TRANSFORMATION OF THE TRANSIT (DOPPLER) AND GPS STATIONS TO ADINDAN DATUM

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مُسْتَخْلَص

أنشئت الشبكة القومية (المحلية) للإحداثات في السودان في القرن السابق بالطريقة التقليدية القديمة التي تعتمد علي مساحة المثلثات والترافيرسات وتم تحسيب تلك الإحداثيات اعتمادا علي الاهليليج المحلي المسمي باهليليج كلارك 1880 واعتمدت الشبكة القومية في بدايتها علي نقطة مرجعية تم تأسيسها في أدندان علي الحدود السودانية المصرية ولهذا سمي بمرجع إسناد أدندان.

ثم بدا تكثيف هذه الشبكة وعمل امتدادات لها بنظام الدوبلر (ترانزت) الذي يعتمد في تحديد الإحداثيات استخدام نظام الأقمار الاصطناعية علي الاهليليج العالمي (النظام الجيوديسي العالمي) 1972، ثم استبدل هذا النظام بنظام تحديد المواقع العالمي(GPS) الذي يعتمد علي النظام الجيوديسي العالمي 1984.

في هذه الدراسة تم استخدام نقاط مشتركة بين النظام التقليدي القديم علي مرجع الإسناد المحلي أدندان ومرجعي الإسناد العالميين المتتاليين (النظام الجيوديسي العالمي 1972 و1984) لإيجاد معامل التحويل بين مرجعي الإسناد العالميين ومرجع الإسناد المحلي أدندان وأيضا تمت المقارنة بين نتائج هذه الدراسة التي تعتمد علي بيانات تطبيقية ونتائج سابقة تم تحديدها بطريقة نظرية وتقريبية وأظهرت النتائج عدم التطابق بين الدراسات القديمة ودراسات هذه الورقة التي تعتمد علي تطبيقات عملية تتضمن أخطاء الشبكة المحلية التي تم إنشاؤها بالطريقة التقليدية القديمة.

ABSTRACT

Seventeen control points given on the World Geodetic System 1984 (WGS84) and Adindan datum are used to determine transformation parameters between WGS84 and Adindan datum. Using Doppler stations on Adindan datum ,and the transformation parameters of Doppler satellite datum (WGS72) and Adindan , differences in parameters between the datum of GPS(WGS84) and Doppler (WGS72) were computed. These differences are not properly equal to that adopted by USA Defense Mapping Agency (DMA). This is due to erroneous reductions of measured distances to the Clark 1880 ellipsoid, and to the fact that geoid heights were not known perfectly.

Keywords: Adindan-Sudan, Doppler and GPS datums (WGS72,WGS84).

1. INTRODUCTION

As the rapidly emerging industrial technology develops, more precise geodetic information can be achieved. For some areas of the world there still is little or no observational materials. For these areas, additional or new surveys are required to relate major datums of the world more precisely and develop standard world system which will satisfy future needs. The geodetic satellite has provided useful techniques for such surveys. There are several important advantages in the satellite method of collecting geodetic information which can be summarized as:-Geocentric positions can be determined directly; world wide coverage is possible; longer geodetic ties can be accomplished; information regarding important parameters of the gravitational field can be obtained; and the geoid-ellipsoid suppuration at places of known heights above geoid can be obtained. The aim of this paper is to develop techniques which adapt different satellite positioning systems with Adindan datum.

2. THE TRANSIT SATELLITE (DOPPLER) POSITIONING SYSTEM

The transit satellite system was originally developed by the US Navy in cooperation with the Applied Physical Laboratory of Johns Hopkins University.

It was called the US Navy Navigation Satellite System, or Transit. The technical approach grew from experiments to determine the orbit of the first artificial satellite, Sputnik 1, by measuring the Doppler shift of its radio radio signal.

The Transit System became operational in 1964 and was used at first for the navigation of the Navy's polarize submarine fleets. In 1968 its use widened to include off-shore oil exploration, and geodetic and geophysical surveys. There are currently 6 Transit Satellites orbiting the earth; each satellite has a polar orbit with a period of about 1 hour, 47min, at an altitude of about 1100 km above the earth's surface. As a satellite travels around the earth, it continuously broad casts a serial stream of digital data that is phase-modulated on highly stable carrier frequencies of approximately 400 and 150 MHZ.

In geodetic and land surveying application data from multiple satellite passes are collected at fixed locations to be measured and are processed in two possible ways, point positioning and translocation. In point positioning data from a single receiver are used to obtain the location components, latitude, longitude, and height. Horizontal positioning accuracy of about 5 m can be achieved with the use of 25 satellite passes [8]. The point positioning is used only in cases where approximate locations are needed.

Where the survey task requires accuracies better than 1m, the semi-short arc translocation, or shortly translocation method, is applied. This method involves two or more satellite receivers are located at the remote sites whose positions are to be determined.

3. THE GLOBAL POSITIONING SYSTEM (GPS)

The Transit Satellite System is unable to provide the accuracy for surveying at "the parcel and traverse Level. Transit gives submetre accuracy only by observing more than one day. There are only six Transit satellites available for global coverage. A consequence is that there are waiting times between satellites of to one and half hours. The Transit satellites are only 1100 km above the earth and thus are being affected more by local gravity field variations than are the much higher orbiting GPS satellites. Transit satellite transmission at 150 MHZ and 400 MHZ are more susceptible to ionospheric delay and disturbances than are the higher frequency GPS transmissions. Finally, clock technology has improved considerably over recent years to insure stable satellite transmissions.

The Navigation System with Time and Ranging (NAVSTAR) Global Positioning system (GPS) is an all-weather, space-based navigation system, which has been designed primarily for the United States Department of Defense to satisfy the requirements of the military forces [12]. It has been developed since 1973, and became fully operational in 1994, allowing the world wide and instantaneous determination of a vehicle's position and velocity (i.e., navigation) as well as the precise coordination of time. Actually, by GPS techniques, baseline vectors are measured and relative positions of points are accurately determined. This is equivalent to measuring slope distance, azimuth, horizontal angle and vertical angle between the stations. Therefore, GPS surveys yield; distances, horizontal coordinates and heights.

GPS uses pseudoranges derived from the broadcast satellite signal. The pseudorange is derived either from measuring the travel time of the (coded) signal and multiplying it by its velocity or by measuring the phase of the signal. In both cases, the clocks of the receiver and the satellite are employed. Since these clocks are never perfectly synchronized, instead of true ranges "pseudoranges" are obtained where the synchronization error (denoted as clock error) is taken into account [6]. The key to the system's accuracy is the fact that all signal components are precisely controlled by atomic clocks. The GPS satellites have four on board time standards- two rubidium and two cesium clocks. These highly accurate frequency standards being the heart of GPS satellites, produce the fundamental L-band frequency of 10.23 MHz. Coherently derived from this fundamental frequency are two signals, the L_1 and the L_2 carrier waves generated by multiplying the fundamental frequency by 154 and 120, respectively, thus yielding L_1 = 1575.42 MHz, L_2 = 1227.60 MHz . Thus L_1-signal has a wave length of about 0.19m and L_2 – has a wave length 0.244m. These dual frequencies are essential for the elimination of the major source of error i.e. ionospheric refraction. The pseudo ranges that are derived from measured travel time of the signal from each satellite to the receiver use two pseudo-random noise (PRN) codes that are modulated (superimposed) into the two base carrier waves. The first code is the C/A-code with an effective wave length of 293.1m is modulated only on L_1 and is purposely omitted from L_2. The second code is the P-code (precision-code) also designated as the precise positioning services (PPS), which has been reserved for use by the U.S. military and other authorized users. The P-code with an effective wave length of 29.31m is modulated on both carriers L_1 and L_2 are also continuously modulated with the navigation data (satellite message) bit stream at 50 megabits per second, i.e. 50 MHz about the health, clock information and position of the satellite. Receivers which only measure L_1 carrier and C/A-code are known as single frequency receivers and receivers measuring both L_1 and L_2 carriers and C/A-code (sometimes P-code as well) are called dual frequency receivers. To be able to measure carrier(s), receivers must be able to either decode incoming modulated signals (coded receivers) or square them to get L_1 and/or L_2 carrier phases. The formation of C/A code is not classified, thus, available to users worldwide, but, the P-code is generally classified There are two important types of GPS observations (observable): pseudo range and carrier phase. Carrier phases are sometimes also referred to as-carrier beat phases. Pseudo range techniques are generally used for navigation. In high precision surveying the carrier phase is used. Although the (undifferenced) phases can be used directly, it has become common practice at least in surveying applications, to process certain linear combination of the original carrier phase observation (double differences and triple differences) [9].

4.The relation between the Cartesian (X,Y,Z) and Ellipsoid (ϕ , λ) coordinates

The relation between the Cartesian and ellipsoidal are given as

$$X = (N + h) \cos \phi \cos \lambda \qquad (1a)$$

$$Y = (N+h) \cos\phi \sin \lambda \qquad (1b)$$

$$Z = (N(1-e^2) + h)\sin \phi \qquad (1c)$$

Where, $N = a / (1-e^2 \sin^2 \phi)^{1/2}$ and $e^2= (a^2-b^2)/a^2 = 2f-f^2$,a is the semi-major axis, b is the semi minor axis, e is the first eccentricity and f is the flattening of the ellipsoid. From eq. (1a), (1b)and (1c) it is possible to define ellipsoidal coordinates in terms of the Cartesian coordinates as, $\tan \phi = Z(N + h)/\{ (X^2 + Y^2)^{1/2} (N(1-e^2)+h)\}$ may be solved iteratively, $\tan \lambda= Y/X$, $h = (X^2 + Y^2)^{1/2} \sec\phi - N$ (2c)

Since ellipsoidal coordinates of the receivers k and m are known, it can directly be transferred to projection coordinates (plane coordinate of N = Northing, E = Easting plus H = Elevation) using the associated projection equations such as Universal Transverse Mercator (UTM) projection. Hence, among other quantities for slope distance s' and horizontal distance S, we have,

$$S'_{km} = (\Delta X_{km}^2 + \Delta Y_{km}^2 + \Delta Z_{km}^2)^{1/2} \qquad (3)$$

$$S_{km} = (\Delta N_{km}^2 + \Delta E_{km}^2)^{1/2} \qquad (4)$$

5. DATUM TRANSFORMATIONS

Transformation between co-ordinate systems is routinely carried out in surveying. If the co-ordinates are given for a number of stations common to both co-ordinate systems, the transformation parameters can be estimated from a least-squares solution. When measuring with GPS there is usually a need for a transformation because GPS measures co-ordinates on a different system to that used in any one particular country. Therefore the results obtained from GPS need to be transformed into the local co-ordinate system.

5.1 Transformation Models

The transformation of three-dimensional coordinate systems for the purpose of transforming geodetic datums has been given much attention, in particular since geodetic satellite techniques made it possible to relate local geodetic datums to a geocentric datum. Three-dimensional transformations are more suitable for use with satellite positioning for a number of reasons. They are typically global in concept, they enable solution for height as well as horizontal position, and they are mathematically rigorous. The complete three-dimensional transformation involves seven parameters that relate Cartesian co-ordinates in the two systems. There are three-translation parameters to relate the origins of the two systems (ΔX, ΔY, ΔZ),three rotation parameters, one around each of the co-ordinate axis (ε, ψ, ω) to relate the orientation of the two systems and one scale parameter (ΔL) to account for any difference in scale between the two systems. We can consider a geodetic system defining a rectangular co-ordinate system (X,Y,Z) where the origin is at the centre of the reference ellipsoid. The parameters of this ellipsoid will be the equatorial radius a and the flattening f. Knowing X,Y,Z and a and f we can compute the geodetic co-ordinates (ϕ, λ, h) of points in the "old" system. We next may consider a new rectangular co-ordinate system X_1,Y_1,Z_1 whose origin may be (for example) at the centre of mass of the earth. Given the parameters a_1 and f_1 of a new reference ellipsoid we can compute the geodetic co-ordinates (ϕ_1, λ_1, h_1) of points in the new system.

In the past few years there has been a growing interest in the relationship between geodetic datums and the geocentric coordinate systems. This has been due to a variety of reasons, the most important of which is a need to combine the results of satellite geodesy with terrestrial networks. Coordinates derived from satellite observations may be related to a geocentric system, while geodetic coordinates derived from terrestrial observations are defined with respect to a particular non geocentric reference ellipsoid. The purpose of this investigation is to describe a method for determining the relation ship between the local datum in Sudan (Adindan) and satellite datums (WGS72 and WGS84). Each of Bursa-Wolf and Molodensky-Badekas models were tested and the result of the test is stated in [10] and it was concluded that Bursa-Wolf model is not suitable for datum transformation between local and satellite datums because it was seen that Bursa-Wolf model has big standard deviation of the values of the translation parameters. Accordingly it is suitable to choose the Molodensky-Badekas model for the computation of the datum transformation considered in this paper.

5.1.1 The Molodensky-Badekas Model:

The Molodesky-Badekas model [4] removes the high correlations that may exist between the odel parameters by relating them to the centroid of the network or some other convenient point M, with in the network. This model gives the same answers for the baseline length and angles of the survey network, and for the scale and rotation parameters, as the Bursa-Wolf model [7]. However, the translation parameters are different and have higher a posterior precision

$$\begin{vmatrix} X_1 \\ Y_1 \\ Z_1 \end{vmatrix} = \begin{vmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{vmatrix} + \begin{vmatrix} X_m \\ Y_m \\ Z_m \end{vmatrix} + \begin{vmatrix} (1+\Delta) & \omega & -\psi \\ -\omega & (1+\Delta) & \varepsilon \\ \psi & -\varepsilon & (1+\Delta) \end{vmatrix} \times \begin{vmatrix} X-X \\ Y-Y_m \\ Z-Z_m \end{vmatrix} \qquad (5)$$

Where (X_m,Y_m,Z_m) is the average local position of the common points (Figure1).

Rearranging:

$$\begin{vmatrix} X_1 \\ Y_1 \\ Z_1 \end{vmatrix} = \begin{vmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{vmatrix} + \begin{vmatrix} X_1 \\ Y_1 \\ Z_1 \end{vmatrix} + \begin{vmatrix} \Delta & \omega & -\psi \\ -\omega & \Delta & \varepsilon \\ \psi & -\varepsilon & \Delta \end{vmatrix} \times \begin{vmatrix} X-X \\ Y-Y_m \\ Z-Z_m \end{vmatrix} \qquad (6)$$

The seven parameters for either the Bursa-Wolf or the Molodensky models can be solved for

in a least-squares adjustment. The adjustment uses points with co-ordinates in both the satellite and local datum a long with their estimated variances and derives least squares estimates of the seven transformation

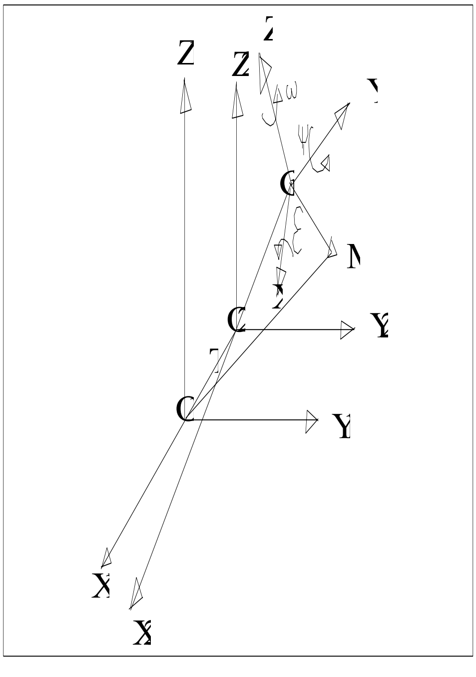

Figure1: Molodensky-Badekas model

parameters to fit the differences between the two sets of co-ordinates. The reliability of these derived parameters is usually expressed in terms of standard deviation or variances.

6. PREVIOUS INVESTIGATIONS

The datum transformation between Adindan and WGS-72 and WGS-84 have been obtained by [1] from 11 stations distributed all over the Sudan. The estimated transformation parameters and their corresponding standard errors are given in Table 1 . The datum transformations WGS72 and WGS84 as they are stated in [3], (transformation between WGS-72and WGS-84 (Molodensky, DMA Recommendation): $\Delta X = \Delta Y = 0$, $\Delta Z = 4.5$m, Δa=2.0 m, $\Delta f = 0.3121057\times10^{-7}$).

Table 1: Transformation parameters between WGS72 and WGS-84 and Adindan datum(RX=ε, RY=ψ, RZ=ω)

Parameters ±σ	WGS72	WGS-84
ΔX (m)	-150.3 ±1.97	-156.6 ± 2.64
ΔY (m)	-28.7 ± 1.97	-16.5 ± 2.64
ΔZ (m)	201.1± 1.97	207.9 ± 2.64
ΔL (ppm)	0.82 ± 2.86	- 0.98 ± 4.31
$RX \times 10^2$	-03.6 ± 1.11	- 5.01 ± 1.59
$RY \times 10^2$ sec	4.4 ± 1.43	2.5 ± 1.84
$RZ\times 10^2$ sec	-5.4 ± 1.53	- 12.4± 3.50

Note: Results of the previous investigation

7. PROCEDURES

For the purpose of the translation parameters determination between satellite and local datum a Fortran computer program was written to handle Molodensky-Badekas model. The program follows the combined least squares adjustment technique. The input data consist of the ellipsoid coordinates of the two systems common to satellite (Transit or GPS) and the Adindan datum. The output is the Cartesian (X,Y,Z) coordinates and the transformation parameters between the two systems with their standard deviation and residuals.

The translation parameters between Adindan and WGS72 were estimated using 14 stations distributed all over the Sudan. The estimated translation parameters and their corresponding standard errors are given in Table 2. The results seem to be consistent with small variation (2m in ΔX, 0.2 m in ΔYand -0.8m in ΔZ) from the results obtained by [1] (Table 1).

In this study, also well distributed GPS observation stations covering the whole country (Sudan) have been selected so as to be utilized in the determination of datum transformation parameters between Adindan and WGS-84 datums. Therefore these points have to be common on the two systems, this is why the GPS points are choosed to be in the local network (Adindan datum). They were observed with geodetic GPS receivers, in static mode, and processed as a single point averaged to more than one hour observation time, relative to WGS 84 ellipsoid, using different receivers (where the points located at the Red Sea State and Khartoum State were observed by SOKKIA, GSS1A receivers and points at West Kordofan State were observed by integrated receivers of Trimble and Ashtech, belong to British company named RACL. They are dual frequency receivers used to observe the three points in West Kordofan relative to base line in the same area established with dual frequency carrier phase GPS relative to International Geodetic Service (IGS) stations. The remaining 9 points were observed by IGN (French, International company) with air ports positioning project in Sudan using the Civil Aviation Authority (Sudan) Trimble dual frequency receivers. The translation parameters between Adindan and WGS84 were estimated using the common 17 stations. The estimated translation parameters and their corresponding standard errors are given in Table 2. The results seem to be different from the previous investigation shown in Table 1.

Table 2: Transformation parameters between WGS72 and WGS-84 and Adindan datum(RX=ε, RY=ψ, RZ=ω)

Parameters ±σ	WGS-72	WGS-84
ΔX(m)	-147.2 ±0.89	-146.0±0.89
ΔY(m)	-34.2 ±.0.89	-33.5±0.89
ΔZ(m)	200.4±.0.89	205.3±0.89
ΔL(ppm)	-1.57±1.35	-1.34±1.35
Rx 10^3 sec	1.64 ±1.87	1.64±1.87
Ry 10^3 sec	2.18 ±1.87	2.18±1.87
Rz 10^3 sec	-14.8±2.6	-14.8±2.6

8. CONCLUSION AND FUTURE RECOMMENDATION

Concluding that the Molodensky-Badekas model, (with its small standard deviation) is suitable for the local and satellite datum transformation. Referring to the results shown above, it could be concluded that: Neither the satellite reference system or the terrestrial datum is perfect. Both contain systematic errors which affect the transformation model, thereby producing distortions in the data analysis The estimated translation parameters and their corresponding standard errors given in Table 2, showed variations in the solutions when compared with the investigations shown in Table1. These variations may be due to use of different station coordinates, the number and geometric distribution of the stations used and also the variations are due to that the first investigations (Table 1) were not done using the actual observed GPS values but they used to determine the theoretical values of the translation parameters between transit system datum (NWL-9D, WGS-72 and WGS-84) by adding the theoretical shift values between the two systems, where this study is using the direct and actual observation values collected by the Geodetic GPS receivers since 1995 up to the time of preparing this study and accordingly it is well known that the GPS observed values are affected by the errors of GPS system ,also the error is due to that they are processed using the broadcast ephemeris and there are no relative connection between these stations where each of them was a control point of different project which computed by broadcast ephemeris.

9. FUTURE RECOMMENDATIONS

For the GPS points to fit in the existing local system after transformation, it is very important to make sure of the accuracy of the local coordinates especially the orthometric height. In order to obtain accurate ellipsoidal heights, the geoid separation at the measured points must be known. This may be determined from geoidal model, here in Sudan the geoid separation of the Clarke 1880 ellipsoid is neglected and it is approximated to zero, but it is known that there are discrepancies between the orthometric height and the height related to the surface of the geoid , so the neglection of the geoid height is not the optimal case. Also it is better to establish the origin of the local datum at the center of the network by establishing the datum by the astronomical geodetic orientation using a number of Laplace stations, distributed all over the country.

The datum transformation basically works by taking the Cartesian coordinates of the GPS measured points (WGS-84 ellipsoid) and comparing them with the Cartesian coordinates of the local coordinates, from this, shifts, rotations and a scale factor are calculated in order to transfer from one ellipsoid to another, this system of transformation will be used over virtually any area as long as the local coordinates (including height) are accurate, and also for this method it is always recommended that the surveyor have at least three points for which the coordinates are known in the local system and in WGS-84 , it is possible to compute transformation parameters using only three common points but using four allows for residuals to be calculated.

For any precise GPS survey the absolute coordinates of one site in the network have to be known in WGS-84 to the possible accuracy. This can be accomplished by setting a geodetic GPS receiver at the station, in the static mode having a good GDOP values and utilizing the single point processing software to get the absolute coordinates of the station. The minimum observation for the computation of a reliable single point position is probably about one hour with four or more satellites and good GDOP. The longer the observation time, the better the single point position will be. Referring to the practical aspects it is not recommended to use the published values of the transformation parameters which installed in the software of the geodetic GPS (each GPS receiver software has its own parameters) because they are approximated to the whole region not to the area under consideration, and always they have a variation from the actual parameters of the considered area. It is recommended for the surveyor to determine his own transformation parameters using control points distributed over the area under consideration.

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