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Evaluation of the Direct UTM Coordinates Transformation Method Based on the Standard 7-Parameters Transformation

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Abstract: GNSS (global navigation satellite system) observations produce the geodetic position including latitude, longitude, and altitude (or ellipsoidal height) concerning the global reference datum WGS84 (Word Geodetic System 1984), which usually should be converted to another local datum to get the desired position meaning in a physical sense, coordinates of points in the local datum are usually calculated by the seven-parameter transformation method. This paper aims to validate the methods of position transformation between WGS84 and the Iraqi local datum Karbala 1979 using the UTM (universal transverse Mercator) projected coordinates directly. The proposed algorithm was tested for 10 ground control points in Erbil city and many selected points in other different cities over all Iraqi territory. The control points are measured by the CHCNAV i73 GNSS receiver. For the evaluation procedure, the RMSE (root mean square error) of the transformed coordinates is calculated with an average value of ±10.715 m as an estimated uncertainty of the direct UTM coordinates transformation method over Erbil city territory, and more than ±12 m over different places over Iraqi territory.

Key words: Direct UTM coordinates transformation, global datum WGS84, local Iraqi datum Karbala 1979.

1. Introduction

The transformation of the coordinates between different datums is one of the most used calculations in geomatics applications such as surveying, geodesy, photogrammetry, and associated professions [1], especially with the wide use of the GNSS (global navigation satellite system) positioning. The GNSS observations provide the geodetic position including latitude, longitude, and altitude (or ellipsoidal height) based on the global reference datum WGS84 (Word Geodetic System 1984), GNSS can also provide the projected coordinates easting & northing (E, N) which are defined according to the UTM (universal transverse Mercator) projection on the Iraqi territory. Hence, it is essential to transform these measured positions from the global datum (WGS84) to the local reference datum. The increased use of GNSS receivers for measuring the positions of physical features in ground-based surveys (such as the positions of the rivers, buildings, roads, and elevations of the ground) requires the need for coordinate transformation [1].

2. Global & Local Datum

The datum is a rotational ellipsoid that is identified by its origin and position, as well as its size and shape. The reference datum can be a local datum for an area defined by the geodetic position and azimuth of a point as the origin in that region or a global datum defined by the geocentric of the earth mass such as WGS84 [2]. GNSS receivers determine the position, essentially, based on the global datum (WGS84), the origin of this datum is the center of the Earth. This is indicated by the center of gravity, the local datum in Iraq (that was used for the period before 2003) is the Karbala 1979 which is established by the Pol-Service company in 1979.

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This datum was produced according to the ellipsoid Clarke 1880 [3].

3. Datum Transformation

A geodetic datum transformation is a computational rule that converts measured coordinates from one reference frame to coordinates from another, the computational rule is determined by a set of required datum transformation parameters [4]. Datum transformation ranges from a simple three-parameter transformation to a complicated seven-parameter transformation with a 14-term adjustment that requires multiple steps [5].

3.1 Three-Parameter Transformation

Three-parameter transformation converts the geodetic coordinates into ECEF (Earth-centered, Earth-fixed coordinate system) X-Y-Z coordinates, then shifts the origin and converts back to the other datum's origin to define the position according to the new reference datum. This is a crude method that only works on small areas or in case of no rotation between the datums. The general formula for the three-parameter transformation is as follows [6]:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_T = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_S + \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix}$$

where: T represents the coordinates of the target point, S represents the coordinates of the source point, and ($\Delta X\, \Delta Y\, \Delta Z$) represents the datum shift between the two datums (source & target).

3.2 Seven-Parameter Transformation

A seven-parameter transformation follows the same procedure as an ECEF origin shift, but it includes the rotation along the whole three axes as well as the scale correction. The general formula for the seven-parameter transformation is as follows [7]:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_T = \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} + (1+S) \begin{bmatrix} 1 & -RZ & RY \\ RZ & 1 & -RX \\ -RY & RX & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_S$$

where: S is the scale factor and the differential rotation angles around the first, second, and third axes, respectively, are Rx, Ry, and Rz.

4. Data Collection (GNSS Observation)

A study area of 20 × 14 km square in Erbil city was selected for this research as shown in Fig. 1. A set of GCPs (Ground Control Points) were observed using the post-processing static GNSS positioning to evaluate the accuracy of the transformation algorithm of the suggested direct method. The data acquisition is done by using the CHCNAV i73 GNSS instrument. The GCPs are selected to cover the whole study area. During the static GNSS surveying technique, the receivers are motionless during the observation. Because static work most often provides higher accuracy and more redundancy than kinematic work, it is usually done to establish controls [8]. The observation of each station took a measurement consciously for 5 h during the morning time for 10 days.

The coordinates of the GCPs are acquired based on the projection of UTM zone 38N and the datum WGS84 which is uploaded to https://geodesy.noaa.gov/OPUS/ website for post-processing based on the nearest CORS (Continuously Operating Reference Station). OPUS (Online Positioning User Service) chooses them according to the numerous quality control tests that are performed on the CORS archived data to select the best CORS as a source of GNSS corrections [9].

Table 1 shows the results of post-processing for the ten selected GCPs, which are obtained with a precision of millimeters.

In order to determine a precise local UTM coordinate (according to Karbala 1979) for those 10 GCPs, a ready online software called SPTA (surveyor pocket tools application) has been used (see Fig. 2). The SPTA is used as a reference for transformation between the global datum WGS84 and the local datum (based on ellipsoid Clarke 1880). The transformed coordinates are shown in Table 2.

Fig. 1 Study area: Erbil city.

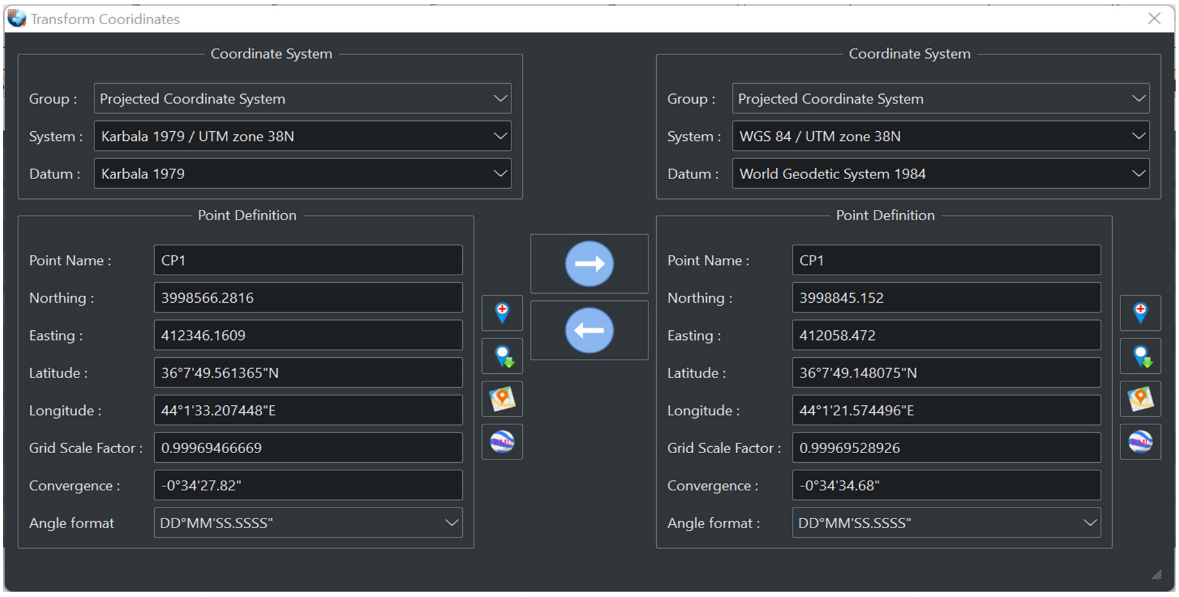

Fig. 2 SPTA for transformation between different datums.

Table 1 Geodetic and UTM coordinates based on global datum WGS84 for the observed GCPs. (OPUS Reports)

Points	Lat. (Φ)	Long. (λ)	Easting (m)	Northing (m)	Precision (m)
CP1	36°7′49.14808″	44°1′21.57449″	412,058.472	3,998,845.152	±0.007
CP2	36°14′8.29694″	44°4′39.65459″	417,120.565	4,010,479.004	±0.008
CP3	36°14′14.81849″	43°58′55.11623″	408,522.361	4,010,766.037	±0.011
CP4	36°12′36.92844″	44°8′54.45085″	423,455.978	4,007,605.574	±0.007
CP5	36°12′20.28413″	43°57′46.57504″	406,773.727	4,007,255.11	±0.019
CP6	36°13′6.43022″	44°4′2.62427″	416,177.884	4,008,581.61	±0.004
CP7	36°12′30.63406″	43°59′55.04744″	409,985.168	4,007,540.3	±0.004
CP8	36°9′51.16676″	43°57′22.24112″	406,116.647	4,002,667.005	±0.005
CP9	36°10′10.30696″	44°4′50.58408″	417,323.887	4,003,143.496	±0.007
CP10	36°10′20.50219″	44°1′17.42844″	412,001.827	4,003,509.684	±0.012

Table 2 Geodetic and UTM coordinates based on local datum Karbala 1979 for the observed GCPs. (Reference data)

Points	Lat. (Φ)	Long. (λ)	Easting (m)	Northing (m)
CP1	36°7′49.56137″	44°1′33.207448″	412,346.161	3,998,566.282
CP2	36°14′8.71809″	44°4′51.296111″	417,408.25	4,010,200.124
CP3	36°14′15.24917″	43°59′6.770220″	408,810.053	4,010,487.157
CP4	36°12′37.33952″	44°9′6.079542″	423,743.657	4,007,326.696
CP5	36°12′20.71268″	43°57′58.226728″	407,061.421	4,006,976.233
CP6	36°13′6.85022″	44°4′14.264536″	416,465.57	4,008,302.731
CP7	36°12′31.05949″	44°0′6.695006″	410,272.859	4,007,261.422
CP8	36°9′51.59077″	43°57′33.887549″	406,404.341	4,002,388.132
CP9	36°10′10.71954″	44°5′2.215418″	417,611.572	4,002,864.622
CP10	36°10′20.92089″	44°1′29.067732″	412,289.516	4,003,230.81

5. Method of Direct UTM Coordinates Transformation

The direct method of UTM coordinates transformation was discussed as a new easy method of transformation by an MSc thesis at Baghdad University in 2005. The algorithm of this method of transformation is derived based on changing two essential datum elements: the semi-major axis (a) and the eccentricity (e^2) [10].

$$N = K_\circ.\{B + \frac{N\delta\lambda^2}{2\rho^2} sin\varphi cos\varphi + \frac{N\delta\lambda^4}{24\rho^4} sin\varphi cos^3\varphi(5 + tan^2\varphi + 9\eta^2 + 4\eta^4) + \frac{N\delta\lambda^6}{720\rho^6} sin\varphi cos^5\varphi(61 - 58tan^2\varphi + tan^4\varphi)\} \quad (1)$$

$$E = K_\circ.\{\frac{b}{\sqrt{1-e^2}}.\lambda_\circ + \frac{N\delta\lambda}{\rho} cos\varphi + \frac{N\delta\lambda^3}{6\rho^3} cos^3\varphi(1 - tan^2\varphi + \eta^2) + \frac{N\delta\lambda^5}{120\rho^5}(5 - 18tan^2\varphi + tan^4\varphi)\} \quad (2)$$

Eqs. (1) & (2) show that the projected UTM coordinates (E & N) are a function of the elements of the datum's geometry, i.e.

$$N = g\,(a, e^2) \text{ and } E = f\,(a, e^2)$$

$$N_L = g\,[(a_G + \Delta a), (e^2{}_G + \Delta e^2)] \text{ and } E_L = f\,[(a_G + \Delta a), (e^2{}_G + \Delta e^2)] \quad (3)$$

$$N_L = N_G + \Delta N \text{ and } E_L = E_G + \Delta E \quad (4)$$

where: N_G & E_G are the UTM coordinates based on global datum WGS84; N_L & E_L are the UTM coordinates based on local datum Karbala 1979.

Obviously, the two parameters of direct UTM transformation are the differences (ΔE & ΔN), which can be determined using the Taylor expansion through the partial derivatives of the functions (Eq. (3)) above [10].

$$\Delta N = \frac{\partial g}{\partial a}\Delta a + \frac{\partial g}{\partial e^2}\Delta e^2 + 1/2\{\frac{\partial^2 g}{\partial a^2}(\Delta a)^2 + \frac{\partial^2 g}{\partial (e^2)^2}(\Delta e^2)^2 + 2\frac{\partial^2 g}{\partial a \partial e^2}(\Delta a \Delta e^2)\}$$

$$\Delta E = \frac{\partial f}{\partial a}\Delta a + \frac{\partial f}{\partial e^2} + \Delta e^2 + 1/2\{\frac{\partial^2 f}{\partial a^2}(\Delta a)^2 + \frac{\partial^2 f}{\partial (e^2)^2}(\Delta e^2)^2 + 2\frac{\partial^2 f}{\partial a \partial e^2}(\Delta a \Delta e^2)\} \quad (5)$$

Thus, for a set of points Eq. (5) can be written as follow:

$$\begin{bmatrix} \Delta N_1 \\ \Delta E_1 \\ . \\ . \\ \Delta N_n \\ \Delta E_n \end{bmatrix} = \begin{bmatrix} \frac{\partial N_1}{\partial a} & \frac{\partial N_1}{\partial e^2} & \frac{\partial^2 N_1}{\partial a^2} & \frac{\partial^2 N_1}{\partial (e^2)^2} & \frac{\partial^2 N_1}{\partial a \partial e^2} \\ \frac{\partial E_1}{\partial a} & \frac{\partial E_1}{\partial e^2} & \frac{\partial^2 E_1}{\partial a^2} & \frac{\partial^2 E_1}{\partial (e^2)^2} & \frac{\partial^2 E_1}{\partial a \partial e^2} \\ & & . & & \\ & & . & & \\ & & . & & \\ \frac{\partial N_n}{\partial a} & \frac{\partial N_n}{\partial e^2} & \frac{\partial^2 N_n}{\partial a^2} & \frac{\partial^2 N_n}{\partial (e^2)^2} & \frac{\partial^2 N_n}{\partial a \partial e^2} \\ \frac{\partial E_n}{\partial a} & \frac{\partial E_n}{\partial e^2} & \frac{\partial^2 E_n}{\partial a^2} & \frac{\partial^2 E_n}{\partial (e^2)^2} & \frac{\partial^2 E_n}{\partial a \partial e^2} \end{bmatrix} \cdot \begin{bmatrix} \Delta a \\ \Delta e^2 \\ (\Delta a)^2 \\ (\Delta e^2)^2 \\ \Delta a \Delta e^2 \end{bmatrix} \quad (6)$$

Then, the UTM coordinates according to the local datum will be calculated directly as follow [10]:

$$\begin{bmatrix} E \\ N \end{bmatrix}_{Clarke} = \begin{bmatrix} E \\ N \end{bmatrix}_{WGS84} + \begin{bmatrix} \Delta E \\ \Delta N \end{bmatrix} + \begin{bmatrix} \Delta_{Zone} \\ 0 \end{bmatrix} \quad (7)$$

6. Evaluation of Direct UTM Transformation Method

Since the algorithm of the direct method is established basically on the two parameters (ΔE & ΔN), the methodology of evaluation will be done based on the uncertainty in the calculated values of these parameters ($\delta\Delta E$ & $\delta\Delta N$). The following Eq. (8) of the RMSE (Root Mean Square Error) is used to determine the uncertainty of the position:

$$RMSE_P = (\delta\Delta E^2 + \delta\Delta N^2)^{1/2} \quad (8)$$

where:

$RMSE_P$: is the Root Mean Square Error in the position.

$\delta\Delta E$: is the estimated error in easting ($\delta\Delta E$ = calculated - reference).

$\delta\Delta N$: is the estimated error in northing ($\delta\Delta N$ = calculated - reference).

Thus, according to Eq. (8) the average uncertainty of the algorithm of the direct method for the selected control points in Erbil city is estimated as equal to ±10.715 m. Fig. 3 shows the obtained uncertainty for each control point.

Furthermore, the same algorithm is applied for different locations along the meridians and parallels in the Iraqi territory, which means different latitude (φ) and longitude (λ), the locations of these points are measured from Google Earth. The following flow chart shows the results of them, Fig. 4 illustrates the position uncertainty for the different selected points in Iraqi

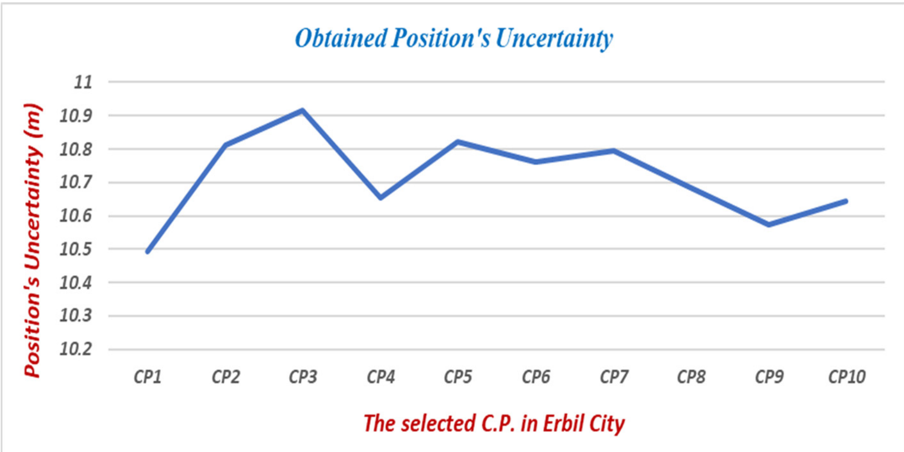

Fig. 3 Tolerance in position's uncertainty over Erbil city territory.

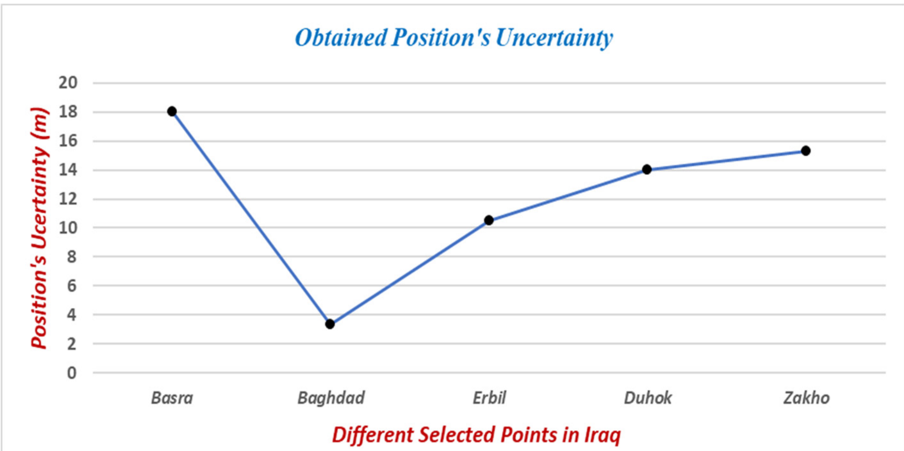

Fig. 4 Position's uncertainty due to variation in the value of latitude.

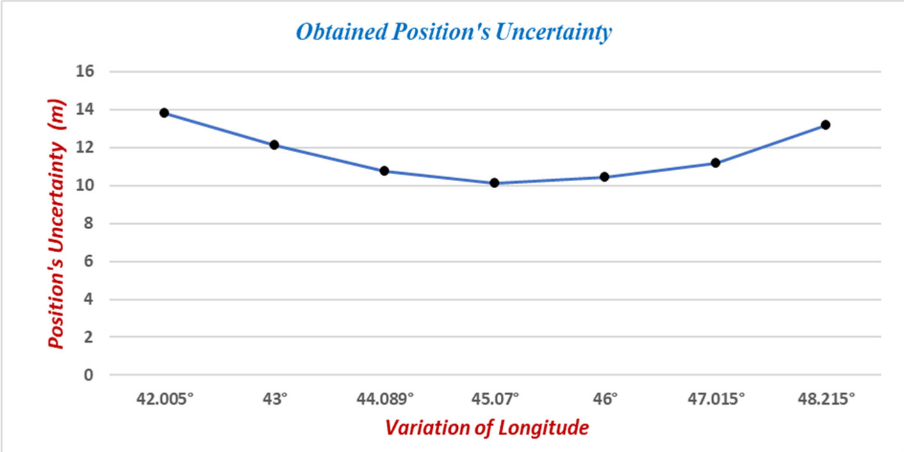

Fig. 5 Position's uncertainty due to variation in the value of longitude.

Table 3 Estimation of position uncertainty.

Location	Average uncertainty		
	$\delta\Delta E$ (m)	$\delta\Delta N$ (m)	Position (m)
Erbil city	-3.72	-10.047	10.715
Variation of latitude	-2.797	-3.39	12.231
Variation of longitude	-0.669	-9.986	11.654

territory, the flow chart shows that the applied algorithm gives the smallest position uncertainty in Baghdad city and the highest position uncertainty in Basra city.

Fig. 5 illustrates the position's uncertainty for different selected points along approximately fixed parallels with different longitudes, it shows that the applied algorithm gives smallest position uncertainty for those points located around the longitude ($\lambda = 45°$). The average of estimated uncertainty for easting and northing is summarized in Table 3, which shows that the average of uncertainty is increasing according to the variation of the latitude's value.

7. Conclusion

The main features of this work are summarized in the following points:

Coordinates transformation traditionally can be done using different methods, meanwhile, there is a method (suggested by Omer A. [10]) that can be used for the transformation of the projected coordinates between different datums directly.

This research concerns the evaluation of the algorithm of the direct method regarding different cases and positions over Iraqi territory.

The experiment data are performed by GNSS observations based on the DGPS (Differential Global Positioning System) (CHCNAV i73 instrument) using the static method for 10 selected control points to cover the area distributed over the boundary of Erbil city.

The evaluation results for the direct method show that the uncertainty of the proposed transformation algorithm is ±10.715 m within Erbil city and more than ±12 m over Iraqi territory.

It is worth mentioning that these large transformation uncertainties lead to a conclusion that the used algorithm, which is based on only two factors (a & e^2), must be extended to regard the latitude as a third significant factor.

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