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(Review Article)

Analysis of 3D positions processed from CORS in southern Ghana

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Abstract

Differential mode of processing GNSS in the preferred choice for high precision assignments in areas where there are active reference stations. Studies into the performance of these continuously operating reference stations (CORS) have mainly been centered on either session times or baseline lengths. Active CORS have emerged replacing the old passive stations. However, these innovations in the science of spatial data acquisition needs to be monitored for networks strength and sensitivity. In this study, GPS data from five CORS stations for 12 days were used and processed with RTKLib. The research was restricted to baseline lengths of 2.5 to 13.5 km with varying session lengths starting from 1 hour to 24 hours. 3D error for each baseline and 3D RMS for each group of baselines were subsequently computed. A plot of the results was analyzed and compared. This comparison reveals that Geodetic accuracy (below 1cm) is achieved after 4 hours of observation session showing that the precision of Rtklib baseline solution can reach sub-centimeter level and therefore can yield reliable results in almost any professional project.

Keywords: CORS; GPS baseline; Accuracy; RTKLib; DGPS Measurement Technique

1. Introduction

The Global Navigation Satellite System (GNSS) has completely changed the manner that surveyors, GIS/LIS professionals, engineers and others measure positional coordinates (Eckl et al., 2001). Users can now compute baselines and 3D positions of points with sub-centimeter accuracy using Continuously Operating Reference Station (CORS) as references. CORS operations, corrections computations and dissemination is based on differential GNSS (DGNSS) concept (Hofmann-Wellenhof et al., 2007). DGNSS quality and integrity are based on inter-station distances and errors do accumulate as spatial and temporal decorrelation occurs (Fotopoulos and Cannon, 2000). In DGNSS positioning, the increase in the baseline length affects the precision of the determined position and this accuracy is also a function of the satellite geometry. It is also meaningful to note that satellite geometry has an amplifying effect on other GNSS sources of error (Lonchay, 2009).

There have been several scientific studies on GNSS accuracy. Beutler et al. 1989 gave a practical formula for the relationship between GPS baseline length and accuracy with the aim of giving a rule for the best possible GPS baseline accuracy at a given time. Similar studies were conducted e.g. by Dong and Bock (1989), Davis et al. (1989) and Larson and Agnew (1991). All of them gave GNSS accuracy as a function of baseline distance. Eckl et al. (2001) added observing time as one factor of GPS accuracy. The study used GPS data with sessions from 4 to 24 hours and reference lengths between 26 and 300 km. Soler et al. (2006) has extended observation times to cover shorter sessions (1-4 hours). Dogan (2007) also studied the accuracy of GPS with observation times of 4 to 24 hours following the methodology outlined in Eckl et al. (2001). All these studies are invaluable and report on accuracies as a factor baseline length and/or session times. However, none of the studies considered an adjusted network to serve as true coordinates for deviations and RMS computations and comparisons. In addition, this study considers short baselines.

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Five (5) Continuously Operating Reference Stations-CADT, GEOT, GAEC, GWCL, and PDSA located in Accra were used to investigate the precision of computed 3D positions using an open source RTKLib software.

2. Study Area and Methods Employed

In this study, the goal is to investigate the precision of GNSS baseline processing based on an open source software in DGPS surveying. A geodetic network of five (5) CORS Stations in Accra (Figure 1) with a maximum baseline length of 13.5km and minimum baseline length of 2.5km was formed. The network is made up of 10 baselines, with station CADT as the fixed station. These CORS are owned and managed by Companies in the greater Accra region as shown in Table 1.

Table 1 Locations of various CORS, marker names and their Companies with approximate coordinates

Companies	Marker Name	Receiver Type	Latitude(dm) and Longitude(dm)	Height(m)
Cad Consult Ghana	CADT	Trimble NETR9	5 37 N and 0 14 W	57.168
Ghana Atomic Energy Commission (GAEC)	GAEC	TPS NET-G3A	5 40 N and 0 14 W	68.953
Geo-Tech Surveys	GEOT	TPS NET-G5	5 34 N and 0 12 W	46.173
Ghana Water Company Ltd (GWCL)	GWCL	Leica GR10	5 33 N and 0 12 W	56.516
PDSA Company Ltd	PDSA	Trimble R5	5 35 N and 0 11 W	89.393

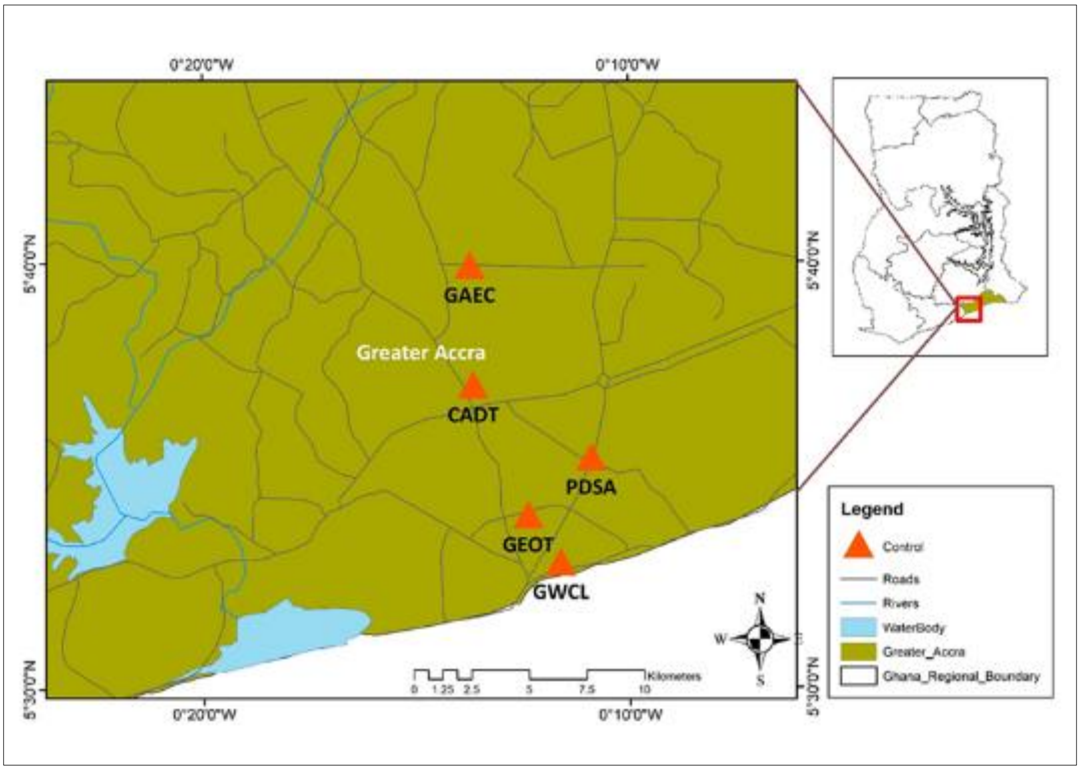


Figure 1 Map of study area showing station locations.

2.1. GNSS data logging and download

GNSS measurements were conducted simultaneously in a single 24-hour session for 12 consecutive days for the geodetic network shown in Figure 2 with a perimeter of 28.2Km.

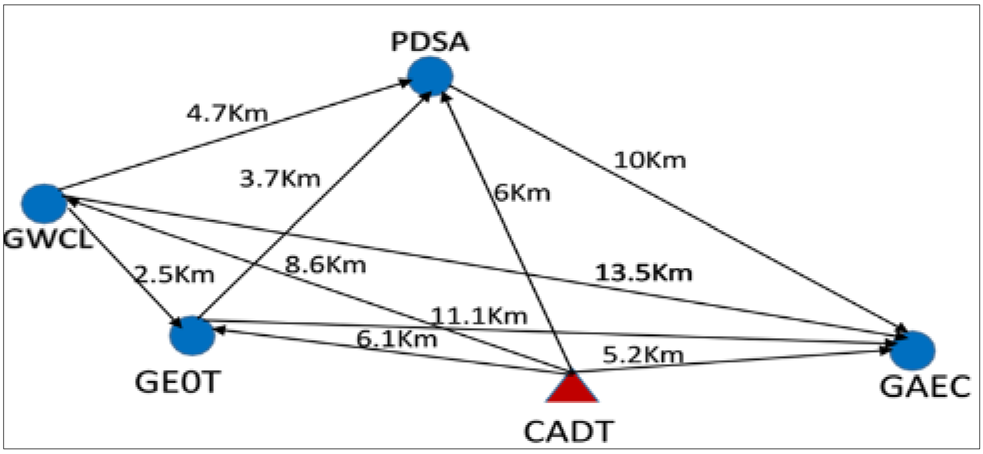


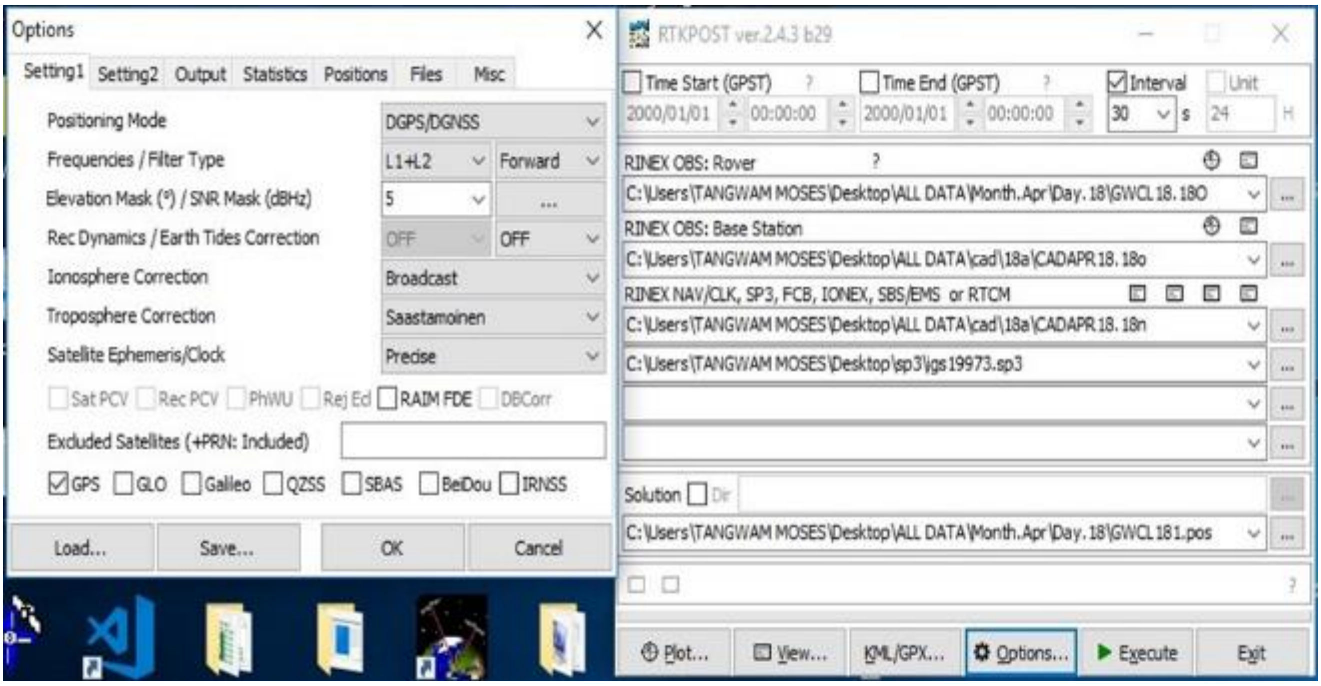
Figure 2 Planned geodetic network

Figure 3 Accra CORS (CADT) Source: Cad Consult

The five stations made up a network polygon which is stable in geometric sense and gives adequate checks for adjustments to be conducted on them. 2 Trimble receivers (NETR9 and R5), 2 Topcon receivers (NET-G3A and NET-G5) and 1 Leica GR10 were used in the measurements. The observation parameters were defined with satellite elevation angle of 5 degrees, all data logs were converted and decimated [30 secs] using Teqc since the original logging were logged at different sampling rate (Estey and Meertens, 1999).

2.2. Data Processing

Data were processed using Rtklib (Takasu and Yasuda, 2009). Final precise orbits from IGS were used in all baseline processing and setting an elevation cut-off of 5 degrees criterion, observation interval: 30 secs, orbits used: Precise, frequencies type: L1 and L2, tropospheric model: Saastamoinen, positioning mode: DGPS/DGNSS (Figure 4). Because of the mixing of different antennas all phase center offsets and variations were taken care off by using the ANTEX file (Rothacher & Schmid, 2006). Station CADT was used as the base station/control station and the other four as rovers. CADT coordinates were obtained after averaging results from four (4) online GPS data processing facilities and gLAB using PPP techniques. After post-processing, the results gave differences in coordinates (baseline vectors) computed in terms of a 3D earth centered earth fixed coordinate system based on the WGS 84 ellipsoid. Least squares adjustment was conducted on the observations to arrive at the 'true' positions of the unknown points following Ghilani, (2017). The differences in X, Y and Z for each baseline from the "true" position after the network adjustment were computed for analysis. In addition to the 12-day 24-hour sessions, the longest and shortest baselines in the network were analyzed differently by splitting data into different time spans.



Positioning Mode: DGPS/DGNSS
Frequencies / Filter Type: L1+L2, Forward
Elevation Mask (°) / SNR Mask (dBHz): 5
Rec Dynamics / Earth Tides Correction: OFF, OFF
Ionosphere Correction: Broadcast
Troposphere Correction: Saastamoinen
Satellite Ephemeris/Clock: Precise
☐ Sat PCV ☐ Rec PCV ☐ PhWU ☐ Rej Ecl ☐ RAIM FDE ☐ DBCorr
Excluded Satellites (+PRN: Included)
☑ GPS ☐ GLO ☐ Galileo ☐ QZSS ☐ SBAS ☐ BeiDou ☐ IRNSS

RTKPOST ver.2.4.3 b29
☐ Time Start (GPST) 2000/01/01 00:00:00 ☐ Time End (GPST) 2000/01/01 00:00:00 ☑ Interval 30 s ☐ Unit 24 H
RINEX OBS: Rover
C:\Users\TANGWAM MOSES\Desktop\ALL DATA\Month.Apr\Day.18\GWCL18.18O
RINEX OBS: Base Station
C:\Users\TANGWAM MOSES\Desktop\ALL DATA\cad\18a\CADAPR18.18o
RINEX NAV/CLK, SP3, FCB, IONEX, SBS/EMS or RTCM
C:\Users\TANGWAM MOSES\Desktop\ALL DATA\cad\18a\CADAPR18.18n
C:\Users\TANGWAM MOSES\Desktop\sp3\igs19973.sp3
Solution ☐ Dir
C:\Users\TANGWAM MOSES\Desktop\ALL DATA\Month.Apr\Day.18\GWCL181.pos

Figure 4 Rtklib settings and parameters used in the study.

3. Resulting statistics

Taking each baseline and the various sessions, T (1, 3, 4, 6, 12 and 24) values considered, the positional coordinates estimate of the 'unknown' stations were compared with their 'true' coordinates and the corresponding offsets(differences) were resolved into DX, DY and DZ components. The baselines were grouped (grouped by baseline length) into two from 2.5km to 6.0km and 6.1km to 13.5km and coordinates differences obtained in centimeters were grouped according to the two groups of baselines. RMS values in each component differences were computed for each baseline group and each value of T. 3D errors for each baseline were also computed. Any positional offset for the individual components that exceeded the corresponding RMS value by 3 was eliminated and corresponding RMS value was re calculated. Appendix A presents these offsets in DX, DY, DZ, computed RMS and 3D errors. In all, 2.2% of the 1-h sessions were eliminated, 1.9% of 3-h sessions were eliminated, 0.5% of 4-h sessions were eliminated, 0.2% of the 6-h sessions were eliminated and 0% for 24-h sessions.

The 3D error and RMS are computed as follows:

$$\text{3D Error} = \sqrt{DX^{2} + DY^{2} + DZ^{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

$$RMS = \sqrt{(e_1^2 + e_2^2 + e + \cdots + e_n^2)/n} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Where e is the difference between each measurement obtained and the 'true' value. Smaller RMS values indicate very accurate baseline solutions.

4. Precision analysis

Figure 5 present our derived statistics graphically. Figure 3 shows how computed 3D error values vary as a function of baseline length, L using 1, 3, 4, 6, 12 and 24 hours of data. The figure attempts to show what level of accuracy is obtainable given a constant amount of observation time and a variable baseline distance. All data was collected on the same day in order to compare results under similar conditions as possible (such as the available satellite constellation).

In all the graphs the 3D error of the solutions is used. If readers are more specifically interested in horizontal or vertical components, see Appendix A.

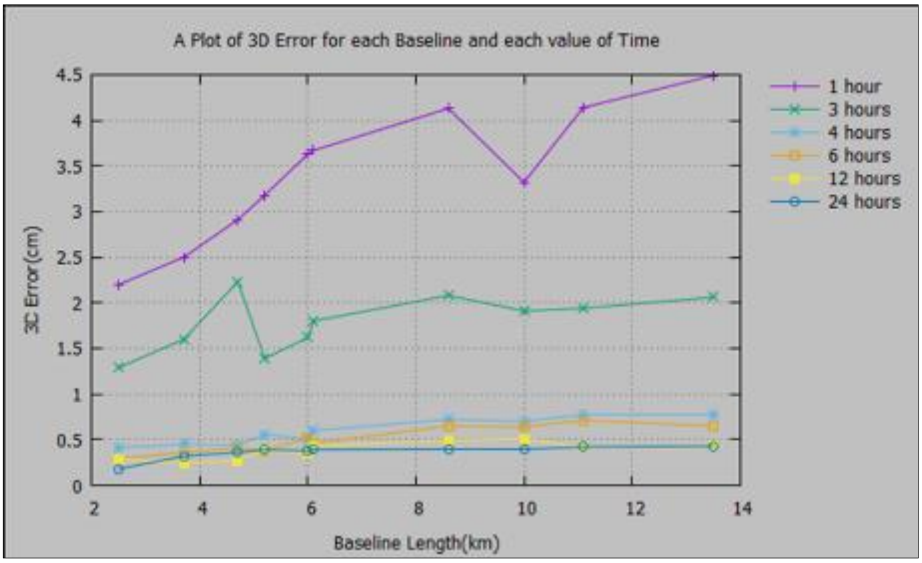


Figure 5 3D Error as a Function of Baseline Length using 24 Hours of Data

Statistical analysis in a form of F-test was conducted on the 3D RMS (precision) results of the two groups of baselines (2.5-6.0km and 6.1-13.5km). The test was conducted at α=0.05(95% confidence interval); that is, 0.05 significant level. The null hypothesis (H_0) states that there is no significant difference between the average mean precision on the two groups of baseline processing results while the alternative hypothesis (H_A) states otherwise. The outcome of the test results indicates that there is no significant difference among the two groups; that is the two samples come from the same population.

Figures 6 and 7 also represent graphically our derived statistics showing 3D RMS error as a function of observation time using 1, 3, 4, 6, 12 and 24 hours of data.

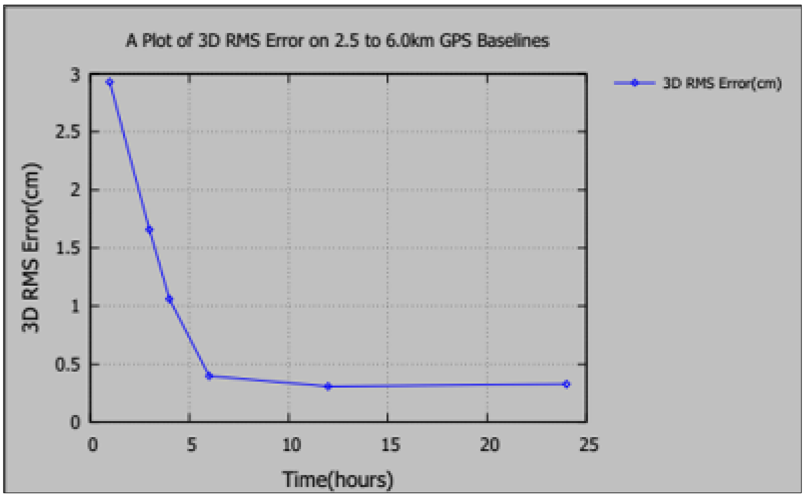


Figure 6 3D RMS Error as a Function of Time for Baseline Lengths of 2.5 to 6.0 km

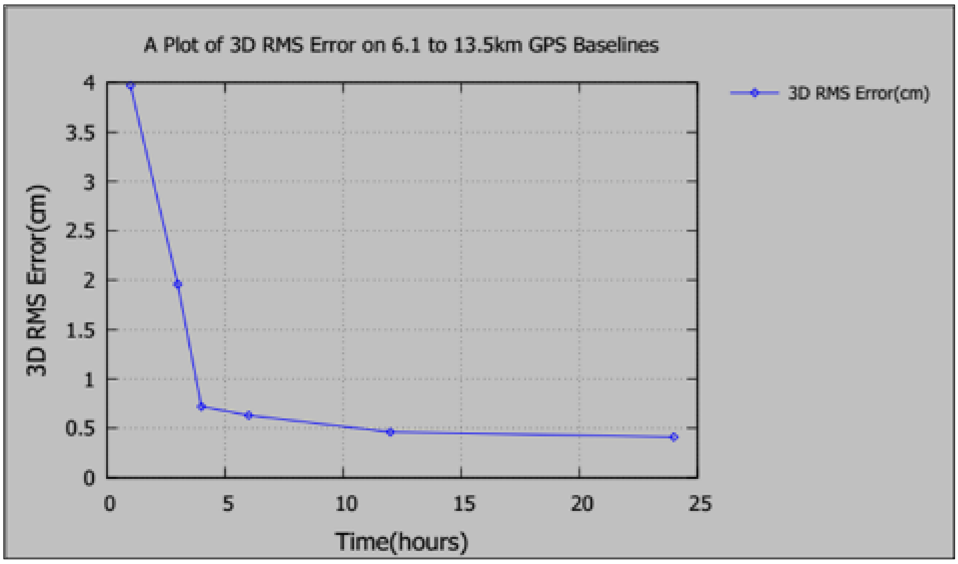


Figure 7 3D RMS Error as a Function of Time for Baseline Lengths of 6.1 to 13.5 km

5. Discussions

Figure 5 shows the behavior of precision in the form of 3D errors with respect to baseline lengths and there is a slight distance-dependency of accuracy on baseline especially on short observing sessions (the violet and green lines) therefore variance ratio test was conducted on the average precisions of the two baseline groups to ascertain between the level of precision achieved by the two groups of baselines. The F-test also indicated that there is no significant difference between the level of precision obtained by the baseline processing involving the CORS at 2.5-6.0km and 6.1-13.5km making the accuracy dependence on baseline Length (L not exceeding 13.5km) so slight.

Figures 6 and 7 re-enforces the above findings that rtklib can attain 0.3cm to 4cm which reflect geodetic accuracy however emphasizing to the lower end. The upper end may be considered in some less accuracy demanding measurements but for accurate surveying one should consider to use lower end (< 2 cm). The largest 3D RMS is 4cm and is seen when processing 1 hour of data for baseline group of 6.1 to 13.5km and the best level of observed 3D RMS accuracy is seen when processing 24 hour of data on the 2.5 to 6.0km baseline group as 0.3cm. Figures 5 through 6 also generally display that considerable improvements are seen when collecting 4 hours of data as opposed to 1 hour, and 6 hours of data as opposed to 4 hours for all baseline groups. Slight differences are seen in all baseline groups from 6 hours of data collection to 24 hours. Therefore, this suggests that little improvements are seen when collecting more than six hours of data. Improvement in the precision and the reliability of the baseline length is achieved after 4 hours of observations.

Dogan et al. (2014) also showed examples of obtainable precisions as a function of baseline length given specific observation times and our results show consistency when compared with their work. Other investigators (Häkli, Koivula, and Puupponen, 2008; Okorocha and Olajugba 2014; Gezgin, 2015) recently conducted experiments to study the precision of GPS baseline processing. Häkli, Koivula, and Puupponen used a commercial GPS software (Trimble Total Control), Okorocha and Olajugba 2014 also used a commercial GPS processing software (Trimble Business Center) and Gezgin 2015 also evaluated their measurements in Leica Geo Office 8.3 (LGO) as a commercial software and GAMIT/GLOBK as a scientific software. 24-h results represent the best performance of GPS in our study and thus these were compared to those of (Häkli, Koivula, and Puupponen, 2008; Okorocha and Olajugba 2014; Gezgin, 2015). Our findings were compatible with their results and all these studies are valuable and give information of the reachable precision when commercial and scientific GPS processing software are used. Our results also fall within the formal accuracy interval of geodetic network.

6. Conclusion

Our main aim was to analyze the precision of GNSS baseline solutions based on baseline length and different observation sessions. Previous studies have been reaching mainly the limits of commercial and scientific software. The main difference between our and previous studies is that we computed our baselines with an open source software and adjusted our network.

The F-test indicated that there is no significant difference between the two groups of baselines variances statistically indicating that the dependency of positioning precision on baseline length L is so slight. That is not to say that positioning precision is independent of L but that the dependency is negligibly small. Geodetic accuracy (below 1cm) was achieved at 4 hours of observation session showing that the cost-effective duration of observation for baseline length determination is 4 hours and that after 24 hours no significant improvement in the quality of our estimates can be expected.

The evaluated open-source software (Rtklib) passed the tests successfully by showing that the precision of inner coincidence of Rtklib baseline solution can reach sub-centimeter level and therefore can yield reliable results in almost any professional project.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interests.

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Appendix

Appendix A Baseline differences, 3D errors and 3D RMS in cm

Baseline differences and 3D RMS (2.5 to 6.0 km)					
Processing Time: 1 hour					
Baseline	**Length(km)**	**DX**	**DY**	**DZ**	**3D ERRORS**
GWCL-GEOT	2.5	-1.44	-1.22	-1.12	2.20
GE0T-PDSA	3.7	-1.50	-1.53	1.30	2.50
PDSA-GWCL	4.7	1.66	-1.72	1.66	2.91
CADT-GAEC	5.2	1.86	1.93	-1.72	3.18
CADT-PDSA	6.0	-2.12	2.03	2.14	3.63
RMS		1.73	1.71	1.63	2.93
Baseline differences and 3D RMS (6.1 to 13.5 km)					
Processing Time: 1 hour					
Baseline	**Length(km)**	**DX**	**DY**	**DZ**	**3D ERRORS**
CADT-GEOT	6.1	-2.18	2.04	2.13	3.67
CADT-GWCL	8.6	2.25	-2.50	2.39	4.13
PDSA-GAEC	10.0	1.50	-2.57	1.45	3.32
GAEC-GEOT	11.1	2.55	2.27	2.34	4.14
GAEC-GWCL	13.5	3.19	-2.87	1.32	4.49
RMS		2.40	2.47	1.98	3.97
Baseline differences and 3D RMS (2.5 to 6.0 km)					
Processing Time: 3 hours					
Baseline	**Length(km)**	**DX**	**DY**	**DZ**	**3D ERRORS**
GWCL-GEOT	2.5	1.25	-0.22	-0.23	1.29
GE0T-PDSA	3.7	0.28	1.54	-0.33	1.60
PDSA-GWCL	4.7	1.56	-1.58	0.23	2.23
CADT-GAEC	5.2	1.13	0.50	-0.65	1.39
CADT-PDSA	6.0	1.01	1.25	-0.15	1.62

RMS		1.13	1.16	0.36	1.66
Baseline differences and 3D RMS (6.1 to 13.5 km)					
Processing Time: 3 hours					
Baseline	**Length(km)**	**DX**	**DY**	**DZ**	**3D ERRORS**
CADT-GEOT	6.1	1.18	-1.19	0.66	1.80
CADT-GWCL	8.6	-1.95	-0.70	-0.21	2.08
PDSA-GAEC	10.0	1.50	-1.17	0.04	1.91
GAEC-GEOT	11.1	1.45	1.17	0.54	1.94
GAEC-GWCL	13.5	1.59	-1.27	0.32	2.06
RMS		1.55	1.12	0.42	1.96
Baseline differences and 3D RMS (2.5 to 6.0 km)					
Processing Time: 4 hours					
Baseline	**Length(km)**	**DX**	**DY**	**DZ**	**3D ERRORS**
GWCL-GEOT	2.5	0.11	-0.10	0.38	0.41
GE0T-PDSA	3.7	0.25	-0.15	-0.34	0.45
PDSA-GWCL	4.7	-0.22	-0.28	0.25	0.44
CADT-GAEC	5.2	0.31	-0.24	-0.41	0.56
CADT-PDSA	6.0	0.37	0.29	0.19	0.50
RMS		0.59	0.50	0.73	1.06
Baseline differences and 3D RMS (6.1 to 13.5 km)					
Processing Time: 4 hours					
Baseline	**Length(km)**	**DX**	**DY**	**DZ**	**3D ERRORS**
CADT-GEOT	6.1	-0.29	0.47	0.24	0.60
CADT-GWCL	8.6	-0.41	0.40	-0.43	0.72
PDSA-GAEC	10.0	0.36	0.44	0.41	0.70
GAEC-GEOT	11.1	0.48	-0.43	0.43	0.77
GAEC-GWCL	13.5	0.48	-0.48	-0.38	0.77
RMS		0.41	0.44	0.38	0.72
Baseline differences and 3D RMS (2.5 to 6.0 km)					
Processing Time: 6 hours					
Baseline	**Length(km)**	**DX**	**DY**	**DZ**	**3D ERRORS**
GWCL-GEOT	2.5	0.03	-0.07	0.28	0.29
GE0T-PDSA	3.7	0.11	-0.13	-0.32	0.36
PDSA-GWCL	4.7	-0.12	-0.17	0.35	0.41
CADT-GAEC	5.2	0.21	-0.24	-0.21	0.38
CADT-PDSA	6.0	0.26	0.31	-0.34	0.52
RMS		0.16	0.20	0.30	0.40
Baseline differences and 3D RMS (6.1 to 13.5 km)					

Processing Time: 6 hours					
Baseline	**Length(km)**	**DX**	**DY**	**DZ**	**3D ERRORS**
CADT-GEOT	6.1	-0.29	0.27	0.24	0.46
CADT-GWCL	8.6	-0.41	0.41	-0.30	0.65
PDSA-GAEC	10.0	0.32	0.43	0.34	0.64
GAEC-GEOT	11.1	0.45	-0.43	0.34	0.71
GAEC-GWCL	13.5	0.46	-0.27	-0.38	0.65
RMS		0.39	0.37	0.32	0.63
Baseline differences and 3D RMS (2.5 to 6.0 km)					
Processing Time: 12 hours					
Baseline	**Length(km)**	**DX**	**DY**	**DZ**	**3D ERRORS**
GWCL-GEOT	2.5	0.20	-0.19	0.10	0.29
GE0T-PDSA	3.7	0.12	-0.11	-0.18	0.24
PDSA-GWCL	4.7	-0.10	-0.11	0.22	0.27
CADT-GAEC	5.2	0.24	-0.27	0.15	0.39
CADT-PDSA	6.0	-0.22	-0.25	0.10	0.35
RMS		0.18	0.20	0.16	0.31
Baseline differences and 3D RMS (6.1 to 13.5 km)					
Processing Time: 12 hours					
Baseline	**Length(km)**	**DX**	**DY**	**DZ**	**3D ERRORS**
CADT-GEOT	6.1	-0.25	0.29	-0.19	0.43
CADT-GWCL	8.6	-0.32	0.29	-0.22	0.49
PDSA-GAEC	10.0	0.29	0.32	-0.28	0.51
GAEC-GEOT	11.1	0.27	-0.21	0.24	0.42
GAEC-GWCL	13.5	0.22	-0.30	-0.25	0.44
RMS		0.27	0.28	0.24	0.46
Baseline differences and 3D RMS (2.5 to 6.0 km)					
Processing Time: 24 hours					
Baseline	**Length(km)**	**DX**	**DY**	**DZ**	**3D ERRORS**
GWCL-GEOT	2.5	0.05	-0.02	0.17	0.18
GE0T-PDSA	3.7	0.10	-0.01	-0.30	0.32
PDSA-GWCL	4.7	-0.11	-0.10	0.32	0.36
CADT-GAEC	5.2	0.22	-0.29	0.12	0.39
CADT-PDSA	6.0	-0.24	-0.21	0.21	0.38
RMS		0.16	0.17	0.24	0.33
Baseline differences and 3D RMS (6.1 to 13.5 km)					
Processing Time: 24 hours					
Baseline	**Length(km)**	**DX**	**DY**	**DZ**	**3D ERRORS**

CADT-GEOT	6.1	-0.25	0.25	-0.16	0.39
CADT-GWCL	8.6	-0.21	0.27	-0.20	0.40
PDSA-GAEC	10.0	0.21	0.23	-0.25	0.40
GAEC-GEOT	11.1	0.23	-0.22	0.27	0.42
GAEC-GWCL	13.5	0.22	-0.27	-0.26	0.43
RMS		0.23	0.25	0.23	0.41

Authors short biography

	**Moses Tangwam** is an accomplished scholar in the field of geomatic engineering and geographic information science (GIS). He obtained his undergraduate and first master's degrees in Geomatic Engineering from Kwame Nkrumah University of Science and Technology, KNUST, showcasing his dedication to the discipline. Currently pursuing his second master's degree in GIS at Michigan Technological University, Tangwam continues to expand his expertise in spatial analysis and technology. With a passion for leveraging geospatial data to address real-world challenges, he is poised to make significant contributions to the field. Beyond academia, Tangwam enjoys exploring the intersection of technology and environmental sustainability.