On Problems of Coordinates, Coordinate Systems and Transformation Parameters in Local Map Production, Updates and Revisions in Nigeria

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SUMMARY

A coordinate system forms a common frame of reference for the description of positions and on the other hand, coordinates are simply an ordered set of numbers that are used to describe the positions or features in a coordinate system (Featherstone and Vanicek, 1999). Transformation parameters are required to move from one system to another. In Nigeria, we have different coordinate systems based on different origins which are used for various mapping purposes. Also, new technologies like global positioning system have provided new methods of coordinates' determination. The map production, update and revision are based on geographical coordinates; map-grid coordinates or coordinates in an arbitrary system. Some others are based on old (local) system. There are no truly accepted transformation parameters. The consequences are obvious confusion and misrepresentation of features.

In fact surveyors and survey practitioners are already using the new technology based on geocentric system while most available maps and map coordinates are in local system. The effect or implication is multiple data sets on different systems. Thus, this paper has emphasised on a clear choice of coordinate systems and coordinates especially as new methods of spatial information capture emerge. It described the methodology of making different coordinates compatible to be employed in spatial referencing by determination of transformation parameters. This therefore will help in generalising features for representation in two dimensions on flat piece of paper. Hence, a recommendation has been made to unify all the different coordinates or made to be compatible and flexible by employing least squares adjustment principles to determine the transformation parameters.

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1. INTRODUCTION

The science of geodesy has provided us with two different types of coordinate systems. These are geocentric and regional (local) coordinate systems. The origins and axes of these coordinate systems are different. While the geocentric coordinate system has its origin at the centre of the mass of the earth and the regional (local) coordinates system has its centre different from the geocentre. These coordinate systems are associated with the term 'datum', which uses coordinates referred to the surface of defined ellipsoid of revolution Featherstone and Reit (1998).

Historically, different ellipsoids have been chosen by different countries of the world in order to simplify surveying and mapping in their region and as such these ellipsoids are not necessarily geocentric. In Nigeria, the regional (local) coordinate system is the Minna Datum based on Clarke 1880 ellipsoid. The geocentric system of Nigeria is the WGS84 ellipsoid. These datums are defined using two parameters i.e. semi-major axis (a) and flattening (f). The numerical values are shown in the Table 1. Several assumptions were made in the definition. For Minna Datum, it assumed that ellipsoidal height (h) is equal to Orthometric height (H). This implies that geoidal height (N) is zero; the normal and vertical coincided.

Table 1 Parameters of Minna and WGS84 Datums

Parameter	Minna Datum(Clarke 1880)	Geocentric Datum (WGS84)
a (m)	6378249.145	6378137.000
f	1/293.465	1/298256223563

Source: Ono (2002)

To fully describe positions in relation to the earth, the geodetic coordinate system and Cartesian coordinate system are employed. The geodetic coordinate system comprises a right –handed orthogonal three-dimensional coordinates made up of geodetic latitude (φ), geodetic longitude (λ) and ellipsoidal height (h). They refer to the surface of specific ellipsoid of revolution about its minor axis. The Cartesian coordinate system is the three-dimensional orthogonal axes in the X, Y, and Z directions. Thus, a corresponding triplet of Cartesian coordinates refers to these axes. The X-axis is directed towards the intersection of the Greenwich meridian and equatorial plane. The Z-axis is aligned towards the North Pole of the earth's rotation. The Y-axis is orthogonal to X and Z axes and completes the right–handed coordinate system (See Fig. 1).
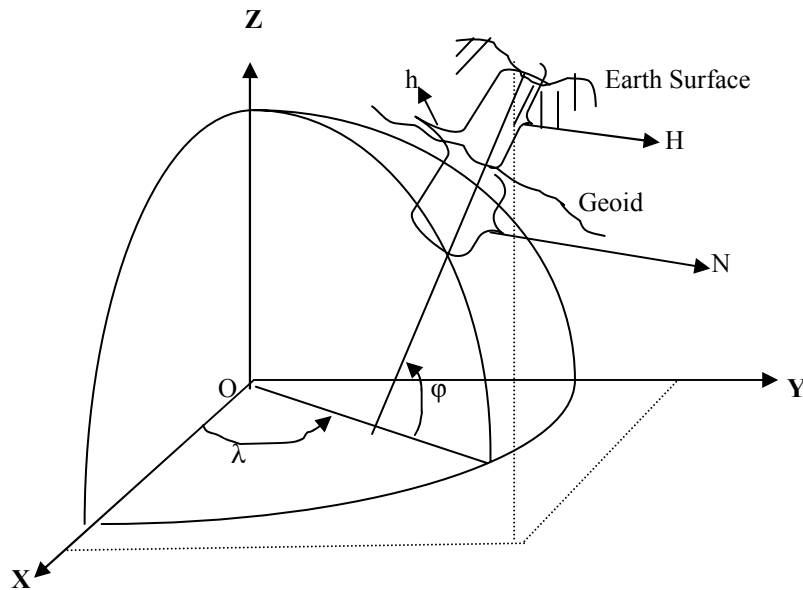
Usually, the more easily plottable and understandable coordinates are the eastings (E) and northings (N), which leads us again to another system, called plane (rectangular) coordinate system. The geodetic coordinate system or cartesisan coordinate system can be projected to plane coordinate system through appropriate projection models.

Now in our map production, up-dates and revision, we must make clear choice of the following transformations:

        (1) Geocentric datum and geodetic coordinate system to
            plane coordinate system
        (2) Geocentric datum and Cartesian coordinate system to
            plane coordinate system
        (3) Minna datum and geodetic coordinate system to plane
            coordinate system
        (4) Minna datum and Cartesian coordinate system to plane
            coordinate system

From the above, (1) and (2) are based on the modern methods and recent digital data capture depend on them while (3) and (4) are the old existing data mostly based on ground methods and old instrument bedecked with inherent errors. Unfortunately our maps for revision are mostly based on the later.

2. GEODETIC TO CARTESIAN COORDINATE CONVERSION

Geodetic coordinates as shown in Fig. 1 can be converted to Cartesian coordinates as they have the same ellipsoid and the axes are aligned with minor and major axes of that ellipsoid. Heiskanen and Moritz (1967) gave the conversion models as

$$X = (N + h)\cos\varphi\cos\lambda \qquad (1)$$
$$Y = (N + h)\cos\varphi\sin\lambda \qquad (2)$$
$$Z = (N(1 - (2f - f^2)) + h)\sin\varphi \qquad (3)$$

where N is the radius of curvature in the prime vertical given as

$$N = \frac{a}{(1 - (2f - f^2)\sin^2\varphi)^{1/2}} \qquad (4)$$

The constants a and f are the dimensional parameters of either the regional or geocentric ellipsoids. In local ellipsoids, the parameter h is not known but if Geoid-ellipsoid separation is known along with orthometric height (H), then we can use the relation (5) to find h, as given by Heiskanen and Moritz (1967). Also, see Fig. 1.

$$h = H + N \qquad (5)$$

where

H $\longrightarrow$ orthometric height

N $\longrightarrow$ Geoid- ellipsoid separation (no confusion with prime vertical radius of curvature N)

Conversely, Cartesian coordinates can be converted to geodetic coordinates, which may involve iterative procedure to realise latitude (φ). Thus from (1), (2) and (3) we have a close solution by Featherstone and Reit (1998) as:

$$\lambda = \tan^{-1}\frac{Y}{X} \qquad (6)$$

$$\varphi = \tan^{-1}\left[\frac{1}{1-f}\tan u\right] \qquad (7a)$$

where

$$u = \tan^{-1}\left(\frac{1}{1-f}\frac{Z}{\sqrt{X^2+Y^2}}\right) \qquad (7b)$$

and

$$h = \frac{(X^2+Y^2)}{\cos\varphi} - N \qquad (8)$$

The parameters of the appropriate ellipsoid must be applied. An iterative solution programmable in FORTRAN language is given in Ono (2002).

So far, these conversions are just in the same system. If the choice is to be made here, there will be complications or confusion. But the modern methods of data collection (capture) are based on geocentric systems, and existing maps which are sources of data capture are based on local system. Here lies the problem. Will our map production, up-dates and revision be on geocentric coordinate system or regional coordinate system? Or the data obtained in geocentric system that are in digital form and more compatible with other data types for easy map generalisation be changed to regional (local) system. Could it be a matter of choice? But, transformation parameters are not available. Consider the scenario, where GPS determined positions are to be reconciled with the rest of the positions known on the Clarke 1880 ellipsoid. A solution in form of transformation of the coordinates with transformation parameters has to be used to get the coordinates in the desired coordinate system.

To accomplish this, a seven – parameter transformation is applied to the three-dimensional Cartesian coordinates of equations (1) to (3). This comprises an origin shift in three dimensions ($\Delta X, \Delta Y, \Delta Z$), a rotation about each coordinate axis ($\alpha_x, \alpha_y, \alpha_z$) and a change in scale (Δs). The equation follows thus (Featherstone and Vanicek, 1999)

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{Minna} = \begin{pmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{pmatrix} + (1+\Delta s)\begin{pmatrix} 1 & \alpha_z & -\alpha_y \\ -\alpha_z & 1 & \alpha_x \\ \alpha_y & -\alpha_x & 1 \end{pmatrix}\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{WGS84} \qquad (9)$$

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The values of these parameters have not been determined which is a very serious hindrance to map production, updates and revision. Featherstone and Dentith (1997) has suggested the use of three-origin shifts as provided in DMA(1987) since the complete set of seven parameters is not always available. They posited that this could provide coordinate transformation accurate to approximately 20m. The values for Nigerian system are shown Table 2. Now for three-parameter shift, equation (9) according to DMA(1987) reduces to

$$
\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{Minna} = \begin{pmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{pmatrix} + \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{WGS84}
\tag{10}
$$

Table 2 Transformation Parameters (Local Geodetic system to WGS 84)

Local Geodetic System	Reference ellipsoid and parameter Differences			Number of Doppler station used to determine transformation parameters.	Transformation Parameters		
	Name	Δa (m)	Δf *10^4		ΔX (m)	ΔY (m)	ΔZ (m)
Minna Datum	Clarke 1880	-112.145	-0.54750714	6	-92	-93	122

Source: DMA 1987

The assumptions made are that local rotation axes coincide with geocentric axes. These make the rotation parameters equal to zero. Also, scale factor is equal to zero.

3.   THE PROBLEM

Our problem may have a very easy solution. That is, to move to geocentric system (WGS84) since data acquisition is best compatible to other modern data types. But it is evident that this move will require major changes to all maps and other GIS products in Nigeria. Hence, we must create the awareness of multiple coordinate systems and the ability to transform from one coordinate system to another. This is imperative if map production, updates and revision or data integration is to take place. Also, the cost of acquiring this technology is still too high for our pockets. You can just imagine what it will cost for the reproduction of all our existing maps on WGS84 datum. It will be grossly costly.

We have to admit of the problem at hand and seek a way forward. The existence of multiple coordinate systems is really a hindrance to our map production, updates and revision. Therefore we must make effort to identify them, know them, know their relationship and finally are able to move from one system to the other. Further more; even data integration will become possible then. We want to realise a situation where data gathered in WGS84 datum are projected using some parameters to coincide closely with Minna datum coordinates of the

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same point as if they had been projected from Clarke 1880 ellipsoid. On certain occasions it may be difficult to perceive the difference by any map user. Fig.2 is flow chart for moving from one coordinate system to another if we know the transformation parameters either in Cartesian form or plane rectangular form

So, the task before us is to achieve uniformity in our map production, updates and revision. So, all the data from several sources especially the spatial data should be identified and from which coordinate systems. Then, we must set for ourselves the job of determining these parameters to move from one system to the other or unifying the systems. This will remove the doubt, the confusion of bequeathing the people a wrong product. The cartographic society should superhead the determination of these parameters. An inappropriate referencing system or multiple referencing systems will restrict future use of the GIS and map products. We agree with Heywood, et al (1998) that we must have to adopt a flexible and lasting referencing system since these maps and map products are intended to last many years.
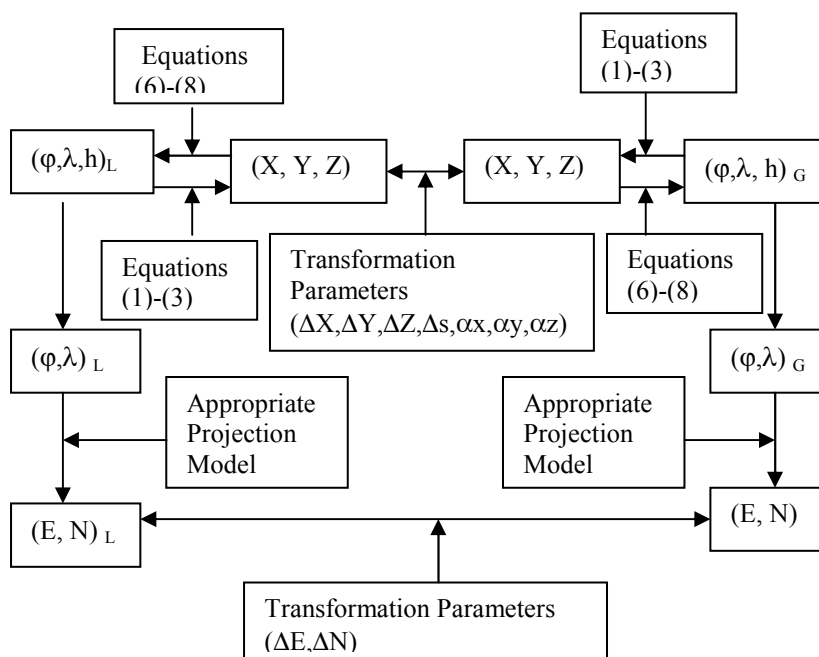

Fig.2 Transformation of coordinates from one system to the other (i.e. local to Geocentric)

4.   DISCUSSION AND CONCLUSIONS

Earlier in the paper, we have that data presentation is better done in two-dimensional plane rectangular coordinates. In Nigeria, we have such two plane rectangular systems namely; the Nigeria Transverse Mercator projection (NTM) and the Universal Transverse Mercator projection (UTM). These two systems are well described in Uzodinma and Ezenwere (1993). Ezeigbo (1998) has stated that to move from NTM to UTM or vice-versa (see Fig.3) is not a problem but the problem lies in moving from local system to geocentric system because of non-availability of transformation parameters.
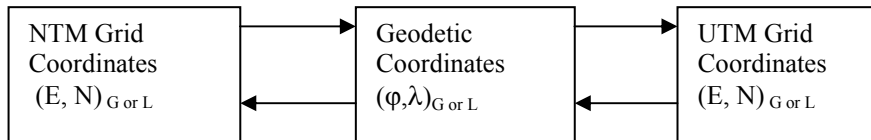
Fig.3 Conversion of NTM to UTM or Vice-versa

What this implies is that we can project geocentric coordinates to either NTM or UTM plane coordinates. Also, we can project local coordinates to either NTM or UTM. But, the problem still remains, that is, NTM or UTM plane coordinates projected from geocentric coordinates still remain NTM or UTM geocentric plane coordinates. So are NTM or UTM plane coordinates projected from local system, remaining NTM or UTM local plane coordinates?

The way out is to achieve homogeneity in our reference system. This is possible through the accurate determination of transformation parameters in terms of geodetic coordinates or Cartesian coordinates or plane rectangular coordinates (see Fig.2). There are available models for this coordinate parameterisation in Ono (2002). The procedure for determining these parameters entails observing some common points in the two systems and carrying out least squares adjustment by using equation (9).

The three-shift parameter model of equation (10) may not accurately serve our long-term purposes. Already, 20m accuracy error has been attributed to it coupled with the fact that the three-shift parameters (ΔX, ΔY, ΔZ) were determined based on six Doppler stations. The Doppler stations are based on WGS72 datum, which requires some parameters to move to WGS84 datum. Besides, six co-located stations are deemed too small as it allowed only little redundancy for a least squares adjustment expected to achieve a high accuracy. Though, there is ease in the computations and adjustment exercise.

In conclusion, the choice of which coordinate system and coordinate to enhance the quality and generalisation of map production, map-updates and revision must be made. And to make it, involves the determination of transformation parameters which will enable us to integrate data no matter from which source the data come from or are captured. The choice or recommendation of determination of transformation parameters may seem to be too theoretical or mathematical or even complicated for those of us involved in the map production, updates and revision with little background in sciences. One should realise, however that it will be a wasted effort spent on map production, updates and revision if those concerned do not use all the modern and mathematical advantages in mapping exercise. You dare not bequeath confusion and complications to the future.

REFERENCES

Ezeigbo, C.U. (1998) Presentation and Quality Management in
        Geographic information System (GIS) in Ezeigbo, C.U. (ed.).
        Principles and applications of geographic information systems.
        Dept. of Surveying, University of Lagos, Akoka
DMA (1987) Dept. of Defense, World Geodetic System 1984-

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Its definition and relationship with local geodetic system, DMA Technical Report 9350, 2, Washington D.C.

Featherstone, W.E. and Dentith, M.C. (1997) A geodetic approach to gravity data reduction for Geophysics. Computers and Geosciences Vol. 23 No. 10 pp 1063-1070

Featherstone, W. and Reit B-G (1998) Modified map projection: Transforming map-grid coordinates between the Australian Geodetic datum and geocentric datum of Australia. Surveying Australia. pp. 32-37

Featherstone, W. and Vanicek, P. (1999) The role of coordinate systems, coordinates and heights in horizontal datum transformations. The Australian Surveyor Vol. 44 No. 2

Heiskanen, W.A. and Moritz, H. (1967) Physical Geodesy. W.H. Freeman and Company, San Francisco.

Heywood, I., Cornelius, S. and Carver, S. (1998). An introduction to Geographic information Systems. Addison Wesley Longman Limited New York.

Ono, M.N. (2002) Integration of three-dimensional terrestrial and satellite geodetic networks for enhanced utilization. Unpublished Ph.D. thesis. Dept of Geoinformatics and Surveying, UNEC.

Uzodinma, N.V. and Ezenwere, O.C. (1993) Map Projections – Practical computations on the Transverse Mercator Projection. EL'Demak Company, Enugu.

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ONO, Matthew N. (Ph.D) is a Senior Lecturer with several publications to his credit. The publications centred on his special interest of geodesy, geoinformatics, cadastral surveying etc. He has supervised and guided undergraduate and postgraduate students on their projects to earn their degrees. Presently, he is engaged in researches in geodetic controls, geodynamic studies, global positioning system applications etc.

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