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COMPARISON OF GPS COMMERCIAL SOFTWARE PACKAGES TO PROCESSING STATIC BASELINES UP TO 30 KM

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ABSTRACT

The objective of this paper is to present a comparison between three of GPS commercial software packages, namely Trimble Business Center TBC, Leica Geo Office LGO, and Topcon Magnet MGT, for processing GPS static baselines up to 30 km. The study was based on statistical analysis of the discrepancies between every two software packages for the output of baseline vectors in Easting, Northing, and Ellipsoidal height, for 14 GPS static baselines ranging from 2 to 30 km, where these baselines were processed using TBC, LGO, and MGT. The results supported by statistical analysis showed that the 3d positional discrepancies $\delta P3_d$ between TBC and MGT has a mean value of 31 mm and 8 mm standard deviation; while the 3d positional discrepancy between TBC and LGO has a mean value of 25 mm with 6 mm standard deviation; finally the 3d positional discrepancy between MGT and LGO software has a mean value of 31 mm with 9 mm standard deviation. These findings are about 3 ppm in the 3d positional discrepancy, which can be considered insignificant in the daily GPS topographic survey works. However, in case of monitoring activities using GPS static technique, it is recommended to use the same GPS software to process the static data to overcome any discrepancies due to using more than one GPS software.

Keywords: GPS, GPS static technique, trimble business center, leica Geo office, topcon magnet.

INTRODUCTION

Post processing is used in Differential GPS to obtain precise positions of unknown points by relating them to known points such as survey control points. The GPS measurements are usually stored in computer memory in the GPS receivers, and are subsequently transferred to a computer running the GPS post-processing software. The software computes baselines using simultaneous measurement data from two or more GPS receivers. The baselines represent a three-dimensional line drawn between the two points occupied by each pair of GPS Receives. The post processed measurements allow more precise positioning, because most GPS errors affect each receiver nearly equally, and therefore can be cancelled out in the calculations. On the other hand, Differential GPS measurements can also be computed in real-time by some GPS receivers if they receive a correction signal using a separate radio receiver, for example in Real Time Kinematic RTK, or Virtual Reference Stations VRS [1].

A variety of GPS software packages are available for GPS data processing. Universities and government departments involved in research have developed these packages for commercial daily processing of GPS data for the surveying activities around the world, as well as for the high precision scientific applications. Examples for some GPS scientific packages are [2]:

- GAMIT/GLOBK/TRACK: developed by Massachusetts Institute of Technology MIT.
- GIPSY-OASIS II: developed by Jet Propulsion Laboratory JPL.
- GPSTk**:** developed by Applied Research Laboratories ARL, University of Texas at Austin.
- Bernese: developed by Astronomical Institute of the University of Bern AIUB.

On the other hand, there are multi GPS commercial software packages available in the market now, which are used in the daily GPS work. Some of these software packages are:

- LGO: Leica Geo Office software, developed by Leica Company.
- TBC: Trimble Business Center software developed by Trimble Company.
- MGT: Topcon Magnet software developed by Topcon Company.

The main distinctions between commercial and scientific software packages are [3]:

- The commercial software is invariably written to handle data from particular GPS instrument type, while the scientific software is instrument independent, accepting data in RINEX format.

- The commercial software tends to be user friendly, requiring minimum analyst input. The scientific software tends to have been developed for research and precise positioning purposes, offering many options and requires more analyst skill to use, and has many features and supports more complex data modeling.

- The commercial software is optimized for GPS surveying accuracies i.e. for the level of few PPMs relative accuracy, whereas scientific software generally addresses very high accuracy applications. The scientific software has more sophisticated modeling and processing strategies, such as the ability to adjust orbit parameters, estimation of troposphere and ionosphere models, etc.

- The commercial software tends to use sub-optimal data processing algorithms i.e. processing data on a single-baseline mode, even if more than two GPS receivers are operating simultaneously. On the other hand, the scientific software has multi-baseline and multi-session capabilities.

The objective of this paper is to present a comparison between three of GPS commercial software packages, namely Trimble Business Center TBC, Leica Geo Office LGO, and Topcon Magnet MGT, for processing GPS static baselines up to 30 km. The study will be based on statistical analysis of the discrepancies between every two software packages for the output of baseline vectors in Easting, Northing, and Ellipsoidal height. In this context, review of GPS static technique and GPS errors will be presented. The methodology of investigation, as well as the description of the field test will be described. Finally, the analysis of the obtained results supported with the statistical analysis will be presented, from which conclusions will be drawn.

2. REVIEW OF GPS STATIC TECHNIQUE AND GPS ERRORS

The GPS observables are ranges which are deduced from measured time or phase differences based on a comparison between received signals and generated signals. Mainly, there are two types of GPS observables, namely the code pseudoranges and carrier phase observables. In general, the pseudorange observations are used for coarse navigation, whereas the carrier phase observations are used in high-precision surveying applications. This is due to the fact that the accuracy of the carrier phase observations is higher than the accuracy of code observations [4].

Beside the two GPS observables, the GPS satellite transmits a navigation message. The navigation message is a data stream added to both L1 and L2 carriers as binary bi-phase modulation at a low rate of 50 Kbps. It consists of 25 frames of 1500 bits each. The navigation message contains, along with other information, the coordinates of the GPS satellites as a function of time, the satellite health status, the satellite clock correction, the satellite almanac, and atmospheric data. Each satellite transmits its own navigation message with information on the other satellites, such as the approximate location and health status [5].

The general form of code pseudorange observation equation is [2]:

$$P = \rho + c(dt - dT) + dion + dtrop + dorb + \varepsilon^{p} \qquad (1)$$

Where P is the observed pseudorange, ρ is the unknown geometric satellite to receiver range, c is speed of light, which is equal to 299,792,458 m/s, *dt* and *dT* are satellite and receiver clock errors respectively, d^{ion} and d^{trop} are the errors due to ionospheric, tropospheric refractions respectively, d^{orb} is the orbital error, and ε^{p} is the code measurement noise. The precision of a pseudorange derived from code measurement is about 1% of the chip length. Consequently, a precision of about 3m and 0.3m is achieved with *C/A*-code and *P*-code pseudoranges respectively [2].

The observation equation of the phase pseudorange is

$$\Phi = \rho + c(dt - dT) + \lambda N - d^{ion} + d^{trop} + d^{orb} + \varepsilon^{\varphi} \qquad (2)$$

Where *c, dt, dT,* d^{ion}, d^{trop}, and d^{orb} are as previously defined, the measured phase is indicated in meters by Φ; λ is the carrier wavelength, *N* is the phase ambiguity, and ε^{φ} is the combined receiver and multipath noise.

There are different GPS techniques of observations. GPS Static technique is the common method for control networks, due to its high accuracy. Static technique positioning by carrier phase at present, is the most frequently used method by surveyors, as it is more accurate as compared to the code pseudorange measurements [6]. The principle of static relative positioning, is based on determining the vector between two stationary receivers, this vector is often called baseline. According to this terminology, the process is called single or multipoint baseline determination. In static surveying 1 ppm to 0.1 ppm accuracies are achieved, which is equivalent to few centimeters and millimeter accuracy, for short baselines of some kilometers [7]. The static surveying is usually applied in high accuracy surveying projects, such as establishing new geodetic networks, densification of existing first order control networks or lower order network, crustal movements, and structural deformation.

GPS measurements are subjected to some errors, which will affect the accuracy of the final results. There

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are two basic types of errors, which are the systematic errors or biases, and the random errors. Generally, the biases that affecting the GPS measurements fall into three categories which are: satellite biases, receiver biases, and signal propagation biases [8]. Satellite biases consist of biases in satellite ephemeris, satellite clock, and the effect of selective availability SA. The later was internationally terminated by the U.S. Government in May 1, 2000. Satellite biases are affecting both code and phase pseudorange measurements. Receiver biases usually consist of receiver clock bias, receiver noise and antenna phase center variation. The signal propagation biases appear due to tropospheric refraction, ionospheric refraction, and multipath. Beside the effect of these biases, the accuracy of the computed GPS position is also affected by the geometric locations of the GPS satellites as seen by the receiver. Generally, the more spread out the satellites are in the sky, the better the obtained accuracy, which is denoted as Dilution of Precision DOP [9].

The minimization of these errors can be done through four approaches [10]. The first is by modeling these errors mathematically and counts for them in the adopted observation equation. The second approach is based on a differential solution to cancel out, or at least greatly reduce many of these errors. The third approach is concentrated on using linear combination between the GPS observables. The fourth approach is depending on using precise products such as precise satellite ephemeris and satellite clock offsets, through multinational GPS agencies such as the International GPS Service IGS.

In addition, the GPS measurements include some observational random errors, moreover, the un-modeled small systematic errors inherent on the system due to multipath and imaging, antenna phase center movement, and residual biases, are usually treated in practice as contributing part of the resulting random errors [11].

3. METHODOLOGY OF INVESTIGATION

The objective of this paper is to compare the 3-d projected coordinates Easting, Northing, and Elevation resulted from processing GPS static baselines up to 30 km, using three commercials GPS software packages namely Trimble Business Center TBC [12], Leica Geo Office LGO [13], and Topcon Magnet MGT [14]. The methodology will be based on the statistical analysis of the behavior of discrepancies in the UTM coordinates Easting E, Northing N, and Ellipsoidal Height h of 14 GPS baselines ranging from 2 to 30 km. These baselines were processed using TBC, LGO, and MGT software packages.

The field test was conducted in Riyadh, Saudi Arabia in June 2015. The GPS campaign was started by set up a GPS receiver of Trimble R8 [15], dual frequency receiver at a Reference Control Point RCP. A second GPS of the same Trimble model was setup at 14 existing control points. Figure-1 shows the site vicinity, the general layout of the reference control point and the 14 existing control points. The observational operating parameters were the same for the three receivers, which were: static mode, elevation angle 15 degrees, and 15 seconds epoch rate. The observational duration for each baseline was 60 minutes for the baselines up to 10 km, 90 minutes for baselines up to 20 km, and 120 minutes for baselines up to 30 km.

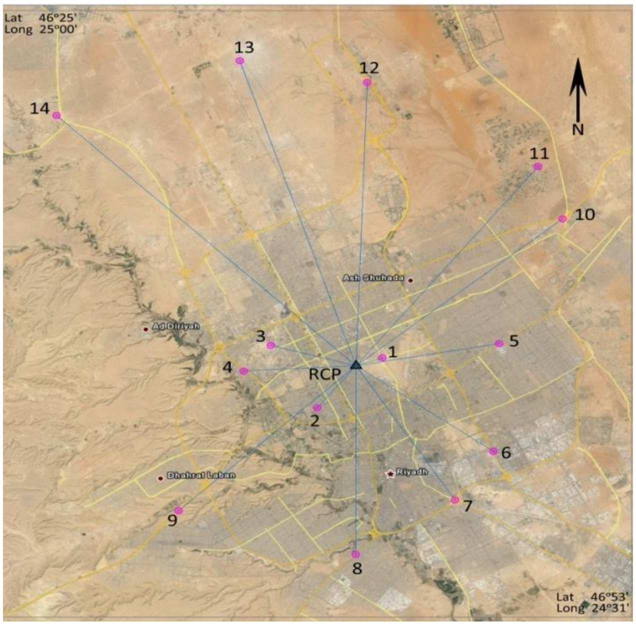

Figure-1. Site vicinity of the GPS campaign.

The raw data of the GPS campaign were downloaded and converted to Rinex format using TBC software, and were archived for processing using LGO, TBC, and MGT. Using the Rinex archived data, each software was processed the data of 14 GPS baseline, by fixing the coordinates of the Reference Control Point. The processing parameters were the same for all three software packages as follows:

- Using GPS satellites only.
- Dual frequency processing using L1 and L2 signals.
- Satellite mask angle is 15 degree, and 15 sec epoch interval.
- Broadcast ephemerids.
- No Troposphere or Ionosphere models were selected.

All GPS resulted baselines were projected into UTM coordinate system with zone number 38 north for analysis of results.

4. ANALYSIS OF RESULTS

The analysis of the results will be based on statistically testing the discrepancies in resulted E, N, and h coordinates, as well as the positional discrepancies between every two software packages. These discrepancies for the 14 GPS baselines between TBC and MGT software packages can be expressed as:

$$\delta E_{TBC-MGT} = \Delta E_{TBC} - \Delta E_{MGT}$$
$$\delta N_{TBC-MGT} = \Delta N_{TBC} - \Delta N_{MGT} \qquad (3)$$
$$\delta h_{TBC-MGT} = \Delta h_{TBC} - \Delta h_{MGT}$$

Where: $\delta E_{TBC-MGT}$, $\delta N_{TBC-MGT}$, and $\delta h_{TBC-MGT}$ are the discrepancies in GPS baselines vectors in Easting, Northing, and Ellipsoidal Height respectively, between solving the static data by TBC software and by MGT package.

ΔE_{TBC}, ΔN_{TBC}, and Δh_{TBC}: are the Easting, Northing, and Ellipsoidal Height vectors of a GPS baseline processed by TBC software.

ΔE_{MGT}, ΔN_{MGT}, and Δh_{MGT}: are the Easting, Northing, and Ellipsoidal Height vectors of a GPS baseline processed by MGT software.

The same set of Equations no. 3 can be rewritten between TBC and LGO software, as well as between MGT and LGO software, as follows:

$$\delta E_{TBC-LGO} = \Delta E_{TBC} - \Delta E_{LGO}$$
$$\delta N_{TBC-LGO} = \Delta N_{TBC} - \Delta N_{LGO} \qquad (4)$$
$$\delta h_{TBC-LGO} = \Delta h_{TBC} - \Delta h_{LGO}$$

$$\delta E_{MGT-LGO} = \Delta E_{MGT} - \Delta E_{LGO}$$
$$\delta N_{MGT-LGO} = \Delta N_{MGT} - \Delta N_{LGO} \qquad (5)$$
$$\delta h_{MGT-LGO} = \Delta h_{MGT} - \Delta h_{LGO}$$

Where: $\delta E_{TBC-LGO}$, $\delta N_{TBC-LGO}$, and $\delta h_{TBC-LGO}$ are the discrepancies in GPS baselines vectors in Easting, Northing, and Ellipsoidal height respectively between solving the static data by TBC software and by LGO package.

$\delta E_{MGT-LGO}$,$\delta N_{MGT-LGO}$, and $\delta h_{MGT-LGO}$ are the discrepancies in GPS baseline vectors in Easting, Northing, and Ellipsoidal height respectively between solving the static data by MGT software and by LGO package.

ΔE_{LGO}, ΔN_{LGO}, and Δh_{LGO}: are the Easting, Northing, and Ellipsoidal height vectors of a GPS baseline processed by LGO software.

ΔE_{MGT}, ΔN_{MGT}, and Δh_{MGT}: are the Easting, Northing, and Ellipsoidal height vectors of a GPS baseline processed by MGT software.

On the other hand, the 2d and 3d positional discrepancies δP_{2d}, δP_{3d}, and their associate Standard Deviations $\sigma_{\delta p_{2d}}$, $\sigma_{\delta p_{3d}}$ for every pairs of solutions can be written as [16]:

$$\delta p_{2d_{TBC-MGT}} = \sqrt{(\delta E_{TBC-MGT})^2 + (\delta N_{TBC-MGT})^2}$$
$$\delta p_{2d_{TBC-LGO}} = \sqrt{(\delta E_{TBC-LGO})^2 + (\delta N_{TBC-LGO})^2} \qquad (6)$$
$$\delta p_{2d_{MGT-LGO}} = \sqrt{(\delta E_{MGT-LGO})^2 + (\delta N_{MGT-LGO})^2}$$

$$\delta p_{3d_{TBC-MGT}} = \sqrt{(\delta E_{TBC-MGT})^2 + (\delta N_{TBC-MGT})^2 + (\delta h_{TBC-MGT})^2}$$
$$\delta p_{3d_{TBC-LGO}} = \sqrt{(\delta E_{TBC-LGO})^2 + (\delta N_{TBC-LGO})^2 + (\delta h_{TBC-LGO})^2}$$
$$\delta p_{3d_{MGT-LGO}} = \sqrt{(\delta E_{MGT-LGO})^2 + (\delta N_{MGT-LGO})^2 + (\delta h_{MGT-LGO})^2} \qquad (7)$$

$$\sigma_{\delta p_{2d_{TBC-MGT}}} = \sqrt{\left(\sigma_{\delta E_{TBC-MGT}}\right)^2 + \left(\sigma_{\delta N_{TBC-MGT}}\right)^2}$$
$$\sigma_{\delta p_{2d_{TBC-LGO}}} = \sqrt{\left(\sigma_{\delta E_{TBC-LGO}}\right)^2 + \left(\sigma_{\delta N_{TBC-LGO}}\right)^2}$$
$$\sigma_{\delta p_{2d_{MGT-LGO}}} = \sqrt{\left(\sigma_{\delta E_{MGT-LGO}}\right)^2 + \left(\sigma_{\delta N_{MGT-LGO}}\right)^2} \qquad (8)$$

$$\sigma_{\delta p_{3d_{TBC-MGT}}} = \sqrt{\left(\sigma_{\delta E_{TBC-MGT}}\right)^2 + \left(\sigma_{\delta N_{TBC-MGT}}\right)^2 + \left(\sigma_{\delta h_{TBC-MGT}}\right)^2}$$

$$\sigma_{\delta p_{3d_{TBC-LGO}}} = \sqrt{\left(\sigma_{\delta E_{TBC-MGT}}\right)^2 + \left(\sigma_{\delta N_{TBC-MGT}}\right)^2 + \left(\sigma_{\delta h_{TBC-MGT}}\right)^2}$$

$$\sigma_{\delta p_{3d_{MGT-LGO}}} = \sqrt{\left(\sigma_{\delta E_{TBC-MGT}}\right)^2 + \left(\sigma_{\delta N_{TBC-MGT}}\right)^2 + \left(\sigma_{\delta h_{TBC-MGT}}\right)^2} \qquad (9)$$

The discrepancies in δE, δN, and δh, as well as the 2d and 3d positional discrepancies δP_{2d} , δP_{3d} between processing the GPS static data using TBC and MGT software packages are shown in Table-1, Figures 2 and 3.

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Table-1. The discrepancies in δE, δN, δh and position P between TBC and MGT software packages.

Baseline	**Appox. length** (m)	δE (mm)	**δN (mm)**	**δh** (mm)	δP_{2d} (mm)	δP_{3d} (mm)
BL 1	2075	5	2	14	5	15
BL 2	4754	19	1	1	19	19
BL 3	6621	-15	-4	35	16	38
BL 4	8426	10	-1	31	10	33
BL 5	10836	8	4	43	9	44
BL 6	12777	-6	-1	6	6	9
BL 7	14044	-7	-8	-51	11	52
BL 8	16852	-12	-7	-43	14	45
BL 9	18583	-9	-3	-5	9	11
BL 10	20333	-18	-3	24	18	30
BL 11	22209	-20	8	-23	22	32
BL 12	25222	-5	-6	-24	8	25
BL 13	28294	2	-9	33	9	34
BL 14	31631	4	-14	52	15	54

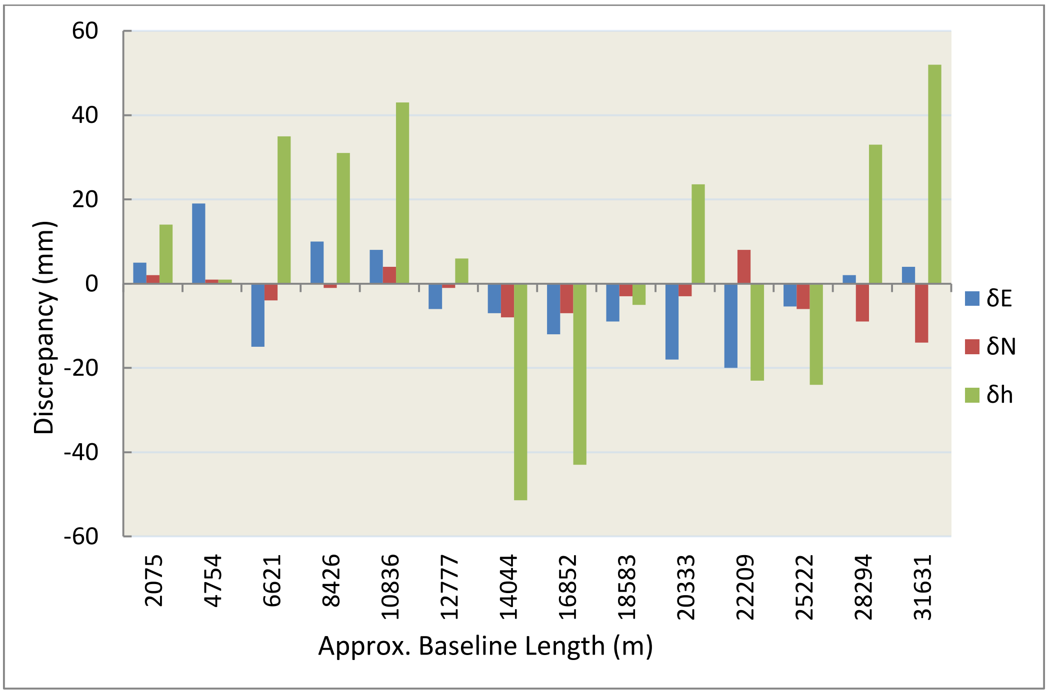

Figure-2. Variation of δE, δN, and δh discrepancies between TBC and MGT Software.

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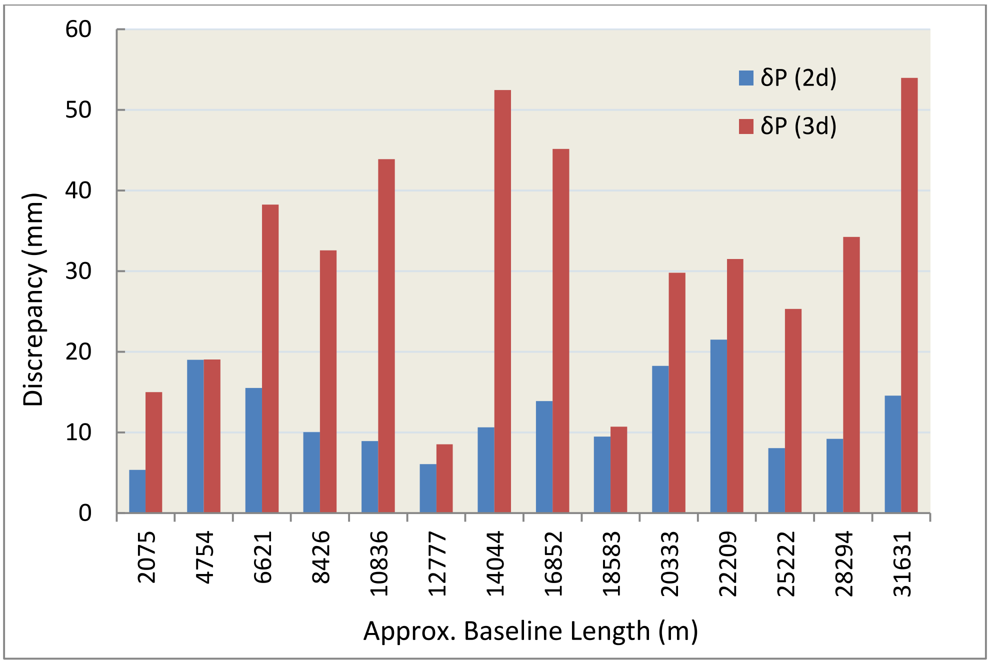

Figure-3. Variation of the horizontal and spatial positional discrepancies between TBC and MGT software.

The descriptive statistics of the above findings are summarized in Table-2. For instance, the δE discrepancies have a mean value -3 mm and standard deviation SD ±11 mm for single determination. The δN discrepancies have a mean value of-3 mm and ±6 mm SD for single determination. The δh discrepancies have 7 mm mean value and ±31 mm SD for single determination. On the other hand, the horizontal positional discrepancy δd_{2d} and the spatial positional discrepancy $\delta d3_d$ have 12 mm and 31 mm mean values, respectively, with standard deviations of ±12 mm and ±32 mm, respectively.

Table-2. Descriptive statistics of the discrepancies between TBC and MGT (mm).

Disc.	**Max.**	**Min.**	**Range**	**Mean**	**S.D$_{single}$**	**S.D$_{mean}$**
δE	19	-20	39	-3	11	3
δN	8	-14	22	-3	6	1
δh	52	-51	103	7	31	8
δP_{2d}	22	5	16	12	12	3
δP_{3d}	54	9	45	31	32	8

The previous set of tables and figures were created again between processing the GPS baselines using TBC and LGO software packages. The findings are presented in Tables 3, and 4 and Figures 4 and 5.

Table-3. The discrepancies in δE, δN, δh and position P between TBC and LGO software packages.

Baseline Id	**Appox. length** (m)	δ**E** (mm)	δ**N** (mm)	**Δh** (mm)	δ$\mathbf{P}_{2d}$ (mm)	δ$\mathbf{P}_{3d}$ (mm)
BL 1	2075	-3	-2	42	4	42
BL 2	4754	15	3	20	15	25
BL 3	6621	0	5	-9	5	11
BL 4	8426	3	-3	14	4	14
BL 5	10836	8	2	12	8	14
BL 6	12777	-15	-5	27	15	31
BL 7	14044	3	-4	-3	5	6
BL 8	16852	-11	-8	9	13	16
BL 9	18583	6	2	-29	6	30
BL 10	20333	-15	-4	14	16	21
BL 11	22209	-17	-6	-37	18	41
BL 12	25222	-16	-6	17	17	24
BL 13	28294	6	-3	47	7	47
BL 14	31631	24	-17	10	29	31

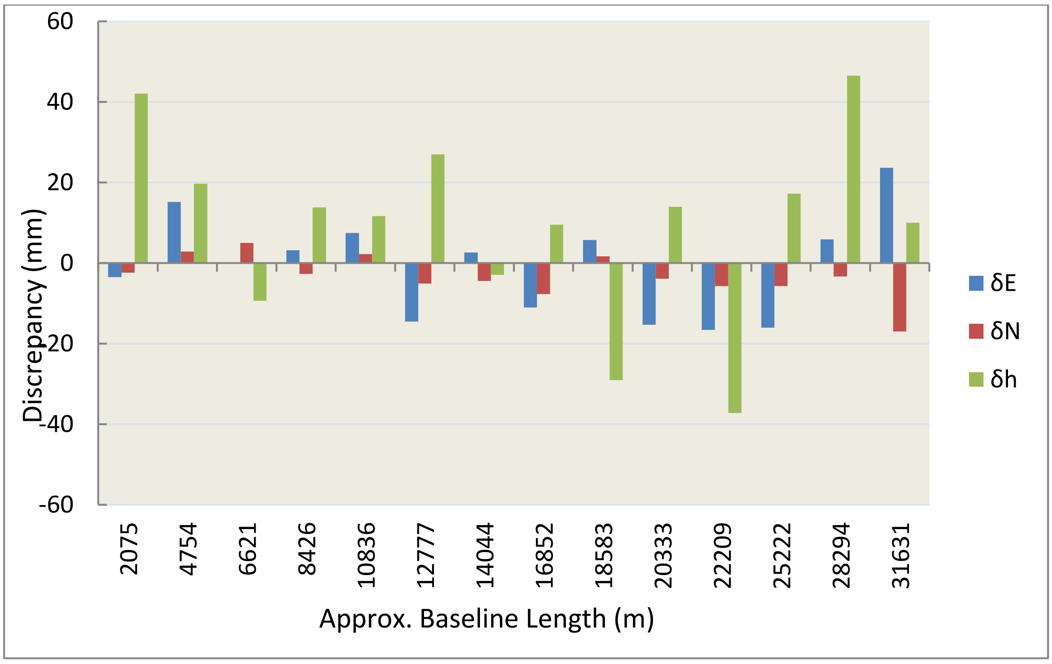

Figure-4. Variation of δE, δN, and δh discrepancies between TBC and LGO Software.

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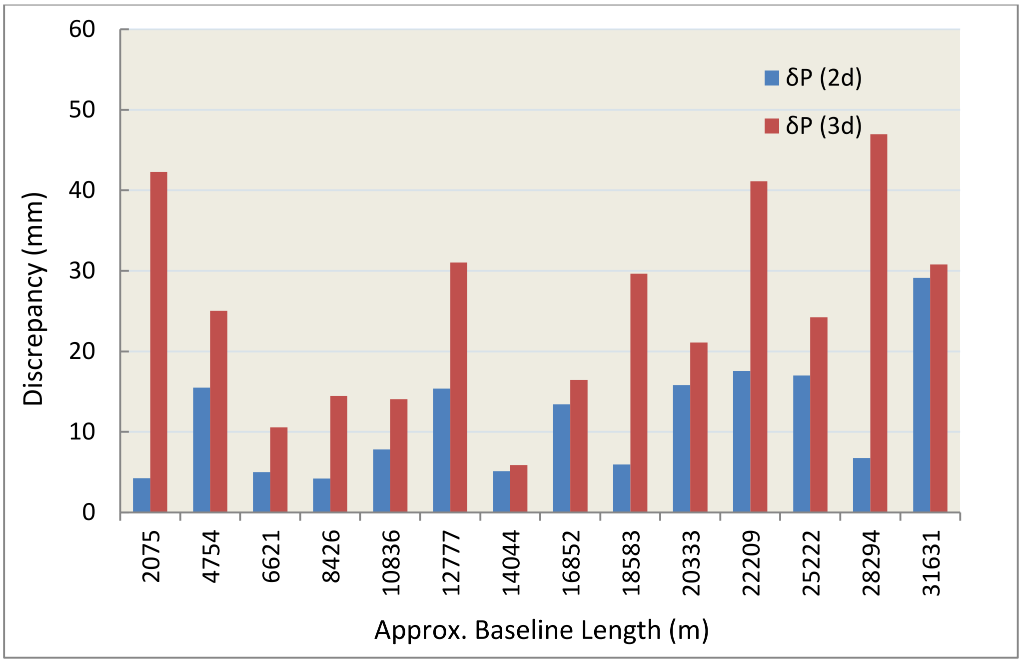

Figure-5. Variation of the horizontal and spatial positional discrepancies between TBC and LGO software.

Table-4. Descriptive statistics of the discrepancies between TBC and MGT (mm).

Disc.	Max.	Min.	Range	Mean	$S.D_{single}$	$S.D_{mean}$
δE	24	-17	40	-1	12	3
δN	5	-17	22	-3	5	1
δh	47	-37	84	10	23	6
δP_{2d}	29	4	25	12	13	4
δP_{3d}	47	6	41	25	23	6

For example, the horizontal positional discrepancy δd_{2d} and the spatial positional discrepancy $\delta d\text{-}3_d$ have 12 mm and 25 mm mean values, respectively, with standard deviations of ±13 mm and ±23 mm, respectively.

The last comparison between the GPS software packages was between MGT and LGO software. In this regard, the results are presented in Tables 5, and 6 and Figures 6 and 7.

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Table-5. The discrepancies in δE, δN, δh and Position P between MGT and LGO software packages.

Baseline Id	**Appox. length** (m)	δ**E** (mm)	δ**N** (mm)	δ**h** (mm)	δ**P**$_{2d}$ (mm)	δ**P**$_{3d}$ (mm)
BL 1	2075	-8	-4	28	10	30
BL 2	4754	-4	2	19	4	19
BL 3	6621	15	9	-44	17	48
BL 4	8426	-7	-2	-17	7	19
BL 5	10836	0	-2	-31	2	31
BL 6	12777	-8	-4	21	9	23
BL 7	14044	10	4	49	10	50
BL 8	16852	1	-1	52	1	53
BL 9	18583	15	5	-24	15	29
BL 10	20333	3	-1	-10	3	10
BL 11	22209	3	-14	-14	14	20
BL 12	25222	-11	0	41	11	43
BL 13	28294	4	6	14	7	15
BL 14	31631	20	-3	-42	20	46

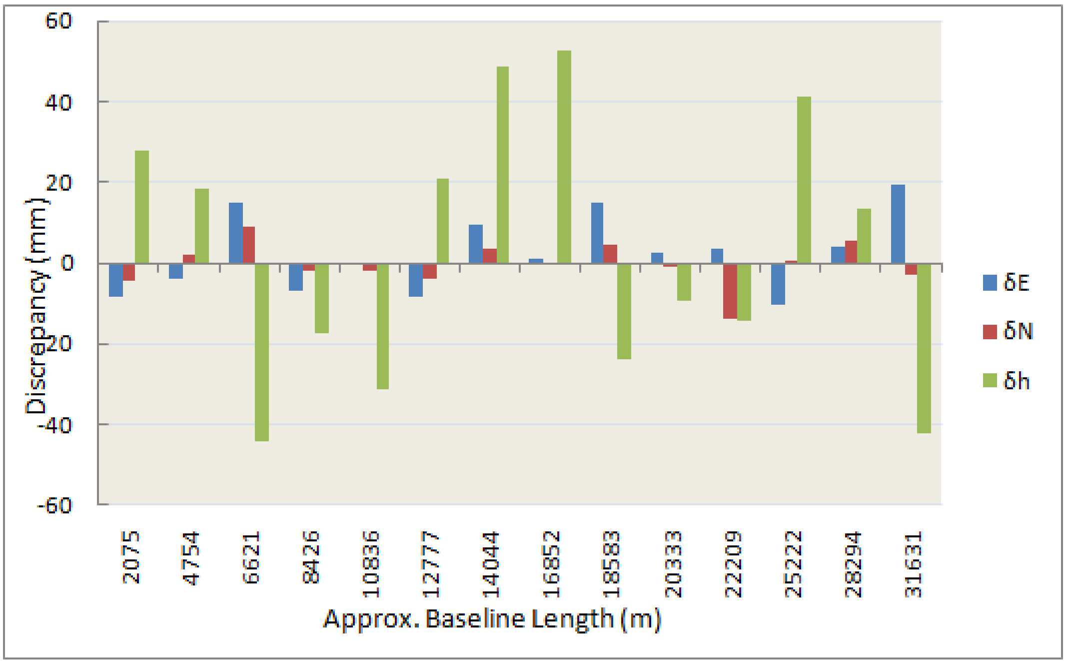

Figure-6. Variation of δE, δN, and δh discrepancies between MGT and LGO Software.

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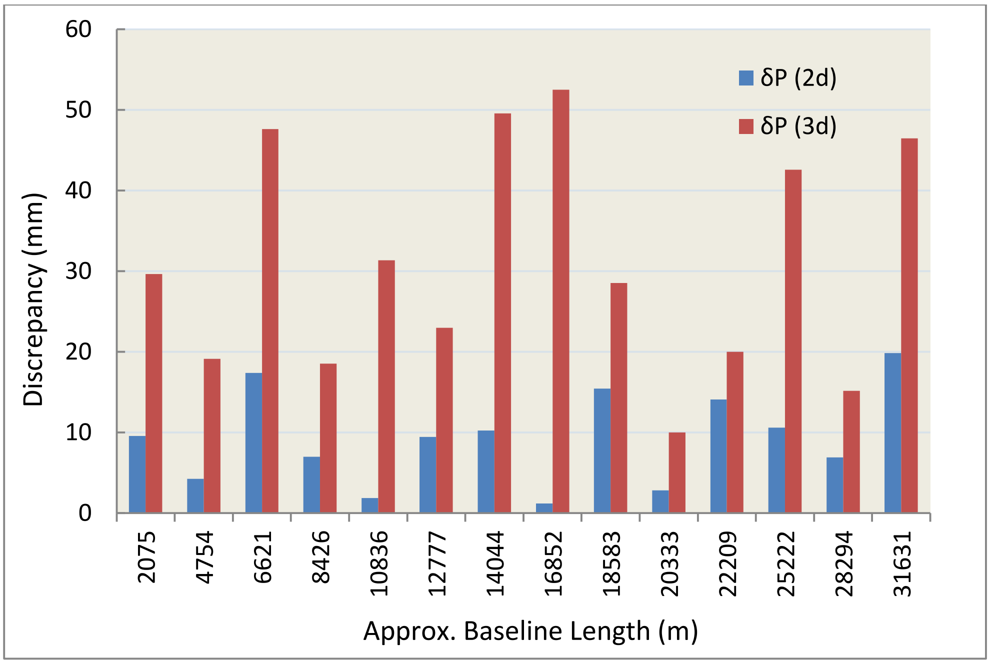

Figure-7. Variation of the horizontal and spatial Positional discrepancies Between MGT and LGO software.

Table-6. Descriptive statistics of the discrepancies between MGT and LGO (mm).

Disc.	Max.	Min.	Range	Mean	$S.D_{single}$	$S.D_{mean}$
δE	**20**	**-11**	**30**	**2**	**9**	**2**
δN	9	-14	23	0	5	1
δh	52	-44	97	3	32	9
δP_{2d}	20	1	19	9	11	3
δP_{3d}	53	10	43	31	32	9

It can be seen that the horizontal positional discrepancy δd_{2d} and the spatial positional discrepancy δd-3_d have 9 mm and 31 mm mean values, respectively, with standard deviations of ±11 mm and ±32 mm, respectively.

5. CONCLUSIONS

This paper compares the output results of baseline vector components in Easting, Northing and Ellipsoidal height, of three commercial GPS software packages namely Trimble Business Center TBC, Leica Geo Office LGO, and Topcon Magnet MGT, for processing Static GPS data of baselines up to 30 km. A GPS campaign was conducted to observe 14 baselines with GPS static technique varying from 2 km to 30 km. The static data were processed, after converting to Rinex, using TBC, LGO, and MGT software. The vector components resulted from each software, were statistically compared to the other two software packages. The analysis of these statistical data showed the following:

a) The discrepancies in δE, δN, and δh, between TBC and MGT software packages, have mean values of -3 mm, -3 mm, and 7 mm respectively. The standard deviations for the previous findings are 3 mm, 1 mm, and 8 mm respectively.

b) The discrepancies in δE, δN, and δh, between TBC and LGO software packages, have mean values of -1 mm, -3 mm, and 10 mm respectively. The standard deviations for the previous findings are 3 mm, 1 mm, and 6 mm respectively.

c) The discrepancies in δE, δN, and δh, between MGT and LGO software packages, have mean values of 2 mm, 0 mm, and 3 mm respectively. The standard deviations for the previous findings are 2 mm, 1 mm, and 9 mm respectively.

d) The 2d positional discrepancies δP_{2d} between TBC and MGT has a mean value of 12 mm and 3 mm standard deviation; while the 2d positional discrepancy between TBC and LGO has a mean value of 12 mm with 4 mm standard deviation. Finally, the 2d positional discrepancy between MGT and LGO software has a mean value of 9 mm with 3 mm standard deviation.

e) The 3d positional discrepancies $\delta P3_d$ between TBC and MGT has a mean value of 31 mm and 8 mm standard deviation; while the 3d positional discrepancy between TBC and LGO has a mean value of 25 mm with 6 mm standard deviation. Finally, the 3d positional discrepancy between MGT and LGO software has a mean value of 31 mm with 9 mm standard deviation.

The previous results showed that the average discrepancies between processing the GPS data using anyone of the three mentioned software TBC, LGO, and MGT are about 3 ppm in the 3d positional discrepancy, which can be considered insignificant in the daily GPS topographic survey works. However, in case of monitoring activities using GPS static technique, it is recommended to use the same GPS software to process the static data to overcome any discrepancies due to using more than one GPS software.

REFERENCES

[1] Guochang Xu. 2007. GPS Theory, Algorithms, and Applications. Second Edition, Springer Publishing, New York, USA.

[2] Hofmann-Wellenhof B., H. Lichtenegger and J. Collins. 2001. Global Positioning System, Theory and Practice. 5th Revised Edition, Springer-Verlag, New York.

[3] Satheesh G. 2005. Global Positioning System, Principles and Applications. Tata McGraw-Hill, New Delhi.

[4] Leick A. 1995. GPS Satellite Surveying. A Willey Inter-Science Publications, John Willey and Sons, New York, USA.

[5] Rizos C. 1997. Principles and Practice of GPS Surveying. Monograph 17, School of Geomatics Engineering, the University of New South Wales.

[6] El-Rabbany A. 2002. Introduction to the Global Positioning System GPS. Artech House Mobile Communications Series, Boston, London, U.K.

[7] Seeber G. 2003. Satellite Geodesy. 2nd edition, Walter de Gruyter, Berlin, New York, USA.

[8] Grant B., C. Rizos, and A. Stolz. 1990. Dealing with GPS Biases, Some Theoretical and Software Considerations. School of Surveying, University of New South Wales, Australia.

[9] Kaplan D. and C. Hegarty. 2006. Understanding GNSS Principles and Applications. Published by Elsevier Ltd., U.K.

[10] Abdel Mageed Kh. 2011. Accuracy Assessment for Processing GPS Short Baselines using Ionosphere-Free Linear Combination. Australian Journal of Basic and Applied Sciences, 5(9).

[11] Kaplan E. and J. Christopher. 2006. Understanding GPS, Principles and Applications. Artech House Inc., Norwood, MA.

[12] Trimble Navigation Company. 2015. Trimble Business Center Office Software.

[13] Leica Geosystems Company. 2014. Leica Geo Office Online Help.

[14] Topcon Corporation Company. 2015. Topcon Magnet Tools Software Help.

[15] Trimble Navigation Company. 2013. Trimble R8 GNSS Receiver User Manual.

[16] Comery A., P. Bott and H. Lee. 2009. Elementary Statistics, a Problem-Solving Approach. 4th Edition, William C. Brown Publishers, California, USA.