

# Comparison of Different Software for GPS Network Adjustment

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**Keywords:** GPS, GPS Software, Geodetic Network, Vector Processing, Adjustment

## SUMMARY

Accuracy and productivity of NAVSTAR GPS enabled its application in solving different geodetic problems - from establishment of reference networks to a survey. The work with this system is a highly automated process - data collecting is reduced mainly to turning a receiver on, while data processing is performed within the branded quality software environment. All necessary functions are available within the software, with well designed user interface which leads the users through the data collection, data processing, and reports creation.

There are a lot of GPS manufacturers in the world market, which implies a set of GPS processing software packages. Each of them is unique in some functions, with different data processing algorithms applied. Usually, the companies do not publish the mathematical models used for baseline processing, network adjustment, and coordinate transformations. Because of that, it is good to know do different software packages give the congruent results. For our study case, we used the measurements in a control network of Banja Luka city. We processed the network in four different software packages: Trimble Total Control, Leica GeoOffice, Spectra Precision Survey Office and Topcon Tools. The conclusions drawn from this study case prove the significant differences in final results, which mean that a special care should be paid in the high precision geodetic surveys, especially the control networks.

# Comparison of Different Software for Gps Network Adjustment

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## 1. INTRODUCTION

Appearance of GPS technology changed completely and made easier data collection of various features. A concept of GPS measurements significantly differs from the traditional surveying measurements which rely on measuring angles, lengths and height differences. Determination of points using GPS means determination of the distance between a GPS device and a satellite, based on measured time interval needed to a signal to reach the GPS receiver on the Earth. For processing the GPS measurements, among a computer with sufficient performance, one needs software which will provide a user with data processing and measurement analysis. In the world market, now we can find different producers of GPS devices which mainly offer their own software packages. However, these solutions do not provide enough information about the mathematical background of the GPS measurements processing. In order to inspect possible differences in the results of GPS baseline processing and a network adjustment, we have processed the same set of GPS measurements in four GPS software packages: Trimble Total Control, Leica Geo Office, Spectra Precision Survey Office, and Topcon Tools.

Trimble Total Control is produced by Trimble Navigation Limited. We used the version 2.73. User interface is simple; all features are placed in an intuitive way, which makes the software easy to use.

Leica Geo Office v. 7 differs a lot from other tested packages, in the field of design. A user used to other packages needs some time to adapt to this user interface. Among design, also logic of data processing and access to the processing features are different. Processing is based on permanent switch from one tab to another, which may confuse the first-time user.

Spectra Precision Survey Office v. 2.20 is relatively new software package. It is based on the code provided by Trimble Navigation Ltd. to Spectra Survey. Graphical design of the software and the features are identical to Trimble Business Center. The manual and help system of the package are related to Trimble web page and the customer service. The design itself is modern, with a rich scope of the features regarding GPS measurements processing. The designers obviously have followed the developments steps of information technologies and user demands. According to that, there are new features, such as, exporting points directly to Google Earth or 3D view points.

Topcon Tools v. 8.2.3 is produced in 2012. The interface is similar to the majority of other software packages. Except the main menu, a desktop is consisted of graphical representation of the project and the tab with the representation of the point's data, loaded files, and the data regarding baseline processing. This software, also, like other used in this paper, offers processing of all kinds of measurements, GPS, angles, total station lengths, and leveled height differences, both separately, or joined in one project.

## 2. GPS MEASUREMENTS PROCESSING

After the measurements, a great attention should be paid to data processing. Today, there are a huge number of the software companies offering different solutions for GPS data processing. It should be mentioned that there are the software solutions for quality control and preparing RINEX files for further processing, which provides assurance to the quality of input data.

During the work with the GPS receivers, there are two known terms related to time - a session and a registration interval. The authors propose different minimal time sessions: 10 min + 1 min/km for L1 receivers, and 5 min + 0.5 min/km for L2 receivers, while other prefer 30 min + 2 min/km, and 30 min + 5 min/km for precise measurements. We used the latter method for defining the time sessions for the network processed in this paper.

The baseline processing is, possibly, the most important phase in a GPS campaign, because the final result depends on it. Parameters that should be monitored during the baseline processing are numerous, such as: integer ambiguity, cycle slip, and definition of a system of equations, signal-to-noise ratio (SNR), and number of satellites, PDOP, or estimation of the measured vector accuracy. During vector processing, certain float solutions may appear which are not used in further network processing. A geodetic expert can analyze such vector, find the segment of the session where the problem arose, and fix it. The programs can display several important alpha-numerical and graphical information that can be analyzed, which will help to choose a particular technique for solving the float vectors.

### 2.1. Trimble Total Control (TTC)

TTC is a software solution for GPS measurements processing produced by Trimble Navigation Ltd, a company founded in 1978, with more that 850 patents. TTC has been developing until 2003 with the final version 2.73.

Creating a project is the first step during the application start, which allows a software organization of data. The project represents a working place, which may contain various sets of GPS data collected with different equipment during a longer period. After opening the new project, the user sets the project parameters (display, tolerances of vector processing and vector closures, etc.). The user can edit these values later, too.

The next step is data import. Here TTC differs from all other packages, because it saves all vector data (measurements, processing, and adjustment) in newly generated \*.obs files. In some way, it is good, because the original measurement data remain in other files. On the other hand, a drawback is the fact that, after each new data loading (into the same or other project), it is necessary to control and sets all measurement parameters again. The program displays all data about GPS antennas, with a review of the producer data and the applied GPS receiver type. Unknown GPS receiver type is marked as "Unknown", while allowing the user to enter the custom data for that particular device. After that, the program draws the points and the observed baselines. Before vector processing, the user has to delete manually all baselines not assumed in an observation plan. There are two processing options - processing all baselines in the project, or single baseline processing. The loop closure is manual, since there is no possibility of selecting more than one vector, which is a drawback of this software.

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There is the feature “Quality” which allows checking of loop closures of all polygons within the project, but it gives only a global report about the polygons, with the report about the quality of other data.

## 2.2. Leica Geo Office (LGO)

Leica Geosystems is a Swiss company founded in 1819 with the name Kern & Co. Leica Geo Office is its software solution for GPS measurements processing.

The first step is data organization, i.e., project creation. LGO differs a lot from other tested packages in the means of data organization, visual interpretation, and the logic of data processing itself. After the program start, the user creates the project and gives it a name. After that, a new window is opened, where the user sets the parameters related to the project itself. It is possible to edit the parameters later, during the GPS data processing.

The next step is import and set of the project files. The drawback of LGO is that it does not allow the change of the GPS antenna height within the offered dialog, but only the change of the point names. Organization of the LGO working desktop is also different from the other packages. It is divided into a number of tabs. The most important tabs for GPS measurements processing are: *View/Edit*, *GPS-Proc*, *Adjustment*, *Points*, *Antennas*, and *Results*.

*View/Edit* is dedicated to graphical display of the data. To process the vector, the user has to switch to *GPS-Proc* tab, where all vectors within their sessions are present. A new drop-down list *GPS Process* occurs, offering the options such as *Processing Mode* and *Processing Parameters*. *Processing Mode* offers automatically vector processing, as well as, interactive processing, where the user chooses a reference station and a rover. After processing the baselines, the user enters the necessary parameters within the option *Processing Mode*. This option opens a window consisting of several tabs. After the baseline processing is completed, the program displays the dialog *Results*, with the data of all processed vectors. Selecting all or a subset of the baselines, a new dialog *Store* appears, allowing the user to save the processed data.

## 2.3. Spectra Precision Survey Office (SPSO)

After starting SPSO, it is obvious that this is software produced recently. A toolbar contains, for example, icons for displaying the points in Google Earth, which is now common to all programs manipulation with the spatial data, creating and displaying 3D models based on RINES files, and also some other features not seen with other tested packages.

The user opens the new project and sets the parameters related to the project itself (option *Project Settings* in the drop-down list *Project*). All the parameters regarding the project can be edited: background color, gridlines colors, coordinate system definition, processing parameters, baseline adjustment, etc., and changed in anytime. After loading of the data, the user can check and edit the point's names, the antenna and the receiver parameters. After the check, the points with the assigned baselines are displayed on the desktop. Prior to data processing, the user has to enter the appropriate processing parameters.

## 2.4. Topcon Tools (TT)

TT is also recent software, offering project visualization at Google Earth. After starting the program, a new project is created using the menu item *Job*, while the parameters justification is performed through the option *Job Configuration*. Editing of the project parameters can be performed later, too. During the project configuration, various ellipsoids and datum definitions are available. This also applies to the projections; UTM and a number of other projections can be used in the projects. Also, the user can create a new datum, defining the transformation parameters to WGS84. After loading the measurements data, using the option *Import*, the desktop displays the sketch of the network, while the tabs contain the data regarding points, loaded files, and the baseline processing data. The user can change the parameters where the change is allowed, for example, the point names, the GPS antenna types, and the antenna heights. After data processing and network adjustment, the tabs are updated with the data obtained from these operations. One possible drawback is the fact that all data regarding the project are kept in a single file, which grows proportionally to the number of measurements. However, the original data remain in their native format (like as TTC).

## 3. RESEARCH AREA

A political and territorial organization of the Republic of Srpska, recognizes the City of Banja Luka, as the biggest political and territorial unit occupying 1 239 km<sup>2</sup>. As the university, economic, finance, political and administrative center of the Republic of Srpska and one of the two entities in Bosnia and Herzegovina, Banja Luka is the second biggest city in Bosnia and Herzegovina with the population of 250 000. The area comprised by the city network of Banja Luka (Fig. 1) is 17 km x 20 km. The average height of the network is 355 m, with the maximal height difference between the adjacent points of 366 m. The distances between the points are 1777 m to 17925 m, with the average distance of 5150 m. There are 24 points in the network. One of them belongs to EUREF network of Republic of Srpska, while 23 belong to the trigonometric networks, mainly of the old city network. Some points are remounted (their numbers has a suffix N), and only one is fixed with a concrete pillar.

## 4. NUMERICAL RESEARCH

For this research, we processed the GPS network of Banja Luka in four GPS software packages, as explained in the previous section. For each program, we presented the following tables:

- 1) the parameters and the results of the basic GPS baseline processing,
- 2) the main data and the results of the loop-closures, and
- 3) the basic adjustment data.

In order to compare the obtain results, after the baseline processing in all four software packages; we kept only those vectors that are processed with the fixed solutions in all programs. The oldest software, TTC, produced the lowest number of fixed baselines, and only these vectors are kept in other packages. Some of the programs processed as fixed even ten baselines more that TTC.

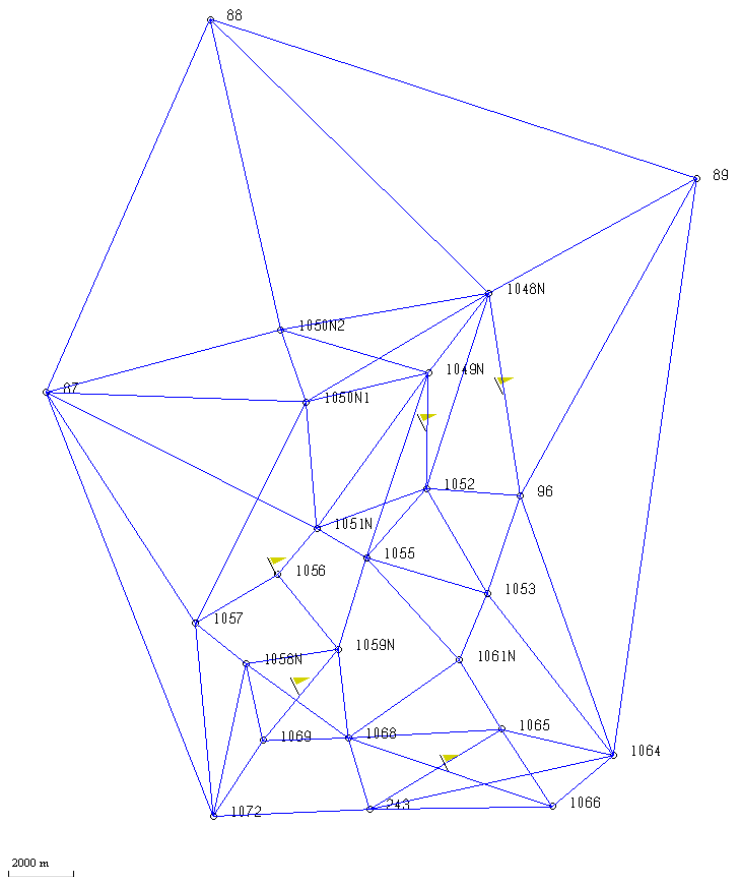


Figure 1. City GPS network of Banja Luka

Table 1: Parameters and results of basic GPS vector processing

Parameter	TTC	LGO	SPSO	TT
Interval of registration	5 s	5 s	5 s	5 s
Boundary elevation angle	10°	10°	10°	10°
Average number of satellites	9	9	9	9
Measurands	L1, L2	L1, L2	L1, L2	L1, L2
Satellite ephemeris	broadcast	broadcast	broadcast	broadcast
Tropospheric model	Hopfield	Hopfield	Hopfield	Hopfield
Max. relative positions RMS	5.0 mm	0.2 mm	19 mm	10 mm
Max. relative heights RMS	8.2 mm	2.6 mm	29 mm	19 mm

Table 2: Basic data and results of loop-closures

Parameter	TTC	LGO	SPSO	TT
Number of loop closures	37	23	46	116
Min. polygon length	8.8 km	8.8 km	Average	6.4
Max. polygon length	45.3 km	45.3 km	26.0 km	37.6
Min. measurement precision	0.07 ppm	0.0 ppm	0.14 ppm	0.04 ppm
Max. measurement precision	3.84 ppm	3.6 ppm	3.09 ppm	3.32 ppm
Min. loop closure	3 mm	0.7 mm	2 mm	0.5 mm
Max. loop closure	88 mm	51.8 mm	62 mm	47.6 mm

Table 3: Adjustment data

Parameter	TTC	LGO	SPSO	TT
Number of GPS baselines	49	49	49	49
Number of unknown points	24	24	24	24
Number of control points	1	1	1	1
RMS	1.11	0.68	0.16	1.14
Max. standardized residual	3.176	2.94	2.93	-
Average standard of absolute positions	16.84 mm	4.42 mm	10.16 mm	4.00 mm
Average standard of absolute heights	16.50 mm	7.29 mm	15.13 mm	11.30 mm
Average standard of relative positions	14.81 mm	5.43 mm	5.63 mm	4.78 mm
Max. long semi-axis of ellipsoid of error	30.3 mm	5.4 mm	13 mm	-
Max. short semi-axis of ellipsoid of error	26.8 mm	3.5 mm	8 mm	-

All vector processed with TTC had the fixed solutions, except 1066-1064. By changing the parameters (the elevation mask and using only the L2 frequency), that vector obtained the fixed solution. After the vector processing, we performed the loop closure check. As mentioned before, TTC cannot check the polygons automatically, but the user should do it manually. Before the adjustment of the processed vectors, it is necessary to set the vital parameters for the final adjustment results. In this particular case, we performed the free adjustment, which is also the quality feature of the baseline measurements. We fixed the point 243, with the coordinates determined in the ETRS89 system. During the adjustment, the baselines 88-89 and 88-87 did not pass the quality check, so we removed them from the further processing. The reason could be the low number and the inconvenient elevation angles of the satellites (Fig. 2), which resulted in the insufficient accuracy.

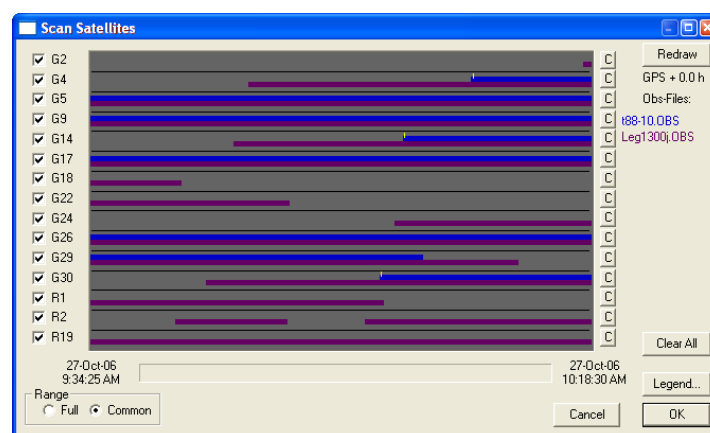


Figure 2. Satellite tracking for the baseline 88-89

The drawback of LGO is lack of the display and print of the detailed report about processing GPS baselines in the project. After the processing and visualization of the baselines, the work is continued in the tab *Adjustment*. Clicking the drop-down list *Adjustment*, the user chooses *Compute Loop*, which calculates the loop closures. To adjust the network, it is necessary to choose the option *Configuration* from the *Adjustment* tab, and its option *General Parameters*, where the adjustment parameters should be set. The network is defined as in TTC, with the point 243, with the coordinates in the ETRS89 system. After the adjustment and the loop closure, LGO transfers the user to the tab *Results*, with the adjustment results. Up to five reports can be registered here, while the user chooses which one of them is to be saved. The reports can be exported to HTML file, or printed.

SPSO does the loop closure automatically by the option *GNSS Loop Closure*, which is located in the drop-down list *Survey*. To display all polygons with complete data, the user should set the report by using one of the offered options within the drop-down list *Reports*. Within the drop-down list *Survey*, there is the option adjustment. The same adjustment parameters as in other programs are entered with the option *Project Settings*.

TT has given the highest number of fixed baselines and closed loops. Due to the comparison reasons, we deleted all baselines that other programs did not process. All processing data (baseline processing, loop closures and adjustment) can be exported to XLS, HTML or ASCII files. The available option *Export* can save the data in other formats (CAD formats for sketch drawing, text data of various types, formats that can be imported to the instruments, etc.).

## 5. DISCUSSION AND CONCLUSION

During the GPS baseline processing, we dropped 46 vectors, including the linear dependent ones. We used the same GPS antenna calibration, ionospheric and tropospheric models in each program, in order to estimate the possible existence of the pure mathematical model influence. The network is adjusted as free, fixing to just one point. After the completed procedures in all software packages, we compared the obtained accuracy estimations, as well as, the values of the particular baselines.

Table 4 represents the differences in accuracy estimation and the baselines adjustment. Analyzing the table, the following conclusions can be drawn:

- LGO shows almost ten times lower relative errors (baseline errors) comparing to other programs (this is noticed in processing of other networks, too),
- LGO closed the lowest number of the figures, polygons, while TT gave almost three times larger number of loop closures,
- Accuracy estimation from the loop closures is, practically, the same in all programs, but their values are the lowest in LGO,
- Accuracy estimation from the adjustment differs between all software's, with the lowest RMS in SPSO. The average position errors are the lowest in LGO and TT, while the average height errors are the lowest in LGO.



Beside the accuracy estimation, we compared the differences of the obtained values of the baselines (Tab. 5) and the adjusted coordinates (Tab. 6). These differences are more important than the accuracy estimation.

Examining the Tab. 5, one can conclude that the differences between the baselines are significant in all combinations. They are smaller when we compare the recent software packages (LGO, SPSO, and TT), which could be expected. If we look only at the relative baseline error, than all differences are insignificant to the accuracy requested for the networks (the highest accuracy is requested for the 1<sup>st</sup> order network, 1:200000).

Table 4: Differences of the processing and adjustment of the GPS baselines

<b>Parameter</b>	<b>TTC</b>	<b>LGO</b>	<b>SPSO</b>	<b>TT</b>
Max. RMS of the relative positions	5.0 mm	0.2 mm	19 mm	10 mm
Max. RMS of the relative heights	8.2 mm	2.6 mm	29 mm	19 mm
Number of loop closures	37	23	46	116
Min. measurement precision from the loop closures	0.07 ppm	0.0 ppm	0.14 ppm	0.04 ppm
Max. measurement precision from the loop closures	3.84 ppm	3.6 ppm	3.09 ppm	3.32 ppm
Min. loop closure	3 mm	0.7 mm	2 mm	0.5 mm
Max. loop closure	88 mm	51.8 mm	62 mm	47.6 mm
RMS from adjustment	1.11	0.68	0.16	1.14
Average standard of absolute positions	16.84 mm	4.42 mm	10.16 mm	4.00 mm
Average standard of absolute heights	16.50 mm	7.29 mm	15.13 mm	11.30 mm

Table 5: Differences of baseline lengths [mm]

Parameter	TTC-LGO	TTC-SPSO	TTC-TT	SPSO-LGO	SPSO-TT
Max. baseline difference	273.98	271.25	272.48	8.94	10.42
Max. baseline difference	-37.31	-29.64	-31.84	-73.70	-135.44
Average baseline difference	15.66	26.06	19.07	-5.36	-4.77
Average absolute baseline difference	25.17	33.54	25.07	7.65	9.26
Average relative error	2 370 000	2 461 000	3 782 000	3 692 000	5 280 000

Table 6: Differences of the adjusted coordinates [m]

Parameter	SPSO-TTC	LGO-TTC	TT-TTC	SPSO-LGO	SPSO-TT
Max. difference dB	0.0940	0.0821	0.0958	0.0000	0.0059
Min. difference dB	-0.0691	-0.0767	-0.0698	-0.0119	-0.0065
Average difference dB	0.0169	0.0099	0.0154	-0.0070	-0.0015
Average absolute difference dB	0.0267	0.0222	0.0263	0.0070	0.0030
Max. difference dL	0.0381	0.0364	0.0395	0.0083	0.0086
Min. difference dL	-0.4935	-0.5001	-0.4898	-0.0075	-0.0027
Average difference dL	-0.0165	-0.0155	-0.0152	0.0010	0.0013
Average absolute difference dL	0.0297	0.0314	0.0305	0.0032	0.0021
Max. difference H	0.2633	0.2610	0.3043	0.0963	0.0410
Min. difference H	-0.0433	-0.0241	-0.0233	-0.0359	-0.0250
Average difference H	0.0524	0.0765	0.0607	0.0241	0.0084
Average absolute difference H	0.0561	0.0787	0.0628	0.0317	0.0136

However, the most important are the differences between the adjusted coordinates (Tab. 6). Also, these differences are significant, especially compared to the older program (TTC). The largest difference, 0.5 m, is noticed at the point determined under a bad intersection of the two baselines (four baselines are measured, by two of them are dropped, because they did not suffice the adjustment Thau-test). If we exclude that point, the next biggest difference is about 3 cm. Similar situations is noticed with the heights: after excluding this point, the biggest difference is decreased from 30 cm to 7 cm, i.e., 15 cm and 10 cm, respectively (Tab. 6). After all, having in mind the obtained accuracy of the adjusted point coordinates, the differences calculated from the tested software packages are significant.

The final conclusion is that, after the analysis of the obtained results, we can safely say that the mathematical models used in GPS processing software packages, which is unavailable for the final users, does have the influence to the final points coordinates, although we tested the free adjustment models, and all of the measurements and the results passed the quality tests present in the programs.

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