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.
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.
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.
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.
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.

Figure 5: GNSS Processing – 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 | UST TP 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 |

| 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       |
|            | -7687.08    |          | 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.
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.

| TOOL | 3D Cartesian Coordinates | UTM | Error Distance (m) |
|------|--------------------------|-----|-------------------|
|      | \(\delta X \) (m) | \(\delta Y \) (m) | \(\delta Z \) (m) | \(\delta N \) (m) | \(\delta E \) (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.

| COMPARISON | Software Difference |
|------------|---------------------|
|            | \(\delta N \) (m) | \(\delta E \) (m) | \(\delta\text{Horizontal} \) (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.          |
| CFP 109  | 05       | 27        | 36.32595     |
| CFP 150R | 06       | 04        | 49.84387     |
| CFP 155  | 05       | 56        | 20.52274     |
| CFP 178  | 06       | 34        | 16.88777     |
| CFP 179  | 06       | 22        | 19.62332     |
| CFP 185  | 06       | 29        | 5.19173      |
| CFP 200  | 05       | 37        | 32.87363     |
| CFP 180  | 06       | 03        | 13.64662     |
| CFP 207  | 05       | 50        | 58.62367     |
| CFP 217  | 05       | 56        | 35.18549     |
| CFP 225  | 05       | 27        | 18.31345     |
| GCS 306  | 07       | 14        | 09.09947     |
| GCS 302  | 06       | 54        | 44.92872     |
| GCS 304  | 06       | 59        | 31.95103     |
| GCS 305  | 06       | 50        | 46.84308     |
| GCS 142  | 06       | 34        | 32.86777     |
| GCS 145  | 06       | 33        | 24.89857     |
| GCS 213  | 06       | 07        | 41.50988     |
| GCS 125  | 05       | 45        | 58.98277     |
| GCS 102  | 05       | 16        | 57.87942     |
| CFP 184  | 06       | 28        | 17.60775     |

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 E (ft.) | Existing N (ft.) | Transformed E (ft.) | Transformed 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        | 998069.26           | 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.
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 Northing 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.

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