SIMPLE PRECISE COORDINATES TRANSFORMATIONS FOR GEOMATICS APPLICATIONS IN MAKKAH METROPOLITAN AREA, SAUDI ARABIA

Gomaa M. DAWOD, Egypt, Meraj N. MIRZA, and Khalid A. AL-GHAMDI, Saudi Arabia

SUMMARY

With the rapid growth of utilizing the Global Positioning System (GPS) technology in Saudi Arabia, the issue of transforming GPS-based coordinates to the local coordinates system becomes a crucial concern for geodetic and geomatics applications. Traditional similarity mathematical models for datum conversion (such as Molodensky-Badekas formula) do not take into account the systematic errors exist in national geodetic networks. This paper aims to develop simple, still precise, coordinate transformation algorithms particularly for Geographic Information Systems (GIS) applications. A dataset of high-precision geodetic control points with known GPS and the Saudi geodetic datum (Ain El-Abd 1970) coordinates, within the metropolitan area of Makkah city, has been compiled and utilized in data processing. Results of classical 7-parameters similarity transformation are presented. Additionally, four regression formulas have been developed to convert GPS coordinates (geographic and projected sets) to their local values just by using a calculator. Precision estimates of these regression equations have been anticipated to be within 0.30 meter. Compared with the accuracy of pre-defined transformation parameters utilized in commercial GIS software (which is about 10 meters), the obtained accuracy is quite reasonable for geomatics activities. The proposed approach is practical and decreases both costs and time of engineering surveying, integrated GPS/GIS projects, and topographic mapping.

Key words: GPS, GIS, Datum transformation, Geomatics applications, Saudi Arabia.

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1. INTRODUCTION

Global Navigation Satellite Systems (GNSS) furnish the principal technology for geomatics and geodetic activities in Kingdom of Saudi Arabia (KSA). The rapid growth of utilizing the Global Positioning System (GPS) in KSA has necessitated the definition of the mathematical relationship between global and national geodetic datums. Traditional datum transformation formulas, such as Bursa-Wolf (Bursa, 1962) and Molodensky-Badekas (Badekas, 1969), have some disadvantages particularly that they do not account for systematic errors exist in old triangulation geodetic networks, which is the case in many countries established their geodetic skeleton in the first half of the twenty century. Hence, different datum conversion techniques have been propose, e.g. finite elements (Kohli and Jenni, 2008), least squares by different weights (Shaker et al, 2007), least-squares collocation (You and Hwang, 2006), and total least-squares estimation (Felus, and Burtch, 2009). GNSS networks are currently being established to cover the entire Arabian Peninsula to realize a new reference geodetic frame (Al-Sahhaf et al, 2010). Consequently, the datum conversion from the World Geodetic System 1984 (WGS84) to the national Saudi geodetic datum has to be defined. That is an important demand in the undergoing research project of estimating flood hazardous impacts in Makkah city (Mirza et al., 2011). This paper aims to investigate a classical similarity transformation model, and to develop regression models to convert GPS-based coordinates to the Ain El-Abd 1970 national Saudi geodetic datum.

2. AVAILABLE DATA

Makkah city is located in the south-west part of KSA, about 80 Km east of the Red Sea (Fig. 1). It extends from 39^o 35' E to 40^o 02' E, and from 21^o 09' N to 21^o 37' N. The old (still used) Saudi geodetic datum is called Ain El-Abd 1970, which depends on the International (Hayford 1909) ellipsoid utilizing the Universal Transverse Merecator (UTM) as a map projection. A new Saudi Geodetic Datum (SGD2000) is proposed to ease the GPS data utilization for surveying and mapping (Yanar, 2009). Defining parameters of Ain El-Abd 1970 and SGD2000 datums are tabulated in Table 1. A dataset of thirteen first-order GPS stations, with known WGS84 and local coordinates, has been compiled and utilized in the current research (Fig. 2). Ten points have been used in data processing; while the remaining three stations (No. 7, 8, and 9) have been reserved as check points.

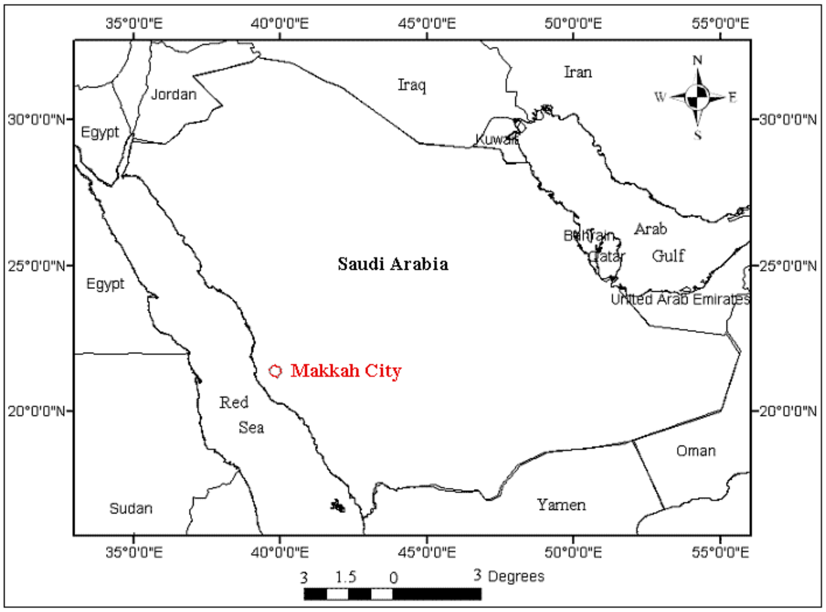

Figure 1: Study Area

Table 1: Parameters of the Saudi Geodetic Datums

Datum Name	Ain El-Abd 1970	SGD2000
Reference Frame	N/A	International Terrestrial Reference Frame (ITRF2000)
Coordinates Epoch	N/A	2004.0
Ellipsoid	Hayford 1909	Geodetic Reference System (GRS80)
Semi-major axes	6378388.0 meter	6378137.0 meter
Inverse Flattening (1/f)	297.0	298.257222101
Map Projection	Universal Transverse Merecator (UTM)	Universal Transverse Merecator (UTM)

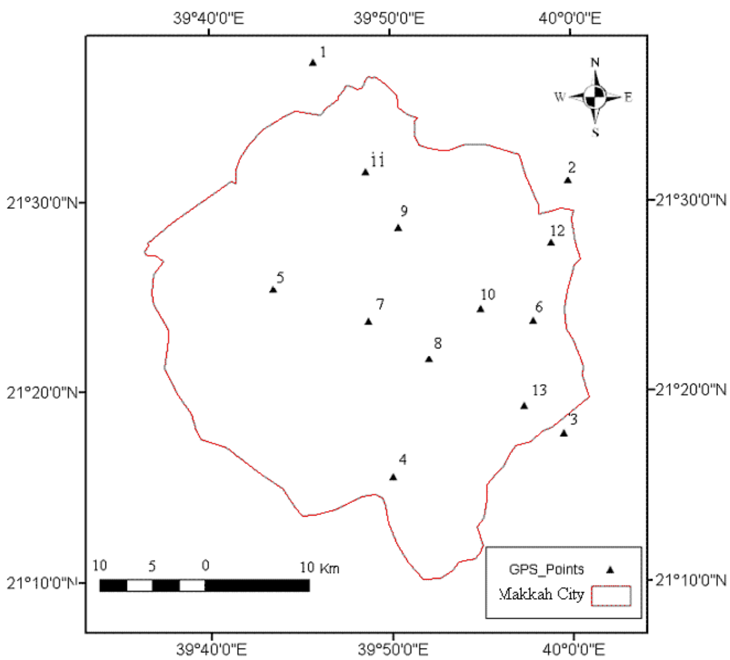

Figure 2: Available GPS Stations

It worth mentioning that several commercial software have implicit estimates of datum transformation parameters between WGS84 and Ain El-Abd 1970 geodetic datums. Usually typical geomatics users utilize these values without giving attention to their accuracy. Table 2 presents values and precision of published datum transformation parameters for KSA (Mugnier, 2008). It can be noticed that the precision of these transformation parameters is within 10 meters, which implies that they are not precise enough for geodetic applications.

Table 2: Values of General Similarity Transformation Parameters

System A	WGS 84
System B	Ain El-Abd 1970
Shift X	- 143 ± 10 m
Shift Y	- 236 ± 10 m
Shift Z	+ 7 ± 10 m

3. PROCESSING AND RESULTS

The first stage of the data processing applied the Molodensky-Badekas similarity transformation model to define the transformation parameters between WGS84 and Ain El-Abd 1970 datums. The accomplished results are presented in Table 3. The accuracy estimates of these parameters have been computed at the three check points, where the average standard deviations of coordinate's difference equals ± 0.212 meter.

Table 3: Results of Molodensky-Badekas Similarity Transformation Parameters

System A	WGS 84
System B	Ain El-Abd 1970
Rotation Origin	
X_o	4559545.892 m
Y_o	3808252.221 m
Z_o	2314350.329 m
Translation Parameters	
Shift X	41.650 m
Shift Y	286.321 m
Shift Z	89.132 m
Rotation Parameters	
Rotation X	-1.91577 "
Rotation Y	10.28662 "
Rotation Z	-14.08571 "
Scale	
Scale Factor	-7.1256 part per million (ppm)

It is known that traditional datum transformation formulas have some weaknesses mainly that they do not account for systematic errors exist in old triangulation geodetic networks. Moreover, simple coordinates transformation models are needed for geomatics applications, e.g. Geographic Information Systems (GIS) data collection. Regression models offer a suitable candidate for developing simple, still precise, transformation formulas that takes into consideration the precision and errors' conditions of the old triangulation geodetic networks (e.g. Dawod and Alnaggar 2000, and Mossa 2009). Theoretically, these models are superior to the conformal transformation models since they can account for non-linear distortions between the terrestrial and satellite datums (Featherstone, 1997). Moreover, regression models have been utilized in many geodetic applications, particularly for fitting gravimetric quasi-geoid to GPS/Levelling data (e.g. Tranes et al, 2007 and Dahoa et al, 2008) and fitting Global Geoid Models (GGMs) to national geodetic data (e.g. Rabah, 2009). Furthermore, the U.S. Defense Mapping Agency (DMA) has published numerous regression models to convert GPS-based coordinates to a variety of local geodetic datums (DMA, 1991).

Several regression models have been developed to define simple relationships between the WGS84 and Ain El-Abd 1970 datums. Derivatives of regression models can be found in many statistical literatures (e.g. Stephens, 1998) and can be summarized as:

A linear regression general form is:

$$y = b_o + b_l\, x \qquad (1)$$

where (x, and y) are coordinates of some known points,
b_o and b_l are unknown regression coefficients; represent the intercept and slope of a line, to be estimated.

The estimates b_o and b_l are determined, so that the sum of squares of deviations about the line is minimized, as:

$$b_1 = S_{xy} / S_{xx} \qquad (2)$$

$$S_{xx} = \Sigma\, x^2 - (\Sigma x)^2/n \qquad (3)$$

$$S_{xy} = \Sigma\, xy - (\Sigma x)(\Sigma y)/n \qquad (4)$$

$$b_o = y' - b_1\, x' \qquad (5)$$

where x' and y' represent the mean of x and y coordinates respectively, and n is the number of data points.

Accordingly, equations 2 to 5 have been applied to develop 4 regression formulas (in the form of equation 1), where the x, and y represent the latitude, longitude, easting, and northing coordinates of the known GPS stations. The first (geographic) group of the developed regression formulas, for Makkah metropolitan area, are:

$$\Delta\varphi = -\ 0.001043117 + 0.0000208\ \ \varphi_{84} \qquad (6)$$

$$\Delta\lambda = -\ 0.003703158 + 0.0000462\ \ \lambda_{84} \qquad (7)$$

where,

$\Delta\varphi$ is the difference in latitude, in degrees, between the WGS84 and Ain El-Abd 1970 datums.
$\Delta\lambda$ is the difference in longitude, in degrees, between the WGS84 and Ain El-Abd 1970 datums.
φ_{84} is the WGS84 latitude, in degrees.
λ_{84} is the WGS84 longitude, in degrees.

Equations 6 and 7 will be used to compute the local geodetic coordinates from the observed GPS coordinates. The accuracy estimates of these transformation equations have been evaluated at the three check points, where the average coordinate difference equals 0.039 ± 0.256 meter.

The second (projected) group of the developed regression models deal with the UTM projected coordinates (Zone 37) as:

$$E_{local} = - 199.224 + 0.00000490 \ E_{84} \tag{8}$$

$$N_{local} = - 112.363 + 0.00000623 \ N_{84} \tag{9}$$

where,

E_{local} is the UTM East coordinate, in meters, based on Ain El-Abd 1970 datum.
N_{local} is the UTM North coordinate, in meters, based on Ain El-Abd 1970 datum.
E_{84} is the UTM East coordinate, in meters, based on WGS84 datum.
N_{84} is the UTM North coordinate, in meters, based on WGS84 datum.

Hence, equations 8 and 9 can be used to compute the local UTM coordinates from the projected UTM GPS coordinates in a straightforward way. Similarly, the accuracy estimates of these transformation equations have been evaluated at the three check points, where the average coordinate difference equals 0.052 ± 0.267 meter.

Regarding the developed regression models, it is obvious that they are related only for Makkah metropolitan area since they implicitly depend on local GPS datasets. However, this approach can be simply implemented in any other region in Saudi Arabia, or anywhere else, as long as GPS datasets are in hand. For example, similar regression models for Jeddah city have been estimated (Mossa, 2009). Hence, the regression approach is recommended as a coordinate transformation tool for other regions in KSA.

4. CONCLUSION

Coordinates transformations are needed to convert the WGS84-based GPS coordinates to local Saudi mapping system. Obtaining an accurate-consistent transformation parameters set, utilizing the classical similarity transformation models, is not an easy task because of the inaccuracy and inconsistency in the local geodetic networks. In this research, two groups of regression models have been developed to transform geodetic and projected GPS coordinates to their national values for Makkah metropolitan area. The main advantages, of such regression models, are simplicity and accuracy (within 0.3 meter). These models are extremely more accurate than the transformation parameters implicitly found in most commercial GPS software. Moreover, they can be utilized in field surveying works just by using a calculator, which overcomes the complexity of the traditional similarity transformation formulas. Such models are efficient for several types of geomatics activities, for example GIS data collection, engineering surveying, and topographic mapping.

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