Datum Issue in Deformation Monitoring Using GPS

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SUMMARY

In deformation monitoring, the datum issue in the case of the GPS networks determined in different periods is a big puzzle for the most surveyors. The main reason of the puzzle is that some academic software need Earth Orientation Parameters (EOP), polar motion and UT1-UTC parameters, but the most of the commercial software don't need them. If the some part of the GPS softwares use EOP, does the results obtained from other part of the software have to be corrected due to those parameters? To answer this question a practitioner must be aware of the coordinate system in which GPS is referenced.

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1. INTRODUCTION

Before the advent of Global Positioning System (GPS), field works of geodetic networks were an onerous task; intervisibility between network points were a compulsory clause, measurements needed to be reduced to a reference surface (reference ellipsoid or geoid) by a reduction procedure consisting of several steps including some shortcomings, and then non-linear observation equations had to be linearized by Taylor series expansion before the network adjustment. Apart from this, in this term, establishing three dimensional and large scale geodetic networks were not possible by the conventional techniques. The only advantage of the geodetic nets surveyed by the conventional techniques was that the evaluation procedure relating to this kind of the networks was completely inside the geodetic expertise. Therefore, every practitioner of geodesy having average programming skill was able to develop their own software for the adjustment of the geodetic networks.

GPS technology have surmounted all the inadequacies and difficulties of the conventional methods stated above.; large-scale geodetic networks in which distances among the network points reach thousands of kilometers can now be established and positioned with high precision; data collection in the field just consists of mounting receiver on the site points and waiting during a predefined-observation time.

Despite the implementation advantageous of GPS, its evaluation procedure for the geodetic applications is not an easily manageable process contrary to the conventional techniques. To develop a personal software including the entire steps of GPS processing, one must have scientific knowledge on different topics of fundamental and engineering sciences as well as advanced programming skill. For that reason, the most practical way for the surveyors is to use commercial softwares provided by the GPS equipment manufacturers or academic ones developed by some university research teams.

Automation in making observation and use of packet programs in data processing have both led to a fundamental transformation in the geodetic practitioner profile; the new generation of practitioners prefers learning how to use ready packet programs rather than learning theoretical terms, while the former ones had to know theory to make their own programs. As a result of that, especially the datum issue in the case of the GPS networks is a big puzzle for the most surveyors. The main reason of the puzzle is that some academic software need Earth Orientation Parameters (EOP), polar motion and UT1-UTC parameters, but the most of the commercial software don not need them. The most surveyors have no knowledge on why some software apply to these parameters, or some software do not. The answer of this question lay under the datum to which GPS has been referenced. Most practitioners think GPS still works in the WGS84 datum, but this knowledge is not valid any more. The broadcast ephemeredes of GPS satellites are transmitted via satellite signals, and referenced to International Terrestrial Reference Frame 1996 (ITRF96) at actual epoch. The precise ephemeredes published by IGS (International Global Navigation Satellite System Service) are always referenced to the latest ITRF version at actual epoch; now, ITRF05 is the most updated version. The reference epochs are 1998.0 for ITRF96 and 2000.0 for ITRF05 (Gurtner, 1993; Bock, 2004, URL1). At this point, the reference system represented by ITRF has a key role to respond the questions above.

2. Conventional Reference System and ITRF

Positioning on the earth requires an earth-centered and earth-fixed conventional terrestrial coordinate system (CTRS). For such a system:

- the origin is at the earth's center of mass and
- the primary pole is at the intersection point of the earth's axis of rotation and the earth's crust.

However, since the earth's axes of rotation and maximum inertia do not coincide the primary pole moves with respect to the earth's surface. This movement is called the polar motion (Krakiwsky and Wells, 1971). To reduce changes in coordinates caused by the polar motion, a conventional terrestrial pole (CTP) definition is required. This definition was agreed on the average position of the rotation axis during the years 1900-1905. The true rotation axis is referenced to CTP using the polar motion parameters (x_p, y_p).

Table 1. Transformation parameters and velocities between ITRF00 and other ITRF solutions (URL 2)

Parameters Unit Velocities	t_x cm δt_x cm/y	t_y cm δt_y cm/y	t_z cm δt_z cm/y	ε_x .001″ $\delta\varepsilon_x$ .001″/y	ε_y .001″ $\delta\varepsilon_y$ .001″/y	ε_z .001″ $\delta\varepsilon_z$ .001″/y	k ppb δk ppb/y	Epoch
ITRF97	0.67	0.61	-1.85	0.00	0.00	0.00	1.55	1997.0
Velocities	0.00	-0.06	-0.14	0.00	0.00	0.02	0.01	
ITRF96	0.67	0.61	-1.85	0.00	0.00	0.00	1.55	1997.0
Velocities	0.00	-0.06	-0.14	0.00	0.00	0.02	0.01	
ITRF94	0.67	0.61	-1.85	0.00	0.00	0.00	1.55	1997.0
Velocities	0.00	-0.06	-0.14	0.00	0.00	0.02	0.01	
ITRF93	1.27	0.65	-2.09	-0.39	0.80	-1.14	1.95	1988.0
Velocities	-0.29	-0.02	-0.06	-0.11	-0.19	0.07	0.01	
ITRF92	1.47	1.35	-1.39	0.00	0.00	-0.18	0.75	1988.0
Velocities	0.00	-0.06	-0.14	0.00	0.00	0.02	0.01	
ITRF91	2.67	2.75	-1.99	0.00	0.00	-0.18	2.75	1988.0
Velocities	0.00	-0.06	-0.14	0.00	0.00	0.02	0.01	
ITRF90	2.47	2.35	-3.59	0.00	0.00	-0.18	2.45	1988.0
Velocities	0.00	-0.06	-0.14	0.00	0.00	0.02	0.01	
ITRF89	2.97	4.75	-7.39	0.00	0.00	-0.18	5.85	1988.0
Velocities	0.00	-0.06	-0.14	0.00	0.00	0.02	0.01	
ITRF88	2.47	1.15	-9.79	0.10	0.00	-0.18	8.95	1988.0
Velocities	0.00	-0.06	-0.14	0.00	0.00	0.02	0.01	

Developments in satellite geodesy in the early 1980's obliged to define a crust-fixed CTRS, taking into account the plate tectonics as well as the polar motion (4). Plate motions cause progressive inconsistencies in neighborhood relationship between site points on different tectonic plates. As opposed to the polar motion, these inconsistencies are too complex to be modeled by a few parameters. In that case, the solution is to define a reference frame by means of a consistent coordinate set and velocities, in which all tidal effects are removed, of global tracking stations at a certain epoch (Seeber, 1993; Bock, 1998, Leick, 2004).

International Reference Frame (ITRF) is such a reference frame, which is a realization of International Terrestrial Reference System (ITRS) which is a crust fixed CTRS.

Realization, maintenance and improvement of ITRF are the tasks on the responsibility of International Earth Rotation Service (IERS). Depending on advances in defining the very complex nature of plate motions and in data processing and computational techniques, IERS updates the ITRF solutions. These solutions are represented by the short notation ITRFyy where "yy" is the last two digits of the solution year. From the first ITRF88, many solutions were available for ITRF such as ITRF90, ITRF94, ITRF96, and ITRF00. ITRF05 published in 2006 is the most updated ITRF solution. Table 1 shows the transformation parameters and their velocities between ITRF00 and the former solutions.

3. DATUM ASSESSMENT FOR GPS NETWORK OBSERVATIONS IN DIFFERENT EPOCHS

As stated in the section of introduction, coordinates obtained from GPS determination of geodetic networks will be at actual epoch of the related ITRF solution on which satellite orbits are based. ITRF is a realization of a crust fixed CTRS, so these GPS-determined coordinates do not need to be corrected due to the polar motion (Leick, 1995). Besides, those coordinates are free from all tidal effects. However, some academic softwares such as GAMIT require the polar motion and UT1-UTC parameters. The only reason of this requirement is that this sort of the software transforms satellite orbits into inertial space, i.e. Conventional Celestial Reference System (CCRS), and performs orbit interpolations for proper epochs in this reference system using dynamic models (Gurtner, 1993). It is the fact that the relationship of the transformation from CTRS to CCRS is established by

$$\mathbf{X}_{CCRS} = \mathbf{PNR}_3(GAST)\mathbf{R}_1(y_p)\mathbf{R}_2(x_p)\mathbf{X}_{CTRS} \quad (1)$$

where $\mathbf{R}_1(y_p), \mathbf{R}_2(x_p)$ and $\mathbf{R}_3(GAST)$ are the rotation matrices respectively about the axes x, y and z, and GAST is the short notation of Greenwich Apparent Sidereal Time (McCarthy, 1996, Mueller, 1969). Applying $\mathbf{R}_1(y_p)$ and $\mathbf{R}_2(x_p)$ to $\mathbf{X}_{CTRS}$ transforms the coordinates from CCRS to Instantaneous Terrestrial Coordinate System, then applying $\mathbf{R}_3(GAST)$ transforms the coordinates in the instantaneous system to CCRS. GAST connecting the instantaneous system and CCRS is computed as follows

$$GAST = GMST + \Delta\Psi\cos\varepsilon + 0''.00264\sin\Omega + 0''.000063\sin 2\Omega \quad (2)$$

$$GMST = GMST_{0^h UT1} + r\big[(UT1 - UTC) + UTC\big] \quad (3)$$

$$GMST_{0^h UT1} = 6^h 41^m 50^s.54841 + 8640184^s.812866 T_u + 0^s.093104 T_u^2 - 6^s.2\text{x}10^{-6} T_u^3 \quad (4)$$

$$r = 1.002737909350795 + 5.9006\times10^{-11} T_u - 5.9\times10^{-15} T_u^2 \quad (5)$$

In this equation

$T_u : d_u / 36525$,

d_u : number of days from January 1, 2000 $UT1 = 12^h$,

UTC : Universal Time Coordinated,

UT1 : Polar motion free Universal Time.

Here, the foregoing softwares require the polar motion and UT1-UTC parameters to perform the transformation process defined above.

Excepting some software's preference of operating in CCRS, the satellite orbits provided at actual epoch of a crust-fixed CTRS involve only changes caused by plate tectonics. Orbits at actual epochs are invaluable for deformation monitoring because the network determinations in different observation periods can directly be compared with each other to produce deformations, with no need of any correction due to polar motion, UT1-UTC and tidal effects. However, a transformation process can be required for baseline vectors before that they are implemented in the network adjustment under the following situations:

- network campaigns completed in days, weeks or months
- observation periods referred to different ITRF solutions

4. CONCLUSION

Global navigation systems, especially GPS, are among the most important tools that advances in the technologies gifted to geodesy. Due to this technique, to measure distances, to reach high precisions and to monitor small temporal deformations which are not possible by the terrestrial techniques are possible. Of course, these facilities enlarged the interest area of the geodesy. On the other hand, they put the geodesy into the interest area of the related engineering disciplines. Today, there are many practitioners from other disciplines having good command of GPS software for the geodetic applications. However, for a successful application, one has to be aware of the geodetic philosophy on which GPS is based. In this philosophy, the datum issue is in key role. For a consistent positioning and a consistent temporal displacement analysis of a geodetic network, a proper datum and a proper epoch have to be utilized. This topic presents an important advantage to the practitioners from geodesy or surveying because the datum issue is in the core area of the surveyors. However, if a surveyor has not been aware of that knowledge this advantage will, of course, not the case.

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URL 1: geodesy.noaa.gov/PUBS_LIB/ppt/GPS_Orbit_Determination.ppt

URL 2: ftp://lareg.ensg.ign.fr/pub/itrf/ITRF.TP

BIOGRAPHICAL NOTES

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