Development of GNSS software for Ghana Survey and Mapping Division

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Abstract

Processing of Global Navigational Satellite System (GNSS) data forms the basis for the usage of differential systems for obtaining spatial data. All open sources or commercial software packages developed for data processing give specific details to suit the intended purpose of the software. To obtain a uniform format for submitted survey data, Survey and Mapping Division (SMD) in various jurisdictions have specified formats for data submission for all kinds of surveys. In this regard, "GNSS Ghana" Software (GGS), a GNSS standalone Windows-based application with a modern user-friendly interface was developed for geodetic applications such as, projection and datum transformation worldwide, GNSS data post-processing of Receiver Independent Exchange Format (RINEX) files, and generating reports to meet Ghana SMD reporting standards including cadastral computations and reports for submission. To assess the developed software, GNSS data from two International GNSS Service (IGS) stations (BJCO and YKRO) were processed using GGS and three other commercial software such as GNSS Solution Software (GSS), Spectrum Survey Software (SSS), and Leica Geo Office (LGO), and the positional results compared against the existing coordinate. The results revealed that the GGS outperformed the remaining three commercial software packages with a sub-meter level of accuracy. Further assessment was conducted on datum transformation using the coordinates of 21 existing geodetic control points in Ghana. Utilizing the 7-transformation parameters of Ghana, the results gave uncertainties of [0.10ft. ± 0.99ft.] in the eastings and [0.02ft. ± 1.61ft.] in the northings with a 99% confidence level.

***Keywords**: GNSS, positioning accuracy, Projection, Transformation, Cadastral, RTKlib*

1. Introduction

Global Navigational Satellite System (GNSS) is a system widely used by the military, civilian, industrial and scientific communities due to its capabilities and relative advantages, such as 24-hour observation time and all-weather global positioning. Improving the accuracy of long-distance GNSS positioning is still an important topic in current research and development (Bender et al., 2011; Rao et al., 2013; Tsushima et al., 2014; Verhagen et al., 2010; Wang et al., 2016; Yozevitch et al., 2014; Zhang et al., 2013). The important and ever-growing demand for GNSS-related techniques in various areas has spurred on a wealth of research. GNSS receivers designed for survey and mapping applications come in different satellite support systems, components and have autonomous operations with each having its software and online services for processing data. Several different data processing techniques have been developed over the years, and these techniques must meet high precision and accuracy standards (Salazar, 2010). Most GNSS receivers have propriety software for processing data included in the package. Processing of the data is based on the algorithms used in these individual applications, each having its pros and cons. Some also include predefined datums, and coordinate systems, which tend to work best in some regions.

Processing of data from receivers forms the basis of the use of differential systems as a method of deriving the collected spatial data and most processing systems give specific details in the processing reports generated. However, the authorities in charge of Survey and Mapping Divisions (SMD) for most countries have their specifications and report formats to be submitted upon completion of survey projects. These are implemented to avoid confusion and conflicts in data reports from different surveyors. Several online processing services provide GNSS processing results to the user free of charge and with unlimited access. Output solutions/reports are based on differential methods via reference stations or precise point positioning, using precise orbit and clock data (El-Mowafy, 2011; Furones et al., 2012; Ghoddousi-Fard & Dare, 2006; Landau et al., 2009; Leandro et al., 2011; Teunissen et al., 2010). Usually, the outputs are to their specific standards and therefore making GNSS data processing and management.

Unlike most other developed countries, Ghana has no GNSS processing system. Therefore, many surveyors use the default software that comes along with their manufacturers GNSS receivers or any other software they get hands-on to process the data. As a result, when projects are submitted to the SMD, there are discrepancies in the processed data report format from different surveyors. The differences in processing algorithms used in writing programs may also result in different coordinates or outputs (reports) and therefore cause non-conformity in the data gathered at SMD. It is necessary to develop a central GNSS processing software capable of processing most data from all receivers in Ghana using Receiver Independent Exchange Format -RINEX (Gurtner & Estey, 2009) files as input data for consistent homogeneous accuracy standards and easy data integration and achieving.

Little, if any research has been done on the concept of developing computer software for processing GNSS data for local/national purposes in Ghana. Osah, 2013 developed "GeoSuite" a geodetic application for GNSS data post-processing, Datum transformation, and Direct & Inverse geodetic computation for Ghana but does not generate report documents for SMD report use or submission. Open-source GNSS applications like the goGPS (Herrera et al., 2016), RTKLib (Takasu, 2013), and gLab (Sanz et al., 2012) have been researched and tested to be efficient and produce accurate results after processing data as compared to other commercial software (Videkull, 2015), but most of the information produced is not needed for some survey works.

This study was to determine and minimize some of these issues that arise in SMD (due to differences in processing software) by developing a computer program that uses some of the open-source algorithms to process data and produce relevant reports based on the user's preference by work by modifying the existing algorithm to suit the needs and ensure that the reports conform to the standards of SMD and for easy querying. It is to help simplify processing and reports for general purposes and accept a particular format irrespective of the instrument used by the surveyor.

2. Software platform and installation

The software suite was developed using visual C-Sharp (C#) programming language, compiled as an executable program, for use in most popular operating systems including Windows, macOS, and Linux. As a result, it was necessary to develop the software for post-processing and that used external plugins from other developers to stimulate the development process. Some of the downloaded plugins included in the project are:

- SQLite (Kennedy et al., 2017) management of data and some settings were stored in the system, which was generously licensed in the public domain and does not require extensive configurations.
- MetroSuite 2.0 (Gather, 2018) and MetroFramework (Denric, 2016) enhance the user-friendliness and aesthetics of the program.
- MapWinGIS and DotSpatial for the map part of the program from GIS opensource projects (Ames et al., 2018).
- A modified version of ProjNet4GeoAPI (NetTopologySuite, 2019) library to support for 10-parameter transformation and other Spatial conversions.

The algorithms used in the development of the software are based on existing open-source codes. The major part implemented for post-processing of GNSS RINEX data is from RTKLib class libraries with some features modified to suit the standards for processing data and document presentation for cadastral survey in Ghana. The software currently supports all the navigation systems supported by RTKLib version 2.4.3 class libraries (i.e. GPS, GLONASS, BeiDou, GALILEO, QZSS, SBAS). The GNSS Ghana Software has only the executable file for installation and does not require any pre-installed applications.

3. Software Introduction and Features

The software developed at the end of this study comes packed with three main geodetic processing modes (i.e., DGNSS using baseline computation vectors, Cadastral computation, and Projection/ Datum Transformation). GNSS Ghana Software (GGS) currently two input formats, RINEX as GNSS post-processing data format and a delimited data file for other inputs. The entire ecosystem has been designed to help make processing using GGS very simple, and Figure 1 shows the flow chart in the software design.

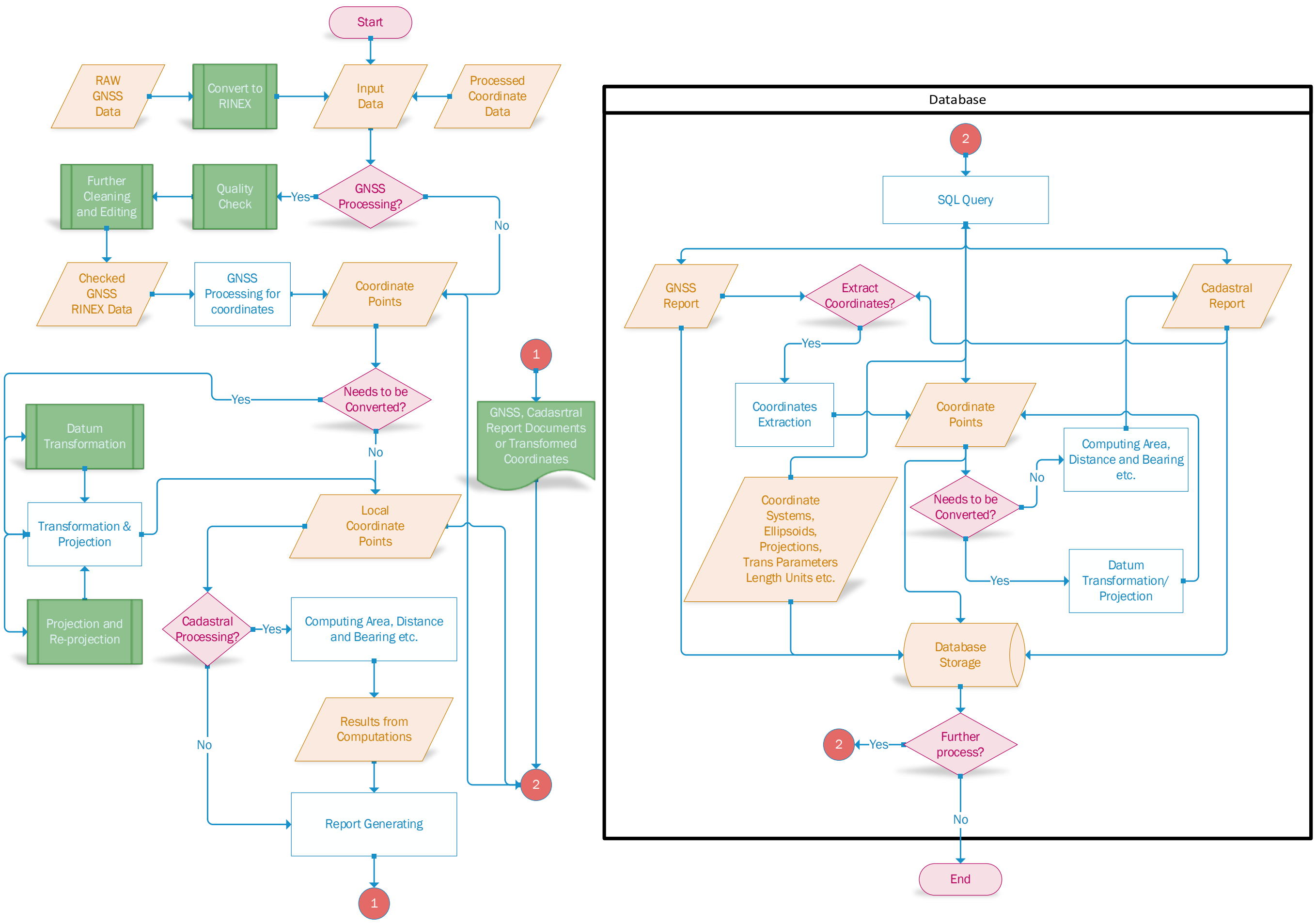


Figure 1: General flow of software design.

Currently, GGS can produce all of the necessary computational documents needed to submit a cadastral report to SMD Ghana, and geodetic calculations (such as exporting cartesian, geographic, and projected coordinates to file or for printing). A screenshot of the Graphic User Interface (GUI) of GGS which allows the processing of GNSS baseline data and performing several calculations is shown in Figure 2.

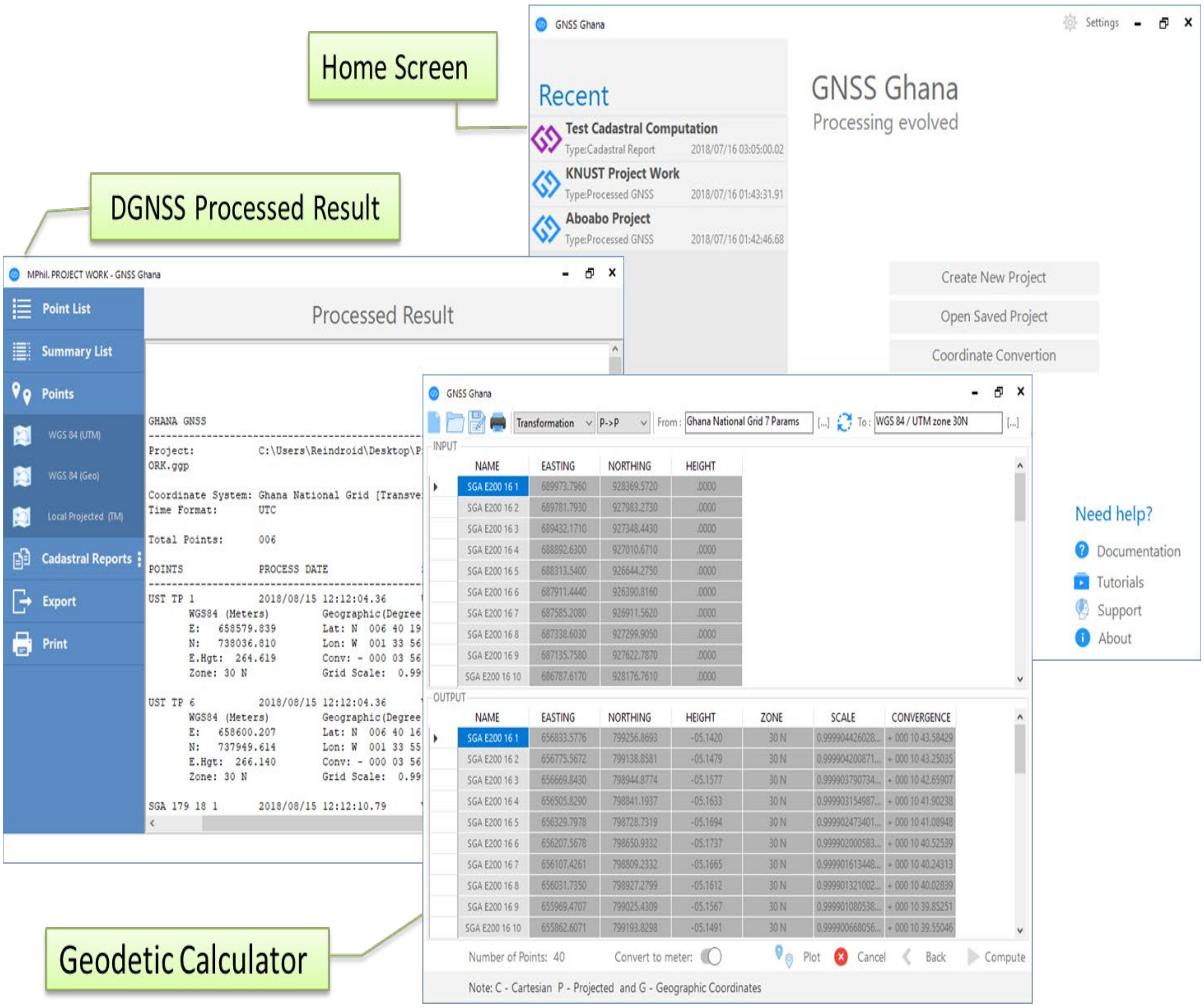


Figure 2: GNSS Ghana home screen and result pages.

GGS's reports are export into formats: PDF and spreadsheet. All GNSS processed reports are exported in PDF format with optional spreadsheets of all site IDs and positions in geographic, UTM, and local coordinate systems. On the other hand, cadastral reports are generated in the standards of SMD Ghana are all in PDF only for uniformity and easy query.

The concept of the kind of data reports that the Ghana SMD requires for both engineering and cadastral surveys, there are certain documents about the survey that must be included. These cadastral reports for the SMD are tabulated in Table 1. Points numbered from 1-5 are all generated from one process within the GGS but the other documents are not supported yet in the developed software.

Table 1: List of documents required by SMD Ghana

No.	***GNSS Post-Processing Reports***	***Cadastral Reports***
1	Point Lists	Beacon Index
2	Summary Lists	Distance and Bearing
3	Extracted Points (Geographic and projected coordinates)	Plan Data
4	GNSS Observation Data	Area Computation
5		Optional report to be used on the map called "Map Data"
6		History of survey
7		Diagram of survey
8		Cadastral Map

4. Data Processing Using GGS

The program as indicated in previous sections has a simple and straightforward GUI with short selective options to choose from and customizations based on the processing type selected. All other configurations have been done in the program and so it does not require any other files and settings to run aside from the few options given. There are detailed, but yet simple documentation and tutorials included in GGS software. Figure 3 below shows the general flow of data and results in GGS. The processing modes are three: GNSS data processing with or without cadastral reports, a standalone cadastral reports generation from points as a project, and the geodetic calculator.

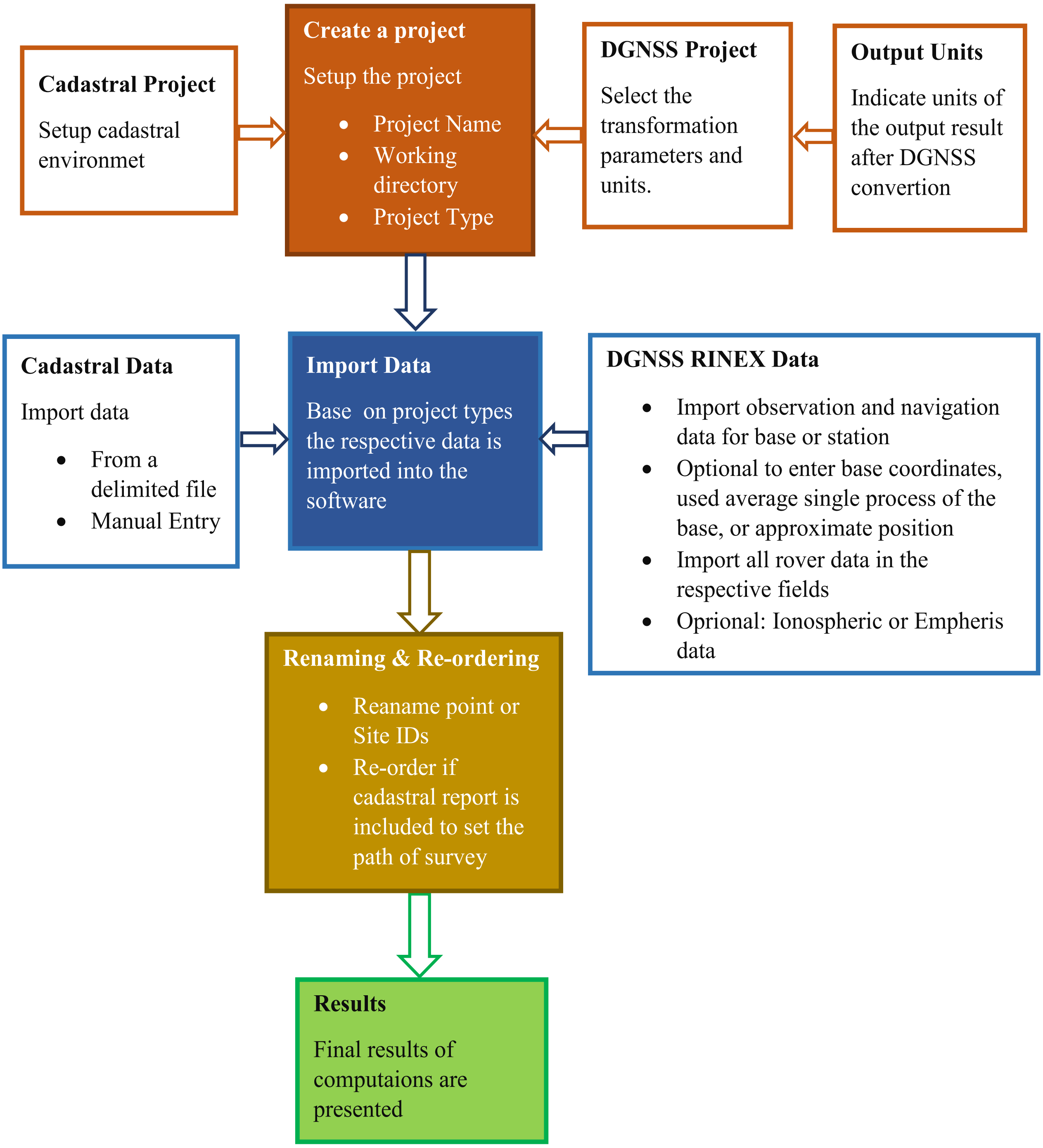


Figure 3: General Steps in processing projects in GGS.

The entire procedures take only four-paged steps (Creating Project, Data Importing, Renaming, and Processed results) to achieve a result or solution for both DGNSS and Cadastral report processing. All outputs can be printed directly from the GGS software.

Figure 4 shows the interface for an additional part of the developed application, the ability to perform a coordinate system conversion. Forward and Inverse projection and datum transformation processes were created in various classes to allow for easy reintegration into multiple or batch conversions and to give support to the world coordinate systems (i.e., Coordinate Reference Systems

– CRS). A collection of most of the known coordinate systems in the world has been prepacked into the program. Therefore, based on the conversion type, either with simple projection with only one CRS or datum transformation with projections (which require both the source and target CRS), the user will have to select the CRS from the world CRS provided or may create a new one to perform conversions to and from either coordinate systems (i.e. Geographic, Cartesian or the Projected coordinate system).

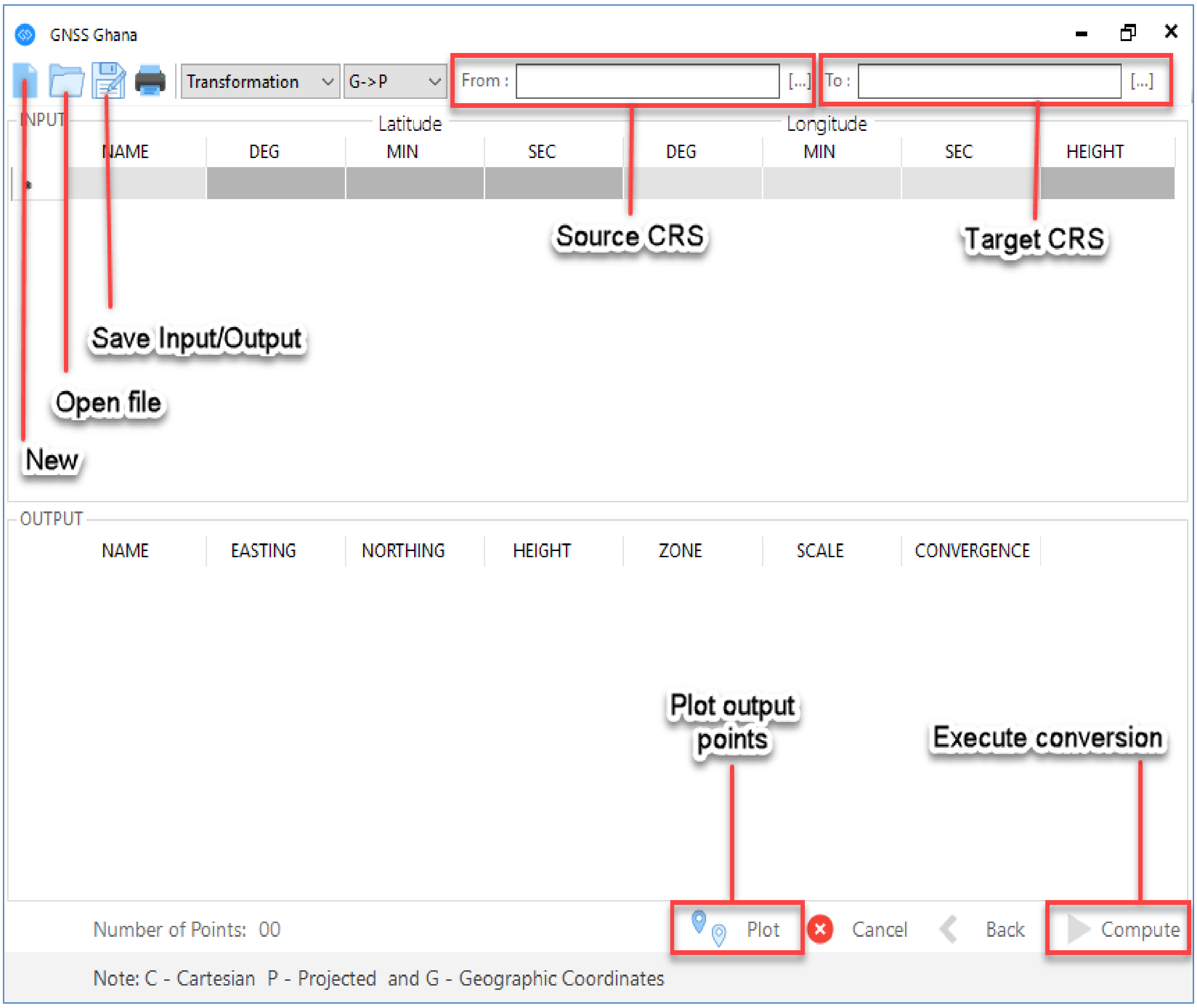


Figure 4: GGS CRS Conversion Interface

5. Results and Discussion

5.1. Generating Reports

A typical example of the output page from GNSS Data processed with cadastral computation reports is shown in Figure 5. Here, the example page looks like this because the cadastral report was checked when creating the project, and therefore an option to indicate the starting control to site points and that of the closing control was set. It can also be changed by using the three dots on the "Cadastral Report" button to reorder the connections of the pillars even afterward. The whole sections under the cadastral report will not be there if not included during project settings.

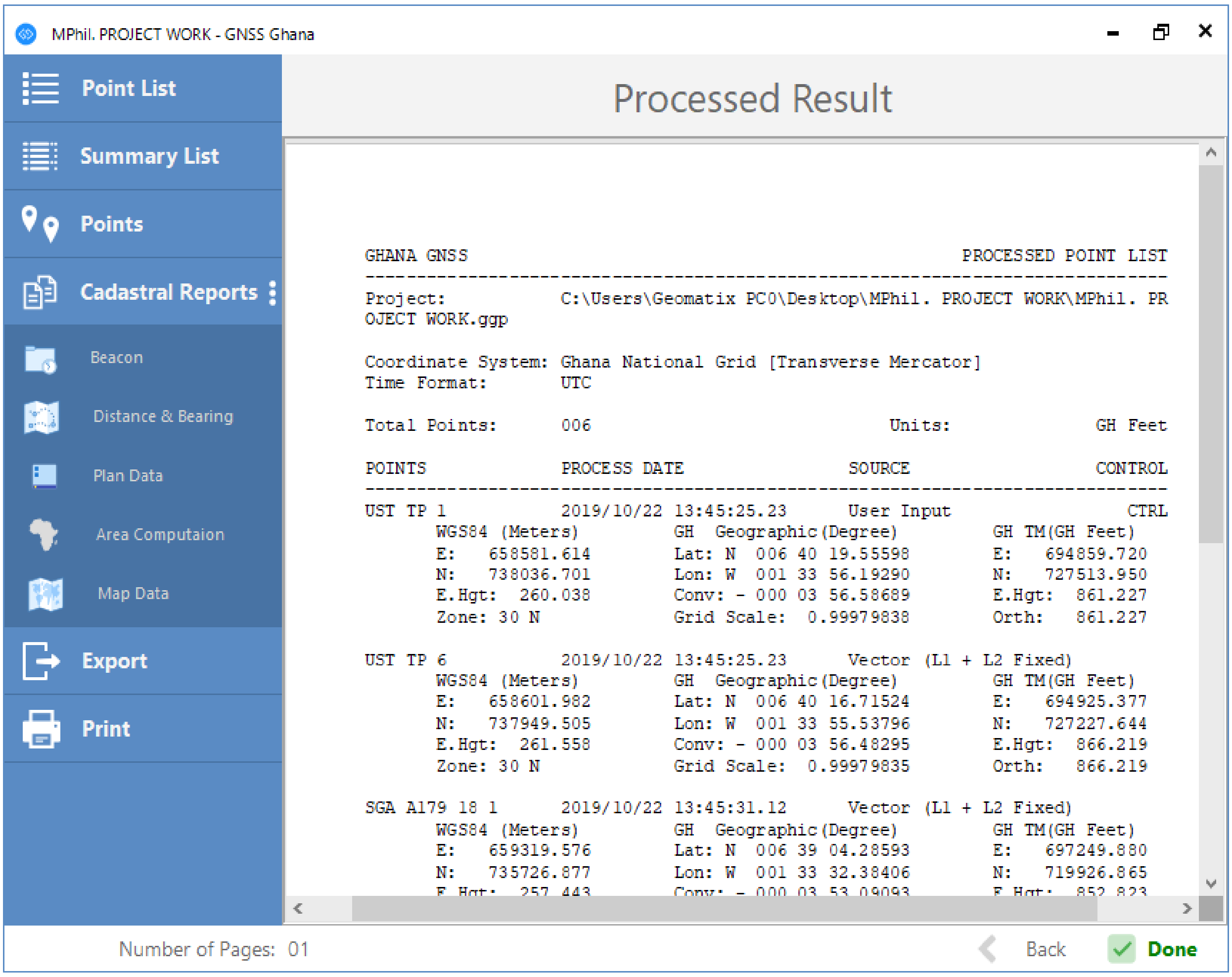
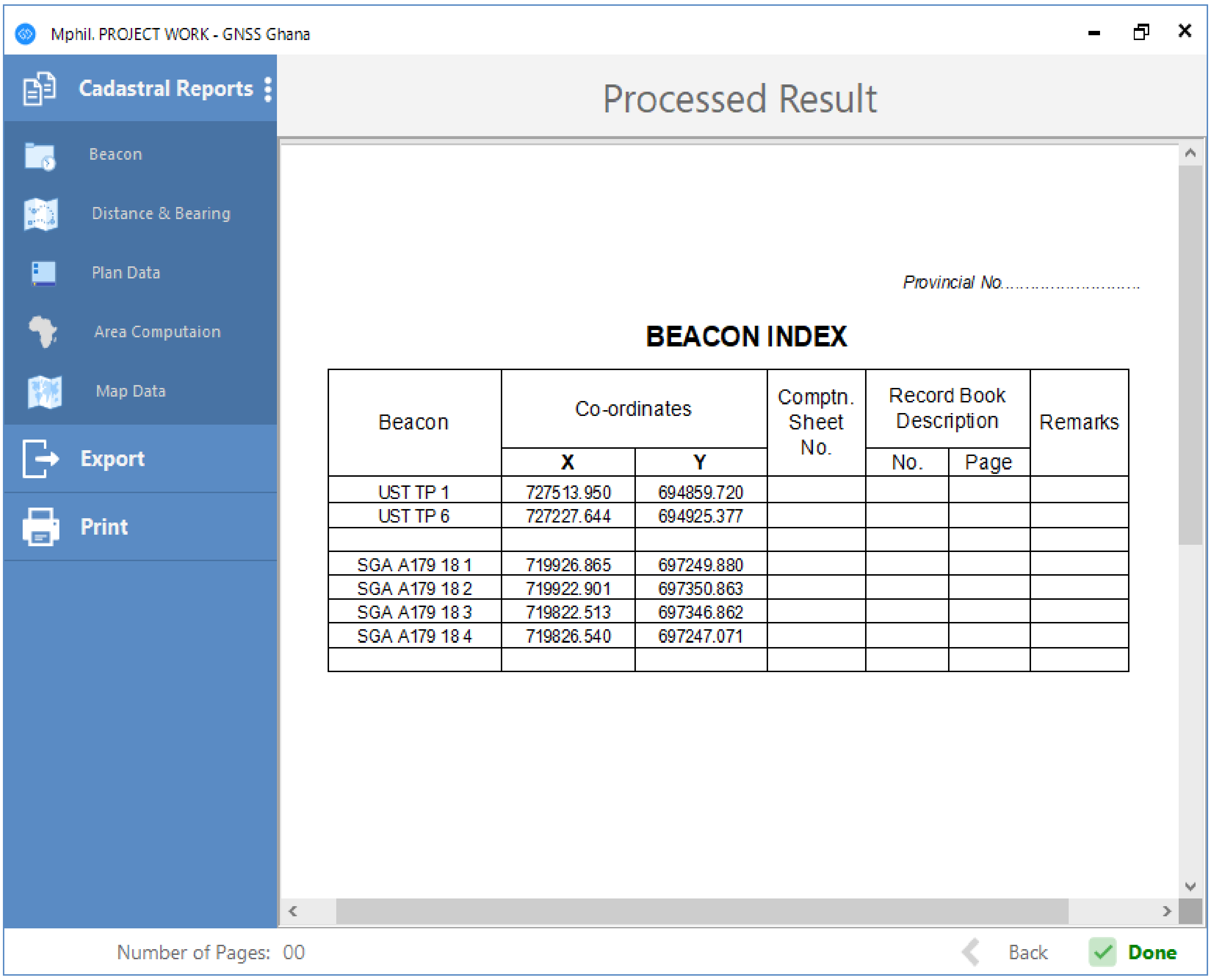


Figure 5: GNSS Processing – Processed Solution interface.

The first three-parts (i.e., "Point List", "Summary List", and "Points") will not show if the project is for only cadastral reports from existing points in the local coordinates. Therefore, only the "Cadastral Report" button with the other two constant buttons (i.e., "Export" and "Print" buttons) are available to the user as shown in Figure 6 below. Upon clicking, the hidden buttons, including "Beacon", "Distance & Bearing", "Plan Data", "Area Computation" and "Map Data", may be used on the cadastral map for printing.



BEACON INDEX

Beacon	Co-ordinates		Comptn. Sheet No.	Record Book Description		Remarks
	X	Y		No.	Page	
UST TP 1	727513.950	694859.720				
UST TP 6	727227.644	694925.377				
SGA A179 18 1	719926.865	697249.880				
SGA A179 18 2	719922.901	697350.863				
SGA A179 18 3	719822.513	697346.862				
SGA A179 18 4	719826.540	697247.071				

Figure 6: Cadastral – Processed Solution interface

GGS also shows more capability in the accuracies of area, distance, and bearing computations like dealing with a piece of land with about 200 or more points on the boundary, and you are required to produce documents mentioned above on that land with probably others surveys you have done too. These will require separate computations for each survey's documentation manually or with several spreadsheet programs. Again, the hustle of extracting processed points for the computation is a different case altogether, but with GGS this is made with ease, and with a click of a button, unlike other propriety software which are not custom-designed to have this feature.

BEARING AND DISTANCE FROM COORDINATES

From Point	SGA A179 18 1	(A)	To Point	SGA A179 18 2	(B)
Xa =	697249.880		Ya =	719926.865	
Xb =	697350.863		Yb =	719922.901	
	-3.96			100.98	
Actual Bearing =	**092 14 45**		**DISTANCE =**	**101.06**	
From Point	SGA A179 18 2	(A)	To Point	SGA A179 18 3	(B)
Xa =	697350.863		Ya =	719922.901	
Xb =	697346.862		Yb =	719822.513	
	-100.39			-4.00	
Actual Bearing =	**182 16 54**		**DISTANCE =**	**100.47**	
From Point	SGA A179 18 3	(A)	To Point	SGA A179 18 4	(B)
Xa =	697346.862		Ya =	719822.513	
Xb =	697247.071		Yb =	719826.540	
	4.03			-99.79	
Actual Bearing =	**272 18 45**		**DISTANCE =**	**99.87**	
From Point	SGA A179 18 4	(A)	To Point	SGA A179 18 1	(B)
Xa =	697247.071		Ya =	719826.540	
Xb =	697249.880		Yb =	719926.865	
	100.32			2.81	
Actual Bearing =	**001 36 16**		**DISTANCE =**	**100.36**	

CONNECTING PILLARS

From Point	UST TP 1	(A)	To Point	SGA A179 18 1	(B)
Xa =	694859.720		Ya =	727513.950	
Xb =	697249.880		Yb =	719926.865	
	-7587.08			2390.16	
Actual Bearing =	**162 30 50**		**DISTANCE =**	**7954.67**	
From Point	SGA A179 18 4	(A)	To Point	UST TP 6	(B)
Xa =	697247.071		Ya =	719826.540	
Xb =	694925.377		Yb =	727227.644	
	7401.10			-2321.69	
Actual Bearing =	**342 35 01**		**DISTANCE =**	**7756.71**	

Figure 7: Sample of GGS Cadastral Bearing and Distance computation report

For a cadastral report on bearing and distance computation based on either DGNSS or direct input of coordinates, GGS creates a report on the point-to-point computations of the site pillars together with the connecting pillars as shown in Figure 7. Similarly, the area computation and the plan data for a piece of land are all prepared automatically for ready submission. These kinds of reports are not provided by the commercial software such as LGO, GSS, and SSS used in this study, since they are designed for general purpose post-processing usage as shown in Figure 8 and Figure 9 below.

AREA COMPUTATION

STATION	X	Y	Y(I)*(X(I+1)-X(I))	X(I)*(Y(I+1)-Y(I))
SGA A179 18 1	719926.865	697249.880	-2763898.52	72700374.61
SGA A179 18 2	719922.901	697350.863	-70005658.43	-2880411.53
SGA A179 18 3	719822.513	697346.862	2808215.81	-71831808.39
SGA A179 18 4	719826.540	697247.071	69951312.40	2021992.75
			-10028.75	10147.44

DOUBLE AREA	=	**20176.19**	sq.ft
AREA	=	**10088.09**	sq.ft
AREA	=	**0.23**	acres
		0.09	hect.

Figure 8: Sample of GGS Area Computation report

PLAN DATA SHEET

FROM	TO	BEARING deg.	min	sec	DISTANCE feet	REMARKS
SGA A179 18 1	SGA A179 18 2	**092**	**14**	**45**	**101.06**	
SGA A179 18 2	SGA A179 18 3	**182**	**16**	**54**	**100.47**	
SGA A179 18 3	SGA A179 18 4	**272**	**18**	**45**	**99.87**	
SGA A179 18 4	SGA A179 18 1	**001**	**36**	**16**	**100.36**	
CONNECTING PILLAR						
UST TP 1	SGA A179 18 1	**162**	**30**	**50**	**7954.67**	
SGA A179 18 4	UST TP 6	**342**	**35**	**01**	**7756.71**	
AREA	=	**0.23 acres**				
	=	**0.09 hect.**				

Figure 9: Sample of GGS Plan Data report

Finally, to make it more efficient and convenient, the section designed to perform point-to-point coordinate conversions between coordinate reference systems for applications are presented in Figure 10 below and all processed points can be viewed in the map interface in the WGS 84 system using the MapWinGIS plugin as shown in Figure 11, where a converted point was plotted on it.

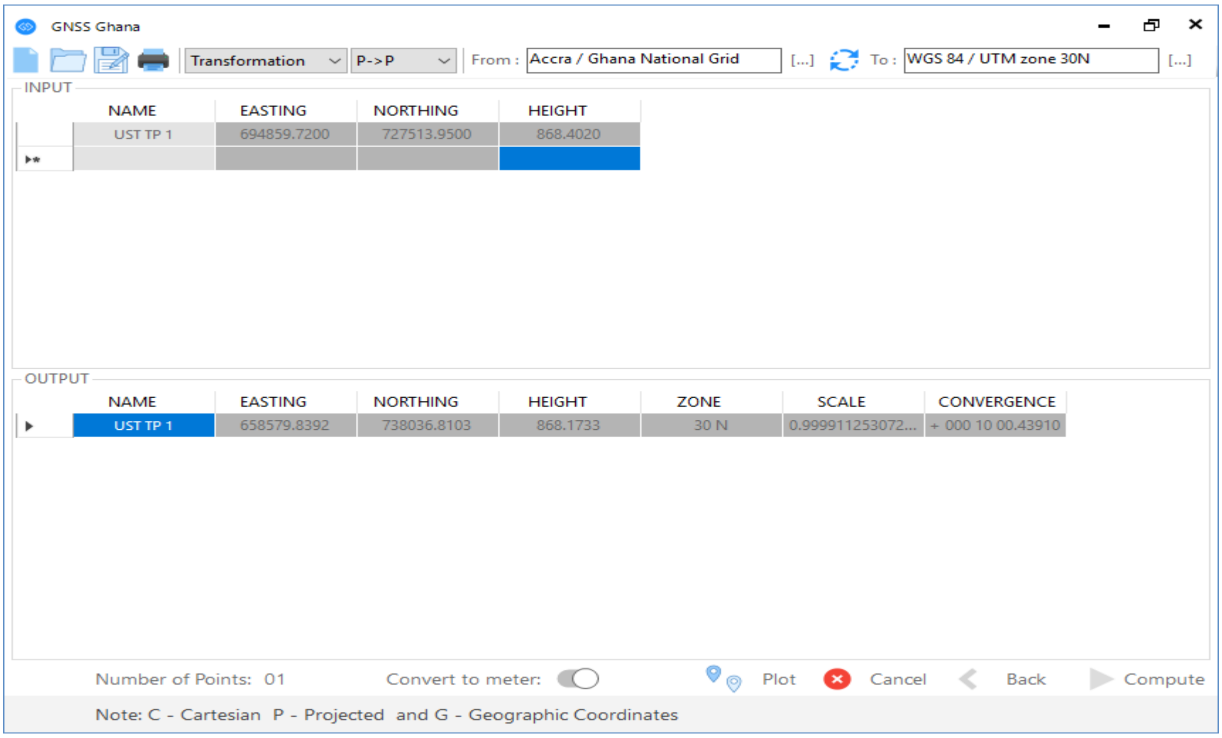


Figure 10: GGS converts UST TP1 to UTM coordinates.

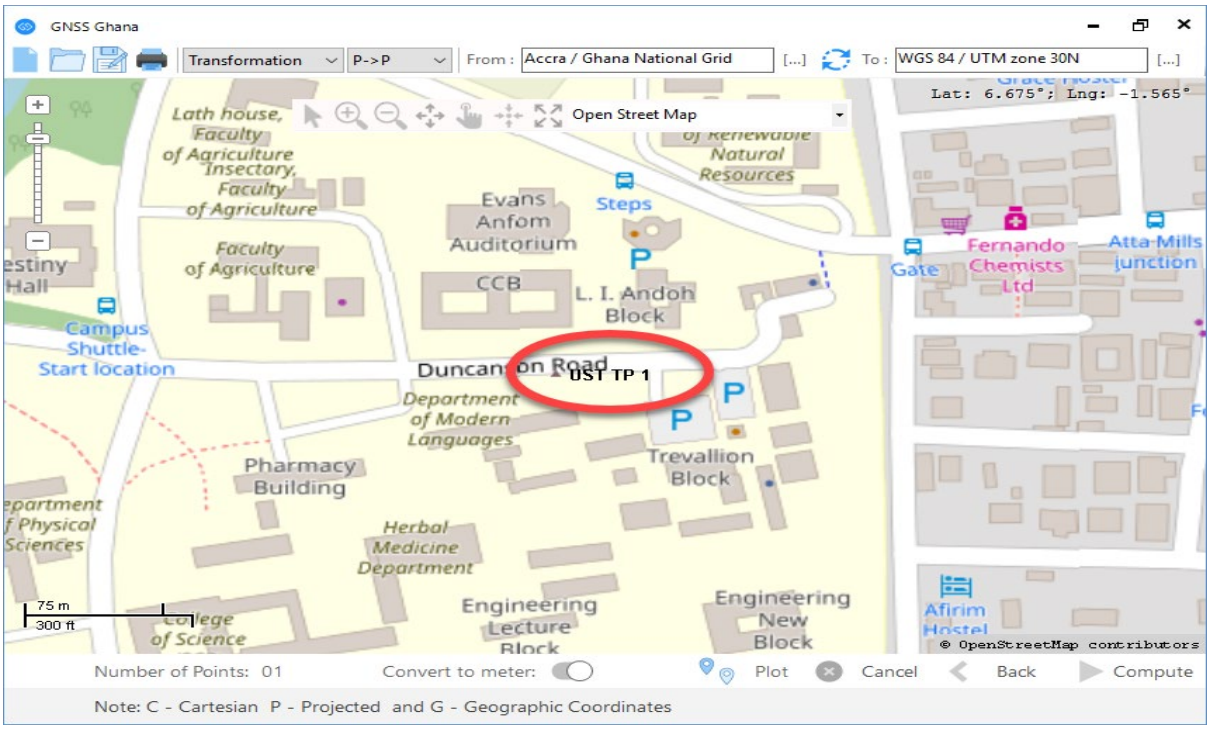


Figure 11: GGS plot of the converted UST TP1 on the map.

5.2. Baseline Processing

Three commercial GNSS processing software packages (i.e. GNSS Solution Software (GSS), Spectrum Survey Software (SSS), and Leica Geo Office (LGO)) were used to access the accuracy of GGS software. All software were used to perform baseline processing on the same data to assess the baseline accuracies of two (2) stations. The base station used as a reference was BJCO in Benin and the other control point processed was YKRO located in Yamoussoukro, Côte d'Ivoire. In this way, if the accuracy is less than or within a sub-meter level, then GGS can be used to process data across the country. The coordinates of the points are shown in Table 2.

Table 2: Coordinates of IGS station.

POINT ID	***3D Cartesian Coordinates***		
	X (m)	***Y (m)***	***Z (m)***
BJCO	6333076.505	270973.437	704551.984
YKRO	6306439.897	-578380.783	757956.481
Note: The coordinates are on the WGS84 datum			

The distance between these two points was computed to be about 851 km. The positional results obtained after processing were initially presented in WGS84 Cartesian coordinates in Earth-Centred Earth-Fixed (ECEF) X, Y, Z from all software and later converted to the geographic coordinate system and Universal Transverse Mercator (UTM) projected system (Northings, Eastings) using the same coordinate conversion tool. This way biases from every software are eliminated as a result of doing the conversion with their software. Post-processed results from all four software packages are presented in Table 3 and Table 4 below.

Table 3: Baseline results from software processed results in WGS84.

TOOL	***3D Cartesian Coordinates***			***UTM Zone 30***		***Baseline Distance***
	X (m)	***Y (m)***	***Z (m)***	***N (m)***	***E (m)***	
GGS	6306440.127	-578380.727	757956.483	760018.892	252450.274	851448.198
GSS	6306440.048	-578380.901	757956.414	760018.831	252450.093	851448.370
LGO	6306439.985	-578380.873	757956.429	760018.854	252450.115	851448.345
SSS	6306439.906	-578380.921	757956.368	760018.802	252450.060	851448.391

Table 4: Geographical coordinates from processed results.

TOOL	***Latitude***			***Longitude***			***Ell. Height (m)***
	Deg.	***Min.***	***Sec.***	***Deg.***	***Min.***	***Sec.***	
GGS	006	52	14.01622	-005	14	24.33219	270.406
GSS	006	52	14.01422	-005	14	24.33808	270.335
LGO	006	52	14.01496	-005	14	24.33736	270.272
SSS	006	52	14.01328	-005	14	24.33915	270.191

Table 5 below shows the differences in each software results from the known control point's coordinate. The baseline from each tool used gave relatively close values to the computed distance from the actual known coordinates taken with about 0.15m deviation.

Table 5: Comparison of the processed results against the known.

TOOL	3D Cartesian Coordinates			UTM		Error Distance (m)
	δX (m)	δY (m)	δZ (m)	δN (m)	δE (m)	
GGS	0.230	0.056	0.002	-0.024	0.077	0.080
GSS	0.151	-0.118	-0.067	-0.085	-0.104	0.134
LGO	0.088	-0.090	-0.052	-0.062	-0.082	0.103
SSS	0.009	-0.138	-0.113	-0.114	-0.137	0.178

It could be deduced from GGS that the results were within 0.1m from the known coordinates of YKRO. Though the deviations, per standards of different surveys and mapping divisions of different countries, may generally be accepted, the GGS's performance in terms of the deviation from the true values was better than the other software. Table 6 below shows the results of comparing the different software packages against each other.

Table 6: GGS difference in results from other software packages.

COMPARISON	Software Difference		
	δN (m)	δE (m)	δHorizontal (m)
GGS - LGO	0.038	0.159	0.163
GGS - GSS	0.061	0.181	0.191
GGS - SSS	0.090	0.214	0.232

5.3. Coordinate Conversion

Another feature of the software is the tool for geodetic calculations which also provided promising results. There were no material errors in the results of the forward, reverse, and Cartesian projections. Table 7 shows the 21-WGS 84 geographic coordinates in Ghana used in the study.

Table 7: Existing WGS 84 coordinates (WGS 84 ellipsoid).

Point ID	***Latitude***			***Longitude***			***Ell. Height [m]***
	Deg.	***Min.***	***Sec.***	***Deg.***	***Min.***	***Sec.***	
CFP 109	05	27	36.32595	-00	25	24.81756	78.341
CFP 150R	06	04	49.84387	00	03	00.86059	358.724
CFP 155	05	56	20.52274	-00	07	19.18038	524.556
CFP 178	06	34	16.88777	-01	09	52.78660	616.042
CFP 179	06	22	19.62332	-01	01	59.90811	493.174
CFP 185	06	29	5.19173	-01	55	30.56291	
CFP 200	05	37	32.87363	-00	33	33.54116	33.544
CFP 180	06	03	13.64662	-01	17	10.34588	437.507
CFP 207	05	50	58.62367	-01	57	58.14538	400.701
CFP 217	05	56	35.18549	-00	43	46.93701	311.009
CFP 225	05	27	18.31345	-01	30	03.96620	275.081
GCS 306	07	14	09.09947	-01	37	49.67440	536.167
GCS 302	06	54	44.92872	-02	01	00.32719	561.004
GCS 304	06	59	31.95103	-01	26	43.21590	621.058
GCS 305	06	50	46.84308	-01	44	36.31138	417.153
GCS 142	06	34	32.86777	-00	45	56.05383	782.369
GCS 145	06	33	24.89857	-01	24	42.82870	503.604
GCS 213	06	07	41.50988	-00	44	56.05705	327.169
GCS 125	05	45	58.98277	-00	03	54.52938	97.464
GCS 102	05	16	57.87942	-00	44	03.86026	83.408
CFP 184	06	28	17.60775	-01	41	41.39103	472.125

The datum transformation of these control points to Ghana National grid coordinates using the 7-transformation parameters produced results shown in Table 8 below which were compared to the existing coordinates in Ghana's local coordinate system (feet) in the War office ellipsoid. These results did not consider the height or elevation values since the interest of the research was in the horizontal positional accuracy.

Table 8: Numerical comparison between transformed and existing coordinates.

Point ID	***Existing***		***Transformed***		***Differences***	
	E (ft.)	***N (ft.)***	***E (ft.)***	***N (ft.)***	***ΔE***	***ΔN***
CFP 109	1109433.05	286868.63	1109433.64	286864.77	-0.59	3.86
CFP 150R	1281255.21	512174.18	1281256.42	512177.15	-1.21	-2.97
CFP 155	1218791.85	460739.72	1218793.36	460741.69	-1.51	-1.97
CFP 178	840169.51	689861.56	840170.42	689862.51	-0.91	-0.95
CFP 179	887815.70	617579.48	887814.82	617581.77	0.87	-2.29
CFP 185	564228.30	658750.36	564229.74	658752.06	-1.44	-1.70
CFP 200	1060041.45	346933.94	1060041.35	346930.69	0.10	3.25
CFP 180	795978.88	502139.98	795976.89	502141.70	1.99	-1.72
CFP 207	548934.64	428353.90	548936.99	428356.60	-2.35	-2.70
CFP 217	998070.31	461992.40	998069.02	461990.26	1.29	2.14
CFP 225	717756.06	285019.85	717754.38	285025.31	1.68	-5.46
GCS 306	671516.26	931057.32	671515.02	931053.57	1.24	3.75
GCS 302	531310.67	813987.32	531312.11	813984.44	-1.44	2.88
GCS 304	738496.56	842589.26	738494.23	842588.17	2.33	1.09
GCS 305	630369.77	789811.15	630370.29	789809.50	-0.52	1.65
GCS 142	984942.00	691483.15	984940.68	691482.81	1.32	0.34
GCS 145	750479.52	684673.93	750480.89	684675.54	-1.37	-1.61
GCS 213	991066.89	529124.19	991064.89	529125.08	2.00	-0.89
GCS 125	1239541.76	398140.35	1239546.28	398142.55	-4.52	-2.20
GCS 102	996471.72	222464.16	996470.29	222458.07	1.43	6.09
CFP 184	647795.79	653823.60	647796.32	653823.88	-0.53	-0.28

Results from transformation calculations as seen above gave the maximum values of the transformed from the existing to be [6.09 ft.] and [2.33 ft.] in the northing and easting coordinates respectively, while the minimum values of deviations are [-5.46 ft.] in northing and [-4.52 ft.] in easting. To visualize the effects, Figure 7 shows the residual plot from the existing coordinates and converted.

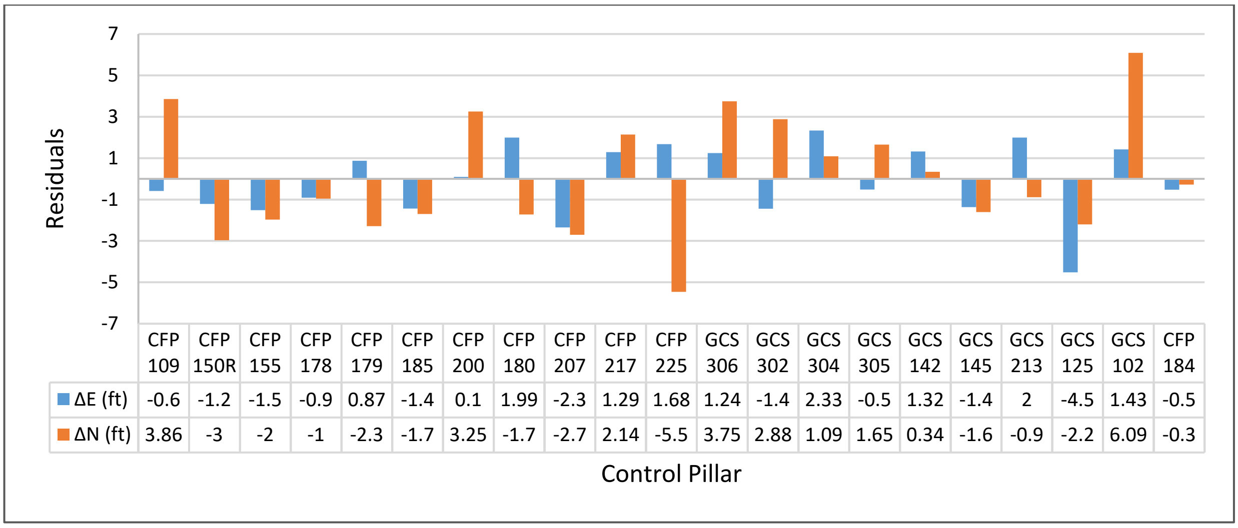


Figure 12: Residuals in Easting and Northing Coordinates (ft.)

The mean and standard deviation of the differences respectively are [-0.10 ft. and 1.75 ft.] in easting and [0.02 ft. and 2.86 ft.] in northing. Also, the standard errors for this dataset as per the result from using GGS gave [±0.38 ft.] in the easting and [±0.62 ft.] in northing. However, the accuracy of GGS at a 99% confidence level on the points with the 7-transformation parameters for eastings was [0.10 ft. ± 0.99 ft.], and for northing [0.02 ft. ± 1.62] ft.

The general investigation in datum transformation shows that the residuals in Northings were much higher than that of the Eastings. This is a result of inhomogeneity in establishing the geodetic framework coordinates (i.e. controls pillars themselves). During the establishment of the control pillars, instead of the adjustments conducted and applied to the control pillars wholly so that the error would be evenly distributed across the board in the country, they were rather adjusted partly throughout the country. Therefore, not rendering them homogeneous. This could be the reason why the results have some high residuals in both the northings and eastings, which is also following the researches performed on the geodetic framework of Ghana by many researchers (including Ayer & Tiennah, 2007; Ayer & Fosu, 2008; Ayer, 2008; Annan et al., 2016; Ziggah et al., 2017) with Dzidefo (2011), who aimed at investigating and further proposing a method for transforming coordinates of points from the War Office coordinate system to the WGS 84 coordinate system and vice versa.

6. Conclusions

In this paper, a GNSS processing application called "GNSS Ghana" software (GGS) was developed for GNSS data (RINEX) post-processing, Cadastral computation with reports, and an additional tool for Direct, Inverse projection and Datum transformation with a modern GUI. GNSS data can be processed using the developed application for all survey works that do not require accuracies higher than the accuracy stated for this application. The use of the software requires a few steps in the procedures involved to get a positional result. The software was tested and validated for positional accuracy with two IGS stations' data (BJCO and YKRO) in West Africa and was processed using GGS and three other commercial software. The experimental results indicated that the developed software outperformed the commercial software in this study indicating that GGS is suitable for processing GNSS data in Ghana. Additionally, the output reports from GGS has been refined and summarized, therefore recommended for both engineering and cadastral survey report submissions in Ghana. This will help structure the reporting system and minimize the discrepancies in the processed data reports from different surveyors based on the standards that are required by Ghana SMD and bring about uniformity in reports for file assessments and queries. Moreover, the datum transformation functionality of GGS was also tested and the results showed that it can be used within and outside Ghana. The functionality supports worldwide conversion of coordinates for datum transformations and projections between projected, geographic, and cartesian coordinate systems with minimal errors in the conversion with any coordinate reference system.

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8. Statement of Competing Interest

The authors have no competing interests.

9. References

Ames, D. P. ., Meems, P., Faust, J., Leprêtre, O., Leschinsky, S., & Angeletti, R. (2018). *The MapWindow Project - Home*. https://www.mapwindow.org/#support

Annan, R. F., Ziggah, Y. Y., Ayer, J., & Odutola, C. A. (2016). Hybridized centroid technique for 3D Molodensky-Badekas coordinate transformation in the Ghana geodetic reference network using total least squares approach. *South African Journal of Geomatics*, *5*(3), 269–284.

Ayer, J, & Fosu, C. (2008). Map Coordinate Referencing and the use of GPS datasets in Ghana. *Journal of Science and Technology (Ghana)*, *28*(1), 1106–1127.

Ayer, J, & Tiennah, T. (2007). Datum Transformations by Iterative Solution of the Abridging Inverse Molodensky Formulae. *Journal of the Ghana Institution of Engineers*, *5*(1).

Ayer, John. (2008). Transformation models and Procedures for Framework Integration of the Ghana National Geodetic Network. *The Ghana Surveyor*, *1*(2), 52–58.

Bender, M., Stosius, R., Zus, F., Dick, G., Wickert, J., & Raabe, A. (2011). GNSS water vapour tomography– Expected improvements by combining GPS, GLONASS and Galileo observations. *Advances in Space Research*, *47*(5), 886–897.

Denric, D. (2016). *MetroFramework* (Version 1.4). http://denricdenise.info/download/

Dzidefo, A. (2011). *Determination of transformation parameters between the World Geodetic System 1984 and the Ghana geodetic network.*

El-Mowafy, A. (2011). Analysis of web-based GNSS post-processing services for static and kinematic positioning using short data spans. *Survey Review*, *43*(323), 535–549.

Furones, M., Esteban, Á., Anquela Julián, A. B., Berné Valero, J. L., & Sanmartín, M. (2012). Kinematic GNSS-PPP results from various software packages and raw data configurations. *Scientific Research and Essays*, *7*(3), 419–431.

Gather, M. (2018). *MetroSuite .Net Framework* (Version 2.0). https://www.vb-paradise.de/index.php/Thread/81271-UPDATE-15-01-2018-MetroSuite-2-0-Holt-euch-den-modernen-Windows-8-Style/

Ghoddousi-Fard, R., & Dare, P. (2006). Online GPS processing services: An initial study. In *GPS Solutions* (Vol. 10, Issue 1, pp. 12–20). https://doi.org/10.1007/s10291-005-0147-5

Gurtner, W., & Estey, L. (2009). The Receiver Independent Exchange Format-Version 3.01. *Central Bureau of the EUREF Permanent Network (EPN),[Online] Available at: Ftp://66.33.199.208/Pub/Data/Format/Rinex301.Pdf [Accessed on December 2017]*.

Herrera, A. M., Suhandri, H. F., Realini, E., Reguzzoni, M., & de Lacy, M. C. (2016). goGPS: open-source MATLAB software. *GPS Solutions*, *20*(3), 595–603. https://doi.org/10.1007/s10291-015-0469-x

Kennedy, O., Hipp, D. R., Idreos, S., Marian, A., Nandi, A., Troncoso, C., & Wu, E. (2017). Small Data. *Data Engineering (ICDE), 2017 IEEE 33rd International Conference On*, 1475–1476.

Landau, H., Chen, X., Klose, S., Leandro, R., & Vollath, U. (2009). Trimble's RTK and DGPS solutions in comparison with precise point positioning. In *Observing our Changing Earth* (pp. 709–718). Springer.

Leandro, R. F., Santos, M. C., & Langley, R. B. (2011). Analyzing GNSS data in precise point positioning software. *GPS Solutions*, *15*(1), 1–13. https://doi.org/10.1007/s10291-010-0173-9

NetTopologySuite. (2019). https://github.com/NetTopologySuite/ProjNet4GeoAPI

Osah, S. (2013). *Developing a GNSS Suite for Geodetic Applications*. Nkrumah University of Science and Technology.

Rao, B. R., Kunysz, W., & McDonald, K. (2013). *GPS/GNSS Antennas*. Artech House.

Salazar, D. (2010). *Precise GPS-based position, velocity and acceleration determination: Algorithms and tools*. 218. https://doi.org/10.1073/pnas.0703993104

Sanz, J., Rovira-Garcia, A., Hernández-Pajares, M., Juan, M., Ventura-Traveset, J., López-Echazarreta, C., & Hein, G. (2012). The ESA/UPC GNSS-Lab Tool (gLAB): an advanced educational and professional package for GNSS data processing and analysis. *Proceedings of Toulouse Space Show*.

Takasu, T. (2013). *RTKLIB: An Open Source Program Package for GNSS Positioning*. http://www.rtklib.com/

Teunissen, P. J. G., Odijk, D., & Zhang, B. (2010). PPP-RTK: results of CORS network-based PPP with integer ambiguity resolution. *J Aeronaut Astronaut Aviat Ser A*, *42*(4), 223–230.

Tsushima, H., Hino, R., Ohta, Y., Iinuma, T., & Miura, S. (2014). tFISH/RAPiD: Rapid improvement of near-field tsunami forecasting based on offshore tsunami data by incorporating onshore GNSS data. *Geophysical Research Letters*, *41*(10), 3390–3397.

Verhagen, S., Odijk, D., Teunissen, P. J. G., & Huisman, L. (2010). Performance improvement with low-cost multi-GNSS receivers. *2010 5th ESA Workshop on Satellite Navigation Technologies and European Workshop on GNSS Signals and Signal Processing (NAVITEC)*, 1–8.

Videkull, R. (2015). Evaluate and develop high-performance GPS navigation using free GPS software. *Master's Thesis in Engineering Physics Department of Earth and Space Sciences Chalmers University of Technology Gothenburg, Sweden 2015*.

Wang, N., Yuan, Y., Li, Z., & Huo, X. (2016). Improvement of Klobuchar model for GNSS single-frequency ionospheric delay corrections. *Advances in Space Research*, *57*(7), 1555–1569.

Yozevitch, R., Ben-Moshe, B., & Dvir, A. (2014). GNSS accuracy improvement using rapid shadow transitions. *IEEE Transactions on Intelligent Transportation Systems*, *15*(3), 1113–1122.

Zhang, Q., Niu, X., Zhang, H., & Shi, C. (2013). Algorithm improvement of the low-end GNSS/INS systems for land vehicles navigation. *Mathematical Problems in Engineering*, *2013*.

Ziggah, Y. Y., Ayer, J., Laari, P. B., & Frimpong, E. (2017). Coordinate Transformation Using Featherstone And Vaníček Proposed Approach-A Case Study Of Ghana Geodetic Reference Network. *Geoplanning: Journal of Geomatics and Planning*, *4*(1), 19–26.