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Mapping Systems and GIS: A Case Study using the Ghana National Grid

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The problem of incompatible projections and conversion between mapping systems is of general concern to those involved in the collection of natural resources data. The Ghana National Grid (GNG) is an example of a mapping system that is not defined in image processing and GIS software and for which the transformation parameters are not readily available in the literature. Consequently, integrating GNG topographic map data within a GIS with data derived from other sources can be problematic. In this paper a practical solution for deriving the required transformation parameters to convert from the World Geodetic System of 1984 (WGS84) to the GNG system is demonstrated. The method uses a single geodetic control point, available 1:50 000 topographic maps and a SPOT satellite panchromatic image geo-referenced to GNG. The resultant parameters are applied to road survey data in Universal Transverse Mercator (UTM) format for overlay with the SPOT image. Despite the approximations made in applying the method, when compared against official estimates of the datum transformation parameters, this relatively simple procedure resulted in estimates that appear acceptable in regard to combining data sets at a nominal scale of 1:50 000.

KEY WORDS: Ghana National Grid, mapping system, datum transformation, Molodensky.

A fundamental requirement of many natural resources projects is for data to be collected in a form suitable for incorporation into a Geographic Information System (GIS). This essentially means that an appropriate spatial referencing or mapping system must be selected for the study region. A mapping system may be defined in terms of an ellipsoid, datum and projection and is designed to provide a consistent coordinate framework for referencing geographic locations in two dimensions.

For natural resources survey it is beneficial if the selected mapping system is the national system used for topographic mapping, since topographic maps provide an important source of baseline data for designing ground surveys. An additional consideration is the increasing use of satellite remote sensing data combined with Global Positioning Systems (GPS) in natural resources survey (e.g. Kardoulas *et al.*, 1996). The image data are often geo-referenced to the local mapping system for comparison with data extracted from the topographic maps. Navigation to survey sites using GPS will normally require the use of a global mapping system that is universally defined such as Universal Transverse Mercator (UTM). Consequently, it is necessary to convert from the local to the global system within the GIS. However, a number of national mapping systems are not explicitly defined in available GIS and GPS software. In this instance any data collected using the global mapping system will not easily be made compatible in the GIS with data geo-referenced in the local system.

Several strategies may be envisaged to overcome the above problem, including separate GIS for the local and global mapping systems or the development of a least-squares polynomial transformation that can be applied to the grid coordinate data. The preferred route to ensuring compatibility of mapping systems within a GIS, however, is to establish the local system as a user defined mapping system. Within any GIS software the basis for defining a mapping system is the specification of:

1. the required ellipsoid shape parameters (semi-major and semi-minor axes and/or the flattening);
2. the transformation parameters defining the position and orientation of the local datum with

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respect to a global datum (usually the World Geodetic System of 1984 i.e. WGS84); and
3 the projection method (e.g. Transverse Mercator) and associated parameters (latitude and longitude of origin, scale factor, false Easting and Northing, grid units).

Normally, there is little difficulty establishing a user defined mapping system since many of the required transformation parameters to convert to WGS84 are readily available (e.g. Department of Defense, 1990). However, not all national mapping systems are included and consequently situations may arise where the parameters required for definition of the mapping system within the GIS are not available. Ghana provides an example of a country where the national mapping system is not defined in common GIS software and GPS receivers. A practical solution to this problem is presented and evaluated in this paper by reference to the Ghana national mapping system. The next section details the basic components of mapping systems and is followed by a description of the mapping system used in Ghana. The method of estimation of the required parameters is explained and the application of the method to GPS survey data presented.

Mapping systems and transformations

There is a general preference for the use of planar grid referencing by Eastings and Northings as opposed to geographic referencing by latitude and longitude for undertaking surveys (Terry, 1997). The mapping system provides the basis for translating the graticule of latitude and longitude, appropriate to an ellipsoidal Earth, into a planar grid referencing system. A definite relation exists between graticule and the planar grid so that a corresponding grid position can be determined for each geographic position and vice versa. To undertake this transformation, it is necessary to model the shape of the Earth. The ellipsoid defines the modelled shape and size of the Earth, while the geoid defines the true shape. A geodetic datum is defined by the ellipsoid and the position and orientation relations of the ellipsoid to a reference model of the Earth. Currently the globally-recognized reference ellipsoid is the Geodetic Reference System 1980 (GRS80) (IAG/IUGG, 1996). However, WGS84 is the global reference model used for GPS (Department of Defense, 1990) and is often the datum upon which mapping system transformations are based. WGS84 has an ellipsoidal shape defined by semi-major axis a = 6378137m and flattening f = 1/298.257223563 and is geocentric.

Global datums, such as WGS84, provide the best approximate model of the true Earth shape on a global basis. On a regional basis, however, deviations between the geoid and the global datums are significant for large-scale mapping. Consequently, local horizontal and vertical datums are still required for specific regions of the globe. Many such local geodetic datums are in existence although only a relatively limited number are in current use (Mugnier, 1997).

In some countries the datum defined by the mapping system may not have the position and orientation relations of the associated ellipsoid to WGS84 readily available. In these circumstances it will be necessary to determine these relations approximately to allow the system to be defined in GIS software.

The Ghana National Grid mapping system

There are currently two mapping systems in use in Ghana, both based on the Transverse Mercator projection. Details of these two systems are provided in Table 1. Topographic maps at 1:50 000 scale, prepared jointly by the Government of Ghana and the Government of Canada, are available for the region surrounding the city of Kumasi. These maps, produced from aerial photographs dating from 1972, use GNG and are in the Transverse Mercator projection based on the Accra datum. The maps provide a source of topographic data, as well as transport and built environment data appropriate to the early 1970s period. In addition, natural resource data are currently being collected through a number of national and international government and non-government funded research projects. These include airborne digital photographic and GPS surveys, interpretation of satellite data and socio-economic appraisals. These data are typically geo-referenced to the UTM projection system using the WGS84 datum.

In order to be able to combine data within a GIS that is digitized from the topographic maps, with newer data recorded using geographic or grid coordinates, it is necessary to define GNG as a user-defined mapping system. The ellipsoid parameters

Table 1. Parameter description of the Ghana National Mapping System

Projection parameters for Transverse Mercator					
Grid origin N 04° 40′ W 01° 00′	False Northing 0 feet		False Easting 900 000 feet	Scale factor 0.99975	
Pre-1977 datum: Accra			Post-1977 datum: Leigon		
Ellipsoid	Semi-major axis (m)	Flattening (1/f)	Ellipsoid	Semi-major axis (m)	Flattening (1/f)
War Office 1924	6 378 300.58	296.0	Clarke 1880	6 378 249.145	293.465

and projection method and parameters are stated on the topographic maps. However, the position and orientation relations of the Accra datum with respect to the WGS84 datum are not generally available (Department of Defense, 1997). Consequently it was necessary to estimate the required parameters although subsequently the parameters were obtained directly from the UK Military Survey. The latter information provides an independent basis for comparison with the derived parameters.

Estimating the datum transformation parameters for the Accra datum

The most frequently applied datum transformation is the Molodensky method and is the method used in this paper. The abridged Molodensky method requires the offsets that define the displacement of the origin of the local datum from WGS84. These can be expressed in geographic coordinates but are more usually expressed in a cartesian frame of reference as ΔX, ΔY and ΔZ (m). The standard method uses ellipsoidal heights and, therefore, requires that the ellipsoid/geoid separation is known. However, since the expected precision in horizontal position of this transformation method is ≤ 5 metres, for this application the ellipsoid/geoid separation is ignored (ICSM, 1998).

The approach taken to estimating the required parameters is explained by reference to the conversion of the coordinates of a single point, although preferably the estimates should be based upon several points covering the study region. For this work a single differential GPS control point was available to the authors (Table 2). The precision of this control point is thought to be a few centimetres. The height information is the height above the WGS84 ellipsoid.

The required offsets can be estimated if the same ground position (for example the control point) can be referenced in geographic coordinates using both local and global datums. The principal difficulty is that the position of the GPS control point is not marked on the 1:50 000 topographic maps. Consequently the geographic grid coordinates of the control point appropriate to the Accra datum were derived by use of a SPOT image geo-corrected GNG using the topographic map sheets. The image was geo-corrected to a level of precision of approximately 18 metres. The map coordinate position of the control point was determined by visual inspection of the SPOT image as shown in Figure 1. These

Table 2. GPS control point information (WGS84)

Geographic	UTM (Zone 30)
6 deg 42 min 52.53750 sec North	655535.08423m E
1 deg 35 min 34.06153 sec West	742421.74146m N
316.981m height	316.981m height

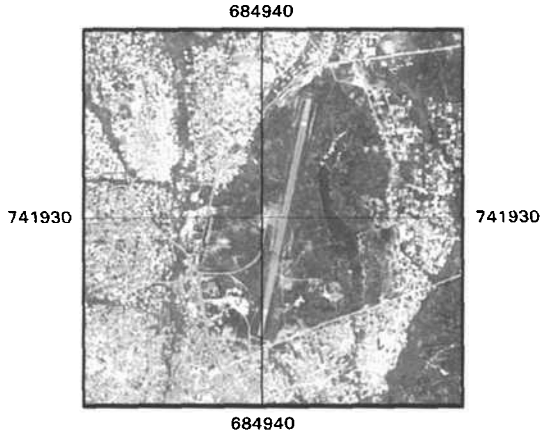

Figure 1 Determination of Ghana National Grid geographic coordinates of Kumasi airport geodetic control point (map scale 1:50 000).

coordinates were used to determine the geographic grid coordinates appropriate to the Accra datum by overlaying a transparency of the SPOT image on the appropriate topographic map sheet and digitizing directly in latitude and longitude. The height of the point above mean sea level was also estimated by interpolation between the height contours. These data are presented in Table 3.

The geographic coordinates were converted to Earth-centred cartesian coordinates from knowledge of the ellipsoid definitions of WGS84 and the War Office ellipsoid (e.g. Botton *et al.*, 1998). Thus,

$$X = (N+h)\cos\phi\cos\lambda$$
$$Y = (N+h)\cos\phi\sin\lambda$$
$$Z = \{N(1-e^2)+h\}\sin\phi$$

where:

$$N = \frac{a}{(1-e^2\sin^2\phi)^{1/2}} \qquad e = \frac{\sqrt{a^2-b^2}}{a^2}$$

ϕ is the latitude
λ is the longitude
h is the height above the spheroid
a, b are the ellipsoid semi-major and semi-minor axes

The results of applying these formulae to the geographic coordinate data in Tables 2 and 3 are shown in the columns 1 and 2 of Table 4. The required cartesian offsets for the abridged Molodensky method are then estimated from,

$$\Delta X = X_{WGS84} - X_{Accra}$$
$$\Delta Y = Y_{WGS84} - Y_{Accra}$$
$$\Delta Y = Y_{WGS84} - Y_{Accra}$$

Table 3. Geographic and grid coordinates for Kumasi airport GPS control point (Accra datum)

Geographic	Ghana National Grid
6 deg 42 min 43.3332 sec North	684940 m E
1 deg 35 min 34.9008 sec West	741930 m N
289.56 m height	289.56 m height

Table 4. Cartesian coordinates and calculated offsets for Kumasi airport GPS control point

	WGS84	Accra datum	Difference	Military survey
X	6 332 545.685	6 332 714.821	−169	−199
Y	−176 087.060	−176 117.551	30	32
Z	740 833.987	740 531.145	303	322

The estimates derived from the single control point are presented in column 4 of Table 4, together with the data from the Military Survey (column 5).

Application to road survey data

The estimated parameters, together with the information on the ellipsoid parameters and the projection method were used to define the GNG as a user mapping system in a GIS. A series of points recorded using a differential GPS in UTM were then converted to GNG coordinates. The data relate to a road survey undertaken along the main ring road in Kumasi. Figure 2 shows the road survey data overlaying the SPOT Panchromatic image of central Kumasi at a scale of 1:100 000. The white line represents the data transformed to GNG using our derived parameters. The black line represents data converted to GNG in which the datum shift is ignored and demonstrates the typical magnitude of error (~30 metres in Easting and 290 metres in Northing in this instance) that can be encountered when datum transformations are incorrectly applied. The spatial equivalence of the transformed road survey data and the SPOT panchromatic image is difficult to determine at this scale. Figure 3 compares the spatial equivalence of the road survey data transformed using our parameters (white dots) and the Military Survey parameters (black triangles) with the SPOT image. The RMS error between the two sets of transformed coordinates (Table 5) is less than 1 metre in Easting but more than 20 metres in Northing. The data transformed using our parameters are greater in magnitude in both Easting and Northing.

The expected precision of the Molodensky method is 5–10 metres. However, this is not achievable by the procedures applied in this work owing to the following constraints.

Table 5. RMS error between the military survey and locally-derived Molodensky parameters

Number of points	Easting (m)	Northing (m)	Overall (m)
2355	0.18	22.36	22.36

Figure 2 Overlay of road survey data on geo-corrected SPOT image map at scale 1:100 000 (white line are data transformed to GNG using estimated parameters, black line are data transformed to GNG without the required datum shift).

1 The height information associated with the control point is the height above the ellipsoid, while the height estimated from the topographic map sheets is the height above mean sea level. The method requires both heights as the height above the respective ellipsoid. This will undoubtedly introduce some error in the estimation process.
2 The precision in geo-referencing the SPOT image is of the order of 15 metres, with an equivalent uncertainty associated with the map coordinates determined for the control point, and consequently in the digitized grid coordinates. It is not clear which of these sources of error is most likely to result in significant differences in the Northings noted above.

Conclusions

The sustainable exploitation or conservation of natural resources, whether at local, national or global scales, requires access to high quality, reliable and up-to-date information. Increasingly, the basic data are geographical in nature, and are derived from remote sensing systems and processed using a GIS. The mapping

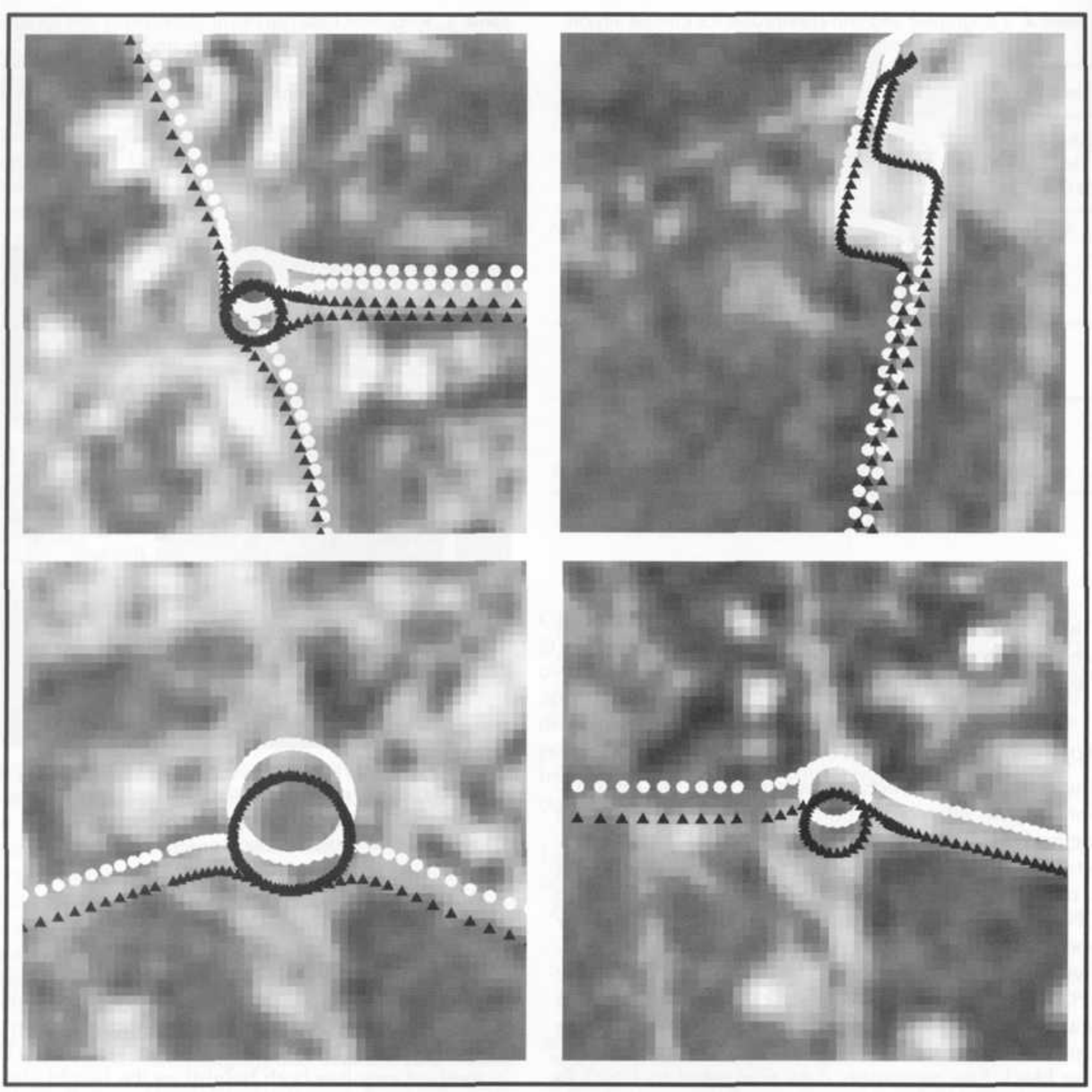

Figure 3 Offset in transformed coordinates using locally derived (white dots) and Military Survey (black triangles) datum transformation parameters (map scale 1:5000).

system provides the fundamental framework to facilitate the efficient integration, management and processing of such data. A basic functional requirement of any GIS is the capability to undertake re-projection between mapping systems and normally no difficulty is encountered. However, situations may arise where the necessary parameters for converting between mapping systems are not available, preventing the efficient integration of data from different survey sources. Currently, there is a lack of information in the literature regarding practical solutions to this problem and their application in natural resources survey.

In this paper the parameters required for application of the abridged Molodensky method for datum transformation are estimated from 1:50 000 topographic maps, a SPOT satellite panchromatic image and a high precision differential GPS control point. In order to estimate the Molodensky parameters it is necessary to have the geographic coordinates reported for the same point and for each datum, as well as the height of the point above each ellipsoid. The geographic coordinates appropriate to the Accra datum were derived from the 1:50 000 topographic maps. Unfortunately the control point is not marked on the map sheets. Consequently, an estimate of the position of the control point was derived by visual inspection of an available geo-referenced SPOT image (geo-referenced to a precision of about 18 metres) and transferred to the map sheets. Subsequently the geographic coordinates were digitized from the topographic map.

An estimate of the height of the point above mean sea level was also made.

The parameters are applied to the transformation of road survey data from UTM to GNG coordinates. The coordinates are compared with those resulting from application of the Molodensky parameters obtained from an official source, the UK Military Survey. Despite the approximate nature of the method, the derived datum transformation parameters appear acceptable for combining data sets at a nominal scale of 1:50 000 within a GIS.

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