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POSITION DETERMINATION OF THE NATIONAL REFERENCE ELLIPSOID OF UKRAINE FOR THE RESULTS OF GNSS OBSERVATIONS[1]

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Reviewed the methodology of the study of the relative placement of the all-earth geocentric coordinate systems ITRS/ITRF 2000 and IAG reference frame coordinate system USK – 2000 based on processing observations at permanent stations GNSS stations and the developed algorithm. Based on the results it is possible to do the following conclusions: reference coordinate axes of the coordinate system USK-2000 and geocentric coordinate system WGS-84 is almost parallel to each other; maximum deviation occurs by Euler angle ω, that describing the rotation of axes about the axis z; represented data suggest that the network of permanent stations, created by the company «System Solution», can be successfully used to stability investigation of Ukraine reference coordinate system, and the algorithm of this research is effective.

1. PROBLEM STATEMENT

Modern reference coordinate system is divided into *global* and *national* or *regional*. The first of them is used for studies of global geodynamic processes (for example, movement of lithospheric plates, the definition of the figure of the Earth), and national one is widely used in the study of regional geodynamic processes (horizontal and vertical movements of the crust, regional variations in the gravitational field), the practice of topographic-geodesic work, precision mapping of the region. Implementation of all these types of works requires appropriate accuracy of the position determination of geodetic networks points.

The current state of geodetic network in Ukraine did not provide with respect to accuracy all these problems a simple transition to global reference system [2,5], which make conditions to the necessity of the creation a new state coordinate system USC-2000 [4]. The coordinate system USC-2000 is responsible of current requirements for providing the single high-precision coordinate basis for

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realization the scientific, research and industrial needs. The coordinate system USC-2000 is modeled according to the ITRS/ITRF 2000 by:

1) the scale of the reference system eq scale systems ITRS/ITRF2000;
2) coordinate axis of reference system parallel to the axes of system ITRS/ITRF2000;
3) accommodation of center reference coordinate system (combined with the center of reference ellipsoid) provide the optimum surface deviations of the reference ellipsoid from the real surface of the Earth on the region of Ukraine, that the corrections by the height of the geoid and deflection of the plumb-in line are minimized.

In the coordinate system USC-2000 as the surface of reference accepted the reference of Krasovsky ellipsoid. The geodetic datum of reference ellipsoid of Ukraine was established in terms of processing of GNSS-observations in 16 points of fundamental astro-geodetic network.

In accordance with modern requirements geodetic datum and reference coordinate system should not vary over time. This condition is almost impossible to fulfill, since the spatial position of the network is affected by many factors associated with vertical and horizontal movements of the tectonic blocks and lithospheric plates. Therefore, the current research is the periodic change in geodetic datum and consideration of them in the practice of geodetic work.

2. ANALYSIS OF LAST RESEARCHES AND PUBLICATIONS

The problem of practical implementation of the national reference ellipsoid was first announced in [1, 5] and in subsequent publications [2, 6], in which the authors rightly call attention to the fact that Ukraine's current reference coordinate system SC-42 does not provide a reliable functional connection with global geocentric coordinate system, does not allow to use the new technologies of the creation and processing of geodetic measurements [5, 6]. That is why the Cabinet of Ministers of Ukraine in 2004 adopted the Resolution number 1259 about the implementation throughout the country the state reference coordinates system USC-2000 [4].

Authors of some publications [1, 8] pointed to the fact that the coordinates of permanent stations, which were used to establish the initial geodetic datum, vary over time and that come into account in different implementations of the International geocentric coordinate systems ITRF (ETRF).

3. RESEARCH WORK

3.1. Problem definition

The object of an article is to investigate the implementation of the above conditions of orientation national reference ellipsoid of Ukraine according to

GNSS observations on the newly produced by company «System Solution» (representative of the company «Leica» in Ukraine) permanent stations.

3.2. Exposition of basic material

Different companies and organizations created a network of permanent stations in Ukraine for distribution of reference coordinate system in a given terrain. One of these networks, created in Western Ukraine in 2014–2015 by company «System Solution», is «Ukrainian permanent network of permanent base stations of global navigation systems" (UPM GNSS), a fragment of which is shown in Figure 1. From the network were used four points: FRKV - Ivano-Frankivsk National Technical University of Oil and Gas (Ivano-Frankivsk), BUCH (Buchach), DLNA (Dolyna) and YARM (Yaremche). They are approximately situated in azimuth evenly at a distance of 70–100 km from Ivano-Frankivsk. All of these stations keep routine GNSS observations using Leica GR-10 receivers with Leica AR-10 antennas

The original materials for the investigation were three-dimensional geocentric rectangular coordinates of stations X, Y, Z, determinated at the same time of observation in the system reference coordinates WGS-84 and in the system ference of coordinates USC-2000.

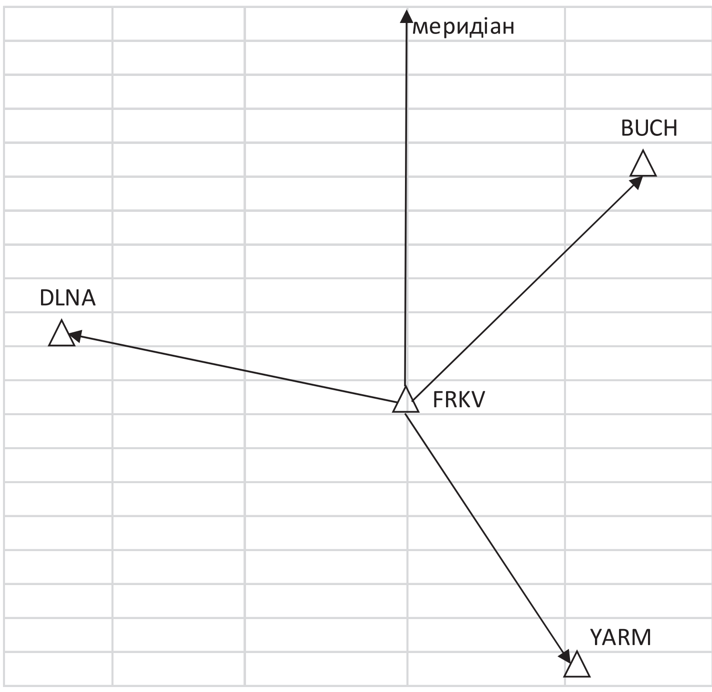

Fig. 1. Fragment of UPM GNSS network

For known algorithm [3] the three-dimensional coordinates of points were transferred to space geodetic coordinates B, L, H, associated with the corresponding reference ellipsoids. On this evidence the difference of corresponding geodetic coordinates that characterize the divergence of initial geodetic datum of national reference ellipsoid with Earth ellipsoid were calculated (Table 1).

Table 1. Difference of space geodetic coordinates

Station name	Differences of coordinates		
	ΔB"	ΔL"	ΔH,м
BUCH	–0,7953	–5,8747	32,4696
DLNA	–0,8605	–5,9137	34,2629
YARM	–0,8557	–5,8407	33,7779
FRKV	–0,8277	–5,8934	33,3563

The data in Table 1 will be used to determine the relative position of geocentric and reference coordinate systems. It is known [3] that the functional relationship between these systems written such equations:

$$\begin{bmatrix} (M+H)dB \\ (N+Y)cosBdL \\ dH \end{bmatrix} = P' \begin{bmatrix} -dx_0 & -\nu_0 Y_0 & -\xi_0 Z_0 \\ -dy_0 & +\nu_0 X_0 & -\eta_0 Z_0 \\ -dz_0 & +\xi_0 X_0 & +\eta_0 Y_0 \end{bmatrix} \quad (1)$$

In (1) P' – transition matrix, determined by such elements:

$$P' = \begin{bmatrix} -sinB\,cosL & -sinBsinL & cosB \\ -sinL & cosL & 0 \\ cosBsinL & cosBcosL & sinB \end{bmatrix} \quad (2)$$

ξ_0, η_0 and ν_0 – the angles of orientation, establishing the relative position of coordinate axes of the two systems (fig. 2), and dx_0, dy_0, dz_0 – linear characteristic of displacement points of origin coordinate systems.

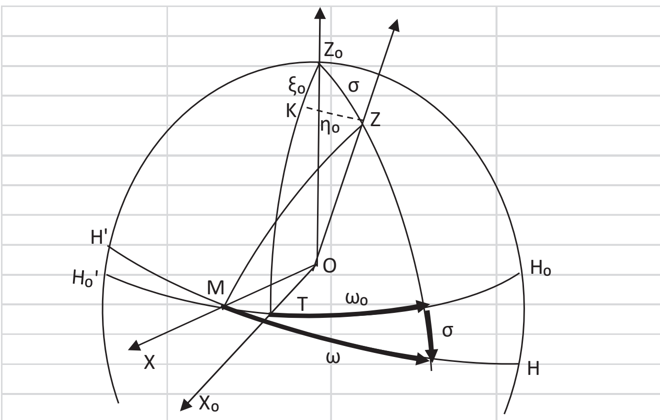

Fig .2. Rotation of axes two coordinate systems

Narrow angles ξ_0, η_0 and ν_0 that characterize the rotation of axes of the two reference systems are functionally related to the Euler angles σ, ω and ω_0 (Figure 3) the following expressions [3]:

$$\sigma = \sqrt{\xi_0{}^2 + \eta_0{}^2};\ \omega_0 = arctg\frac{\eta_0}{\xi_0};\ \nu^0 = \omega - \omega_0. \qquad (3)$$

Taking into account (1) and (2), and considering the possible changes in image scale m, differential changes of space geodetic coordinates in discrete form will be written as:

$$\Delta B = \frac{N}{a(M+H)}e^2 \sin B \cos B \Delta a + \frac{1}{2(M+H)}(N + \frac{M}{1-e^2}) \sin B \cos B \Delta e^2 +$$

$$+\frac{1}{M+H}[(\sin B \cos L \Delta x + \sin B \sin L \Delta y - \cos B \Delta z) + (\sin B \cos L Y^0 - \sin B \sin L X_0)\,\nu_0 + (\sin B \cos L Z_0 + \cos B X_0)\xi_0 + (\cos B\, Y_0 + \sin B \sin L Z_0)\,\eta_0] - \sin B \cos B e^2 m;$$

$$\Delta L = \frac{1}{(N+H)\cos B}(\sin L \Delta x - \cos L \Delta y) + (\sin L\, Y_0 + \cos L X_0)\,\nu_0 + \sin L Z_0 \xi_0 - \cos L\, Z_0\, \eta_0]; \quad (4)$$

$$\Delta H = -\cos B \cos L \Delta x - \cos B \sin L \Delta y - \sin B \Delta z + (\cos B \sin L\, X_0 - \cos B \cos L Y_0)\,\nu_0 + (\cos B \cos L Z_0 + \sin B\, X_0)\xi_0 + (\sin B\ Y_0 - \cos B \sin L Z_0)\eta_0 + (\frac{a^2}{N} + H)m - \frac{a}{N}\Delta a + \frac{N}{2}sin^2 B \Delta e^2.$$

In (4) Δa and Δe^2 characterize the variation of the increases parameters of Krasovsky ellipsoid and WGS-84, which are determined by formulas:

$$\Delta a = a_{кр} - a_{WGS}, \quad \Delta e^2 = e^2_{кр} - e^2_{WGS}. \qquad (5)$$

If we regard in (4) absolute term in an expression:

$$\frac{N}{a(M+H)}e^2 \sin B \cos B \Delta a + \frac{1}{2(M+H)}\left(N + \frac{M}{1-e^2}\right) \sin B \cos B \Delta e^2 - \Delta B = l_1,$$
$$-\Delta L = l_2, \qquad (6)$$
$$-\frac{a}{N}\Delta a + \frac{N}{2}sin^2 B \Delta e^2 - \Delta H = l_3$$

get on the basis of (4) a system of linear equations:

$$a_{11}\Delta x + a_{12}\Delta y + a_{13}\Delta z + a_{14}\nu_0 + a_{15}\xi_0 + a_{16}\eta_0 + a_{17}m + l_1 = 0,$$
$$a_{21}\Delta x + a_{22}\Delta y + a_{23}\Delta z + a_{24}\nu_0 + a_{25}\xi_0 + a_{26}\eta_0 + a_{27}m + l_2 = 0, \qquad (7)$$
$$a_{31}\Delta x + a_{32}\Delta y + a_{33}\Delta z + a_{34}\nu_0 + a_{35}\xi_0 + a_{36}\eta_0 + a_{37}m + l_3 = 0$$

where the coefficients of the unknown parameters that characterize the displacement of origin coordinate systems Δx, Δy and Δz, rotation angles ν_0, ξ_0 i η_0 and scale coefficient m corresponds the coefficients of related amendments in equations (4).

According to observations on the four permanent stations we can comprise the twelve equations of the form (7), and from a compatible solution to get the value of the unknown. We find (Table 2):

Table 2.Characteristics of relative positions coordinate system USC-2000 and WGS-84

Displacement of origin coordinate , m		Rotation angles		Euler angles	
Δx	55,377	ν_0"	0,3597	σ"	0,1648
Δy	–92,147	ξ_0"	0,1648	ω"	0,3596
Δz	–10,297	η_0"	0,0000	ω"$_0$	0,0000
scale image m			–2,2468E-05		

4. CONCLUSIONS

Based on the results it is possible to do the following conclusions:

1) Reference coordinate system USK-2000 is different from the geocentric coordinate system WGS - 84; the coordinates of displaced origin coordinate reference system are given in Table 2, and the magnitude of a vector displacement is 108 m in azimuth 301°;
2) Reference coordinate axes of the coordinate system USK-2000 and geocentric coordinate system WGS-84 is almost parallel to each other; maximum deviation occurs by Euler angle ω, that describing the rotation of axes about the axis z;
3) These parameters relative position of the two coordinate systems have no influence on the scale coefficient;
4) Represented data suggest that the network of permanent stations, created by the company «System Solutions», can be successfully used to stability investigation of Ukraine reference coordinate system, and the algorithm of this research is effective.

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WYZNACZENIE POŁOŻENIA UKRAIŃSKIEJ NARODOWEJ ELIPSOIDY ODNIESIENIA W WYNIKU OBSERWACJI GNSS

Streszczenie

Przedstawiono metodologię powiązania globalnego geocentrycznego układu współrzędnych ITRS/ITRF 2000 z układem współrzędnych odniesienia USK-2000 opartą na przetwarzaniu obserwacji GNSS pochodzących ze stacji permanentnych, według opracowanego autorskiego algorytmu. Uzyskane wyniki pozwoliły wyciągnąć następujące wnioski: osie układu współrzędnych odniesienia USK – 2000 i odpowiednie osie geocentrycznego układu współrzędnych WGS – 84, w zasadzie są równoległe do siebie; maksymalna zmiana występuje dla kąta Eulera ω, który charakteryzuje obrót układu współrzędnych wokół osi Z. Na podstawie obserwacji pochodzących ze stacji permanentnych firmy „System Solutions”, wykazano, że ich wyniki mogą z powodzeniem służyć do badania układu współ-rzędnych odniesienia Ukrainy, a opracowany algorytm daje pozytywne wyniki.

ВИЗНАЧЕННЯ ПОЛОЖЕННЯ НАЦІОНАЛЬНОГО РЕФЕРЕНЦ-ЕЛЛИПСОИДА УКРАЇНИ ЗА РЕЗУЛЬТАТАМИ GNSS - СПОСТЕРЕЖЕНЬ

Резюме

Розглянуто методологію дослідження зв'язку загальноземної геоцентричної системи координат ITRS / ITRF 2000 і референцної системи координат УСК – 2000 на основі опрацювання спостережень перманентних GNSS – станцій за розробленим алгоритмом. Отримані результати дозволили зробити наступні висновки: осі референцної системи координат УСК – 2000 і відповідні осі геоцентричної системи координат WGS – 84, в основному, паралельні між собою; максимальну зміну має кут Ейлера ω, що характеризує поворот координатної системи довкруги осі Z. Репрезентативні дані спостережень, надані мережею перманентних станцій компанії "«System Solutions», можуть успішно використовуватись для дослідження референцної системи координат України, а розроблений алгоритм цих досліджень ефективним.

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