RENEWAL OF GHANA'S GEODETIC REFERENCE NETWORK

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Abstract: In addressing the rising demand for cost-effective land delivery and management processes in Ghana, the Survey Department through the Land Administration Project, embarked on the renewal of the Ghana's Geodetic Reference Network which was based on the War Office 1926 Ellipsoid into the International Terrestrial Reference System. This was in line with the demands by local and international organizations including the committee in the African Reference Frame (AFREF), to utilize the GNSS technology. The first phase of the renewal of the Geodetic Reference Network (GRN) has been completed with the provision of the basic infrastructure in and around the Golden Triangle of Ghana for using the GNSS technology. This has also prepared the nation to join the proposed continental AFREF and the worldwide IGS. This project mainly used the PrePos GNSS Suite developed at the University FAF-Munich for the data processing. Efforts have been made to ease the problem of the user by determining the transformation parameters to be able to convert data to and from the new and old systems. A graphical interface has also been developed in matlab to assist the user.

1. INTRODUCTION

The need to renew the Geodetic Reference Network of Ghana has been driven by the quest for the use of modern and cost effective survey techniques to meet the rising demand for the land related positioning activities in the country. These include general land administration and management, geotechnical investigations, traffic and transportation, meteorology, timing, survey and mapping, engineering, GIS, and other multidisciplinary applications. On the international front, the African Reference Frame (AFREF) initiative, which aims at unifying all national reference frames of the over fifty countries in Africa into a single continental reference system based on the International Terrestrial Reference System (ITRS), stresses on the need for all African countries to join the geocentric reference system (ITRF) to enhance the use of GNSS in the developmental activities of the continent [Wonnacot, 2007]. The AFREF initiators through United Nations Economic Commission on Africa (UNECA) - CODI in 1999 urged all African governments to transform their respective national datum to the worldwide WGS84 and ITRS including Geoid determination [Neilan R, R Wonnacott. 2002]. On the political front the New Partnership on African Development, which Ghana is an active player endorsed the use of GNSS at its meeting in 2002 [NEPAD, 2002]

In view of the above developments and other factors the Survey Department of Ghana, through the Land Administration Project (LAP), under the Ministry of Lands, Forestry and Mines of the Government of Ghana embarked on the establishment of the new Geodetic

Reference Network, which is based on the ITRF to replace the old network based on the War Office 1926 Ellipsoid.

This demand-driven project has been divided into phases, with the first phase covering the Golden Triangle of Ghana already completed and the second phase which is supposed to cover the whole country is soon to begin. The Golden Triangle of Ghana covers a little over a third of the area of the country and has high economic activity in the country. With the three largest cities in the country at the vertices, it has about 58% of the population, almost all the major existing mines, higher land value and many factors that required the use of this modern and efficient method for positioning.

The three permanently operating reference stations have been established at the vertices of this triangle with eighteen second order reference stations spatially well distributed in this area in question. A fourth permanent station has been co-located at the Takoradi Tide Gauge, under the GNSS Upgrade in Tide Gauges in Africa (GUITA) project for the definition of the vertical datum for Ghana. To be able to transform existing data into the new system and vice versa, a set of transformation parameters has been developed for the area in question and a team has been put in charge of the maintenance and to answer to the demands of the user community.

2. PLANNING

2.1. Network Design

The GRN has been designed such that any point within the country will not be more than 100km from a reference station. These were selected based on a good spatial distribution, available infrastructure, power supply, communication, personnel, demand for services and others. Based on the above conditions, fifteen stations have been proposed to form the nationwide core network, one in each Regional Office of the Survey Department, and some selected district capitals [Poku-Gyamfi Y, G W Hein 2006]. This proposal has however been subjected to a few changes, for example the station for the Central Regional Survey office may be replaced with that of the Millineum Development Authority (MiDA) station at Winneba, the one intended for Koforidua Regional Survey Office in the Eastern Region may be located at the Seismological Station of the Geological Survey Department of Ghana at Kukurantumi, where it will be used additionally for scientific research. There are plans to include stations that have been installed by private institutions like the Geotech Systems Ltd in Accra and Tarkwa and those in the country that will meet the required standards. So far four permanent stations have been established; three of them under the LAP and the fourth under the GUITA project. Other stations including the MiDA station at Winneba are scheduled to run soon.

The network in the first phase includes eighteen second order stations which have been located within the network. These are located such that the base-lengths between stations were about 50km on average. Each of these stations had three satellite stations located in the neighbourhood, such that at least two of them will be inter-visible. These serve as ‘points of departure’ for the user community and also help in the re-establishment of the points in case they are disturbed.

2.2. Monumentation

Three kinds of monuments were established, those for the Continuously Operation Reference Station monument, the second order reference stations monuments, and the reference markers. All the stations were selected and constructed bearing in mind the stability of the foundations, minimum obstruction in the skies, avoidance of radio interference and multipath and the availability of power supply, communication facilities security.

2.2.1. Continuously Operating Reference Station Monuments

Four of these stations have so far been established, two of them on rooftops and the other two are ground based. These include the Kumasi ground-based station which is intended to be the fundamental station and the Accra and Takoradi roof-top station. The fourth which is at the Takoradi Tide Gauge is also ground-based

Figure 1 - Monuments for the Permanent Stations

2.2.2. Second-Order Reference Monuments

These are mainly on top of roofs of buildings. Apart from satisfying the basic requirements as GNSS reference station mentioned above, easy accessibility made the choice of government and public buildings, the first choice. High-rise buildings as well as those with visible cracks were avoided. Selected buildings were preferably those that were more than five years old.

2.2.3. Reference Markers

These are all ground-based type ‘C’ pillars located near the second-order reference stations. Due to the intended purpose their locations are easily accessible hence they are protected with special stakes to announce their presence as shown if figure 2

Figure 2 - Reference Marker protected with stakes

2.3. OBSERVATION

The observation schedule depended on the time limit available for the field observation, the number of stations to occupy, the number of times the stations were to be occupied as well as the duration per each session. Factors that were considered for the observation included the deployment pattern and the reduction of the non-productive travel time, (mainly the travel times between stations). The deployment pattern used was the base station (Radial) method with the introduction of two hub stations. This improved the efficiency of the schedule and also reduced the distance dependent errors significantly. The introduction of the two hub stations reduced the longest base-length between a rover and the any base to 81km as against 110km if it had not been introduced. Over 90% of the base-lengths for all observed rover stations were less than 70km with the introduction of the hub stations, as against 90km if they had not been introduced.

Figure 3 - Distribution of the New and Old Stations in the Golden Triangle

In all 20 new stations were observed, out of which three were the permanent stations in Accra, Kumasi and Takoradi and two hub stations at Kade and Assin Fosu. Each of the new stations had three witness stations thus making the points to observe for the new points 80 in number. Twenty-eight trigonometric points were also observed. With the permanent and hub stations recording throughout the observation period, the rest of the 15 other new stations and the 28 trigonometric points were observed for twelve hours each at logging interval of 10s at an elevation angle of 10º. The satellite stations were observed for four hours. Twenty dual frequency receivers were mobilized for the project, with five at the permanent and hub stations, ten for the new Reference Stations as well as the old trigonometric points for the determination of the transformation parameters. The remaining five were scheduled for the observation of the witness stations. The main field observation campaign took ten days, working at 24hrs daily.

3. DATA PROCESSING

After downloading and converting data into the RINEX format, with the proprietary software of the Sokkia, Spectrum Survey, quality checks were made with TEQC and also checking the field record sheets to find if there were no omissions. A few places had to be re-observed before the hub stations observations were discontinued.

3.1. Processing Software

The main data processing software used in this project were PrePos GNSS Suite (PGS) of the University FAF-Munich and Trimble Total Control (TTC) from Trimble Terrasat.

The PrePos GNSS Suite, which is scientific software, has been developed to perform precise GNSS positioning both in static and in kinematic mode by post-mission analysis. The package is organized in three major branches; the first branch focuses on static reference station data analysis with its main module GTCE, the GNSS Troposphere and Coordinate Estimator for static data analysis in large-scale networks. It has several auxiliary and supporting utilities which include DITON for datum transformation. A second module is Semika, the major analysis program for rapid-static and kinematic surveys which was used for the determination of the ITRF coordinates of the New Reference Stations (2nd Order). This is used for GNSS positioning both over long and short baselines (including quick ambiguity resolution capabilities). It includes add-ons like NEADS, NEREUS, RInter and others, for network adjustment, area correction parameter generation and data interpolation and editing respectively. The third of the modules consists of shared programs and auxiliary tools like TERRA, a tool for network adjustment and point positioning using conventional terrestrial measurements which combine GNSS point and baseline results and distance/angle measurements.

The Trimble Total Control software was also used for the determination of the coordinates for the reference markers at the new stations.

3.2. Processing Long Baselines with GTCE

Based on the proximity and reliability of the data from various IGS Stations, two stations MAS1 (Maspalomas) and NKLG (N'kolatang-Libreville Gabon) were selected. MAS1 provides 10s data which is the same as that used for the project and that for NKLG is 30s. The two selected IGS stations were tightly constrained and used to process the baselines for the five stations, Accra, Kumasi, Takoradi, Assin Fosu and Kade. A combined solution of days JD138 to JD144 was computed to produce the coordinates for the first order stations. Corrections were made on station velocity, solid earth tides, ocean loading, sub-daily earth rotation, etc, to obtain ITRF05 coordinates for the stations in Ghana.

3.3. Processing Short Baselines with Semika

Daily files were prepared for the processing of these coordinates to obtain a daily solution for all observed points, both old and new. For better results, the computations were as much as possible restricted to the nearest permanent stations. This was to reduce the distant dependent errors to the minimum. The processing is sequentially performed, these go through cycle slip detection, satellite eccentricity, reading of Klobuchar model for ionospheric correction, reading of the appropriate SP3 files, earth orientation parameters, time differencing and troposphere delay files. There is the deletion of bad sectors at this stage. This is followed by triple difference processing for final phase break detection and precise carrier-phase block adjustment solution. After the processing, interactive optimization is performed using tools provided in the module like the coordinate scatter plot, the 3D viewer, the coordinate diagram and others. This improved the quality of the results. Due to the fact that there is velocity assigned to the stations which reflects to the tectonic plate movement, a fixed epoch of 2007.39 has been assigned to the realization to cater for users at dates other than the observed date

NEADS is the Network Adjustment module which reads SINEX data stored after processing from the SEMIKA. The point mode option was used in this project for the adjustment.

3.4. Processing the Coordinates for the Reference Markers

The coordinates of the witness markers which are on average less than 100m away from the main reference station were computed using Trimble Total Control. The coordinates of the main reference station (2^{nd} order) which are computed using Semika is fixed and used to differentially correct those of the reference markers. Plots of the coordinates to help with the description of the locations and table of the azimuths, ground distances and elevations between points have been provided. Cartesian Geocentric, Geographical and Universal Transverse Mercator (UTM) coordinate for all the stations including the main and satellite points at each station are also provided.

3.5. TRANSFORMATION PARAMETERS DETERMINATION

With the large amount of data in the old War Office 1926 Ellipsoid, changing to the ITRS required that this data be transformed from the old to the new system. To obtain these, parameters had to be provided and these transformation parameters have been determined using DITON for the Golden Triangle and the surrounding regions. With the data in the Ghana Local Grid, there was the need to convert the data to the geographic coordinates in the same system that is the War Office 1926 Ellipsoid. These coordinates of these points were obtained from the Gold Coast Survey Records (1932) Vol I – VI. These were again converted to the Cartesian in the same War Office system. As provided in the previous section, Semika and NEADS have been used to provide adjusted ITRF05 Cartesian coordinates of selected trigonometric common points which had been observed during the campaign. With the two systems in Cartesian, Seven Parameter Helmert's transformation parameters were derived to match the system, using the epoch 1930 to cater for the crustal movement. This provides a two way conversion from War Office to ITRF05 (WGS84) and vice versa.
The resulting residuals which averaged 1.14m had a maximum of 3.01m in the horizontal, showed higher values in the south, though there were no systematic distortions. The derivation of localized set of parameters showed a much improved residual in the decimetre range, and with this, there was the need to derive localized parameters for areas within the Golden Triangle. This however calls for the user community to be extra careful to know the demarcated area for which a particular set must be used especially for cadastral application.
The vertical showed no general trend of errors, but a very high residual, 5.2m at Anyinasu in the north. This indicated that there might have been an error in the height component of the War Office coordinate. This will be explained in the next section of this report.

4. GHANA VERTICAL DATUM

The vertical datum for Ghana at the moment is defined by the reference to the mean sea level obtained from the tidal observation from a point in Accra from 9th April 1922 to 30th April 1923. This was linked to an established monument GCS 121 which was consequently linked to the trigonometric network to obtain the orthometric heights for the points in the network [Ayer J, C Fosu, 2006]. Since the national geoid has not been determined, the use of the global geoid EGM96 was employed in this project. The root-mean-square accuracy of the EGM96 approximately 50cm [Merry C, L 2003; Kenyon S, 2006] and ends up to about 120cm at areas without surface gravity data. With the available gravity data for Ghana, the expected accuracy of the local geoid should be 50cm or better.

With the establishment of three absolute gravity stations by the Geological Survey of Ghana, and increase in the existing gravity data, plans are underway for the determination of the local geoid for Ghana which should improve the GPS levelling in the country. In addition to this, the country is benefiting from the GUITA project, where the reference station that has been co-located with the Takoradi Tide Gauge, one of the oldest in Africa has been linked by precise levelling to the GRN station in Takoradi which is 2km away. With this arrangement the change in sea level will be used to compare the ellipsoidal heights observed by the new Geodetic Reference Network.

With the orthometric height H in the War Office 1926 ellipsoid, obtained from the Survey Records, 1932, the corresponding EGM96 geoidal separation N, and the ellipsoidal heights h obtained from the campaign, the height offsets, dH was derived to test the accuracy of the orthometric heights using the equation

$$h = N + (H+dH) \quad (1)$$

$$dH = h - N - H \quad (2)$$

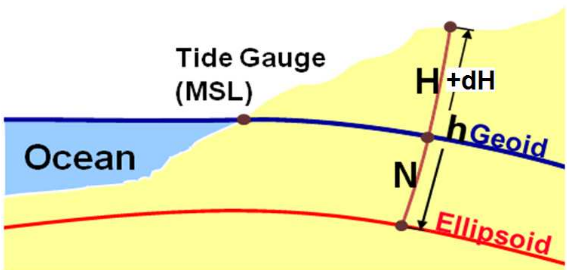

Figure 4 - Diagram showing the relationship Geoid, Ellipsoid and the Geoid Separation

To check the reliability of the vertical system in the project area War Office coordinates with the corrected heights (ellipsoidal) are transformed with the derived transformation parameters and compared with the observed GPS values. The probable error expected from the geoid undulation is roughly 50cm and that of the GPS observation is in the centimetre range, hence the difference, dH, depended mainly on the errors due to the transformation parameters or the orthometric heights. A localized set of transformation parameters used to transform the coordinates of this point still provided unreasonably higher vertical residual than expected. The most probable source of error could be from the original War Office orthometric height that is the source data.

THE INTERACTIVE GHANA GEO-SYSTEM

The Ghana Geo-System is a Graphical User Interface (GUI) operating in matlab with a set of routines to assist the user Geodetic Reference Network system. This has been made such that all the old War Office 1926 and Clarke 1880 (Ghana Modified) data can be transformed into the ITRF and WGS84 using the derived transformation parameters and vice versa. Depending on what a user requires the appropriate button opens up an interactive dialogue boxes which require inputs from the user to provide a solution, e.g. as it is appropriate for most user to work in plane coordinates, the Cartesian coordinates can be projected to the plane coordinate system, either the Ghana Local Grid or the UTM by this system.

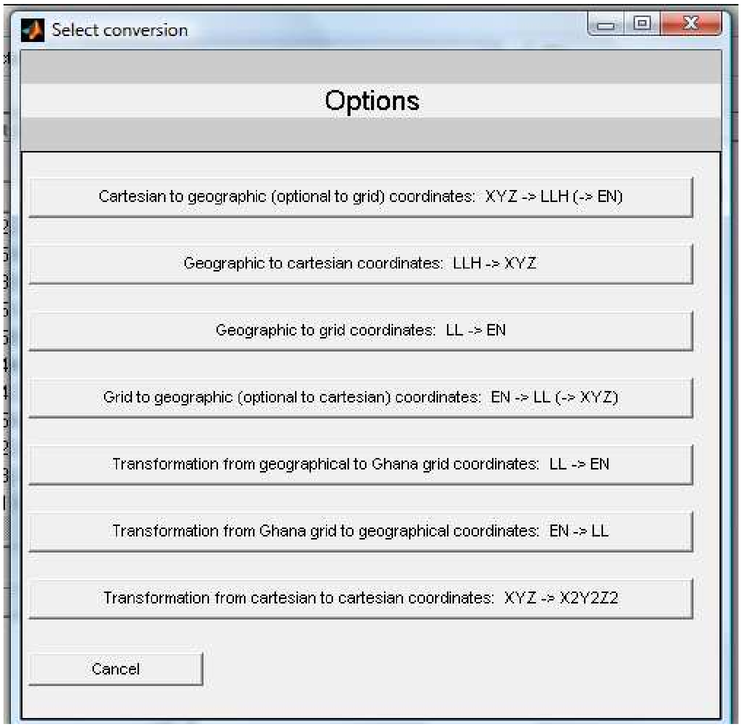

Figure 6 - The graphical display of the options provided in the Ghana Geo-System

5. CONCLUSION

The first phase of the GRN project has established a Geodetic Reference Network in and around the Golden Triangle of Ghana which included three permanently operating stations located in Kumasi, Accra and Takoradi, with the Kumasi station as a fundamental station for the country. These are supposed to finally be part of the AFREF and IGS networks. A fourth reference station at Takoradi that has been collocated with the Takoradi Tide Gauge is to help in the definition of the Ghana's vertical datum and also to monitor the global sea level change, under the GUITA project. Geocentric coordinates in ITRF05 have been determined for all the coordinates of the network. With an ITRS reference station within 50km from every rover, the basic infrastructure for most post-process GNSS applications can be realised in the Golden Triangle. The formal standard deviation for the stations was 1.7cm, 1.1cm and 0.4cm in the X, Y and Z coordinates respectively in the Cartesian coordinates system which translates to an average of 1.2cm and 1.7cm in the horizontal and height components respectively.

The transformation parameters for War Office 1926 has been determined using Helmert 3D similarity transformation for the Golden Triangle of Ghana as well as for more accurate but localised parameters for different areas for cadastral applications. The provision of the Ghana Geo-System has made it easier for the user to work with the new system and also convert data from the old system to the new and vice versa.

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