: GNSS positioning, accuracy, satellite constellation, measurement

1. INTRODUCTION

Global Positioning System (GPS) is currently the only fully functional Global Navigation Satellite System (GNSS). GPS consists of 24 satellites distributed in Earth orbit, sending a radio signal to the Earth. GPS receivers on the basis of these signals can determine its exact position (ellipsoid height, geodetic width and length) at any place on the planet day and night, in all weather conditions. GPS is widely used as a global service in various fields, for commercial and scientific purposes: sea, land and the air navigation, creating maps, determining the exact time, detection of earthquakes and so on. [1]

The aim of this paper is to compare the accuracy of the data obtained by GPS measurement depending on the number of satellites and the chosen method, as well as to show the impact of planning measurements and use of measurement planning applications on the measurement accuracy.

2. THE STRUCTURE OF THE GLOBAL POSITIONING SYSTEM

The main segments of the GPS system are: the users segment, control and space segment [URL1].

Users segment consists of all users of global positioning and their receivers. GPS receiver consists of the antenna that receives signals transmitted by the satellites, processor which processes the signals and the precise hour. The satellites continuously broadcast information about their position, ephemeris, and the time when they send a signal [URL1].

Cosmic segment is the main part of the system. It consists of at least 24 satellites. The satellites are in high orbit at about 20,000 kilometers above the Earth's surface. Such a high altitude allows the signals to cover a larger area. The satellites are arranged in their orbits so a GPS receiver on earth can always receive signals from at least four of them [URL1].

The control segment is controlled by GPS satellites, and manage them by following them and giving them corrected orbital and temporal information. There are five control stations around the world, 4 of which are with no people, which are used for monitoring, and one master control station, which corrects satellite data and sends them back. [1]

3. BASIC CONCEPT OF GPS POSITIONING

GPS is based on the length measurement, and the trilateration positioning method. According to [1], length measuring is achieved by determining time that signal had traveled, or based on the difference phase (comparing the two signals).In accordance with that, there are two types of measurements: code and phase. Phase measurements are much more precise, while the code are mainly used for navigational purposes. The great advantage of this modern technology system is in electromagnetic waves, which spread through the air. This allows that the measurement is performed in all conditions, day and night, rain and clouds.

GPS positioning is determined by the spatial position (coordinates) of stationary or moving objects or points. The concept of determining thepoint's position, is generally divided into [2]:

» Absolute positioning, which involves the use of one receiver through which is measured the length to the satellite via C / A (Coarse / acquisition) and P (Precise) code.

» Relative positioning, where the positions are determined in relation to the coordinate system, in relation to a point or in relation to a set of points that create the geodetic network. [1]

In the preparation of this paper is used Post Processed Kinematic – PPKmethods, so it will be described below.

3.1. Relative positioning– Post processed kinematic method of relative positioning – PPK

Relative positioning requires simultaneous measurements at two or more points. For the application of this method, at least two receivers to simultaneously observe the same satellites (with code or phase measurement)are required. The accuracy of the relative positioning is much higher than the absolute. The application of the relative positioning can avoide, and in some cases eliminate, the effects that limit the accuracy of absolute positioning (clock errors in the receiver, satellites ephemeris errors, the daily atmospheric changes) [2].We distinguish between relatively static positioning and relatively kinematic positioning.

Relative kinematic positioning determines the space vector between the mobile and fixed receivers. In practical applications, stationary receiver of GPS signal is set to a point whose coordinates are known and that is a base receiver or base station. The second receiver is mobile and is set to a point whose coordinates are determined/measured and he has a rover role [3].

The advantage of PPK is that it is not necessary communication between base and rover and the radio link between receivers is not required, which reduces the requirements for additional equipment, makes it easier to work on the ground and leads to the most economical solutions in surveying. The disadvantage of this method is the reliability [3]. You may experience the problem of phase ambiguity during post processing, requiring re-measurements.

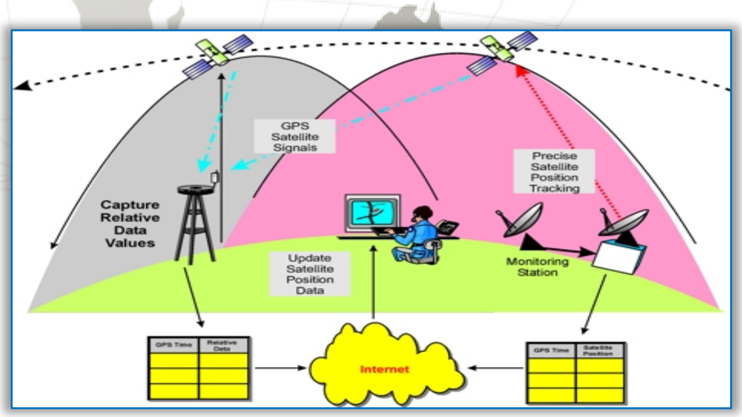

Figure 1: Post Processed Kinematic method of relative positioning [URL2]

4. GPS MEASUREMENT ERRORS

GPS, as well as all surveying methods has its advantages and disadvantages. Benefits of GPS surveying method over traditional surveying methods are: that mutual visibility between two points is not necessary, it can be used at any time of day or night and in any weather conditions, provides the results of a very high accuracy surveying, more work can be done in less time and with fewer people. The flaws of GPS methods are in fact limitations of GPS. For clean GPS reception antenna receiver must have a reception with at least 4 satellites. Also, the satellite signals can be blocked with tall buildings, trees... Therefore, GPS cannot be used inside. So it is difficult to use GPS in town centers or forests. Depending on the different causes of errors, can be divided into 3 groups [4] [5].

4.1. Satellite errors

» Errors due to poor satellite geometry. To make the measurements carried out as precisely as it's possible, satellites should be distributed all over the sky and surveying should be carried out in several directions. The geometry of the satellites is also bad when the receiver is placed near tall buildings and facilities. Then it is necessary to relocate the receiver a few meters to improve accuracy[5]. As measures of quality geometry satellites, DOP (Dilution of Precision) values are used.

» Ephemeris errors. Ephemeris tables represent the position of the satellites for a certain period of time. The result of determination of the GPS control segment based on observations from the monitoring stations are so-called emitting efemride. Accuracy of emitting ephemeris is now 1-2 m. IGS determine the so-called accurate ephemeris, whose accuracy is better than 5 cm. Precise ephemeris can be freely downloaded from the Internet, but they are not available in real time.
» Errors timer in the satellite. GPS satellites are equipped with atomic rubidium and cesium oscillators that very stable maintain its frequency over a long period. However, despite the high accuracy of these clocks, they differ from the GPS time for a small amount, which is not constant [5].
» Errors of theory of relativity. According to this theory, time flows more slowly during the rapid movement of the satellites. With the known satellite speed, measuring error accumulates up to 7 microseconds per day.

4.2. Environment propagation errors

GPS signal on its way from the satellite antenna to the receiver, is passing partly through empty cosmic space, and partly through Earth's atmospheric layer. Speed of GPS signal changes when passing through a medium that is not a vacuum, which results in the additional uncertainty in the measurement of travel time. In them, GPS signals behave differently. Errors that occur during propagation through these layers are errors of jonosperic and tropospheric signal delay [4].

4.3. Receiver errors

» Errors of multiple reflection. Multiple reflection is phenomenon that GPS antenna, in addition to directly receiving signals from GPS satellites, also receives signals that are reflected by the surrounding smooth natural or artificial surfaces. Multiple reflections can be reduced by using special GPS antenna, and if the GPS antenna is not placed near reflective surfaces [4].
» Errors due to noise in the receiver. On the measurement accuracy affects the measurement noise receiver. Noise receivers occurs as a consequence of the electronic components that are still moving electrons, and thus electricity [4].
» Errors of synchronization clock receiver. GPS receivers use quartz clock, which is a great advantage low power, low cost and good short-term stability. Time of these clocks must be matched to the GPS system time. This is usually done automatically, after the start of the registration data from the satellite [4].
» Errors of eccentricity of phase and geometric center. This error is caused by imperfect receiver creation. The phase center varies depending on the direction of the antenna and the strength of the incoming signal. It is recommended, while the vector measuring,a use of pair antennas of the same type and same-oriented[4].

Almanac provides GPS time synchronization with international time standard. Also, a single-frequency receiver provides information about ionosphere errors. Without Almanac, receiver has to seek satellites 'by heart' and their positions, what takes awaya lot of time. Almanac helps in planning the GPS measurements, ie when choosing the most favorable period for the measurement.

5.GPS MEASUREMENTS PLANNING

Planning GPS measurements can be made more efficient by using the program for processing GPS measurements that contains a module for planning. These modules achieve saving time and resources. Below will be discussed planning GPS measurement, where each phase plan to use the module planning programs for data processing, Trimble Geomatics Office. Trimble Planning software is available software that is specially designed to assist in the GPS measurements planning. This is a program that supports any form of analysis in solving the visibility of GPS, GLONASS, IGSO and other satellites in orbit. The program uses data of current Ephemeris and Almanac. GPS almanac, according to [URL 3], is a set of data containing information of the status of the entire constellation of satellites and data for each satellite orbit. Almanac also contains information about the position, the GPS time, the model of the ionosphere and so on. Primarily, almanac allows the receiver to in relation to their position and the weather gets a list of visible satellites as well as their arrangement. Through a variety of graphics, It is shown overall satellite visibility for each individual satellite, PDOP's, elevation, satellites constellation, for any location on Earth and for any period. You just have to enter the coordinates of the places of interest and the desired period. Planning GPS measurements consists of the following phases [6]:

5.1. Choosing a location points

For the selection of the point position commonly are used topographic maps, scale 1: 25000 and other, such as topographic and cartographic plans, plans of special purpose, orthophoto maps, and digital terrain models. There must be a minimum of three given points and is best to use point of the national network for which are known coordinates in both coordinate systems. The three basic conditions for the points selection are that around the point cannot be physical obstacles higher than 20° above the horizon, then near the point is no obstacle with a high reflection coefficient, and preferably in a diameter of about 200-300mnearby points is no source of electromagnetic radiation.

5.2. The choice of observation period

The optimum period of observation, in context of satellites availability, is the period when the maximum number of satellites can simultaneously be observed. The choice of observation period is determined on the basis of: a transparent scheme of satellite position-Sky plot, the position of satellites in azimuth and elevation, the geometry factors (DOP) and the state of the ionosphere. The minimum number of required satellites is 4, and due to obstacles and losing the signal, it is recommended even more. When the visible GPS satellites are close to one another, geometry quality is bad, and the value of DOP is high, so it is needed to choose the observation period when the geometry quality of the satellites is good, and the value of DOP factors low. The default value of elevation mask is 10° or 15° and depends on the hardware and software. It should be chosen the satellites that have signals at a higher elevation. Module planning, the data processing program is used for the second and third phase of GPS measurements planning. Into It, the certain data are injecting (the approximate coordinates of the work place, date and period of the day when measuring is planned, elevation mask and the time zone in which is the work place) and getting the following list:

- The list of the number of satellites with a PDOP values and PNR numbers of satellites
- The list of the DOP values for individual sessions
- The list of satellite position in azimuth and elevation

Module planning is drawing graphics that display data of satellites constellation and visibility, based on the data that were previously inserted into the module.

5.3. Determining the length of the measurements (sessions)

In this phase, the division of the selected observation period at the session (time intervals when measured simultaneously with two or more devices) is done. A session is a specific period of time selected for observation. Duration of the session depends on the accuracy that can be achieved, used methods (static or kinematic), the length of the baseline (vector side), the number of satellites, satellite geometry quality, and signal to noise ratio (SNR). In determining the length of sessions should take into account that the value of GDOP factor is less than 6. Session is terminated when the number of satellites drops below 4 or GDOP value rises above 6.Registration interval is the time interval, in which a recording measurements received from the satellite is done.

5.4. Site Visit

In this planning phase, experts for scouting visit the location in order to inform about it. When the point location meets all the requirements, point may be indicated to accomplish the stabilization.

5.5. Stabilization points

In this phase, GPS point's network stabilization is implemented. Stabilization method is depends on planned budget.

5.6. Organization measurements

It is necessary to define the number of receivers that will be used during the measurement, form the field team, define sessions and calculate costs.

6. FIELDWORK

This chapter presents the GPS measurements planning process, as well as the measure for the purpose of verifying the accuracy of data obtained by measuring, in depending on the number and satellite position. It is planned to carry out two field surveying, in different periods of satellites visibility. It is planned to carry out a measurement of the points of known coordinates to allow later comparison. Before both field surveying, It should be done planning measurements, to determine the satellites visibility for the planned date.

The objective of this paper is to check how accurate the information provided for the application for planning measurements are, and to analyze the accuracy of the data obtained, depending on the number of satellites and their spatial distribution.

Table 1: The exact value of the selected points coordinates

Ordinal point number	Name of point	Longitude	Latitude	Height
1	12699	7410110.44	5011540.81	77.37
2	12696	7410219.11	5011719.37	77.45
3	12697	7410080.34	5011765.45	77.12
4	12692	7410124.62	5011937.67	77.63
5	12694	7410249.63	5011837.69	78.33
6	12028	7410352.49	5012203.99	78.27

The first measurement was on 8 September 2015. It is selected six known points on the University campus in Liman 1, Novi Sad. Before going into the field, It is selected period of measurement, with the help of Trimble planning software (13h-15h). Number of satellites around 13h was the smallest during the day, but It is gradually increased, and around 15h has reached the highest value. The weather was sunny, clear and windy with temperatures around 25° C. From the equipment, Trimble GNSS rover and graphite rod for Rover are used. PPK method was used in measurements. At each point were performed 4 measurements, 3 measurements of the 30s (as a control point) and one measure of 3s (like a topographical point). During the measurements, often it occurred with loss of initialization, next to tall buildings and trees, so there was plenty of time spent on the re-establishment of initialization. After the measurement, obtained data were analyzed. All points are successfully processed and the resulting data are listed in Table 2.

Figure 2: Google Earth snapshot with points on which the measurement was carried out

Table 2: Values obtained by first measuring

Name of point	Longitude (Measured)	Latitude (Measured)	Height (Measured)	Number of visible sattelites	PDOP
12699	7410110.812	5011539.957	77.271	5	4.798
	7410110.814	5011539.959	77.282	5	4.801
	7410110.812	5011539.961	77.297	6	4.074
	7410110.811	5011539.973	77.300	6	4.051
12696	7410219.475	5011718.542	77.401	7	2.544
	7410219.481	5011718.536	77.392	7	2.229
	7410219.485	5011718.536	77.395	6	3.262
	7410219.486	5011718.522	77.382	7	2.550
12697	7410080.722	5011764.602	77.028	8	2.238
	7410080.726	5011764.607	77.034	8	2.242
	7410080.721	5011764.608	77.027	8	2.244
	7410080.719	5011764.609	77.013	7	2.742
12692	7410125.012	5011936.822	77.569	7	2.536
	7410125.007	5011936.823	77.554	6	4.629
	7410125.007	5011936.823	77.558	7	4.588
	7410125.009	5011936.824	77.562	7	4.585
12694	7410250.017	5011836.839	78.252	8	2.123
	7410250.016	5011836.842	78.258	8	2.108
	7410250.013	5011836.843	78.256	8	2.099
	7410250.014	5011836.841	78.256	8	2.105
12028	7410352.855	5012203.150	78.185	8	2.133
	7410352.857	5012203.151	78.188	8	2.126
	7410352.857	5012203.147	78.178	8	2.121
	7410352.851	5012203.148	78.176	8	2.107

In the table 3, the difference between the correct values and the values measured, which we get by subtracting the measured value from accurate, is given. From the table it can be concluded that the height are more accurately determined, with centimeter accuracy. While the length and width specified accuracy is a few decimeters. Also, it can be concluded that with the number of satellites such as 8, 9 and PDOP value around 2-2.5 results are more precise than when the number of visible satellites is 5, 6 and

PDOP value slightly higher, which supporting the theory. It may be noted that the number of satellites increases gradually, as it is predicted in planning time application. PDOP value is also within the limits predicted in graphics from planning time applications. On the points on which there has been a loss of initialization (12699, 12692, 12697), it can be noticed that PDOP value is slightly higher, and the accuracy the smallest, which confirms that poor satellites distribution affects the accuracy and general on initialization.

Table 3: Differences between accurate and measured values (first measurement)

Point name	Longitude difference (accurate-measured)	Latitude difference (accurate - measured)	Height difference (accurate-measured)
12699	-0.372 -0.374 -0.372 -0.371	0.853 0.851 0.849 0.837	0.099 0.088 0.073 0.070
12696	-0.365 -0.371 -0.375 -0.376	0.828 0.834 0.834 0.848	0.049 0.058 0.055 0.068
12697	-0.382 -0.386 -0.381 -0.379	0.848 0.843 0.842 0.841	0.092 0.086 0.093 0.107
12692	-0.392 -0.387 -0.387 -0.389	0.848 0.847 0.847 0.846	0.061 0.076 0.072 0.068
12694	-0.387 -0.386 -0.383 -0.384	0.851 0.848 0.847 0.849	0.078 0.072 0.074 0.074
12028	-0.365 -0.367 -0.367 -0.361	0.840 0.839 0.843 0.842	0.085 0.082 0.092 0.094

Table 4: Values obtained by second measuring

Name of point	Longitude (Measured)	Latitude (Measured)	Height (Measured)	Number of visible sattelites	PDOP
12699	7410111.731 7410111.827 7410111.832 7410111.831	5011540.051 5011539.971 5011539.945 5011539.968	76.567 77.393 77.256 77.390	6 6 7 7	3.515 3.492 2.761 2.764
12696	7410219.489 7410219.487 7410219.489 7410219.495	5011718.536 5011718.538 5011718.538 5011718.543	77.434 77.440 77.449 77.460	8 8 8 8	2.010 2.006 2.000 1.994
12697	7410080.723 7410080.726 7410080.724 7410080.71	5011764.609 5011764.614 5011764.605 5011764598	77.119 77.104 77.107 77.104	7 7 7 7	2.592 2.573 2.556 2.537
12692	7410125.011 7410125.008 7410125.009 7410125.017	5011936.829 5011936.826 5011936.830 5011936.831	77.603 77.606 77.601 77.597	6 6 6 6	3.695 3.673 3.652 3.629
12694	7410250.004 7410250.008 7410250.008 7410250.018	5011836.852 5011836.852 5011836.849 5011836.850	78.335 78.337 78.339 78.345	7 7 7 7	2.339 2.327 2.314 2.299
12028	7410352.860 7410352.862 7410352.862 7410352.852	5012203.152 5012203.159501 2203.160 5012203.157	78.232 78.235 78.239 78.241	7 7 7 7	2.192 2.186 2.180 2.162

The second measurement is carried out by the same procedure as the first, the same method, the same instrument and with the same points. It was carried out two days after the first measurement, in the same period. The weather was sunny and clear with temperatures around 35°C. Results of processing are shown in Table4.
From the table it can be concluded that the height are more accurately determined, with centimeter accuracy. While the length and width specified accuracy is a few decimeters. Also, it can be concluded that with the number of satellites such as 8, 9 and PDOP value around 2-2.5 results are more precise than when the number of visible satellites is 6 and PDOP value slightly higher, which supporting the theory. It may be noted that the number of satellites varies, and at the end, it is the largest, opposite from the application predictions.

Table 5: Differences between accurate and measured values (second measurement)

Point name	Longitude difference (accurate-measured)	Latitude difference (accurate-measured)	Height difference (accurate-measured)
12699	-1,291 -1,387 -1,392 -1,391	0,759 0,839 0,862 0,842	0,803 -0,023 0,114 -0,020
12696	-0,379 -0,377 -0,379 -0,385	0,834 0,832 0,832 0,827	0,016 0,010 0,001 -0,010
12697	-0,383 -0,386 -0,384 -0,370	0,841 0,836 0,845 0,852	0,001 0,016 0,013 0,016
12692	-0,391 -0,388 -0,389 -0,397	0,841 0,844 0,840 0,839	0,027 0,024 0,029 0,033
12694	-0,374 -0,378 -0,378 -0,388	0,838 0,838 0,841 0,840	-0,005 -0,007 -0,009 -0,015
12028	-0,370 -0,372 -0,372 -0,362	0,838 0,831 0,830 0,833	0,038 0,035 0,031 0,029

7. CONCLUSION

In this paper, it should be performed GPS measurements at points known coordinates to test the accuracy of the obtained data, depending on the number and satellites distribution. The number and satellites distribution should be predicted with the help of an application for planning measurements, and also search how many of these applications are really useful.
After data analysis, it was noticed that the application for planning measurements accurately predict measurement conditions and it is very important that the GPS measurement campaign plan in details using the Planning module measurements with the following parameters: PDOP, GDOP, showing the azimuth and satellite elevation-because these factors have very important influence on the accuracy of obtained data by the GPS measuring. The previous applications often can save a lot of time, money and effort. When using the GPS as surveying method, it is also important to choose suitable position points, which are not in the shelter of buildings and trees, so there could not be initialization loss, and thus accuracy reducing and time losing.
The obvious conclusion is that the use of GPS methods for measuring in geodetic purposes is relatively easy and quick surveying way, and it is often easier and faster than using terrestrial methods for the same purpose. GPS method provides data on all three coordinates at the same time. It should be paid attention on factors affecting the accuracy that are best predicted for planning time applications. While GPS technology has many advantages, it should always be chosen the surveying method, which will, depending on the type and scope of work, do a task in an optimal way.

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